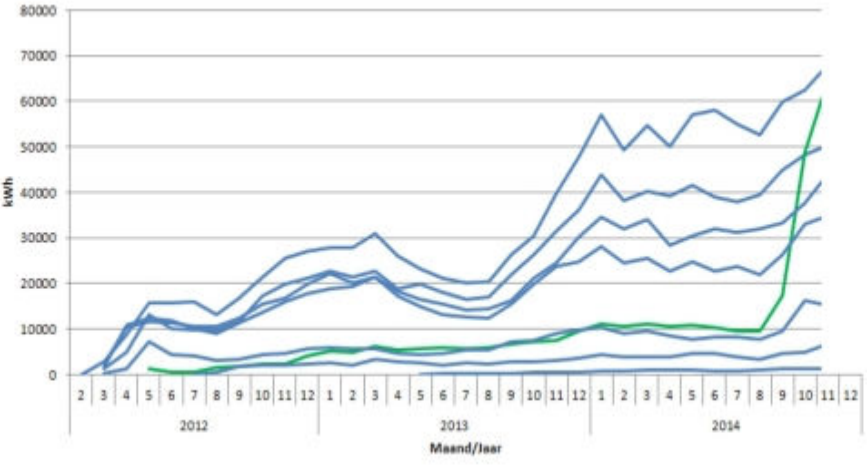

INTERNATIONAL
ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

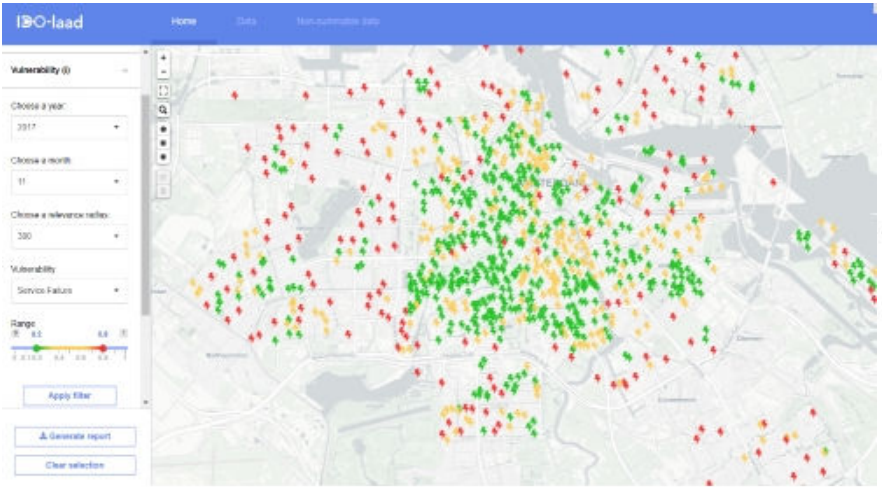

# Exploring a Complex Systems Approach to Charging Infrastructure:

## implications for researchers and policy makers

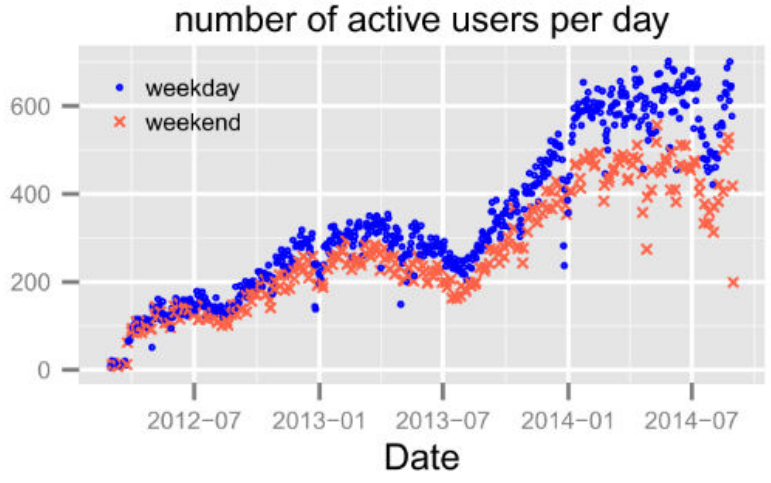
# The IDO-laad research project supports policy makers

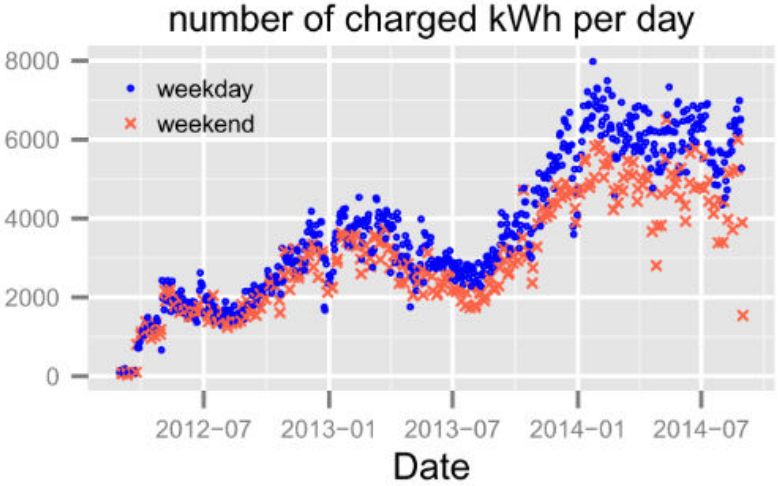
## Monitoring performance



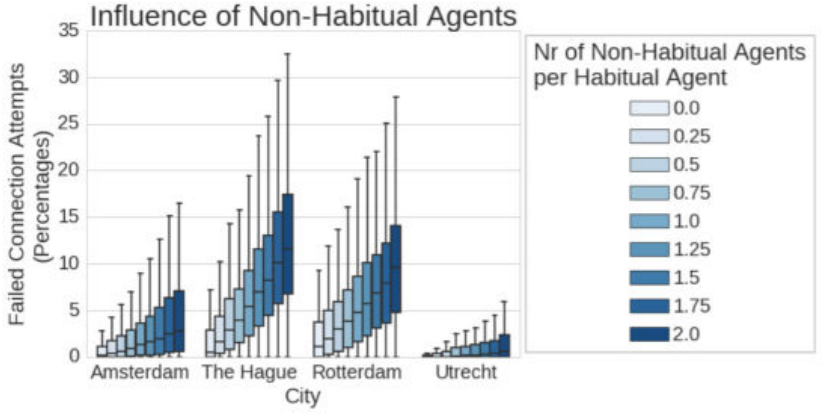




## Predictive analytics




## Modelling & simulation




# The problem of traditional approaches

There exists a gap in current literature on charing infrastructure planning

- Focus on linear scaling rather than non linear effects
- Focus on travelling patterns rather than user behavior
- Focus on performance rather than interactions
- Focus on charging points rather than network formation
- Focus on growth rather than robustness
- Focus on economic feasibility rather than user convenience


EV charging points need EU-wide boost for proposed CO2 targets

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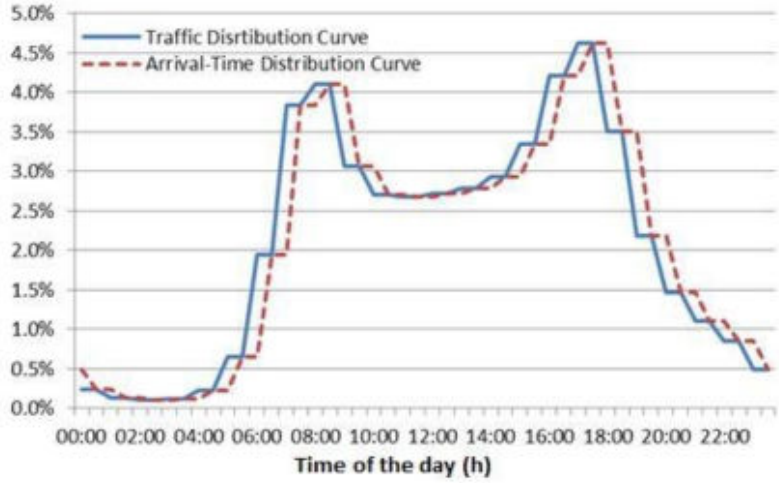


E. S. Xydas, C. E. Marmaras, L. M. Cipcigan, A. S. Hassan, and N. Jenkins, “Forecasting Electric Vehicle Charging Demand using Support Vector Machines.”

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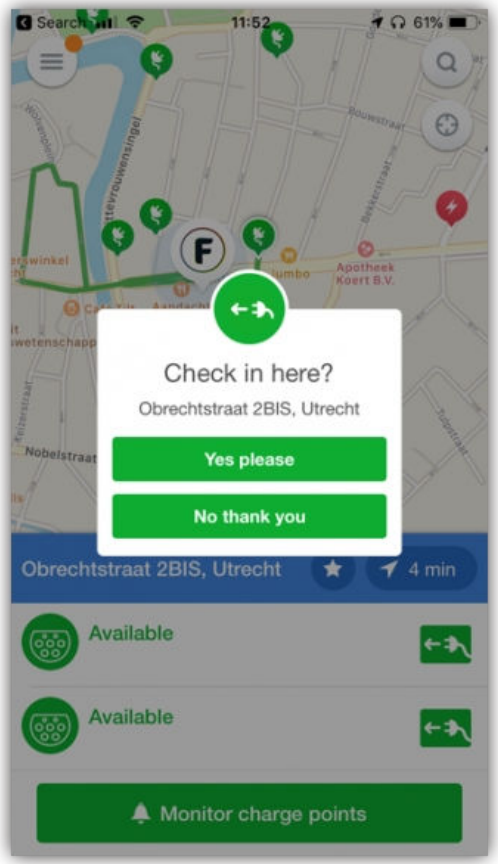

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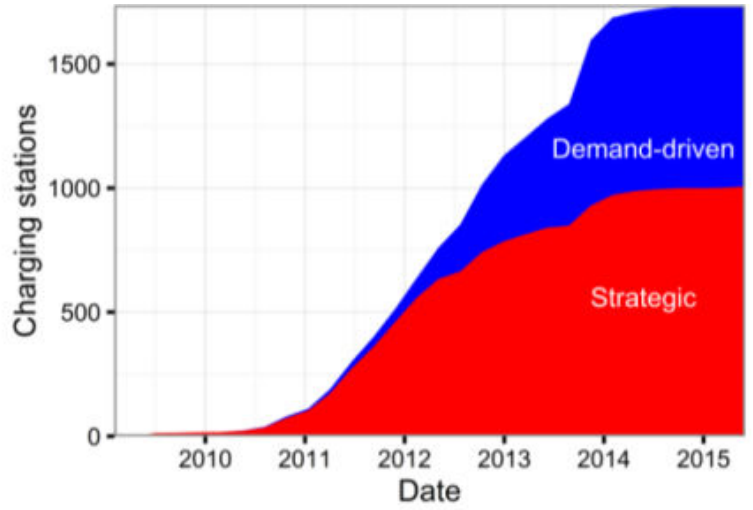


Fig. 1A: Public charging point rollout in the Netherlands between 2012 and 2015

J. R. Helmus, J. C. Spoelstra, N. Refa, M. H. Lees, and R. van den Hoed, "Assessment of public charging infrastructure push and pull rollout strategies: the case of the Netherlands," *Energy Policy*, vol. 121, pp. 35–47, Oct. 2018.

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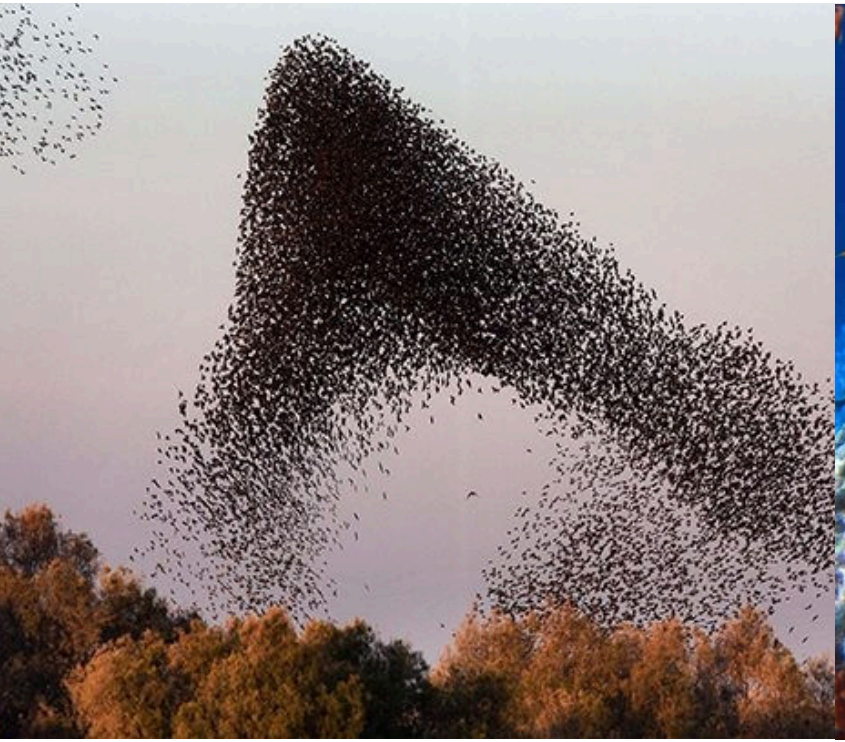
# Complex Systems Theory may help to overcome limitations of traditional approaches

Typical examples of Complex Systems



# Properties of complex systems

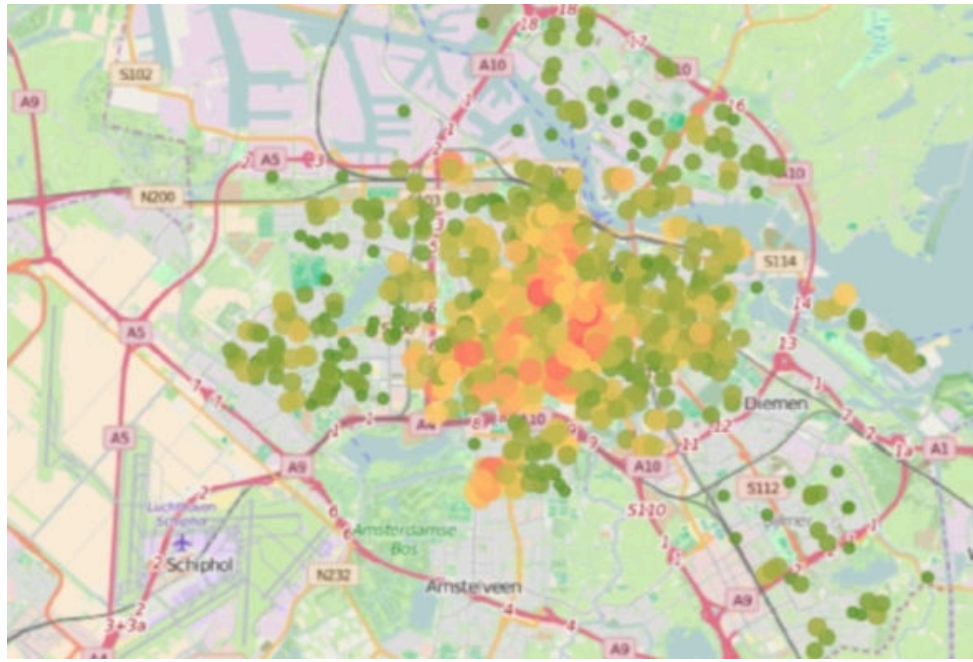
- **Self organization -** no central steering that determines the behavior of users
- **Feedback loops** and **adaptation** – users learn from previous actions and develop strategies
- **Non-linearity** in behavior when scaling the system
- **Emergence** as patterns of non predicted patterns (e.g. competition or collaboration)
- **Robustness** and **vulnerability** of the system in case of outage of 1 charging point
- **Path dependency** – makes is difficult to redo changes of decisions (policies) made earlier

# Illustrations of charging infrastructure as complex system

## Cascading effects of chargepoint perturbations

The are several types of perturbations that can cause an unsuccessful connection attempt:
(1) a malfunctioning CP,
(2) roadblocks (e.g. due to events or repairs)
(3) parking spot occupied by ICE vehicle (being ICED)
(4) non-regular users.

In these cases we assume that EV users are reroute to a new chosen CP in their vicinity. The rerouting behavior may affect the cascade length in the system.



# Illustrations of charging infrastructure as complex system

## Non linear effects of fleet transition from PHEV to FEV*

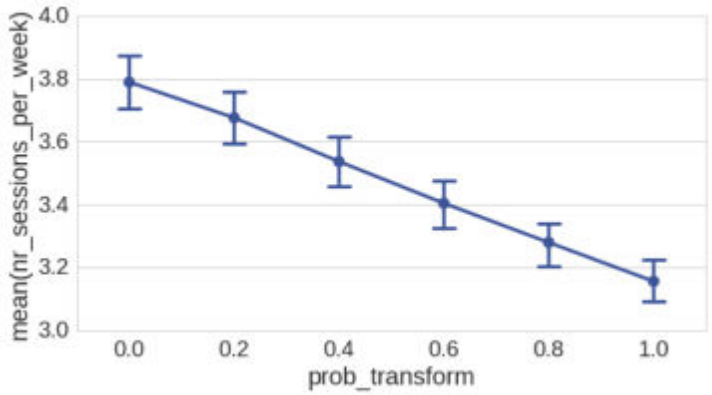
We transform the EV fleet in our simulation from PHEV (battery size <30 and 1 phase charging) to FEV with large battery size (>80 kWh) in the SEVA agent based model** We checked on KPI's and convenience:

- Charging point KPI's showed non linear increase as transition form PHEV to FEV occured
- User convenience increased while CP efficiency increased as well

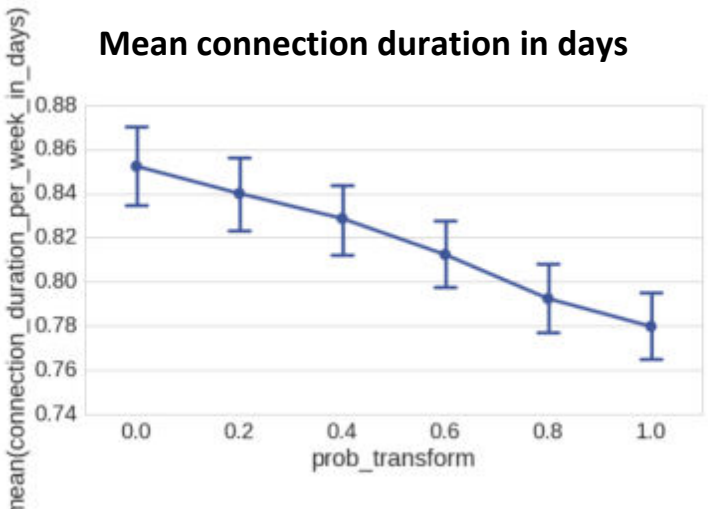
*Currently under review for WEJ

** currently on Arxiv

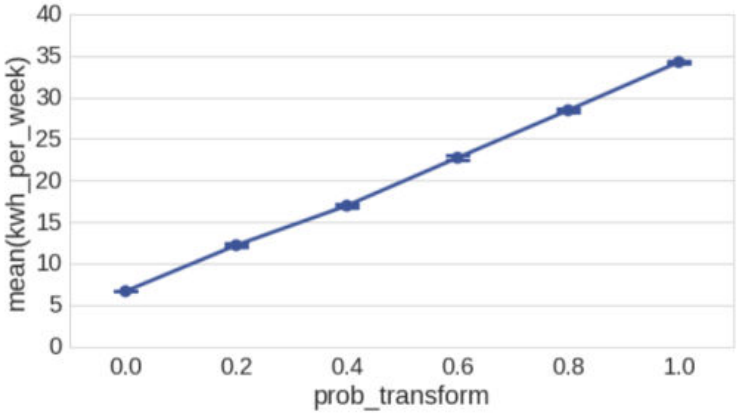
**Nr weekly sessions**




**Mean connection duration in days**




**Mean total Kwh per session per week**



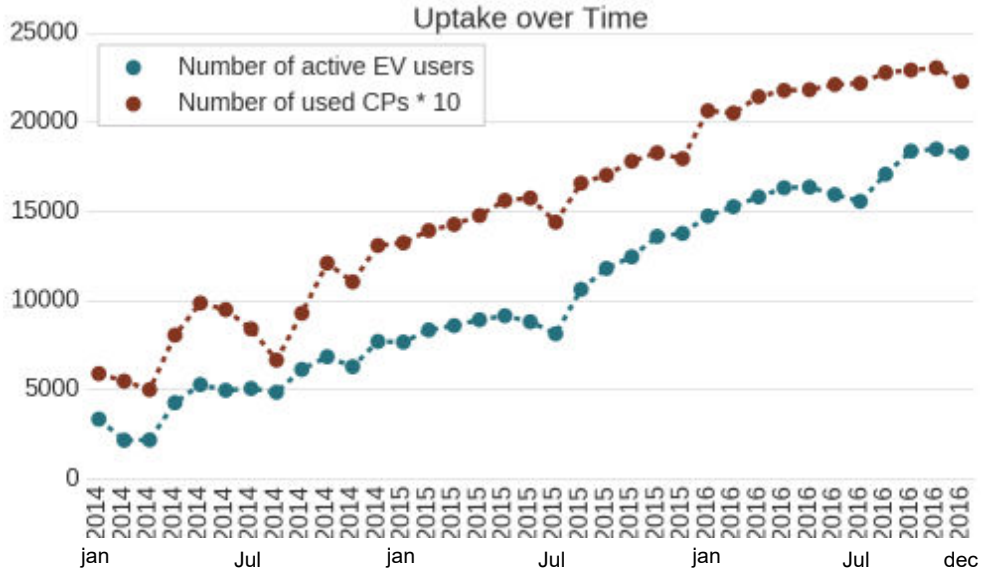
# Illustrations of charging infrastructure as complex system

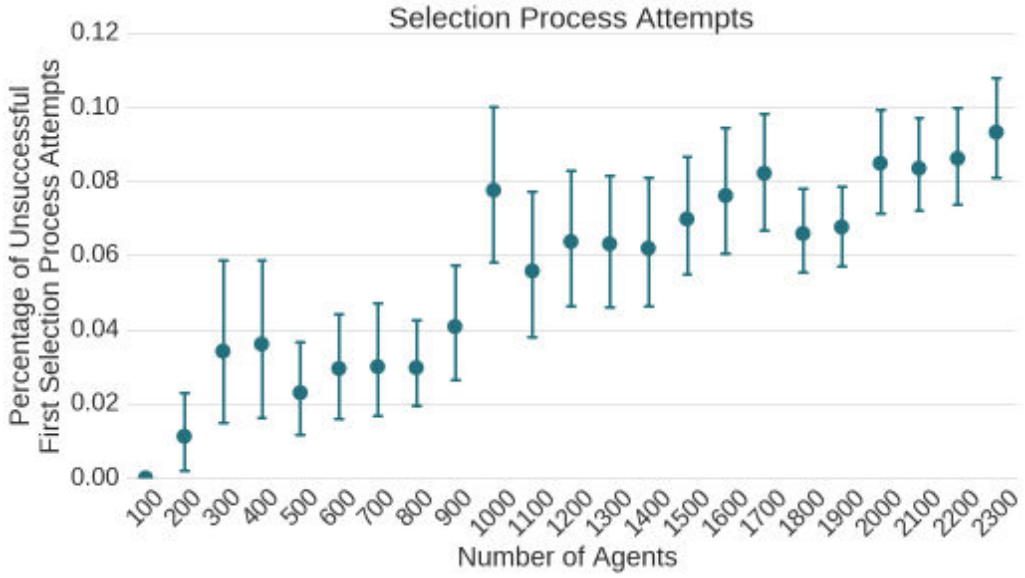
## Simulation of EV user behavior to find unmeasurable patterns

We simulate EV user behavior based on user preferences and activity patterns in time and space

We increase the system in (1) number of EV users and (2) size of charging infrastructure

We find a growing number of failed connection attempts at increase of EV users which can be a driver of inconvenience for EV users. We find network effects and non linear effects of scaling both EV users and Charging points. See also Rick Wolbertus (session D7) on wed. 22 May 9:00. Room Mezzanine 2+3



# Implications for researchers and policy makers

- look beyond the typical key performance metrics of charging infrastructure to gain a better understanding of the interactions between users in the system
- embrace the use of (agent based) simulation model rather than linear planning models
- Focus on nudging EV users' charging behavior to optimize the total performance of the EV system
- Search for critical transitions in user behavior as the charging infrastructure and EV user adoption scales

# END

# Illustrations of charging infrastructure as complex system

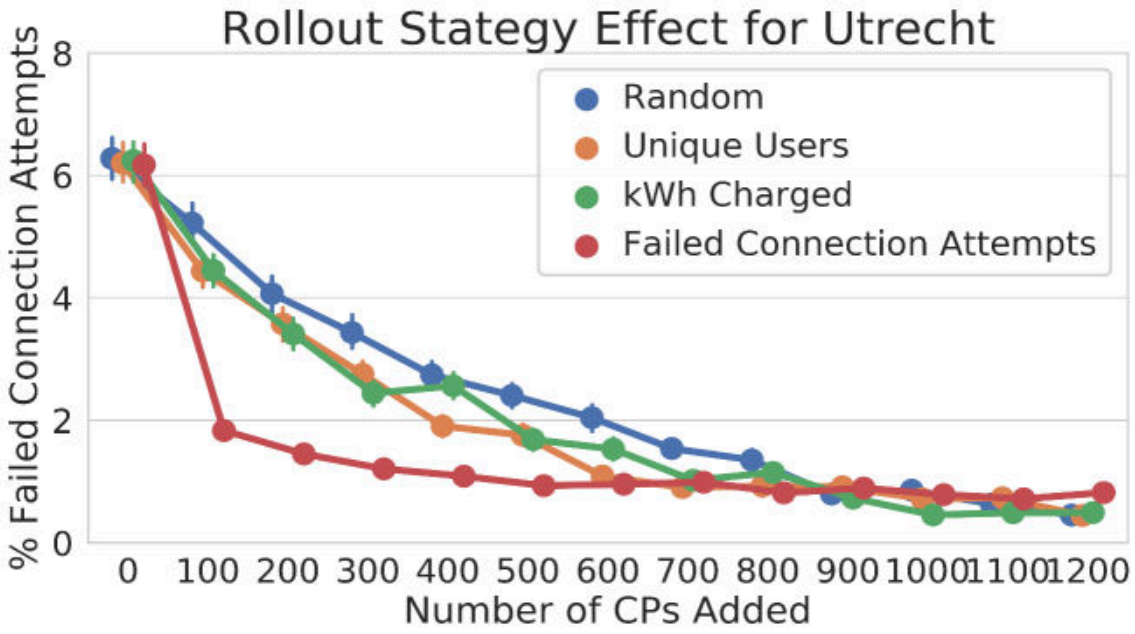
## User convenience driven roll-out strategy

The challenge is to have a rollout strategy that generates most uses convenience for least cost and highest number of users. User convenience is measured in number of failed connection attempts

- Base case: current user population population
- Experiments: extension of current sockets by
  - (i) Random selection of charging locations
  - (ii) Increase at high # unique users
  - (iii) Increase at high performing CPs (in kWh)
  - (iv) Increase on vulnerable CPs

(i) Analysis:

- (v) effect of failed connection attempts
- (vi) Charging infrastructure vulnerability



# Illustrations of charging infrastructure as complex system

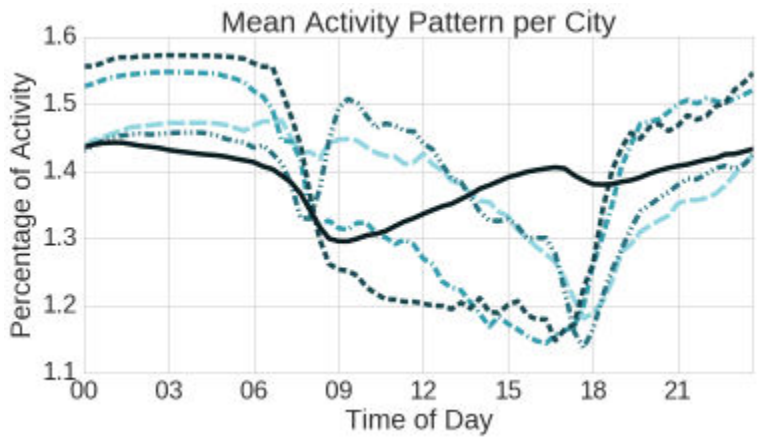
## Nudging EV users to increase total EV infrastructure convenience


| | | CP Preferences | | | |
|---|---|---|---|---|---|
| Session | User | 1st | 2dn | 3rd | 4th |
| 1 | I | 5 | 6 | 4 | 1 |
| 2 | II | 4 | 6 | 1 | 2 |
| 3 | II | 4 | 6 | 1 | 2 |
| 4 | I | 5 | 6 | 4 | 1 |
| 5 | III | 4 | 2 | 3 | 1 |
| 6 | II | 4 | 6 | 1 | 2 |

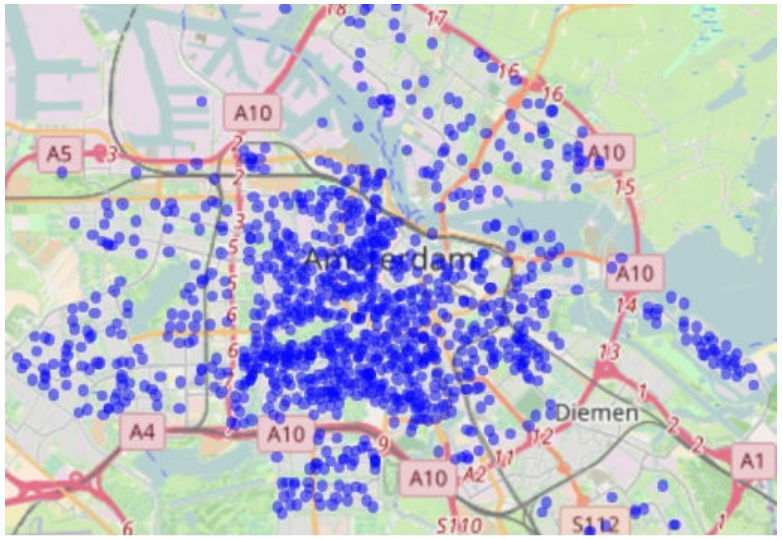
| | Total System Inconvenience | | | | | |
|---|---|---|---|---|---|---|
| Session | CP1 | CP2 | CP3 | CP4 | CP5 | CP6 |
| 1 | 7 | 1 | 5 | N/A | N/A | 5 |
| 2 | 11 | N/A | 0 | 2 | 6 | 0 |
| 3 | 0 | 1 | 5 | 0 | N/A | |
| 4 | 0 | 6 | | N/A | 5 | 4 |
| 5 | 5 | N/A | 1 | 0 | 1 | 2 |
| 6 | 2 | 5 | N/A | N/A | 1 | 0 |

# Charging behavior of agents is modelled by activity patterns, geospatial clusters of activities and discrete choice modelling

## Activity patterns




## Geospatial clustering of destinations




## Discrete choice modelling