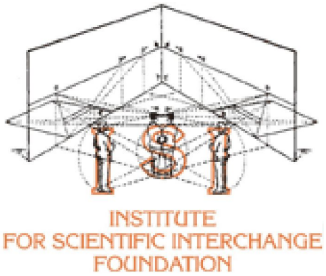
Trainstopping



Modeling Delays Dynamics on Railways Networks

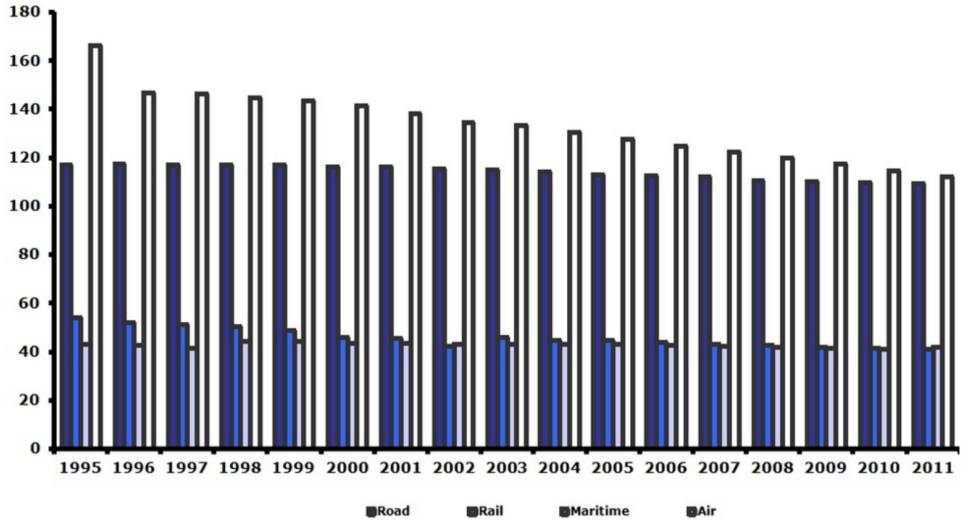
Bernardo Monechi, ISI Foundation
CCS 2016, Amsterdam

The Importance of Railways

- Railway transports have been of utmost importance since end of the 20th century
- Movements of goods, National defence..
- Slight decline in recent times:
  - Short-distance: cheap private transport
  - Long-distance: Air Transport

The Importance of Railways

- Railway Development as an economic metric of national attractiveness
- Railway development policies improved in Europe in the 21th century
- Less polluting than cars or airplanes: reduction of CO2 emissions by 2020
- Tens of Billions of Euros by the European Commission supporting railway infrastructure



Specific CO2 emissions per passenger-km and per mode of transport in Europe, 1995-2011

Picture from: "Energy efficiency and CO2 emissions", European Environment Agency

The Importance of Railways

- A better understanding of the dynamics and the phenomena of rail transport could be helpful in policy making
- Universalities? System's resilience to disruptions?
- **Emergence of congestion? Omnipresence of large delays?**

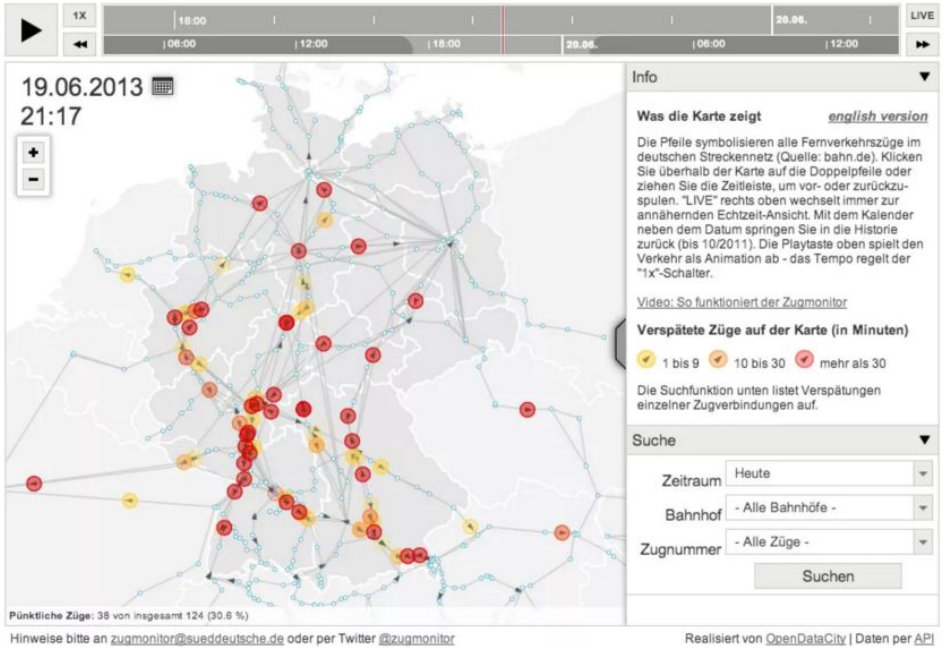
[1] Fleurquin, Pablo, José J. Ramasco, and Victor M. Eguiluz. "Systemic delay propagation in the US airport network." *Scientific reports* 3 (2013).
[2] Campanelli, B., et al. "TREE Model: a Tool to Explore Delay Reduction Scenarios in the ECAC Area." *Proceedings of the Sixth SESAR Innovation Days* (2015).

Datasets: Italian Railways

- Data coming from “ViaggiaTreno.com”
- Real-time info for travellers
- Info about trains from January to November 2015
- For each train: complete schedule, departure delay, arrival delay at each stop

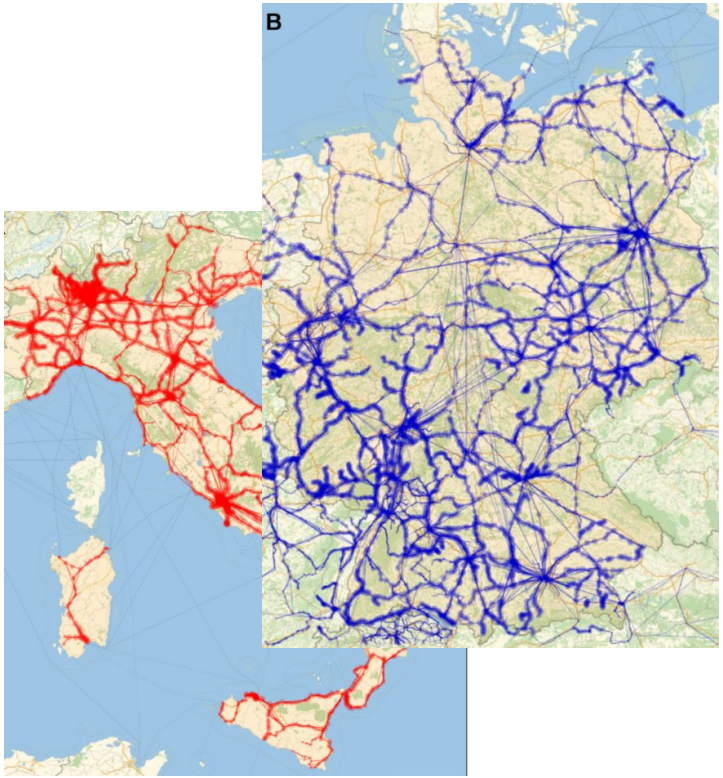
Datasets: German Railways

- Data coming from “ZugMonitor API”
- Real-time info for travellers, but it is long gone...
- Detailed information, delays, schedule, real-time GPS position
- Discarded some info in order to have the same dataset as the Italian one..

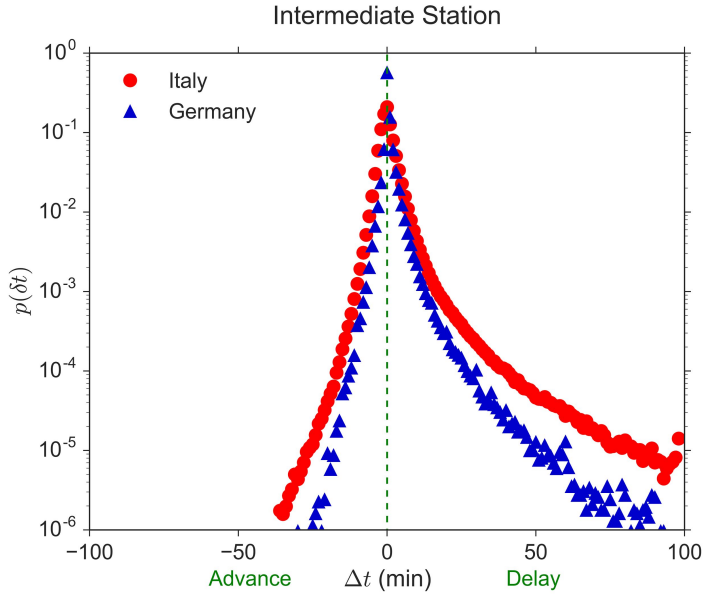


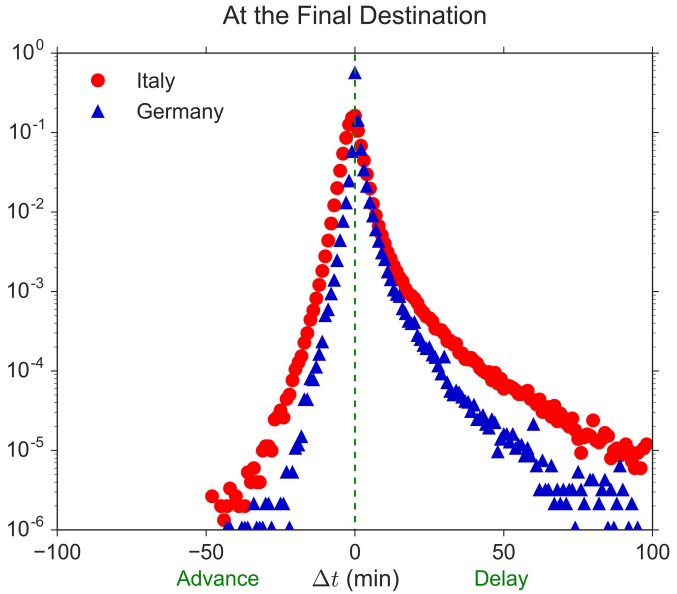
Italy vs Germany

- Different countries with similarities
- Comparable sizes: 41315 (GER) vs 16723 (ITA) km
- Comparable densities: 8.22 (GER) and 12.46 (ITA) km^2 per km of tracks
- Railways are owned by a single large national company (unlike France and UK)
- In both cases we will focus on non high speed commuter trains



Dynamics Generated Delays





- Large tail of “positive delays”
- Negative delay = delay recovery

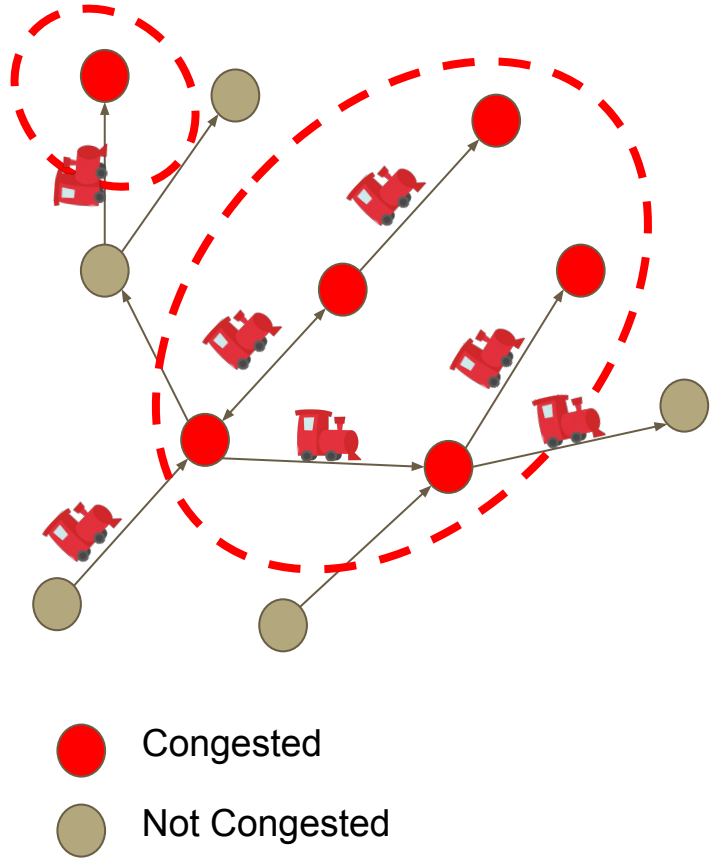
A Very Bad Day in Italy...

- 24h time lapse coming from empirical data
- Italian Railway Network
- Size of nodes = Average Delay

Video: https://www.youtube.com/watch?v=3650uTTyP2A

Congested Clusters

- Congested node: instantaneous delay larger than average delay over the whole sample
- **Cluster of congested nodes**
- Emergence of large clusters ~100 nodes in some case



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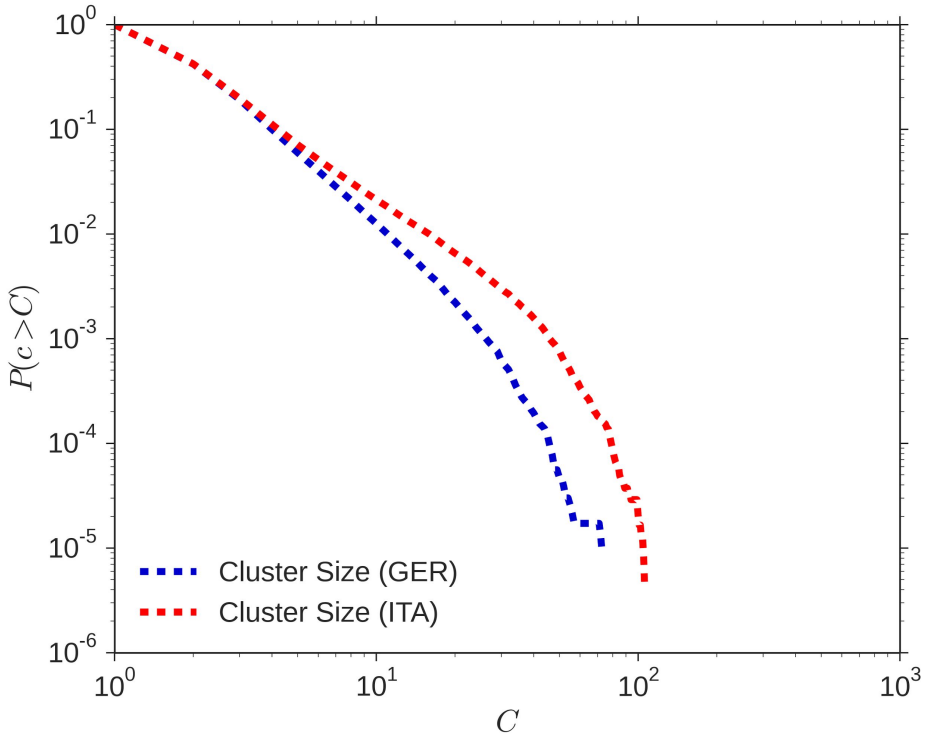
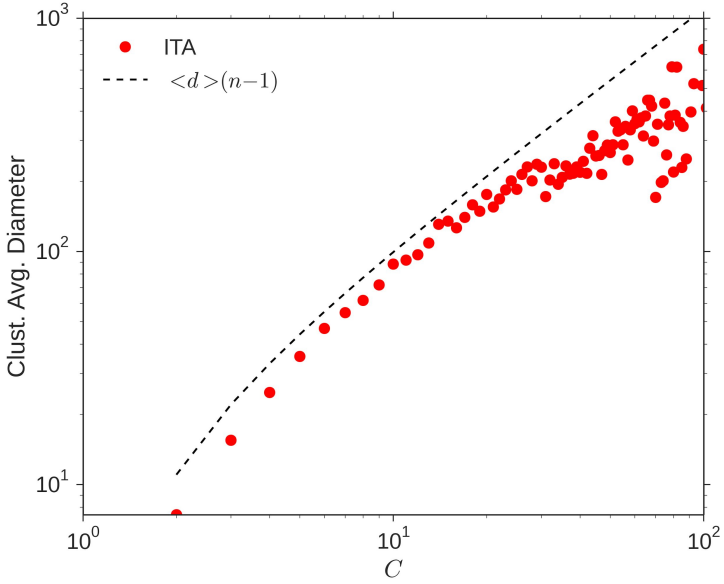
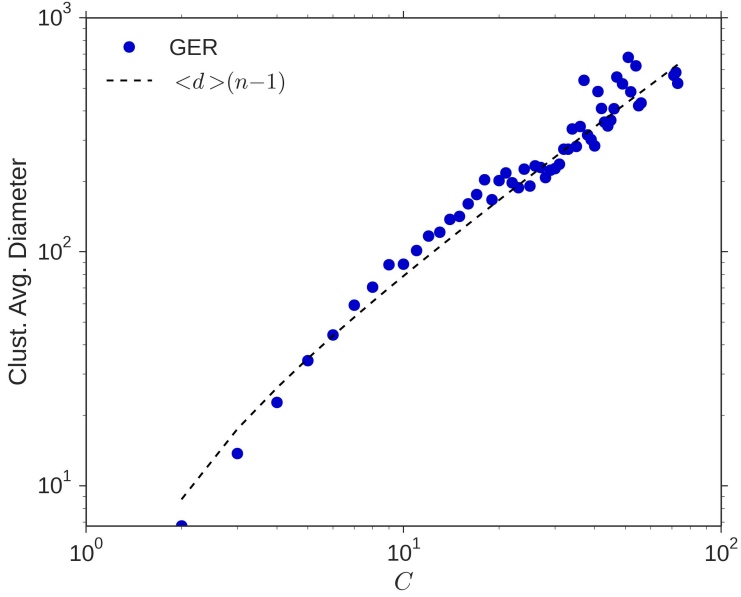


Congested Clusters

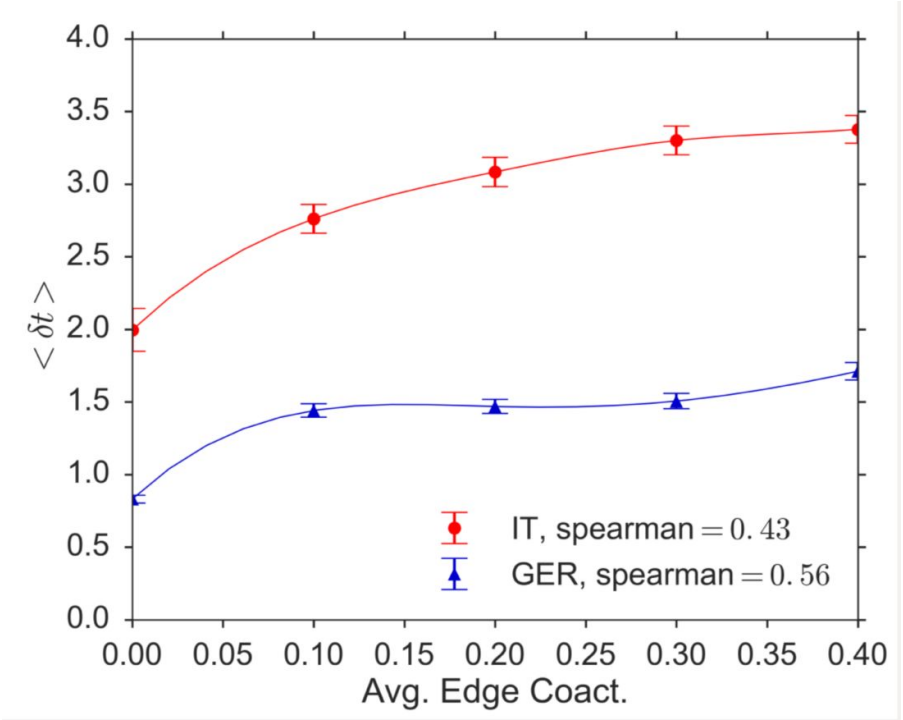




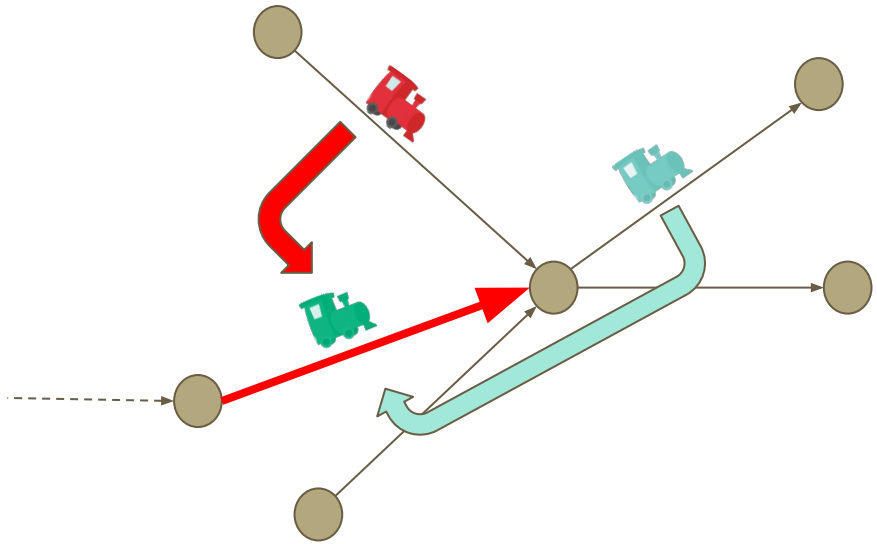
- (Almost) Path-like clusters

The Role of Interaction

- **Average Edge Co-activity**: fraction of times a link is “active” (a train is travelling over it) and at least one of its neighbor links is active too.
- The larger the Co-activity the larger the average delay.
- Possibility of interaction increases the delay



The Role of Interaction

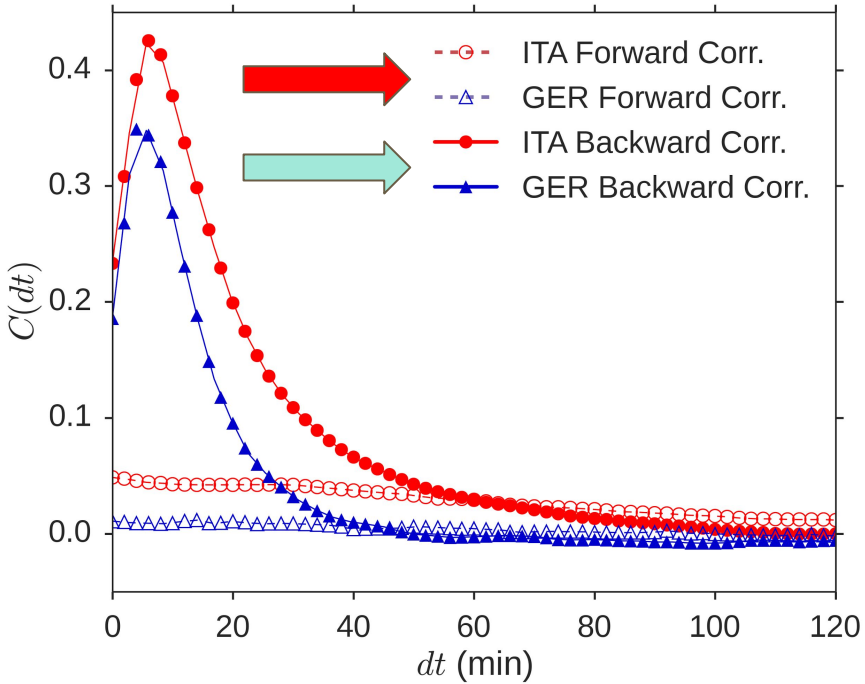


- Interactions with the “previous” links are trivial

“Forward” interactions

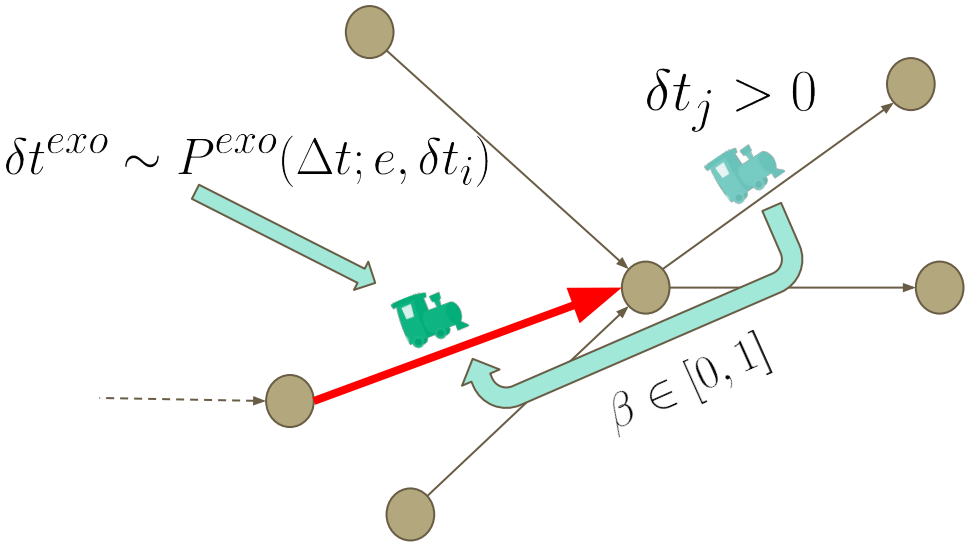
“Backward” interactions

The Role of Interaction



- Correlations between the average delays time serieses of links
- No correlation between links in the “forward” configuration!
- Decaying correlations for links in the “backward” configuration
- **Delays propagate “backwards”**

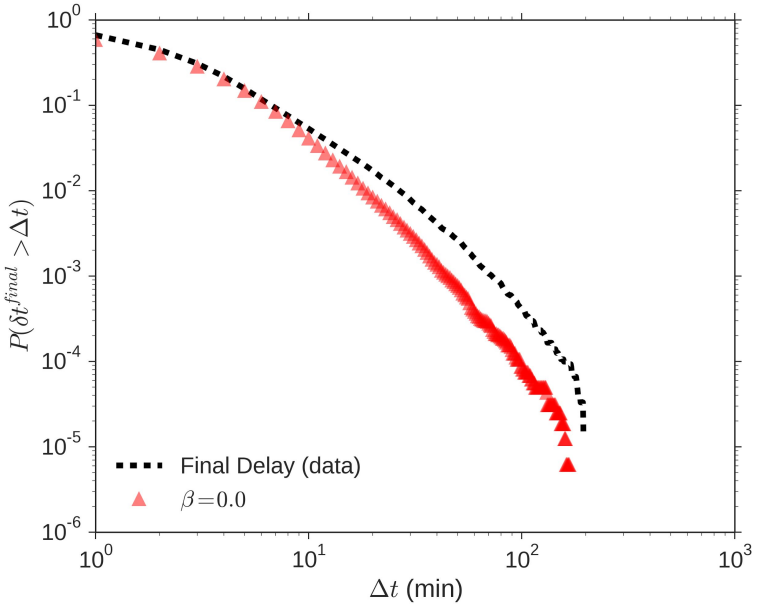
The Delay Diffusion Model

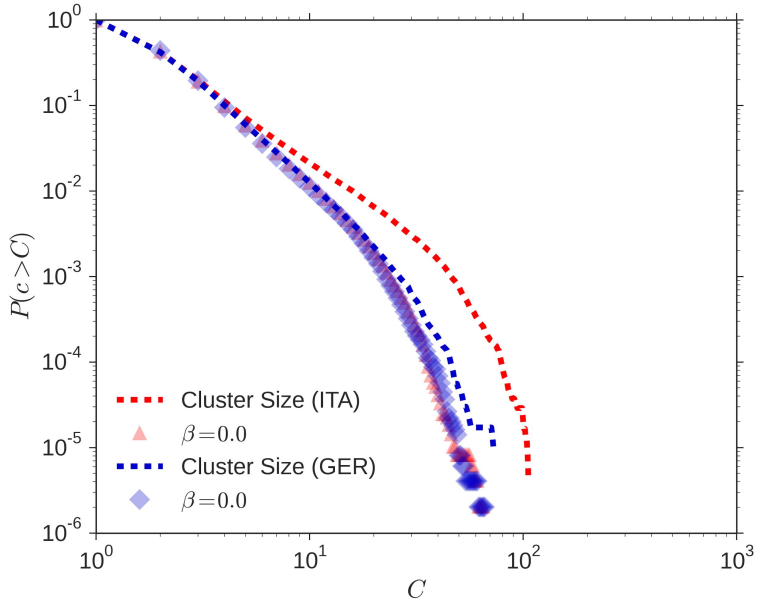


$$\delta t_i \rightarrow \delta t_i + \delta t^{exo} + \delta t_j$$

- Simulate real schedules with real departure delays
- Each time a train starts traveling over a new link its delay can change
- Exogenous link dependent delays:
  - Negative: recovery of delay
  - Positive: delay is getting worse
- “Backward” diffusion of delay with a fixed probability

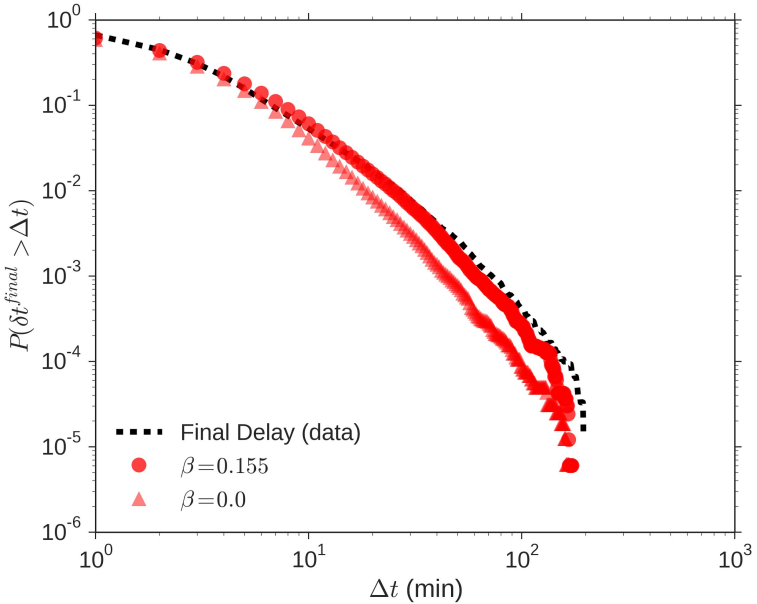
No Diffusion Case $\beta = 0$

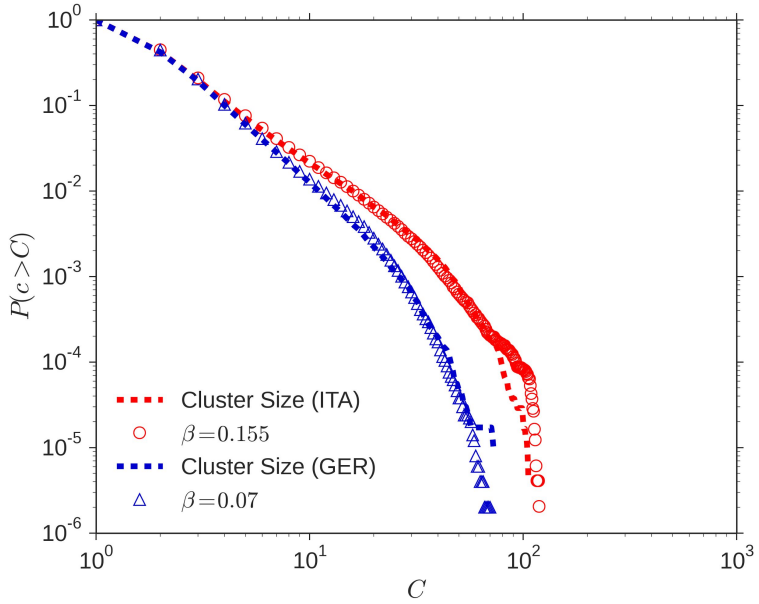




- Smaller tail of large positive delays
- Smaller clusters

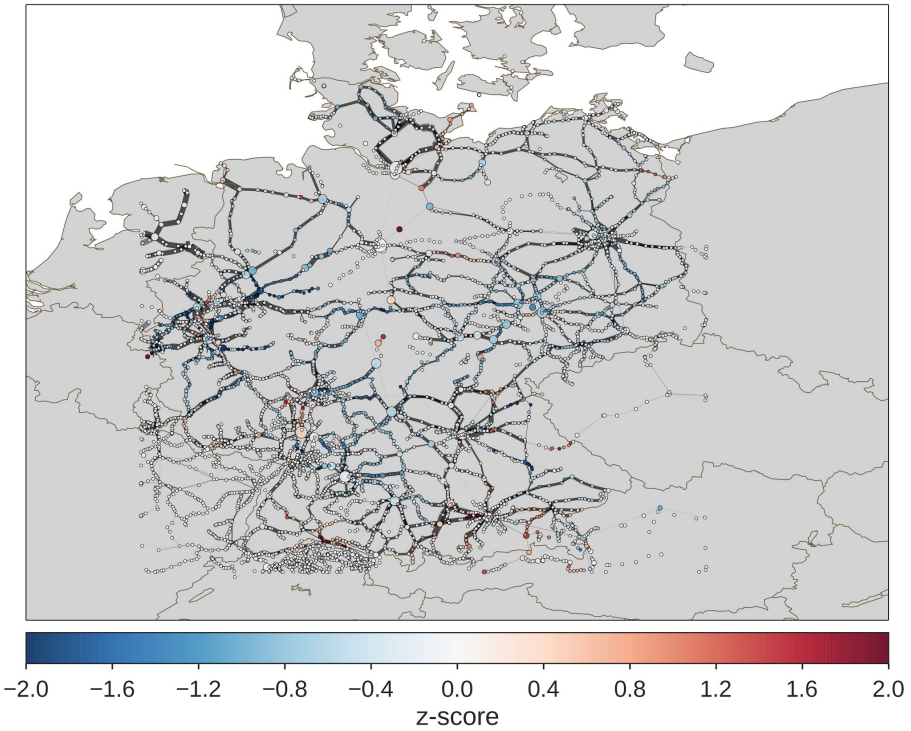
Diffusion Case $\beta > 0$





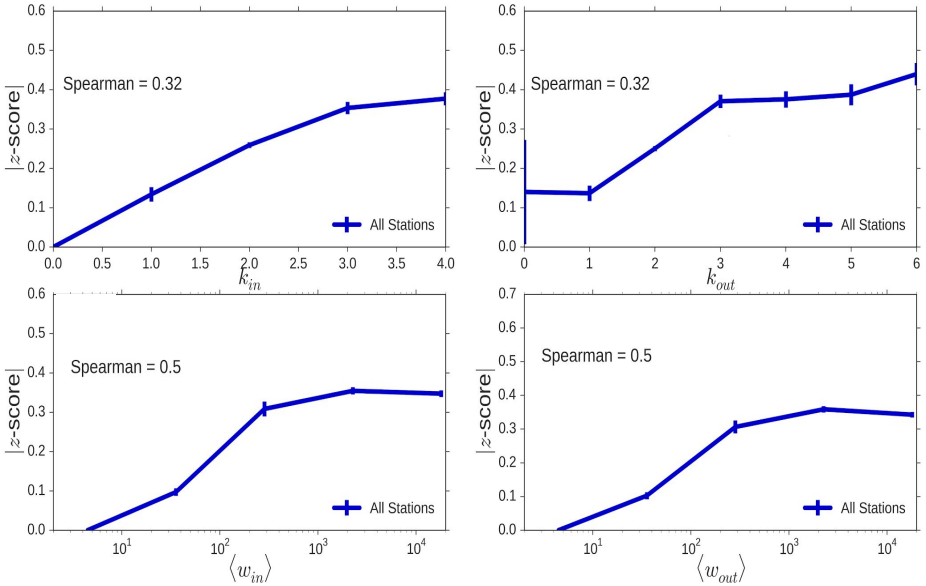
- Interaction leads to large delays and large clusters
- Larger diffusion parameter for Italy

Point-Wise Predictions



- Simulate many realizations of the same schedule
- Z-scores average delay from data vs average delay distribution from simulations
- Large Fraction of Stations with z-score almost zero:
  - 80% Germany
  - 60% Italy

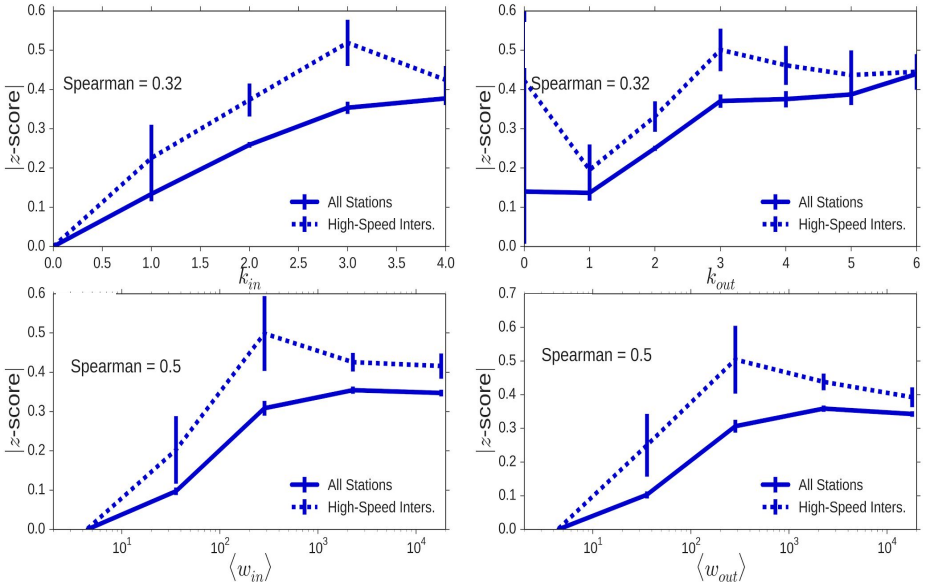
Point-Wise Predictions



- Absolute value of z-score correlated with node degree and traffic

- Topology and traffic dependent diffusion parameter

Point-Wise Predictions



- High-speed layer interaction increases the z-score

- Multilayer Model

Conclusions

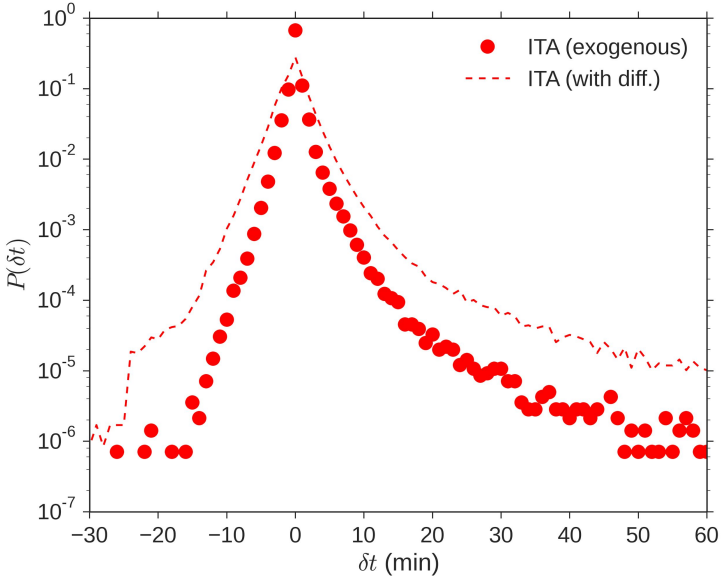
- The commuters railway transport systems are subject to large adverse conditions (extreme delays, large congested areas)
- These conditions are the result of the interplay between “exogenous” events plus diffusion of delays between trains
- Very bad luck does not exists: it is interaction!
- Mean Field Model: diffusion is uniform all over the network
- Interaction between regular and high-speed trains

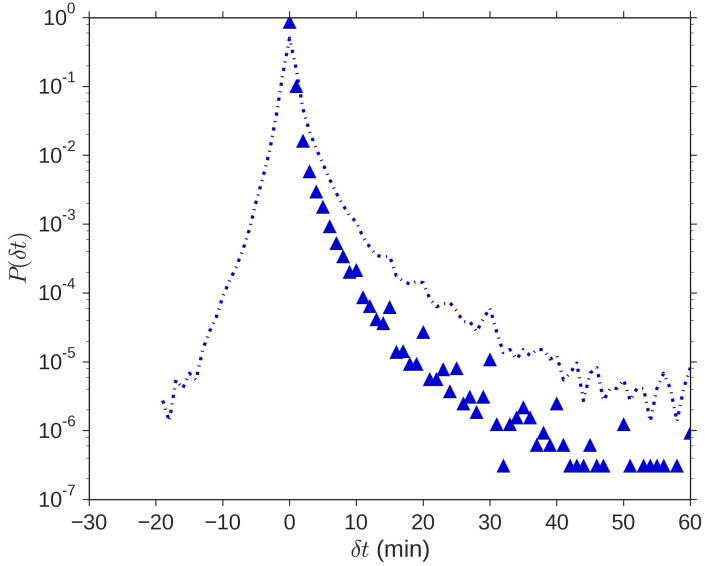
Thanks for the Attention

Collaborators:

Pietro Gravino, ISI Foundation Turin
Vito D.P. Servedio, Sapienza University of Rome
Vittorio Loreto, Sapienza University of Rome
Riccardo di Clemente, MIT Cambridge

Exogenous Delays





Variations of delay when interaction is not possible