Methodology for designing charging infrastructure for a fleet of electric vehicles operating in large urban areas

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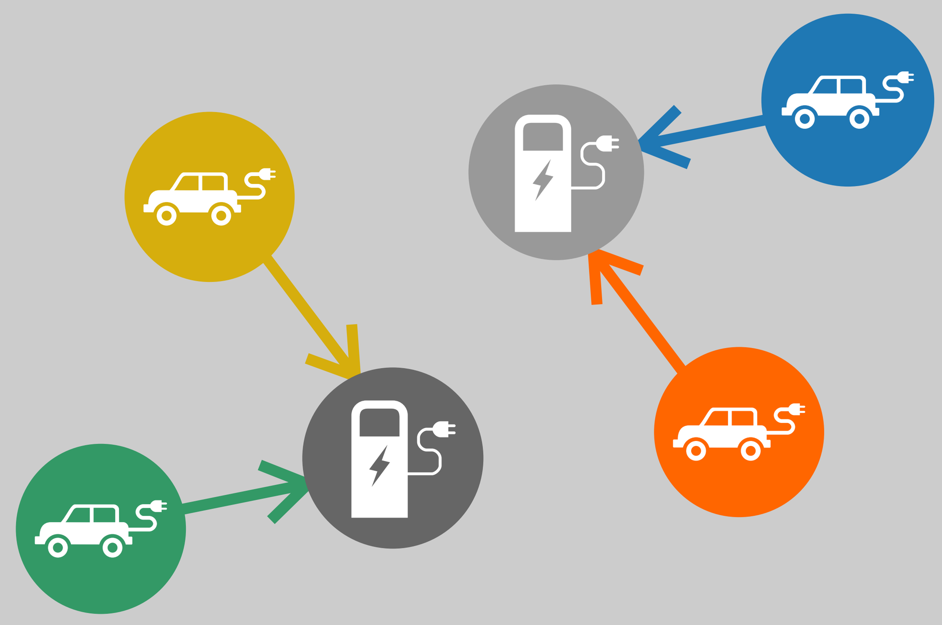
Abstract

We propose a method to design a charging infrastructure for a fleet of electric vehicles operating in large urban areas. Typical examples include a fleet of taxicabs, fleet of vans used in the city logistics or a fleet of shared vehicles. It is assumed that the fleet is originally composed of vehicles equipped with an internal combustion engine, however, the operator is wishing to replace them with fully electric vehicles. To avoid an interaction with other electric vehicles it is required to design a private network of charging stations that will be specifically adapted to the operation of a fleet. In such a case, it is often possible to use GPS traces of vehicles characterizing actual travel patterns of individual vehicles. First, to derive a suitable set of candidate locations from GPS data, we propose a practical procedure where the outcomes can be simply controlled by setting few parameter values. Second, we formulate a mathematical model that combines location decisions with scheduling decisions to ensure that requirements of vehicles can be satisfied. We validate the applicability of our approach by applying it to the data characterizing the driving patterns of a large taxicab fleet operating in the city of Stockholm. Our preliminary results indicate that this approach can be used to estimate the minimal requirements to set up the charging infrastructure.



Two-phase procedure to identify the set of suitable candidate locations for charging stations

Phase 1: Identify the set of candidate locations for charging stations as the locations where many vehicles tend to park for a long enough time.

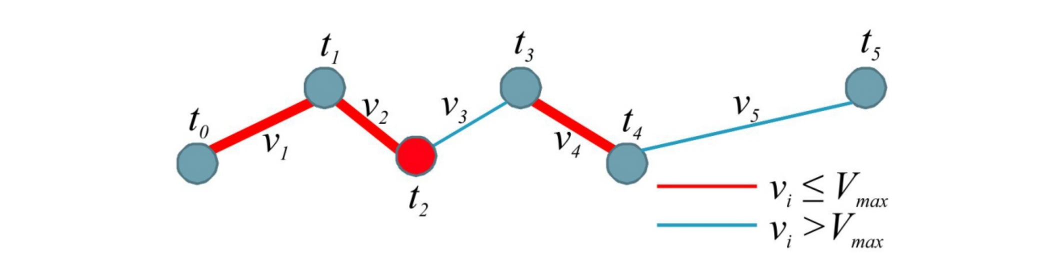
Phase 2: Identify the set of vehicles that can be served by the selected set of candidate locations.

Phase 1: ***Identify the set of candidate locations for charging stations***

Step 1: Identify in the GPS trace the traversals that have the average speed below the speed limit V_{max}.

Step 2: Identify in the GPS trace the maximum connected sequences of traversals longer than the time period T_{min}.

Step 3: Identify as a candidate location the last node of each connected sequence if there is no another candidate location within the distance R_{max}.



Identification of candidate locations from GPS traces of vehicles

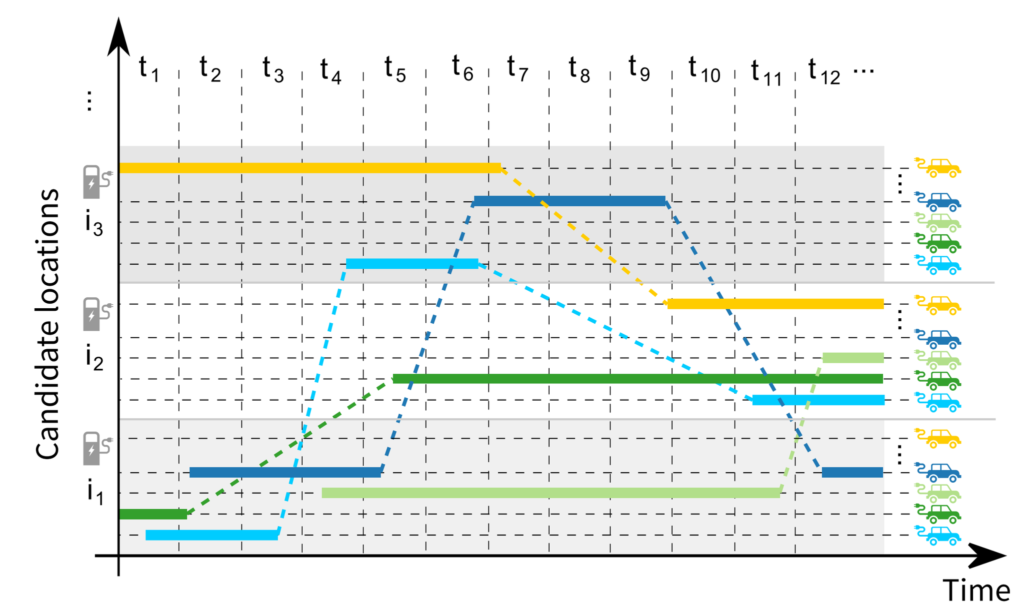


Diagram illustrating the movement of individual vehicles between the candidate locations for a charging station

Location-scheduling optimization problem to create feasible schedule for recharging vehicles

T - set of non-overlapping time intervals for charging

I - set of candidate location for the charging infrastructure

C - set of vehicles

p - maximum number of charging station

R_c - ordered sequence of parking events of vehicle *c*

$B_{itc} \in \{0;1\}$, where $B_{itc}=1$ if the vehicle *c* parks at the location *i* during the time interval *t*

u_{cr} - distance between two parking events *(r-1,r)* of vehicle *c*

Decision variables:

$y_i \in \{0;1\}$ - $y_i = 1$ if the charging station is located at the candidate location $i \in I$

$s_i \in Z^+$ - number of charging points at the station $i \in I$

$x_{ct} \in \{0;1\}$ - $x_{ct}=1$ when vehicle $c \in C$ is being charged during the time interval $t \in T$

$d_{cr} \ge 0$ - the distance that the vehicle $c \in C$ is able to drive at the beginning of the parking event $r \in R_c$

minimize $\sum_{i\in I} s_i$ Minimize the number of charging points

$\sum_{i\in I} y_i \le p$ Do not locate more than *p* charging stations

$M y_i \ge s_i$ Assign charging points only to located charging stations

$\sum_{c\in C} B_{itc} x_{ct} \le s_i$ In each time interval we cannot use more charging points than available

$d_{c0} \le \alpha K$ Limited the driving distance at the beginning

$d_{cr} + \sum_{t\in N_{c,r}} a_{ct} x_{ct} P \le K$ Battery capacity is not exceeded

$d_{cr} \le d_{c,r-1} - u_{cr} + \sum_{t\in N_{c,r-1}} a_{ct} x_{ct} P$ Contiguity in charging and discharging of batteries

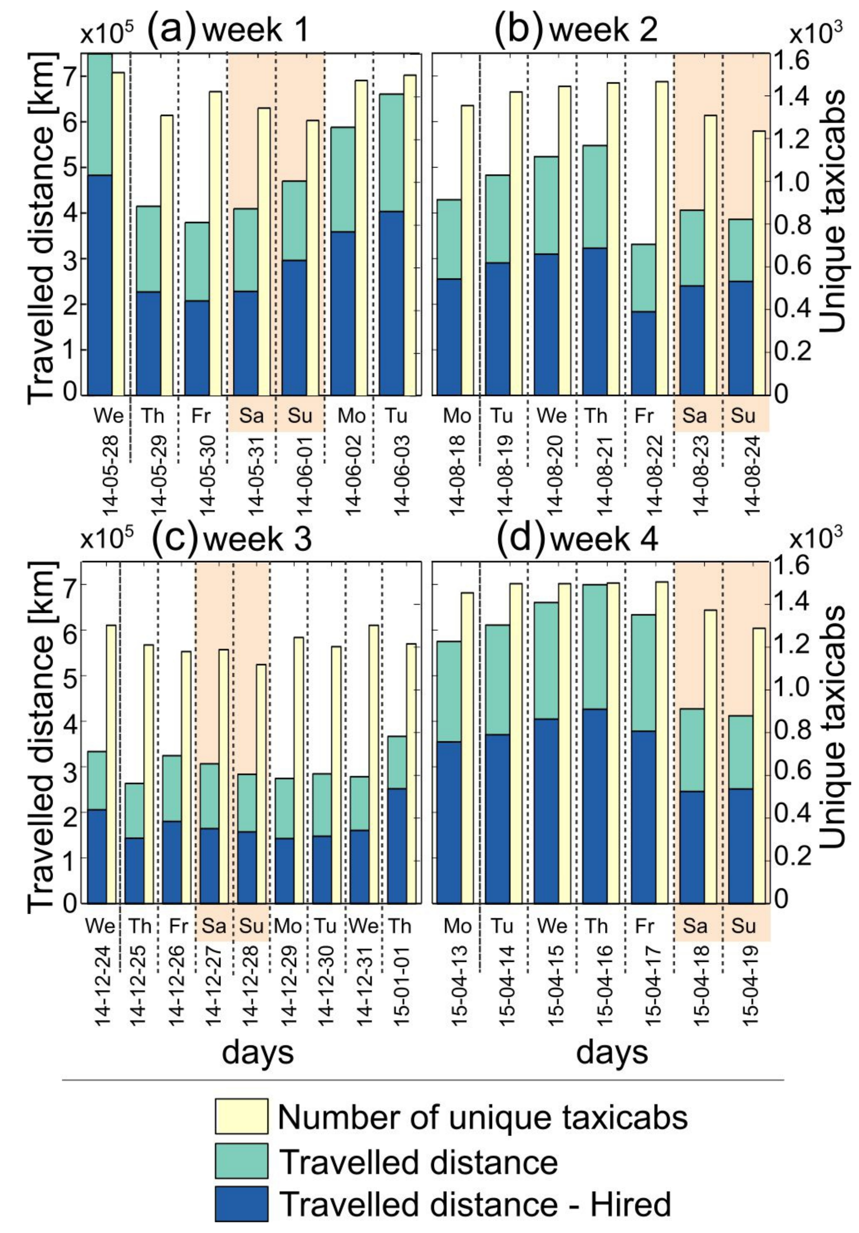
Test data set

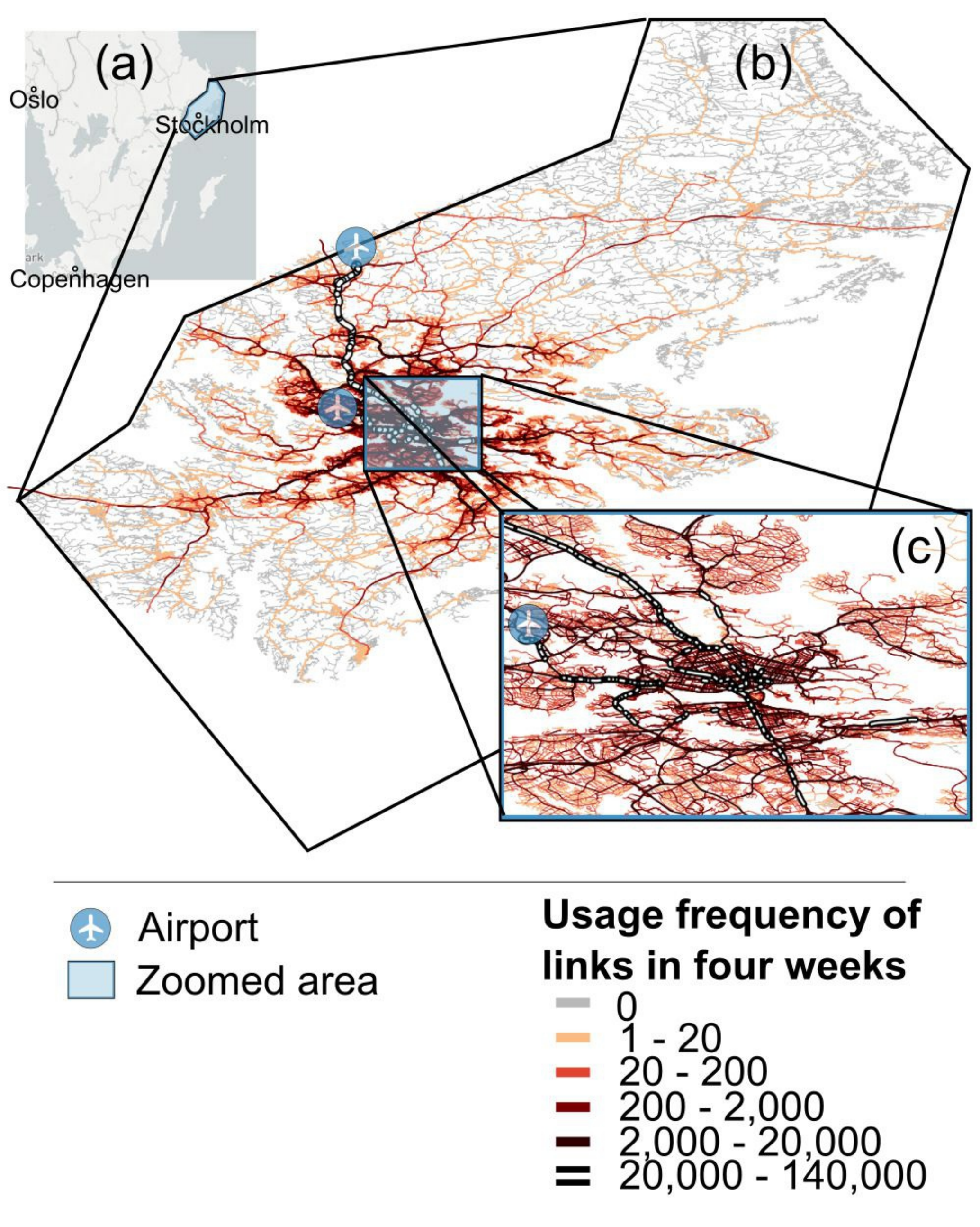
A fleet of taxicabs operating in the area of Stockholm district, Sweden.

Each vehicle reported on average every 90 seconds its ID, GPS position, timestamp and information whether it is hired or not.

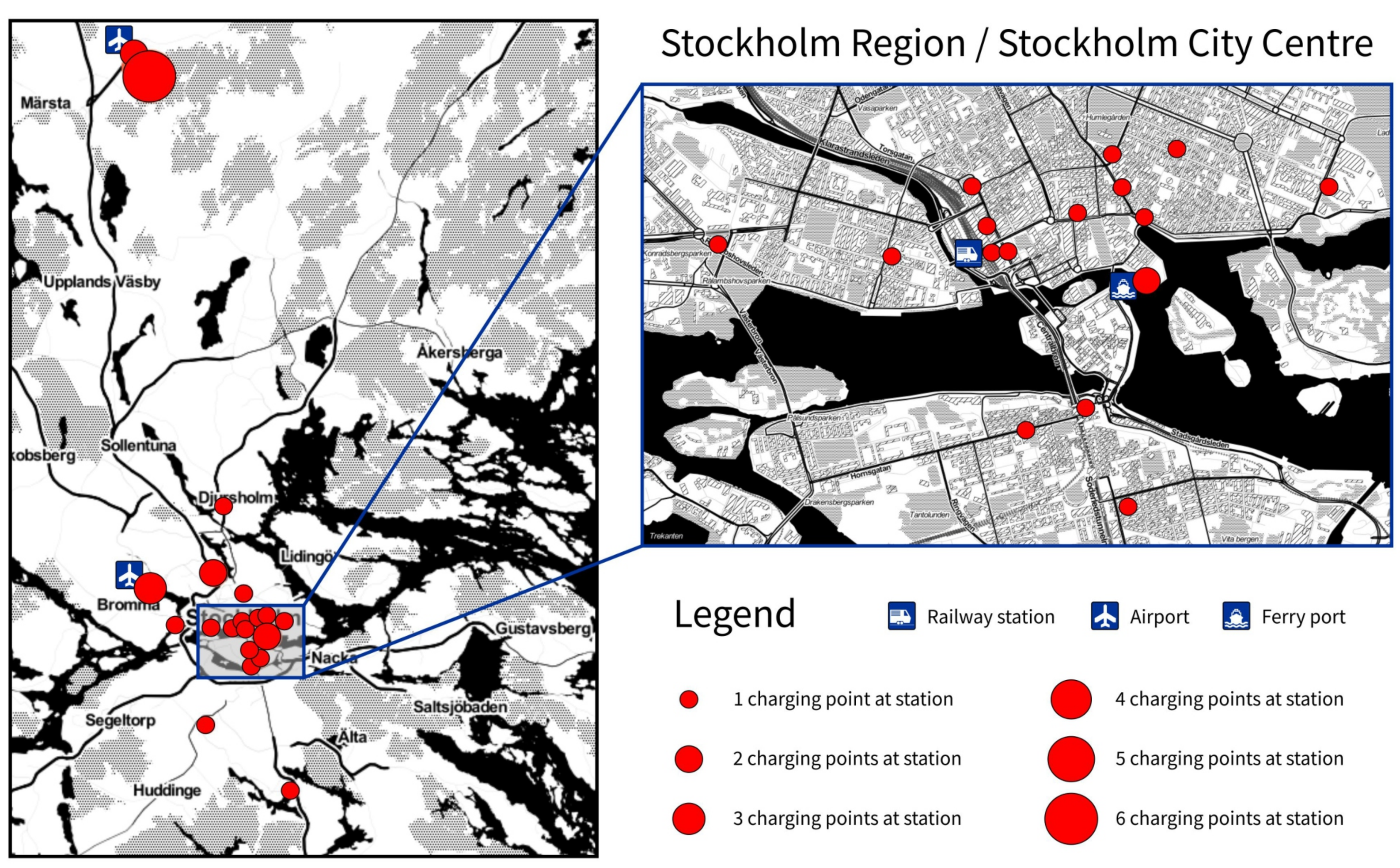
Four weeks selected:

- *Week 1* - typical spring week (1542 taxicabs)
- *Week 2* - typical summer week (1526 taxicabs)
- *Week 3* - Christmas week (1491 taxicabs)
- *Week 4* - special week (1550 taxicabs), *the major disruption of the public transport occurred due to many failed railway connections*





Visualisation of the road network considered in the case study



Locations of charging points obtained for one of scenarios *(Week 1).*
Candidate locations were selected as positions with at least M_{min} = 150 parking events taking place in its circular neighbourhood defined by the radius of R_{max} = 100 meters.

- Proposed approach can be used to ***estimate the minimal requirements*** to set up the charging infrastructure.
- The proposed method is ***able to handle relatively large instances*** of problems independently on the scenario. Most scenarions are often solved to optimality or with small gap only.
- Charging points are typically located at parking lots in the vicinity of airports, railways stations and other public spaces, which seem to be natural locations for them.
- The optimization model has the tendency to select the large set of charging stations with only few charging points. Such design can be also favourable for the electricity network.

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