Investigating the Empirical Existence of Static User Equilibrium

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Smart mobility master

Modeling Traffic and Transportation Networks

October 12th 2018

What is congestion ?

Negative externalities and conjunction of aggregation and dispersion forces in territorial systems [Fujita and Thisse, 1996].

$\rightarrow$ *Congestion is when the volume of use exceeds the infrastructure/system capacity*

Examples: traffic congestion, pedestrian congestion, public transport congestion, real estate market congestion, logistic supply congestion, etc.

Congestion in territorial systems

Crucial role in the evolution of an urban system, at several scales: example of the land-use/transport feedback cycle from [Wegener and Fürst, 2004]

Measures for the congestion of traffic

Various approaches to measure traffic congestion [Rao and Rao, 2012] :

- current average speed
- travel time and delay (associated accessibility indices)
- volumes of vehicles
- level of service
- capacity of the network to answer demand
- generalized costs increase

Fundamental diagram of traffic

Fundamental relation between vehicle density and flow : free flow, critical phase, congested phase.

Theoretical and empirical example from [Daganzo and Geroliminis, 2008]

Traffic phase diagram

Example of theoretical and empirical phases in a ramp configuration [Treiber et al., 2010]

Traffic Modeling : User Equilibrium Frameworks

Transportation network model: graph with edges flows and capacity.

Question: How to compute traffic flows from a demand pattern ?
$\rightarrow$ *Traffic assignment problem*

1. Basic solution: shortest path assignment (betweenness centrality)
2. More elaborate: user equilibrium at which no user can improve his travel time, coined by [Wardrop, 1952] (game theory approach: similar to a Nash equilibrium)
   - mathematical existence generally verified (fixed point theorem), unicity more difficult
   - temporal stationarity assumption: flows are assumed to converge on the considered period, generally rush hour

Extensions of Wardrop's equilibrium

Diverse developments of the SUE:

→ Dynamic Stochastic User Equilibrium [Han, 2003]

→ Restricted Stochastic User Equilibrium [Rasmussen et al., 2015] more realistic in alternatives

→ Boundedly User Equilibrium [Mahmassani and Chang, 1987]

→ Assignment techniques inspired from other fields such as Network Science [Puzis et al., 2013]

Validation and Practical Use

Static User Equilibrium lacks empirical validation in the literature

→ Some examples such as the behavioral study of user route choices ("Wardrop's first principle") in [Zhu and Levinson, 2010]

However still largely used

→ in theoretical literature, as for example [Leurent and Boujnah, 2014] : do refinements in the model such as adding parking cruising flows have a sense if the core is not validated ?

→ in real-world application, such as the MODUS model for Paris Metropolitan area : what are the implications of basing decision-making and traffic management on an unvalidated framework ?

Empirical Investigation of SUE Existence

Research Objective : *Investigate empirically the spatio-temporal stationarity of traffic flows, combining different complementary quantitative approaches*

→ Construction of a real-time dataset for major links of Paris region on 6 month by data crawling

→ Complementarity of approaches (Complex Systems general paradigm) : Spatio-temporal data visualization, Network analysis, Spatial analysis

Data collection: illustration

Crawling of semi-open data may be necessary to study territorial systems

Mobility data: status of VLib stations in real time (easy: API) [Raimbault, 2015]

Data collection

More difficult mobility data: dockless bike sharing. Evaluation of an ad-hoc algorithm.

Data collection

Even more difficult: ad-hoc algorithm and large scale data (150000 records every 12 hours). Example of US gaz prices.

Data collection

Not only for spatial data

Paper citation data: example of a journal not referenced by classical databases. Reconstruction of citation networks.

Dataset Construction

Difficulty to find Open Data on Transportation Systems [Bouteiller and Berjoan, 2013]
→ Construction of an open historical travel time dataset for major links in the region of Paris, collecting in real time public traffic data from `www.sytadin.fr`

Data collection : Each two minutes, automated python script

- fetch raw webpage giving traffic information
- parse html code
- store in a `sqlite` database

Openly available (CC Licence) at
`http://dx.doi.org/10.7910/DVN/X22ODA`

Data summary: more than 2 years (since Feb. 2016), 2min time granularity, effective travel time for 101 links ($\simeq$ 10km spatial granularity)

Interactive Data Visualization

Interactive web-application for spatio-temporal exploration

`http://shiny.parisgeo.cnrs.fr/transportation`

Demonstration of the interactive application

Temporal patterns of congestion

Summary statistics

Distribution of relative times

Summary statistics

Rank size law for relative times: signature of a complex system with extreme events

Summary statistics

Distribution of relative times by link: identification of critical links

Spatio-temporal Variability : Example

Very high spatial variability on 10min time interval, here on 11/02/2016 00:06-00:16

Spatio-temporal Variability

Maximal travel time and spatial variabilities on a two week sample

Stability of Network Measures

Network Betweenness Centrality

$$b_i = \frac{1}{N(N-1)} \cdot \sum_{o \neq d \in V} \mathbb{1}_{i \in p(o \to d)} \tag{1}$$

Temporal Maximal Betweenness Variability

$$\Delta b(t) = \frac{|\max_i(b_i(t+\Delta t)) - \max_i(b_i(t))|}{\max_i(b_i(t))} \tag{2}$$

$\rightarrow$ *Reveals either a proportion of rerouted travels (negative variation) or a minimal proportion of load increase for a single node (positive variation)*

Stability of Network Measures

Temporal maximal betweenness variability on a two weeks period

Spatial Heterogeneity

Spatial Autocorrelation as an index of spatial variability, for link i

$$\rho_i = \frac{1}{K} \cdot \sum_{i \neq j} w_{ij} \cdot (c_i - \bar{c})(c_j - \bar{c}) \tag{3}$$

with spatial weights $w_{ij} = \exp\left(\frac{-d_{ij}}{d_0}\right)$

$\rightarrow$ *Indirect measure of the spatial stationarity of flows : a decreasing correlation implies a chaotic system*

Spatial Heterogeneity

Spatial autocorrelation on a two weeks period for different decays

Theoretical and Practical Implications

Theoretical Implications

→ Need for more systematic comparison of framework validity ([Kryvobokov et al., 2013] compares two LUTI models e.g.)

→ Can still be used e.g. for integration within more complex models

Practical Implications

→ Difficulty of transferring academic results to real-world engineering, that can be tied to habits, myths, political interests, etc. [Commenges, 2013] ; [Offner, 1993]

Conclusion

→ Simple but necessary empirical insights into SUE spatio-temporal stationarity

→ Construction of an open dataset : need for more openness, transparency, reproducibility

→ Strong need for more integrated research : theoretical-empirical, between disciplines, between approaches and objectives, between models (multi-modeling) [Raimbault, 2018]

- All code available at `https://github.com/JusteRaimbault/TransportationEquilibrium`
- Interactive web application `http://shiny.parisgeo.cnrs.fr/transportation`
- Latest version of the dataset available at `http://dx.doi.org/10.7910/DVN/X22ODA`
- Paper: [Raimbault, 2017], open version available at `http://arxiv.org/abs/1608.05266`

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