Delivery Route Based ERS Network Optimization

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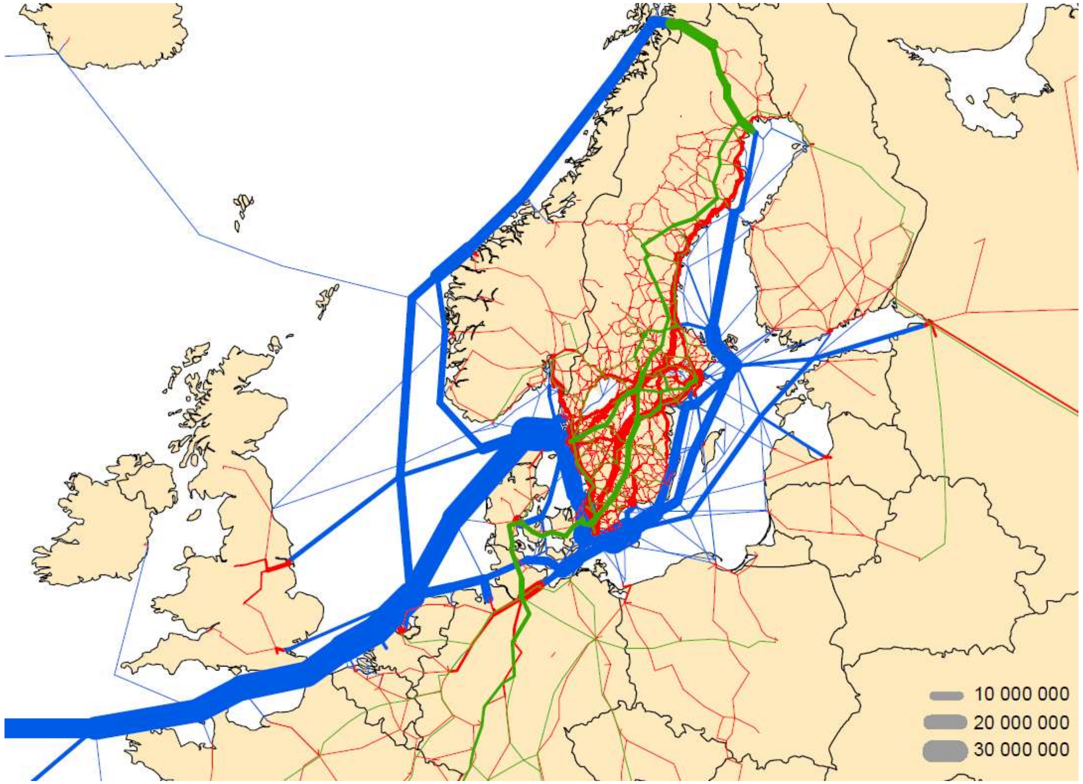
Background

- ERS network infrastructure development aspects:
  - Vehicle-powertrain-infrastructure technologies and trends
  - Current and future transport demand
  - Energy systems and production
  - Logistics operations
  - Environmental impact
  - Business models
  - Policy
  - …
- ERS development is costly: 0.5-0.8 M€/km
- Selecting the right segments to electrify is important

Many Segments to Select From



Total goods flows in 2006 on road (red), rail (green) and sea (blue) according to the national goods transport model Samgods [Trafikanalys Report 2016:7]

Research Questions

- How to estimate the electrification utility of a segment in a partially electrified ERS network for routes of various vehicles having various powertrains and carrying various loads?
- How to find a partial ERS network that maximizes the electrification utility for a given ERS infrastructure investment budget?
- What is the impact of the partial ERS on transport efficiency, environment and logistics?

Flows / Routes as Grounds for Selection

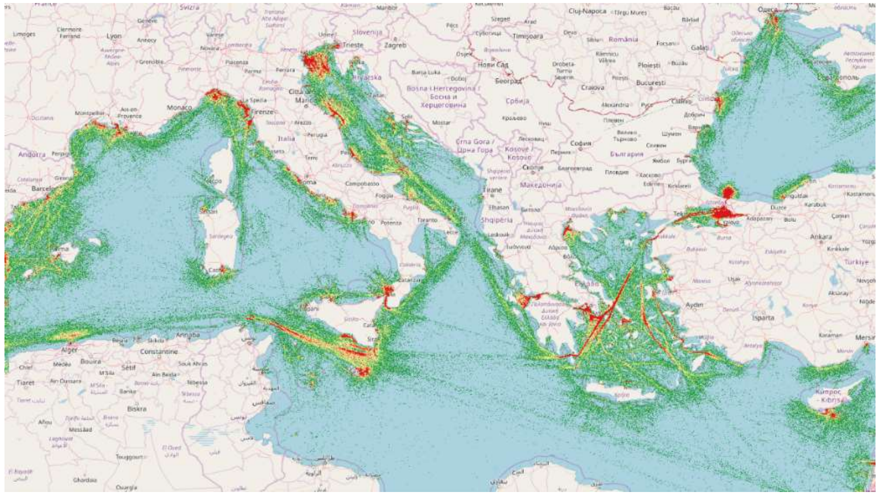
- Current methods try to optimize the ERS network based on "select link analysis which, based on network assignment models / assumptions, provides information of **where** traffic comes from- and goes to at selected links, i.e., the spatial distribution and origin–destination (O–D) pair composition of aggregate link flow".

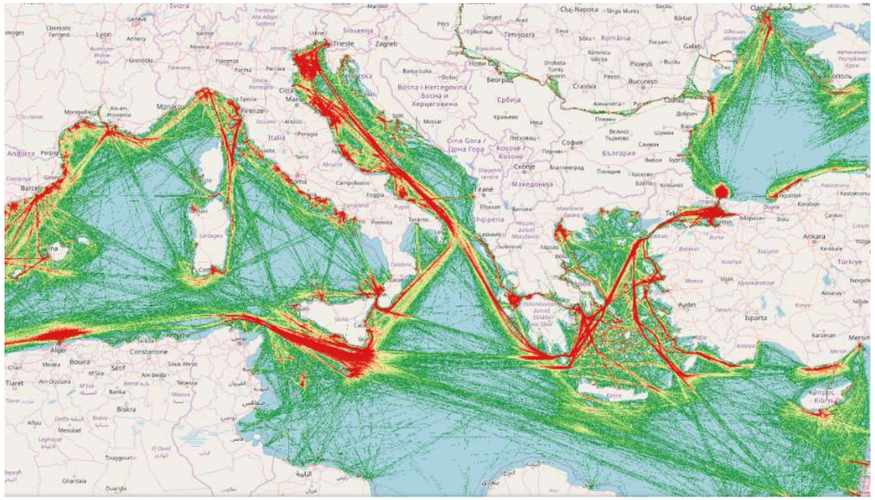
- **BUT** knowing **how** traffic comes from- and goes to at selected links is essential for ERS network planning. **Electrification utility of segments** in a network are **not independent of one another** but largely **depend on which part of the routes include the segments**.

Why Route Based?

Connect the dots...

- Isolated treatment of locations in a moving object trajectory leads to misinformation and suboptimal decisions.



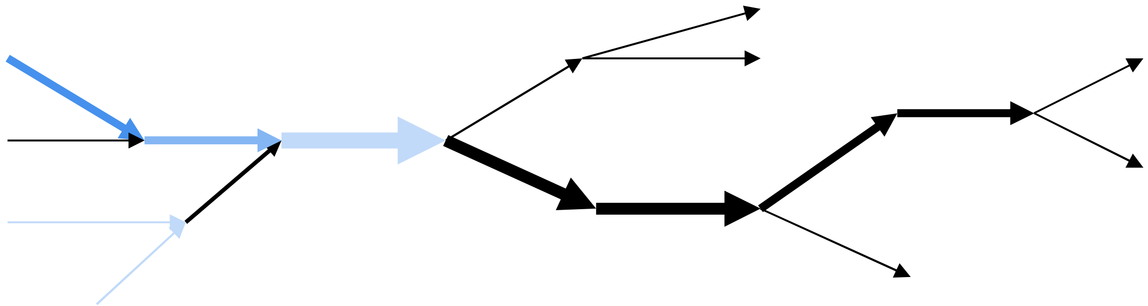


- Vessel traffic density estimates based on isolated location measurements
- Vessel traffic density estimates based on trajectories / routes

Route-Based Electrification Utility

- What does the electrification utility of a ERS segment *S* depend on?
  - Charging and discharging of Vehicle-Load-Powertrain-ERS (VLPE) configurations
  - Topographic and physical characteristic of *s*
  - Number and duration of VLP config traversals on *s*
  - Battery state of VLP configs reaching and leaving *s*
  - Length and spatial distribution of routes of VLP configs reaching and leaving (passing through) *s*

- Shade of blue arrow indicates battery state (darker means higher)
- **Black** arrow indicated empty battery
- **Width of line** indicates number of traversals
- Red arrow indicates electrified segment that "boosts the battery state by two shades"



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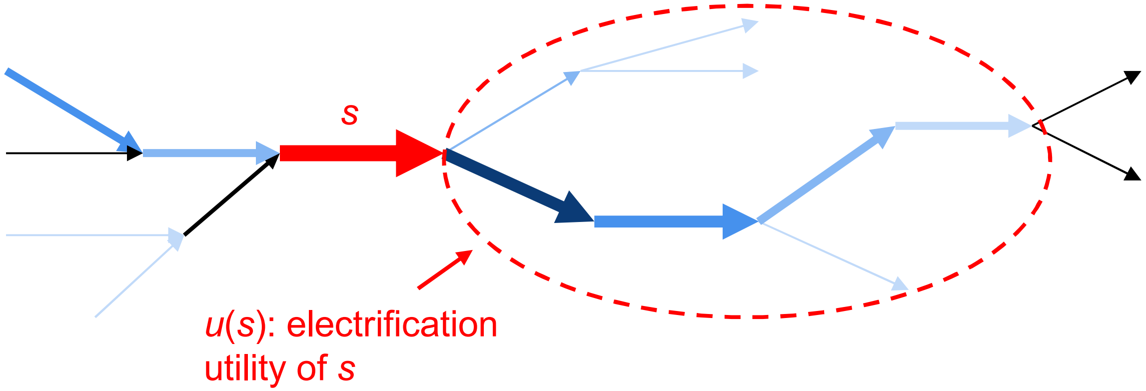

Proof of Concept

Hypothesis: Route based utility is significantly different from segment based utility.

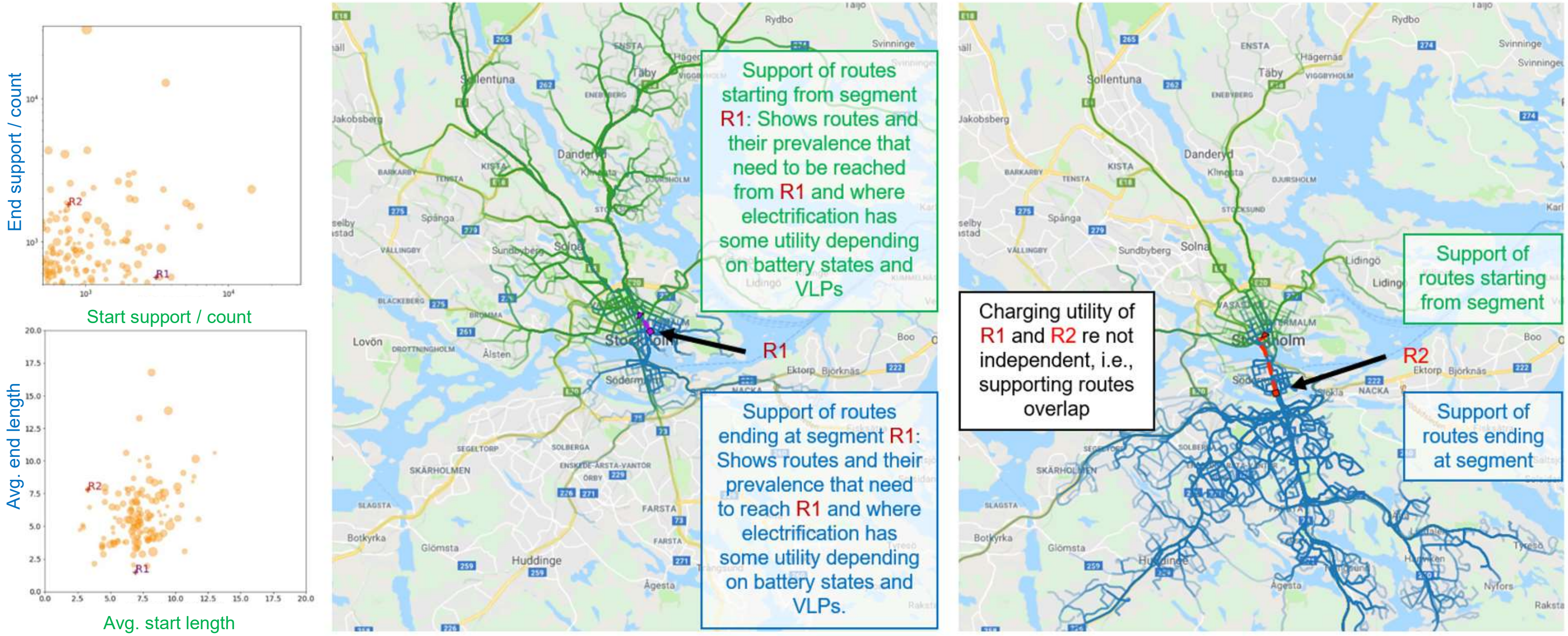

Figure 1: Pre-study based on 600 thousand taxi routes during one month. Scatter plots show the variability of the number of routes (top) and the frequency weighted average length (bottom) of routes that start and end at top, roughly equally frequent segments. Maps show largely differing spatial characteristics and prevalence of routes that start (green) and end (blue) at segments R1 (left map) and R2 (right map) which are roughly equally frequent in routes.

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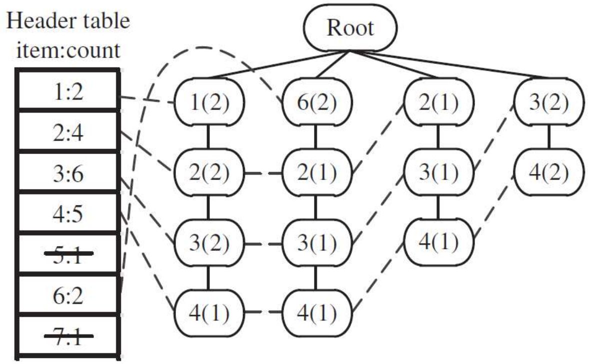
Computational Challenges

- Big Data: > 200K trucks in Sweden produce for a location sampling frequency of every1-60 sec produce 12M – 0.72B (150MB – 10GB) measurements per operating hour
- Exponential number of routes: $2*N*2.x^m$ (typically 100K-10M) possible routes of composed of *m* segments
- Routes are composed of sub-routes through which they form complex spatial / topological relationships → utility of *s1* and *s2* are not independent → combinatorial network optimizations become increasingly complex
- Calculating route based utility requires data processing and queries that are not supported by current Big Data processing tools

Route Based ERS Utility Estimation and Network Optimization

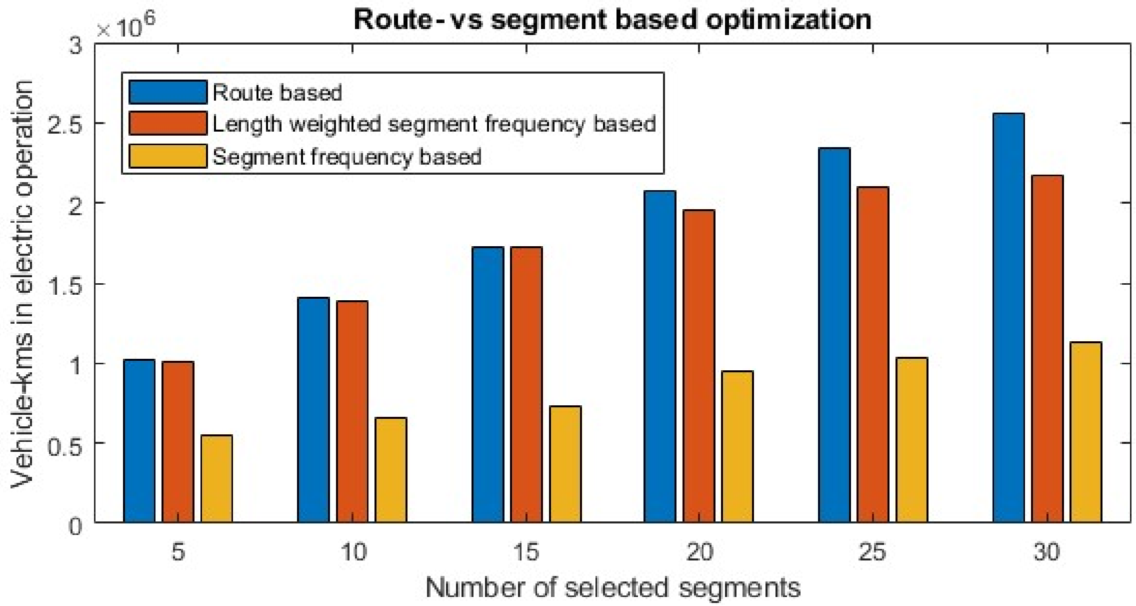
1. Preprocess: Map match and interpolate raw trajectories on transport network.
2. Maintain routes in special data structure: Insert all the routes in an FP-tree *T*. Maintain the count and other route statistics (e.g. load) at each node in *T*. Use the header table of *T* to look up all routes that pass through a given segment.



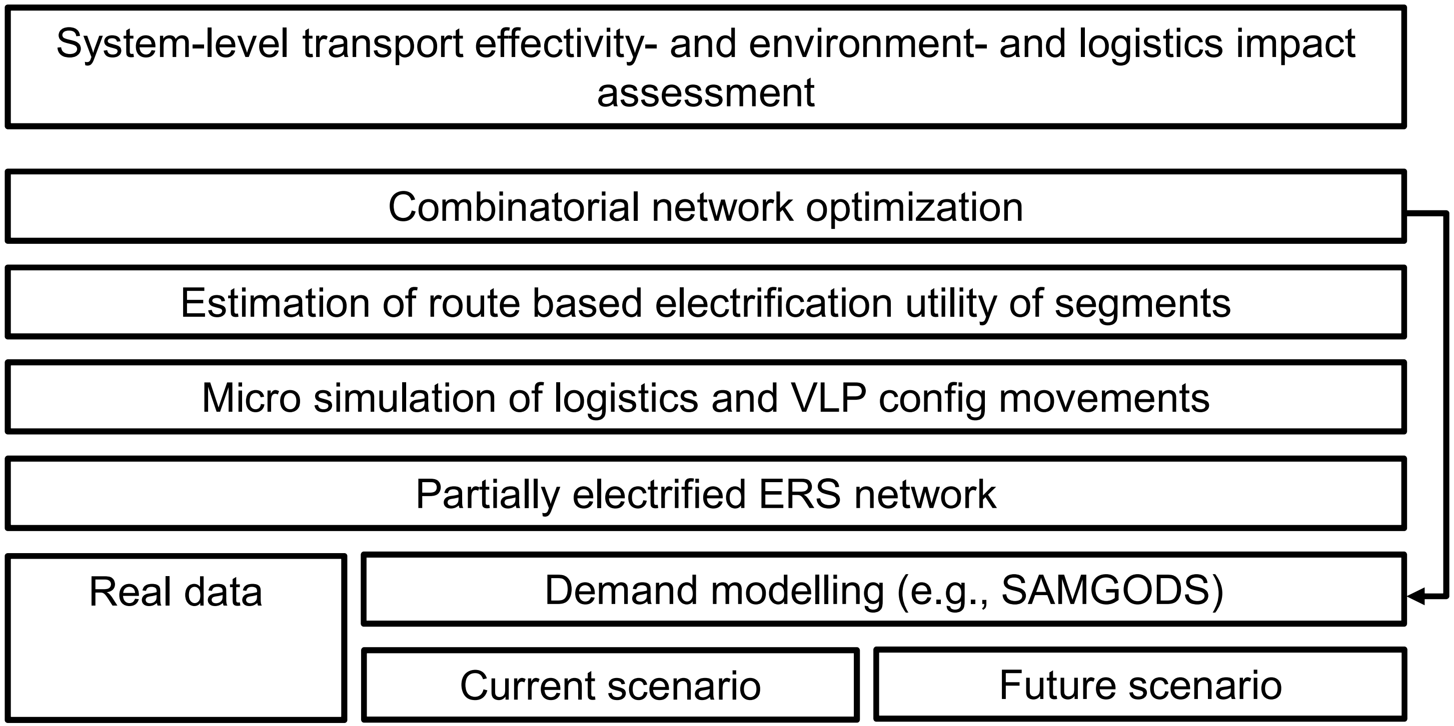
3. Estimate the electrification utility of segments by identifying a segment *s* in the routes in *T* and applying a vehicle energy consumption and charging model *M* to the parts of the routes that include *s* and that follow it.
4. Explore the exponential space of solutions by applying a greedy, heuristic-based guided search algorithm like A* to find the optimal partial ERS network that maximizes the electrification utility <u>given</u> an infrastructure investment budget (number of total length of segments).

Preliminary Results

- Scenario:
  - Vehicle batteries are initially charged to full capacity of 75 KWh
  - Distanced based linear energy use and charging model
  - Charging rate: +22KWh/km (+3%/km)
  - Discharging rate: -15 KWh/km (-2%/km)



Proposed System-Level Research Methodology



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Conclusions and Future Work

- Conclusion
  - Preliminary results indicate that route based ERS network optimization is important

- Future work
  - **Refine** route based ERS network **optimization method** to take into account:
    - Transport loads of routes
    - Average segment traversal times
    - 3D geometry (incline and curvature) and physical (rolling resistance) aspects of segments
  - Integrate into a **system-level methodology**:
    - Allows detailed impact assessments
    - Accounts for transport supply-demand changes
    - Supports decisions about incremental infrastructure investments
  - Extend methodology to **optimize interactions with the energy system**

Thank you for your attention!

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