Denne artikel er udgivet i det elektroniske tidsskrift
Artikler fra Trafikdage på Aalborg Universitet
(Proceedings from the Annual Transport Conference
at Aalborg University)
ISSN 1603-9696
https://journals.aau.dk/index.php/td

trafikdage
NY VIDEN & NETVÆRK

Analysis of Danish Truck Tolling GPS Data

Mads Werngreen, madswerngreen@outlook.dk
Carlos M. Lima Azevedo, DTU
Jeppe Rich, DTU
Thomas Ross, Vejdirektoratet

Abstract

This study presents an analysis of GPS data obtained from the Danish truck tolling system, covering a one-week period with more than 800 million observations across over 60,000 trucks. The analysis extracts mobility patterns from high-resolution data by segmenting raw GPS sequences into trips. These trips are subsequently used in a simulation-based framework to estimate future charging demand.

The simulation is based on a simplified range-based model, where charging events emerge endogenously from observed driving behavior. DBSCAN is applied on simulated charging locations to identify areas of concentrated demand. These clusters form the basis of an optimization problem (MILP) in which cluster centroid locations serve as candidate sites for new charging infrastructure. A key advantage of DBSCAN is its ability to distinguish between clusters and noise, thereby reducing the number of candidate locations and the computational complexity of the MILP.

The results reveal spatial and temporal concentration of charging demand along major transport corridors and during daytime hours. The findings highlight regions with limited existing coverage as key candidates for infrastructure expansion. While the model relies on simplified assumptions, it provides a scalable and data-driven approach for planning charging infrastructure under electrification scenarios.

Introduction

Traditional analyses of transport patterns are typically based on aggregated data or model assumptions, which may not fully capture real-world driving behavior. The introduction of a national road tolling system for trucks in Denmark enables the collection of high-resolution GPS data, providing a unique opportunity to analyze transport patterns based on observed behavior.

This study presents a data-driven framework for analyzing mobility patterns and estimating future charging demand for electric trucks. The approach is divided in sub task

1. **Segmenting GPS data into trips:** The GPS points are divided into sequences constituting trips. The exact definition of a trip is inherently ambiguous. Truck trips should be associated with meaningful activities; a clear example is a trip originating at a storage facility with a destination at a delivery

location. Not all trips from the segmentation describe such clear freight activities, as information about freight pickup and deliveries is not included in the GPS data. This paper will refer to a trip as the result of the segmentation framework.

2. **Simulation of charging demand:** Future charging demand is estimated based on observed driving behavior. The simulation takes a simple rule-based approach, where each truck is assigned a driving range and charging events are generated when the remaining range becomes insufficient to complete the next trip.
3. **Optimization framework:** The charging events generated by the simulation define specific charging locations. These locations are clustered using DBSCAN. Cluster centroids serve as candidate locations for new charging infrastructure. The clusters are then used in an optimization framework to determine the optimal placement of *k* new public fast-charging stations

Data

The analysis is based on GPS data originating from the Danish truck tolling system[1]. The dataset covers a one-week period and contains more than 800 million observations from over 60,000 trucks, with a temporal resolution of approximately 5 seconds. Each observation includes a timestamp geographic position. GPS transmission typically stops when vehicles leave Denmark, meaning international trips are only partially observed.

The data are not map-matched, and this paper investigates approaches that do not require map matching. This simplifies the initial processing and reduces the computational requirements.

Method

The method section is divided into three parts: Segmenting GPS data into trips, Simulation of charging demand, and Optimization framework

Segmentation of GPS data into Trips

Raw GPS trajectories are segmented into trips based on stop detection. A vehicle is classified as stationary when the speed falls below the selected threshold. Stops exceeding a five-minute dwell time threshold define trip boundaries. Additional rules are applied to avoid incorrect segmentation due to mandatory breaks primarily situated at rest areas, missing GPS observations during ferry crossings, and temporary congestion on highways. This reduces false trip boundaries. A similar approach is seen in a Canadian paper [2]

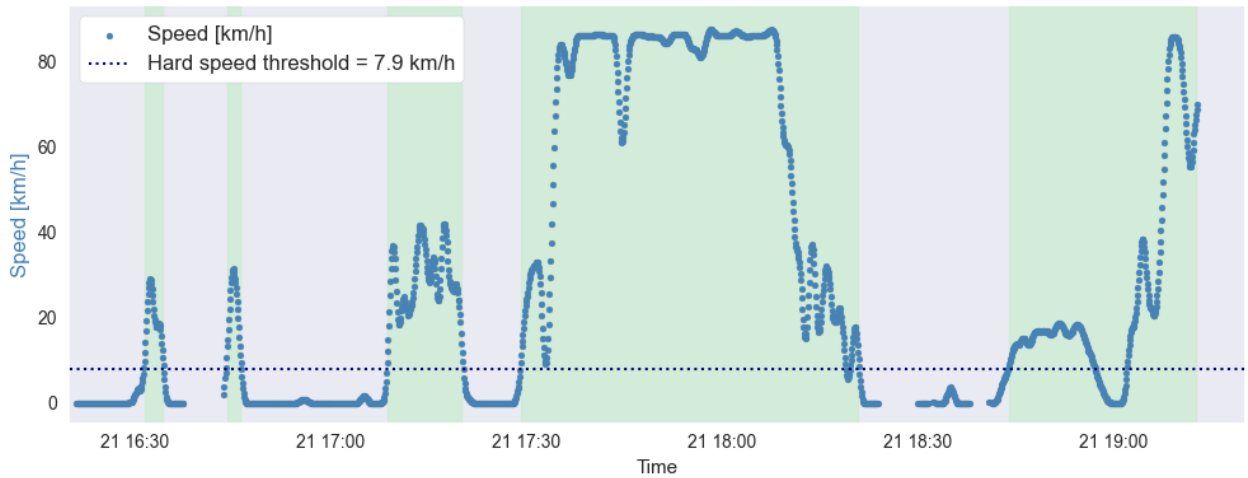

Figure 1: Segmentation of trips using speed threshold

[1] Sund & Bælt Holding A/S. Vejafgifter.dk. https://vejafgifter.dk/en/

[2] Demissie, M. G., & Kattan, L. (2022). *Estimation of truck origin-destination flows using GPS data*. *Transportation Research Part E: Logistics and Transportation Review, 159*, 102621. https://doi.org/10.1016/j.tre.2022.102621

Vehicle speed is estimated from consecutive GPS observations and smoothed using a one-minute rolling average to reduce the influence of GPS noise and temporary slowdowns. The speed threshold was selected heuristically from the combined speed distribution of all observations. The 25th percentile of the distribution yielded the speed threshold of 7.9 km/h

Simulation of charging demand

The identified trips are used as input to a simulation model that estimates charging demand under an electrification scenario. The simulation assumes that all observed trucks are electrified and includes all identified trips. This should not be interpreted as a realistic electrification scenario, but rather as an assumption that each observed truck is equally likely to transition to electric propulsion.

The SoC is represented by remaining driving range which is initialized to 300 km and reduced according to the distance traveled. When charging occurs, the remaining driving range is restored to 300 km.

Charging events occur in two cases:

- **Depot charging:** Stops longer than 6 hours are classified as slow-charging opportunities. These events are assumed to occur primarily at private truck depots.
- **Public fast charging:** When the remaining driving range is insufficient to complete the next trip, a public fast-charging event is triggered. These events are characterized by the need to quickly resume the journey and are therefore assumed to require fast charging.

The analysis focuses on charging events triggered by insufficient range, as these represent demand for public charging infrastructure.

Optimization framework

Charging events are spatially clustered using the DBSCAN algorithm[3] to identify areas of concentrated demand. The advantage of DBSCAN is its ability to distinguish between clusters and noise. Consequently, only areas with a high density of public fast-charging events form clusters, while isolated charging events are classified as noise.

These clusters form the basis of an optimization problem, where the objective is to minimize the weighted sum of distances between cluster centroid locations and their nearest fast-charging station. The weights are based on the number of charging events in each cluster, ensuring that both high-demand areas and underserved regions are considered. The optimization framework uses the existing fast-charging infrastructure together with the candidate cluster locations to construct a distance matrix, which serves as input to the MILP. Each candidate location is associated with a binary activation variable indicating whether a charging station is constructed. The MILP determines which *k* candidate locations should be constructed to minimize the weighted sum of distances.

Results

The intermediate output from the charging-demand simulation shows a spatial concentration of charging demand along major transport corridors and near urban areas in **Figure 2**. In particular, high charging-demand intensities are observed around Copenhagen, the Triangle Region (Vejle, Kolding, and Fredericia), and Aarhus. Additional, but less pronounced, concentrations are visible around Aalborg and Odense. Notably, these locations correspond to the major urban areas of Denmark. Moreover, the major highway

[3] Ester, M., Kriegel, H.-P., Sander, J., & Xu, X. (1996). *A density-based algorithm for discovering clusters in large spatial databases with noise*. In *Proceedings of the Second International Conference on Knowledge Discovery and Data Mining (KDD-96)* (pp. 226–231). AAAI Press.

corridors E20 and E45 exhibit elevated densities compared to the surrounding network, indicating a strong alignment between simulated charging GPS-Based Analysis of Truck Traffic 35 demand and the primary national transport axes. All identified high-density areas are directly connected by these major highways

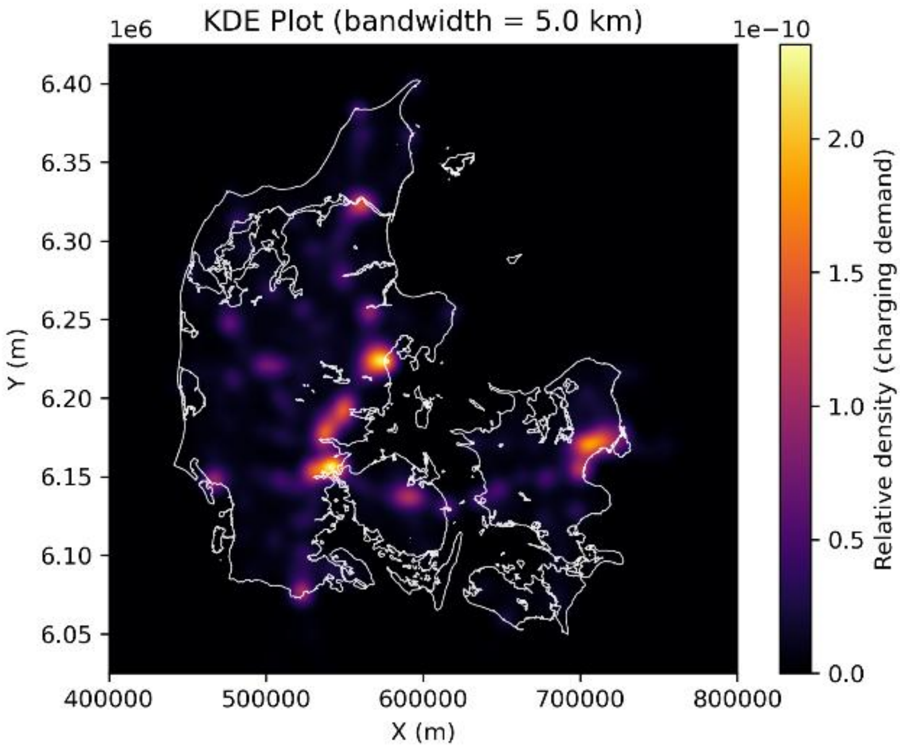

Figure 2: Spatial distribution of fast-charging demand (Note this a smoothing of the discrete localization of the charging events meaning non-zero probability is assigned to

Temporal distribution (**Figure 3**) reveals a clear daily pattern where charging activity increases from the morning hours toward midday, after which a slight decline is observed in the afternoon and evening. During the night, the charging intensity remains at a comparatively low and stable level. This pattern indicates a peak in charging activity around midday, with fewer events occurring in the morning and evening.

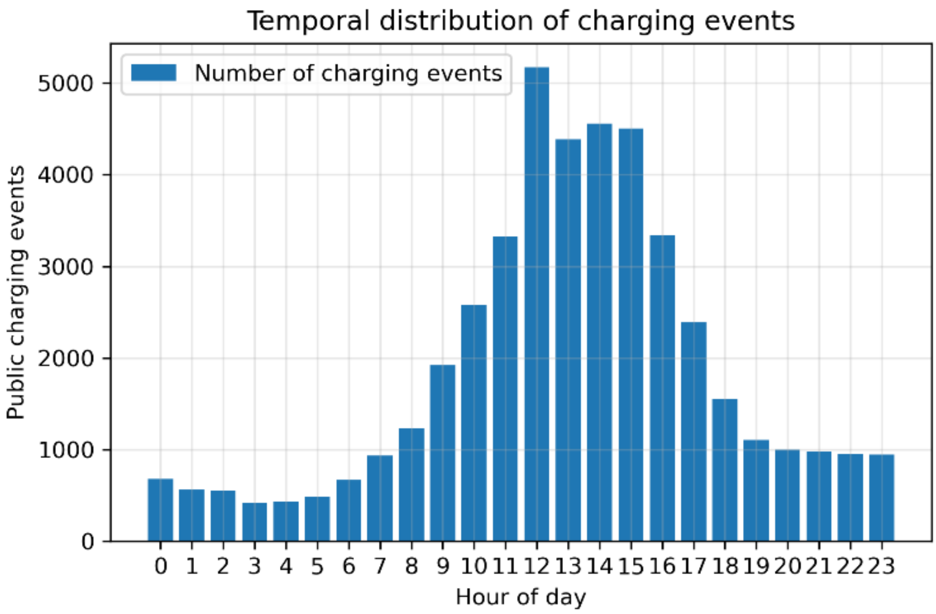

Figure 3: Temporal distribution of fast-charging demand

The result of the optimization framework is illustrated in **Figure 4**. The clusters identified by DBSCAN are shown on the left. Each cluster is represented by a dot, where the size indicates the number of charging events and the color scale represent the distance to the nearest existing public fast-charging station. Existing fast-charging stations are shown as red triangles. Existing public fast-charging infrastructure was obtained from the Danish Road Directorate.

The right panel shows the same clusters after the optimization, where four new charging stations have been constructed at locations selected by the MILP. The new charging stations are shown as orange triangles.

The optimization identifies northwestern and central Denmark as priority regions for new charging infrastructure. The results illustrate the trade-off between serving areas with high charging demand and improving geographic coverage. Consequently, areas with limited existing charging infrastructure in Jutland, together with high-demand regions near Odense, are identified as optimal locations according to the MILP formulation.

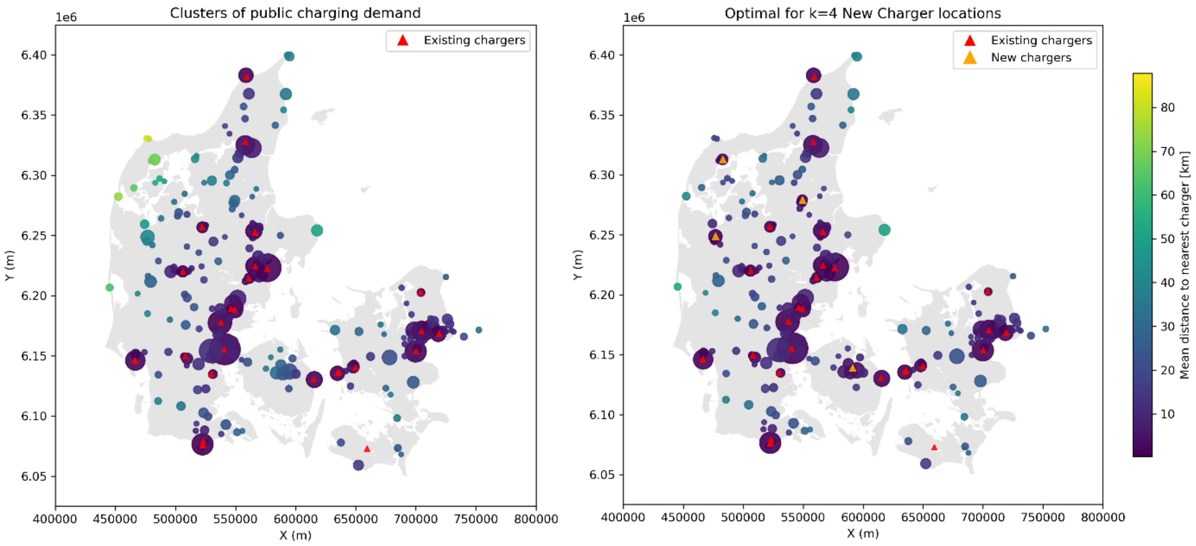

Figure 4: Clustering result and proposed new location when using 4 new locations

Discussion

The simulation of charging demand is based on simplified assumptions regarding vehicle range and charging behavior. The results should therefore be interpreted as an indicative representation of potential charging demand rather than a precise forecast. Consequently, the identified optimal fast-charging locations are based on a simplified prediction of future charging demand.

Furthermore, the clustering method reduces the computational cost of the subsequent optimization but does so at the expense of neglecting isolated charging events that do not belong to a cluster. Another important limitation is that the framework does not account for the proximity of existing charging infrastructure in route planning, as charging demand is assumed to arise near trip endpoints rather than during the trip.

The one-week observation period does not capture seasonal variations in freight transport. The limited duration was a consequence of the computational resources available and the computationally expensive preprocessing of the GPS data.

Consequently, the framework should be viewed as a future decision-support tool rather than a method for determining the definitive optimal locations for fast-charging infrastructure.