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Ministry of Infrastructure and Water Management

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Understanding Behavioral Patterns in Truck Co-Driving Networks

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Complex Networks, Cambridge, UK, December 12, 2018

Introduction

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Problem statement

Obtaining a better understanding of the human behavior of truck drivers through analyzing their co-driving behavior as a network.

Motivation

- Grip on autonomous driving.
- Reduce traffic congestion.

With the use of **network science**.

Data

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- 900,000 trucks
- 10,000,000 measurements
  - License plate (identifier)
  - Time stamp t
  - Location ℓ
  - Speed v

  For Dutch trucks:
  - Maximum allowed mass m
  - Truck place of origin zip
- 17 measurement locations
- 1 year of measurements

Co-Driving Links

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Co-occurrence of trucks a and b takes place if two trucks are at the same place, i.e., their location attribute is identical, so $\ell_a = \ell_b$.

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Co-driving trucks are those co-occurrences (a, b) of trucks that take place within a time window of at most Δt_{max}, so $|t_a - t_b| \leq \boldsymbol{\Delta t_{max}}$.

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Systematically co-driving trucks are those co-driving trucks (a, b) occurring $\Theta = 2$ times.

Co-Driving Network

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The **weighted co-driving network** $G = (V, E)$ consists of *vertices* V (the trucks) and *edges* E. The latter is the set of all trucks involved in systematic co-driving at least 2 times.

Co-Driving Network

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The **weight** $w_{a,b} \geq 2$ (for a given truck pair $(a, b) \in E$) indicates the number of times the two trucks drove together.

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But how to choose the parameter $\boldsymbol{\Delta t_{\max}}$?

Network Construction

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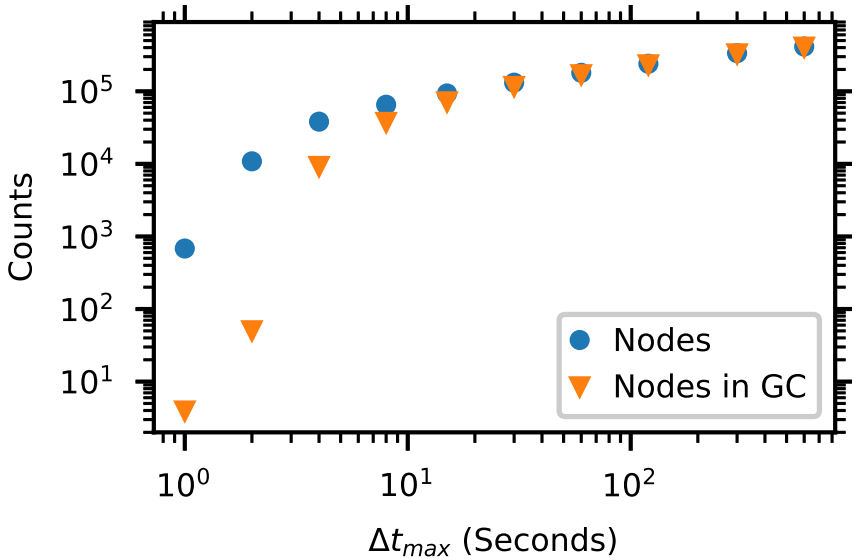

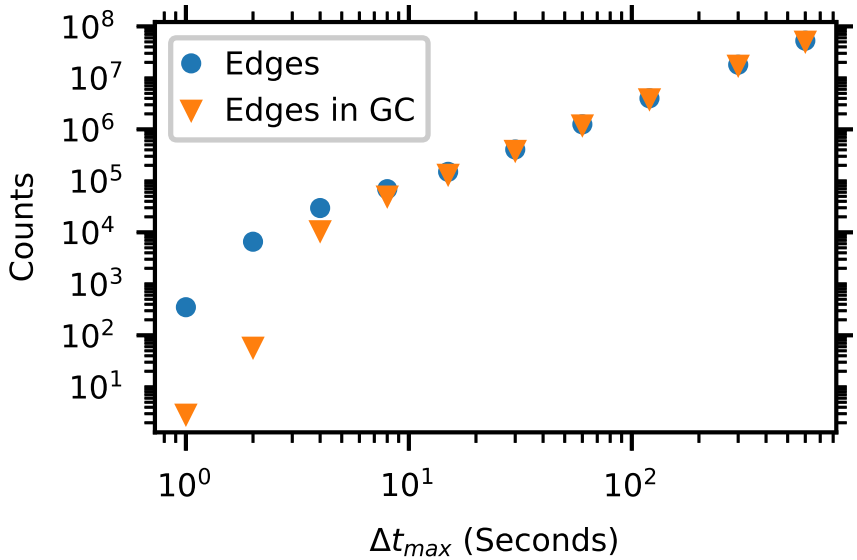

Number of nodes and edges in both the network and its giant component (GC) for different values of Δt_{max}.

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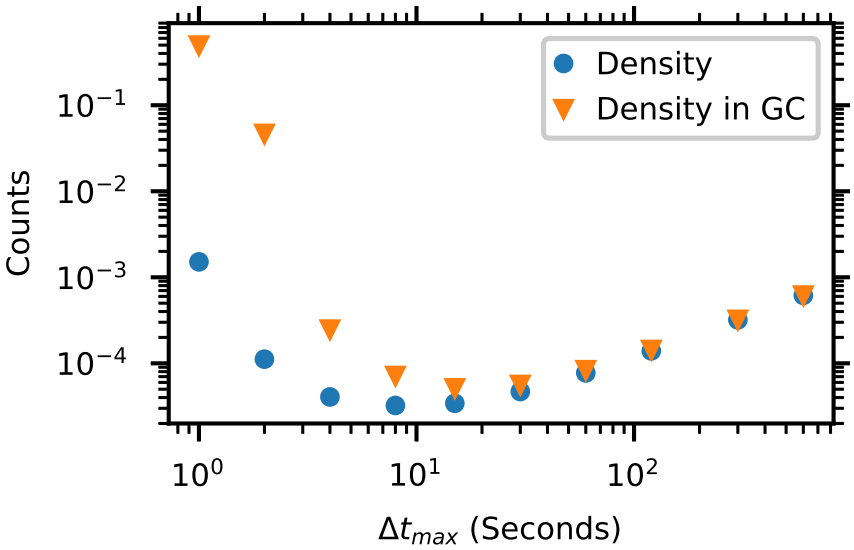
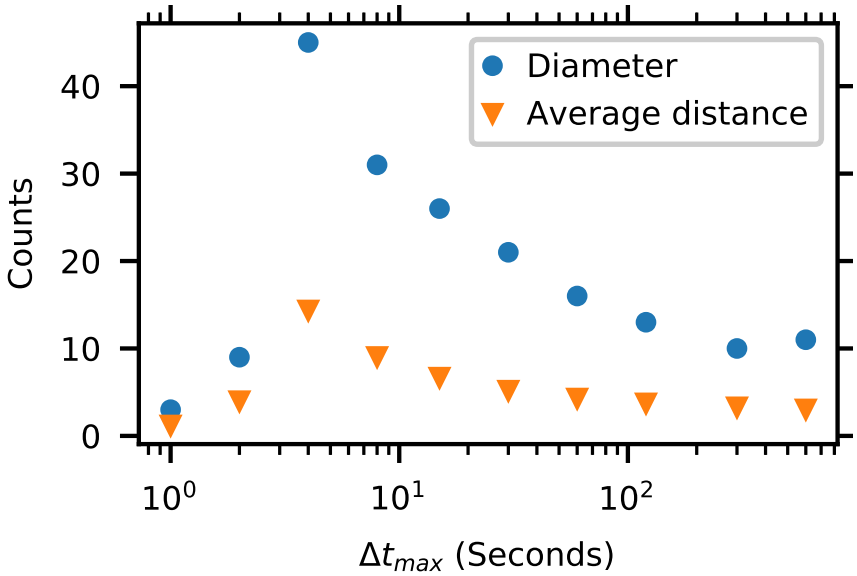


Density in both the network and its giant component.



Diameter and average distance in the network.

Network Statistics

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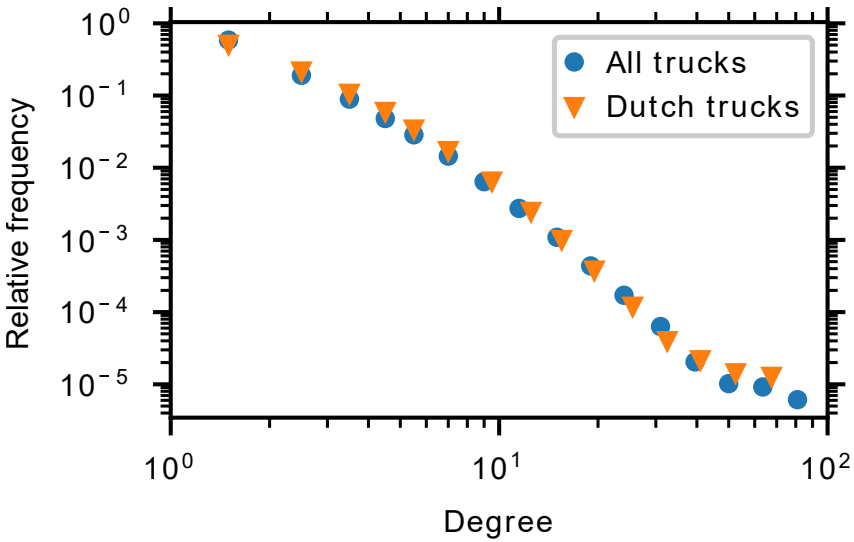
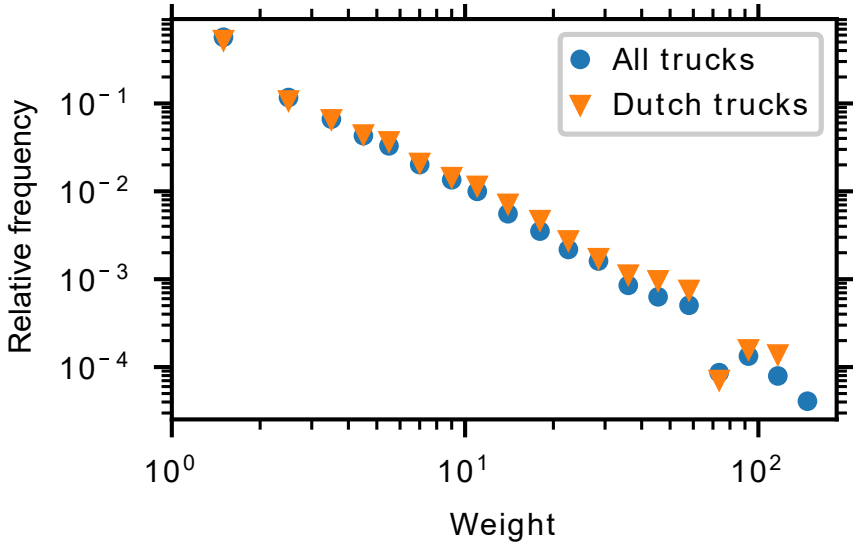
Table: Statistics for full and regional network and their giant component (GC).

Metric	Full Network	Regional Network
Number of nodes	65,290	35,706
Number of nodes (GC)	37,858	22,511
Number of edges	68,958	36,885
Number of edges (GC)	51,730	30,851
Density	3.2×10^{-5}	5.8×10^{-5}
Density (GC)	7.2×10^{-5}	1.2×10^{-4}
Diameter (GC)	31	28
Average distance (GC)	9	9
Clustering coefficient	0.06	0.07
Power law exponent	3.58	3.61

Degree and Weight Distribution





Degree and Weight Distribution

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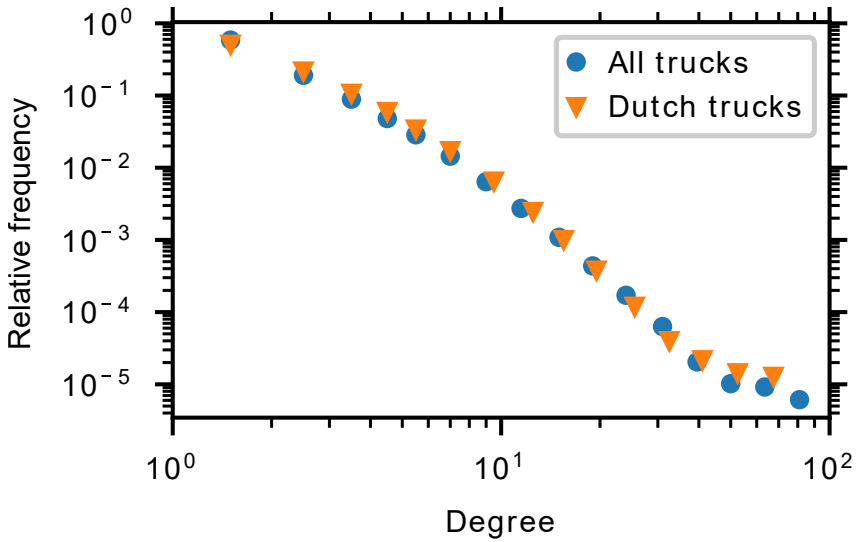

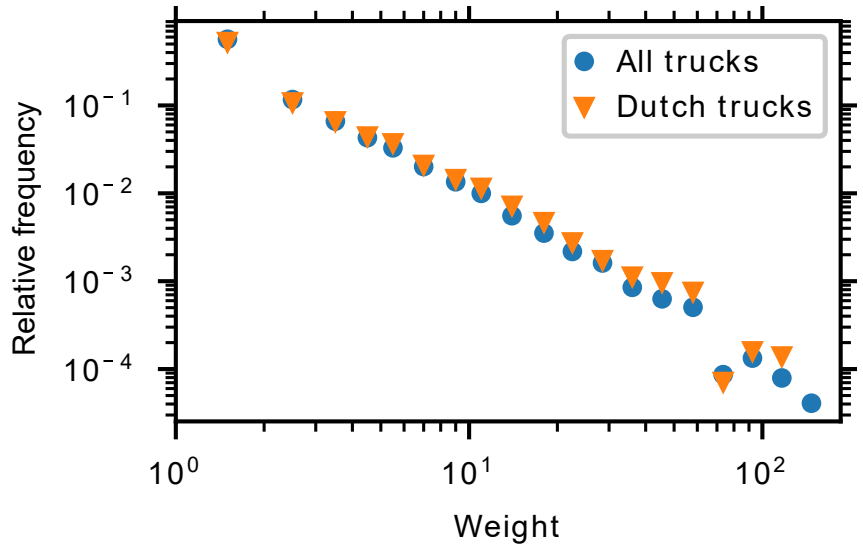

But what kind of links are present in this network?

Attribute Assortativity

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Table: Assortativity of node attributes

Attribute a	Type	Full Network	Regional Network
country	17 categories	**0.56**	-
$\tilde{v}$	numeric	0.55	0.34
n_ℓ	numeric	0.45	0.40
m_{max}	numeric	-	0.35
company	numeric	-	0.29
*zip*4	1,975 categories	-	0.32
*zip*1	9 categories	-	0.41

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Do trucks with similar attributes cluster?

Communities

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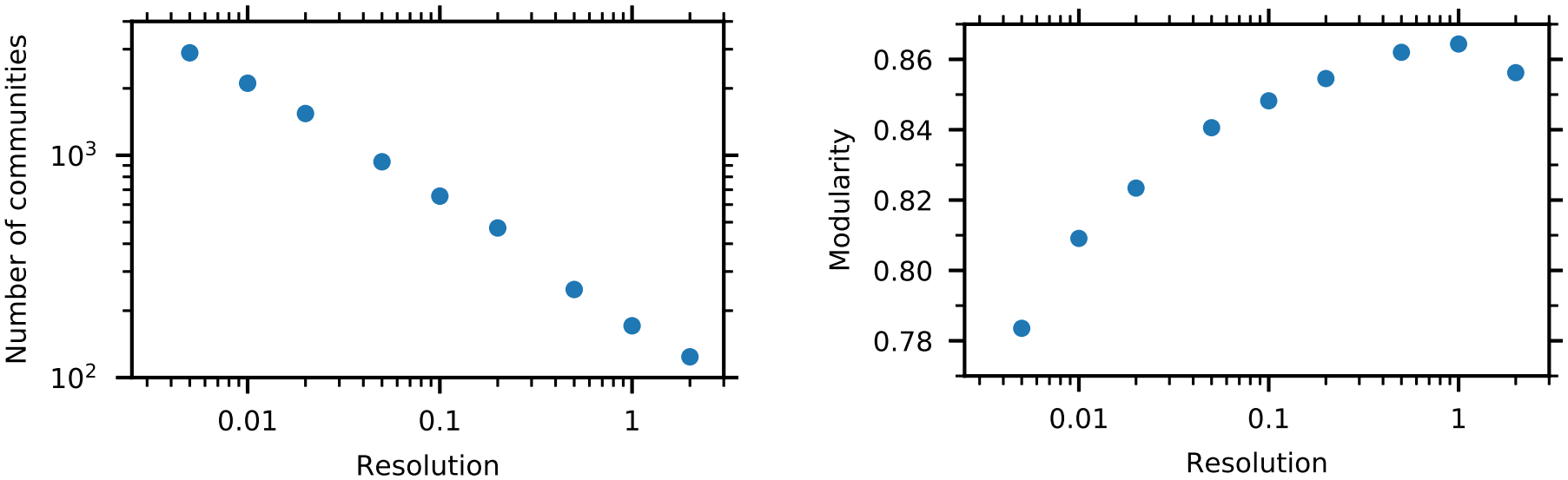

The modularity and number of communities as function of the resolution parameter in the Louvain algorithm.

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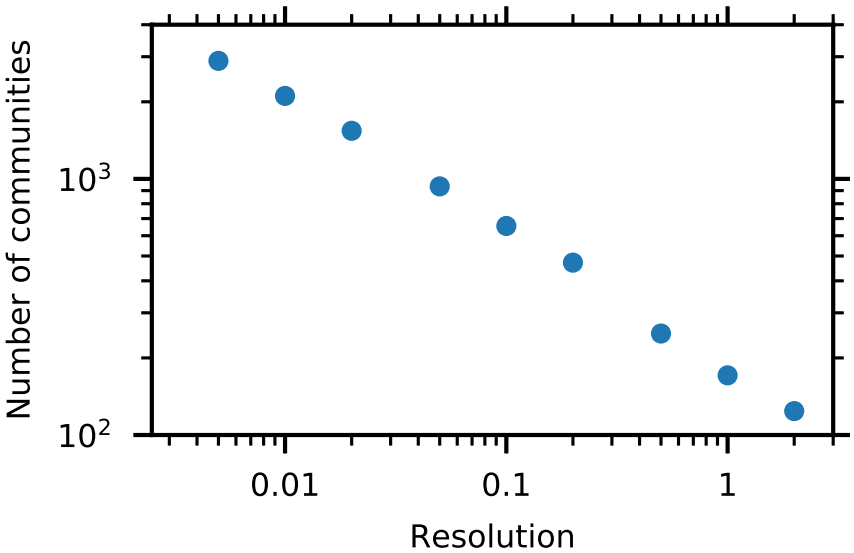

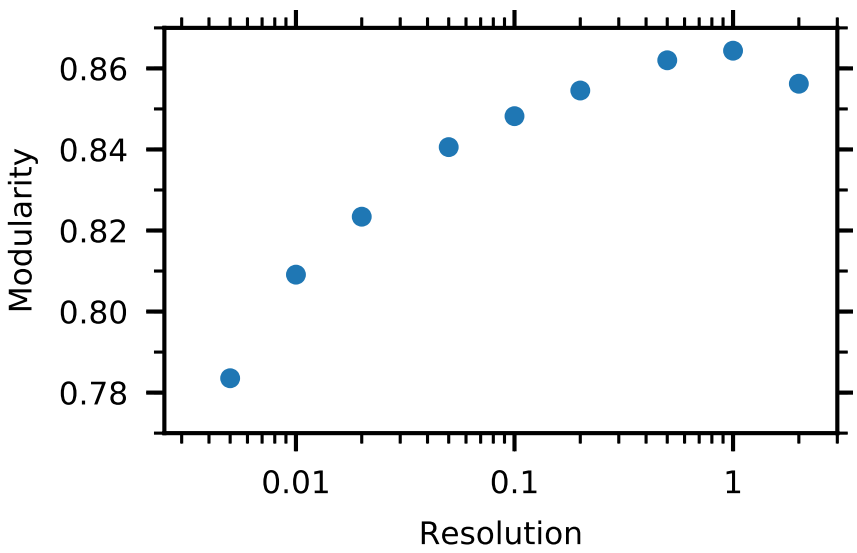

The modularity and number of communities as function of the resolution parameter in the Louvain algorithm.

How to decide on a good resolution?

Understanding Communities

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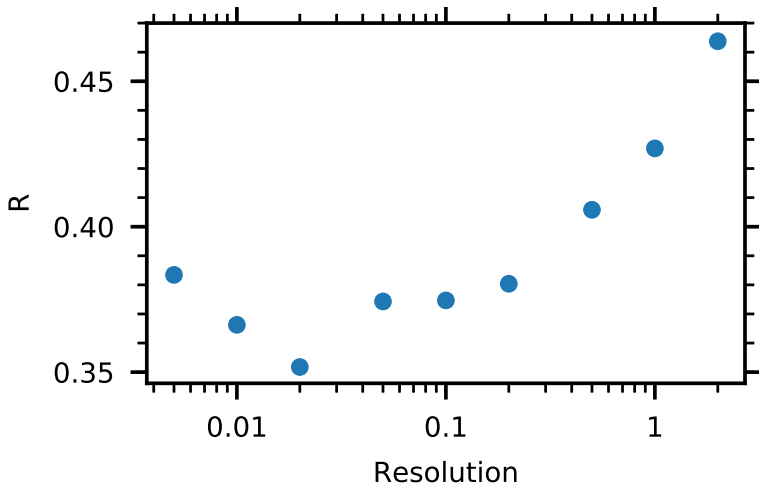
$$R = \frac{1}{|C|} \sum_{c} \max_{a} r_a^{G(c)}$$

- $c \in C$: a single community
- $r_a^{G(c)}$: assortativity of attribute a in induced subgraph $G(c)$ with nodes from community c



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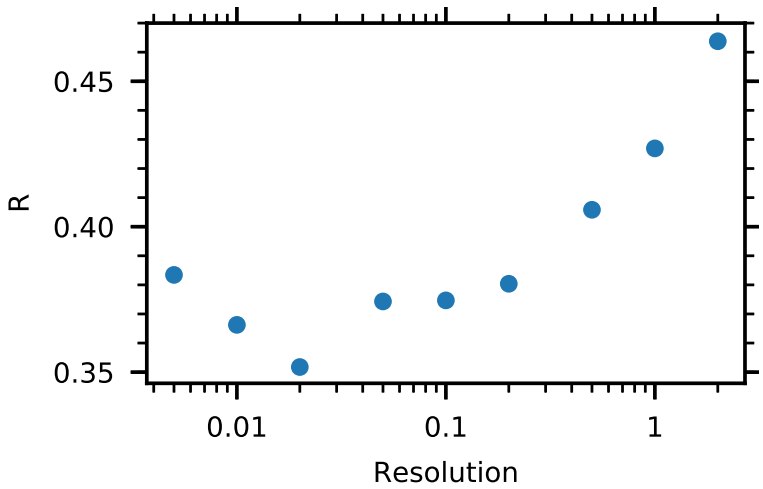

With higher resolution communities are more dominated by the assortativity of attributes.

Conclusion

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- First understanding of co-driving behavior of truck drivers.
- We observed real-world network structure with high modularity.
- Edges in the network were explained using various (geo-)attributes.
- Possible societal impact in reducing traffic congestion and optimizing fuel usage
- **Future work**: network dynamics and applying knowledge in infrastructure domain

Thank you!

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- Questions?

Thank you!

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- Questions?

- E-mail: `g.j.de.bruin@liacs.leidenuniv.nl`
- Leiden Computational Network Science Lab
- `https://cns.liacs.nl`

Measurements

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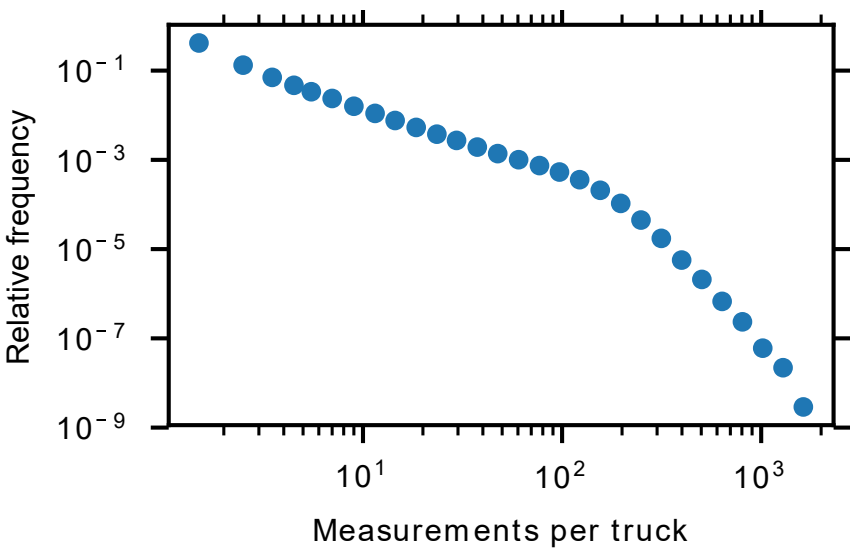

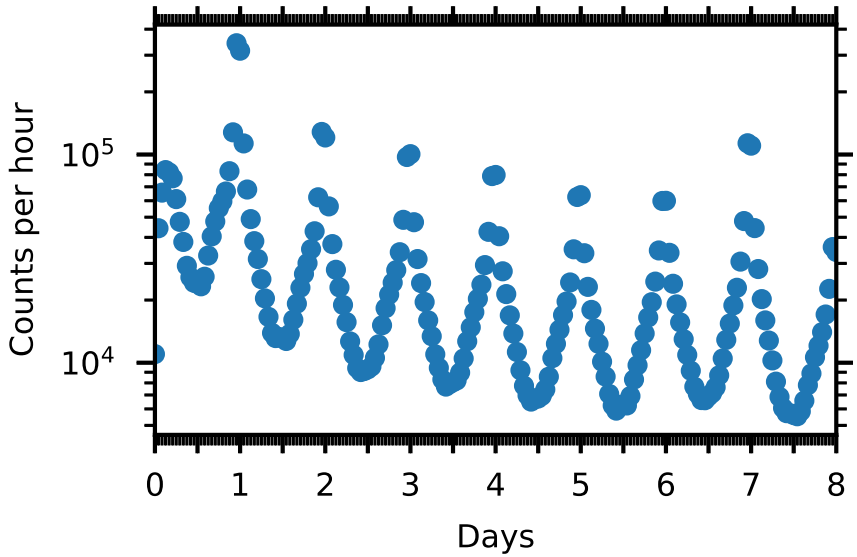

Validation

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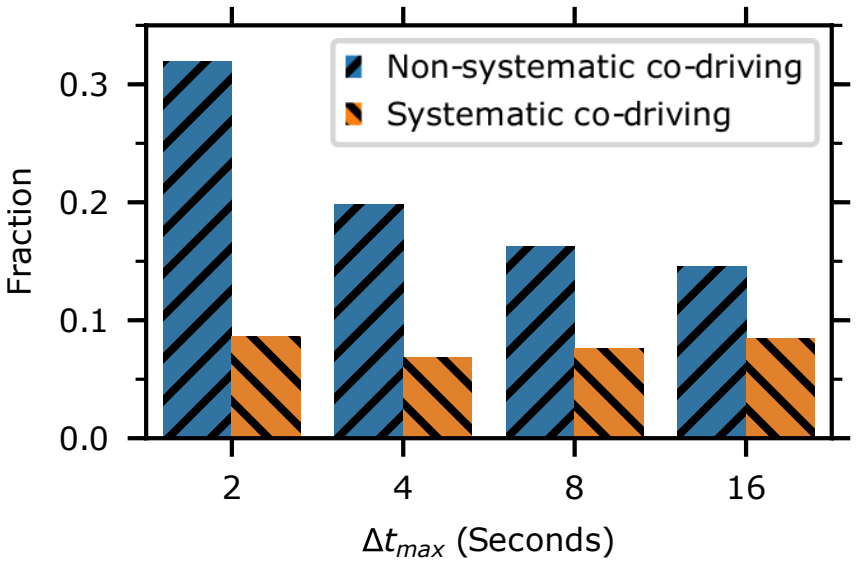

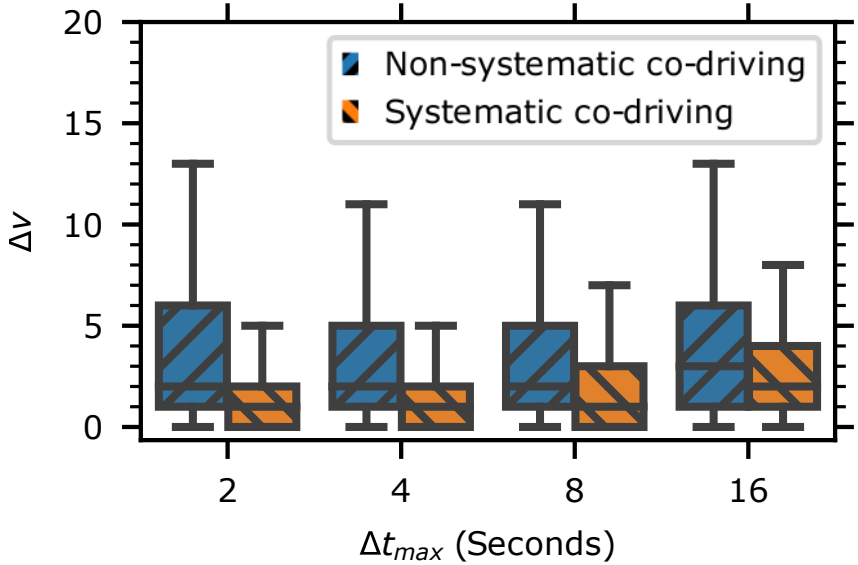

Regional Attributes

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- *city* where the truck is registered
- empty mass m_{empty} of the truck
- maximum mass m_{max} of the truck
- *capacity* of the truck
- *company* that owns the truck
- registration date (*regdate*)
- the 4-digit (postal) zip code of where the vehicle is registered. Attributes zip_1, zip_2, zip_3 and zip_4 each indicate the location with a higher geographic precision.