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Classification of GPS Track Data Using AI Methods

A Case Study of Waste Collection Vehicles

Bachelor thesis
for obtaining the academic degree

Bachelor of Science in Engineering (BSc)

Vorarlberg University of Applied Sciences
Computer Science - Software and Information Engineering

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Dedication

Dedicated to my younger self, who found a fascination in software from a young age and decided to follow his dreams!

And to my parents, who wholeheartedly supported me throughout this journey.

Thank you.

Kurzreferat

Klassifizierung von GPS-Spurdaten mit Unterstützung von KI-Methoden am Beispiel von Abfallsammelfahrzeugen

In der Abfallwirtschaft ist die strategische Tourenplanung ein wichtiger Prozess, in dem durch optimale Gebietsaufteilung eine maximal effiziente Fuhrparkauslastung bei möglichst geringen Kosten ermittelt wird. Dies geschieht in Entsorgungsbetrieben sowohl für bestehende Auftragsgebiete, als auch bei der Kalkulation von neuen Ausschreibungen. Vor Allem bei Regionen, in denen keine Erfahrungswerte vorliegen müssen für eine robuste Tourenplanung zahlreiche unscharfe Annahmen getroffen und manchmal auch Schätzungen vorgenommen werden. Um diese Unsicherheiten durch die Analyse von geographischen Strukturen zur verringern soll eine Technologie in die bestehende Tourenplanungssoftware der Firma integriert werden, die folgende Aufgabenstellung automatisiert lösen kann: Anhand von bestehenden GPS-Aufzeichnungen sollen strukturelle Eigenschaften der jeweilige Sammelgebiete numerisch bewertet und klassifiziert werden. Gleichermaßen sollen anhand von geographischen (und möglichst frei verfügbaren Strukturdaten) aus noch unbekannten Gebieten erhoben werden können um diese auf die selbe Art und Weise klassifizieren zu können. Dadurch entsteht einerseits eine Referenzdatenmenge (von bestehenden Sammeltouren) und eine Vergleichsdatenmenge (aus den neuen Ausschreibungsgebieten). Dort wo die Klassifizierungsdaten übereinstimmen, kann davon ausgegangen werden, dass die planungsrelevanten Kennzahlen aus bestehenden Auftragsgebieten ohne gewagte Annahmen einfach übernommen werden können. Die Klassifizierung von GPS-Daten und geographischen Strukturdaten soll mit Hilfe von künstlicher Intelligenz automatisiert erstellt werden können. Auch die Überlegung, welche geographischen Strukturdaten denn überhaupt aussagekräftig sind um einen Vergleich anzustreben, sollen ggf. mit Hilfe von KI Technologien erfolgen.

Das Ziel der praktischen Arbeit ist es einen Sandbox-Service zu implementieren, der von der bestehenden Software der *infeo GmbH* aufgerufen und mit Daten gefüllt werden kann um so "auf Knopfdruck" Klassifizierungen und Vergleiche von GPS-Daten und Ausschreibungs-Strukturdaten zu erstellen. Die Anwender:innen haben dadurch die Möglichkeit für neue Ausschreibungen entsprechend passende Planungsparameter aus ihren bestehenden Auftragsgebieten zu berechnen und somit die Unsicherheiten bei der Ausschreibungskalkulation deutlich zu reduzieren.

GPS-Datenklassifizierung, Abfallwirtschaft, Künstliche Intelligenz, Geografische Datenanalyse, Maschinelles Lernen, Automatisierung

Abstract

Classification of GPS Track Data Using AI Methods: A Case Study of Waste Collection Vehicles

In waste management, strategic route planning is a crucial process where optimal fleet utilization is determined through the efficient division of service areas, with the goal of minimizing costs. This process is applied by waste disposal companies both for existing service areas and when calculating bids for new tenders. Especially in regions where there is no prior experience, numerous uncertain assumptions and estimates must be made for robust route planning. To reduce these uncertainties through the analysis of geographical structures, a technology will be integrated into the company's existing route planning software, which can automatically solve the following task: Based on existing GPS records, the structural characteristics of the respective collection areas should be numerically evaluated and classified. Additionally, geographical structural data (preferably from freely available sources) from unknown areas should be collected and classified in the same way. This approach will create both a reference data set (from existing collection routes) and a comparison data set (from new tender areas). Where the classification data match, it can be assumed that planning-relevant parameters from existing service areas can be applied to the new areas without risky assumptions. The classification of GPS data and geographical structural data should be automated using artificial intelligence. Furthermore, the consideration of which geographical structural data are meaningful for comparison should, if necessary, also be supported by AI technologies.

The practical goal of this work is to implement a sandbox service that can be called and populated with data by the existing software of *infeo GmbH*, enabling the creation of classifications and comparisons of GPS data and tender structural data "at the push of a button." This will provide users with the ability to calculate appropriate planning parameters from their existing service areas for new tenders, thereby significantly reducing uncertainties in bid calculations.

GPS Data Classification, Waste Management, Artificial Intelligence, Geographic Data Analysis, Machine Learning, Automation

Preface

[Preface Text]

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List of Abbreviations

GPS Global Positioning System

AI Artificial Intelligence

ML Machine Learning

API Application Programming Interface

CSV Comma-Separated Values

DACH Germany, Austria and Switzerland

DBSCAN Density-Based Algorithm for Discovering Clusters in Large
Spatial Databases with Noise

1 Introduction

“The world’s most valuable resource is no longer oil, but data” [1]

In today’s digital age, where electronic devices are a part of everyone’s daily lives, increasing amounts of data are being generated every day, and this trend shows no signs of slowing down. [2] With this increase in data, businesses ranging across all industries recognize the importance of leveraging it for decision-making and operational efficiency. This has led to a growing demand for technologies that can gather insights from data and integrate seamlessly into strategic processes.

One industry in which data-driven decision-making is becoming increasingly important is the waste management industry.

1.1 Motivation

“The Europe Waste Management Market size was valued at USD 116.21 billion in 2023, and is predicted to reach USD 169.37 billion by 2030, at a CAGR of 4.5% from 2024 to 2030.”[3]

This growth reflects the increasing need for efficient and sustainable waste management practices, in response to rising waste volumes across residential, commercial, and industrial sectors.

“The rapid population growth, urbanisation and economic development over the last decades has led to an increase in the generation of solid waste across the world. Providing high-quality waste management services is crucial to safeguard public health and protect the environment, but also to support resource efficiency, climate change mitigation and job creation.” [4]

The waste management sector is considered critical infrastructure and is under growing pressure to adapt to personnel shortages, blackouts, and rising costs. In many cases, the only viable solution is to optimize and automate operational processes. Digital transformation plays a key role in making day-to-day operations significantly more robust and efficient.[5]

This is the mission of *infeo GmbH*, the software company for which this thesis is being conducted:

“Die Abfallwirtschaft ist ein systemkritischer Wirtschaftsbereich und zählt zur kritischen Infrastruktur. Die Branche muss sich vor Personalausfällen, Blackouts und Kostensteigerungen schützen. Das gelingt oft nur durch Automatisierung und Optimierung von Prozessen, die das Tagesgeschäft maßgeblich robuster und effektiver machen.”[5]

This thesis supports the mission of *infeo GmbH* to revolutionize digital processes in the waste management sector by implementing AI-powered tools to automatically classify and compare GPS track data and geographical structural data. The resulting service enables waste management companies to efficiently gather planning-relevant parameters from existing service areas and apply them to new regions, reducing uncertainty, increasing planning accuracy, and accelerating decision-making.

1.2 Problem Statement

Companies operating in the waste collection business have trouble calculating accurate bids for new service areas when expanding their field of business. They often have to make assumptions and rough estimates on several parameters concerning the operation cost in new service areas. A data driven estimation can help create more accurate and less risky assessments for unknown collection locations. This can help reduce uncertainties and improve the accuracy of bid calculations.

1.3 Solution Approach and Goal

Therefore, the goal of this work is to reduce uncertainty for waste collection companies expanding their business to new service areas using existing GPS tracking data. The approach involves classifying the GPS tracking data from known service areas into four categories ranging from urban to rural. AI methods are then used to cluster the data into these categories and to train a classifier able to automate the categorization. Furthermore, algorithms and AI techniques to compare patterns found in the existing data with public geographic data from OpenStreetMap. This functionality is then bundled into a ready to use API service. The endgoal is to provide an API which suggests planning parameters for a given input geofence.

2 Background and Related Work

2.1 Technical Background

2.1.1 Feature Engineering for Geographic data

Geospatial data is not inherently suitable for machine learning algorithms, which is why the extraction of features for each tracking is crucial for a performant and accurate classifier. Extraction of features for GPS data points consisting of latitude, longitude and time

2.1.2 Clustering Algorithms

“Clustering is a useful tool in data science. It is a method for finding cluster structure in a data set that is characterized by the greatest similarity within the same cluster and the greatest dissimilarity between different clusters.”[6]

2.1.2.1 Density-Based Clustering with DBSCAN

DBSCAN (Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise) was introduced by Martin Ester, Hans-Peter Kriegel, Jörg Sander, and Xiowei Xu as an algorithm to identify clusters of arbitrary shape in spatial databases and distinguish noise. It relies on the notion of density-reachability among points based on a distance threshold *Eps* and a minimum number of points *MinPts*.[7]

Let D be a database of points and let $dist(p, q)$ be the distance between points p and q (typically Euclidean).

- The **Eps-neighborhood** of a point p is defined as:

$$N_{Eps}(p) = \{q \in D \mid dist(p, q) \leq Eps\}$$

- A point p is a **core point** if:

$$|N_{Eps}(p)| \geq MinPts$$

- A point q is **directly density-reachable** from p if:

$$q \in N_{Eps}(p) \text{ and } p \text{ is a core point}$$

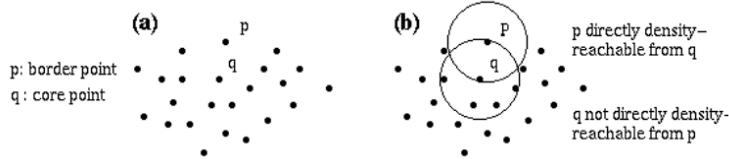


Figure 2.1: DBSCAN: Core points and border points [7]

- A point q is **density-reachable** from p if there is a chain of points p_1, p_2, \dots, p_n such that $p_1 = p$, $p_n = q$, and each p_{i+1} is directly density-reachable from p_i .
- Two points p and q are **density-connected** if there exists a point o such that both p and q are density-reachable from o .

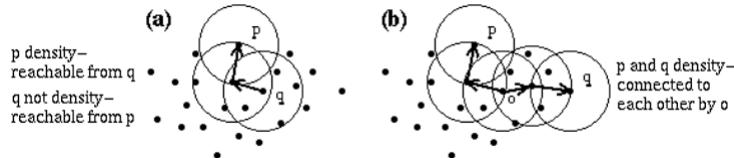


Figure 2.2: DBSCAN: (a) Density-reachability and (b) density-connectivity [7]

This concept allows DBSCAN to detect clusters without requiring the number of clusters as input, unlike other clustering algorithms such as K-Means and CLARANS, making it effective for outlier detection. [7]

2.1.2.2 k-means Clustering

K-Means is the first unsupervised algorithm used to cluster data in an euclidean space and is still widely used to partition a dataset $\{x_1, x_2, \dots, x_n\}$ of size n into $k \leq n$ sets $S = \{S_1, S_2, \dots, S_k\}$ [6]

The goal to minimize the within-cluster sum of squares (WCSS) can be shown with following function:

$$J = \sum_{i=1}^k \sum_{x_j \in S_i} \|x_j - \mu_i\|^2$$

The implementation of the algorithm uses an iterative refinement technique, also known as Lloyd's Algorithm. An initial set of k means is selected, randomly or are more sophisticatedly initialized in adaptations such as k-means++. Then the algorithm repeats the following two steps until the assignments do not change and k-means therefore converges:

1. **Assignment:** Assign each data point to the cluster with the least squared Euclidean distance (mean):

$$S_i = \{x_j : \|x_j - \mu_i\|^2 \leq \|x_j - \mu_l\|^2, \forall 1 \leq l \leq k\}$$

2. **Update:** Update the means of data points assigned to each cluster:

$$\mu_i = \frac{1}{|S_i|} \sum_{x_j \in S_i} x_j$$

2.1.2.3 Combining DBSCAN and k-means

DBSCAN can be used to identify anomalies by dividing the data set into two clusters. Cluster 0 with the valid data and cluster -1 with anomalies. Using the output of DBSCAN and removing the detected anomaly cluster -1 as the input for k-means, a more effective partitioning of the data into k number of groups can be achieved. Without DBSCAN, k-means clustering will likely assign one cluster to outliers of faulty data.

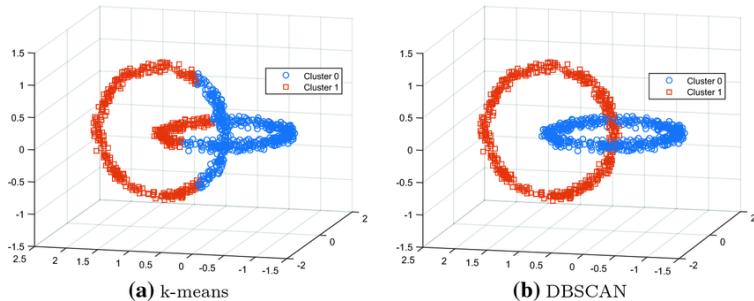


Figure 2.3: Comparison: k-means, DBSCAN clustering algorithms [8]

2.2 Related Work

GPS-Data analysis and classification has been studied in various studies and projects, such as identifying transportation modes or movement behavior. This section highlights related approaches to the classification and comparison of GPS data relevant to the problem of this thesis.

2.2.1 Transportation Mode Prediction with Feature Engineering

Etemad, Soared and Matwin [9] propose a five step framework to predict the underlying transportation mode from GPS traces. The steps of this framework include in order the preparation of data, point feature extraction (e.g., distance, speed, bearing rate and its derivatives), trajectory feature extraction (e.g., min, max, mean and std., percentiles), noise removal and normalization.

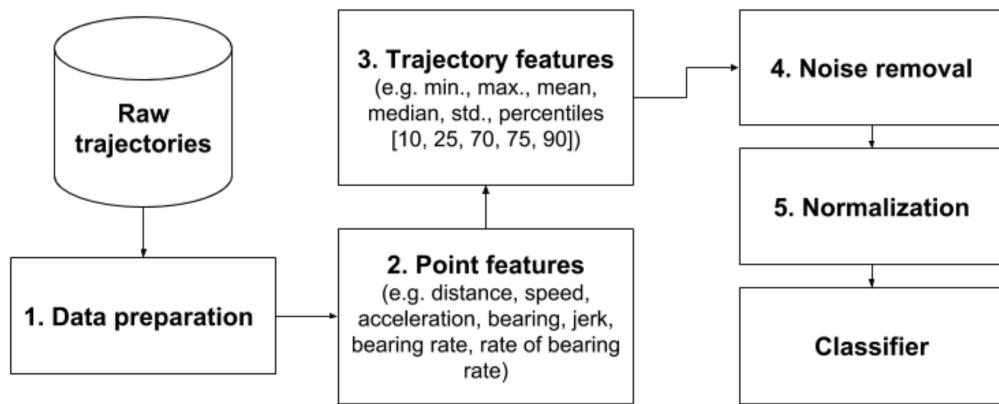


Figure 2.4: Steps of the proposed framework for predicting of transportation modes by Etemad et al. [9]

Their framework achieves competitive results with the classifier scoring 96.5% accuracy and a f1 score of 96.3%. The study shows the importance of noise reduction and feature engineering when working with GPS trace data.

While their work focuses on the classification of transportation modes (e.g., walking, bike, car, etc.), the techniques used for extracting features and noise reduction, are also applicable for the structural classification of waste collection routes, which is the focus of this thesis. [9]

2.2.2 Clustering of GPS Data using Distance-based Features

Koh et al. [10] present a framework to cluster users based on their movement patterns captured via an application on their mobile phones. The authors propose a new metric, *Daily Characteristic Distance (DCD)*, which is used to create a fair comparison between working and nonworking users on workdays and offdays and extract features in combination with *Origin-Destination (OD)* matrix features.

The features derived from the DCD are combined with OD matrix features and are used in a k-means clustering algorithm to group the users into three behavior groups. The study analyses the resulting clusters with two newly proposed metrics: *User Commonality* (percentage of users that visited each point of interest (POI) category) and *Average Frequency* (average percentage of trips to each POI category). [10]

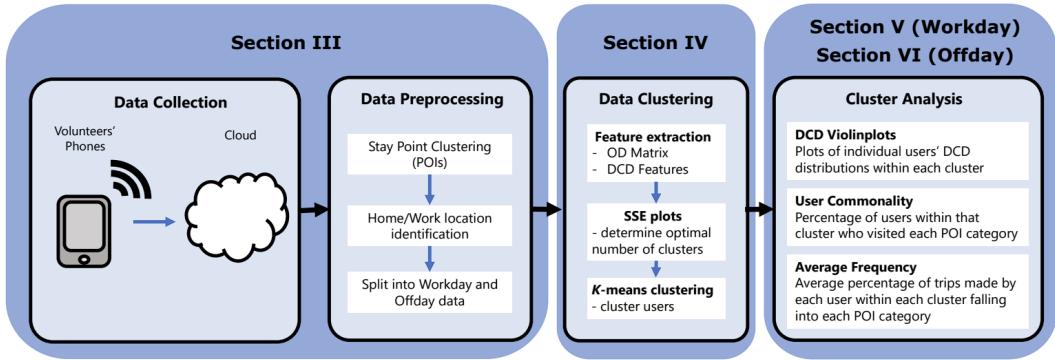


Figure 2.5: Steps of the framework proposed by Koh et al. [10]

The work of Koh et al. shows that meaningful patterns can be extracted from GPS data using unsupervised clustering methods. This approach is highly relevant for this thesis, as it demonstrates that structural characteristics can be derived from engineered features and effectively used for clustering and classification. Although the paper's focus is on GPS traces of individual people and captures data with mobile phones, the underlying methods can be applied for identifying patterns and similarities in GPS track data collected by waste collection vehicles.

3 Problem Definition and Solution Approach

3.1 Description of the Dataset

3.1.1 Overview

The dataset used is a collection of GPS tracking data collected by wastecollection vehicles from various wastecollection businesses and provided by *infeo GmbH*. It represents real-world data collected during regular wastecollection operation in the DACH region.

3.1.2 Source and Collection Method

The data was obtained by the onboard tracking systems installed by *infeo GmbH*, which collects GPS coordinates in regular intervals during regular operation. Each tracking represents a complete wastecollection route taken and includes metadata aswell as a list of GPS coordinates.

3.1.3 Structure of the Data

Each dataset entry represents a single recorded route refered to as *tracking* and contains metadata aswell as a time ordered list of gps coordinates.

Each tracking contains the following fields:

Table 3.1: Structure of a Tracking Entry

Field	Type	Description
<code>id</code>	Integer	Unique identifier of the tracking entry.
<code>name</code>	String	Name of the tracking (randomized for anonymization) identification.
<code>description</code>	String	Route metadata, often includes internal codes.
<code>recorded</code>	DateTime	Start date and time of the tracking.
<code>length</code>	Float	Total length of the route in kilometers.
<code>duration</code>	Integer	Total duration of the tracking in nanoseconds.
<code>vehicleId</code>	Integer / Null	ID of the vehicle (nullified for anonymization).
<code>tourId</code>	Integer / Null	ID of the associated tour (nullified for anonymization).
<code>isExported</code>	Boolean	Flag indicating if the tracking was exported.
<code>editState</code>	Integer	Edit state used by the system.

Each GPS point contains the following fields:

Table 3.2: Structure of a GPS Point Entry

Field	Type	Description
<code>id</code>	Integer	Unique identifier of the GPS point.
<code>time</code>	DateTime	Timestamp of when the point was recorded.
<code>latitude</code>	Float	Latitude coordinate.
<code>longitude</code>	Float	Longitude coordinate.
<code>speed</code>	Float	Instantaneous speed at the time (in km/h).
<code>heading</code>	Float	Direction of movement in degrees.
<code>sequence</code>	Integer	Position of the point in the tracking sequence.
<code>metaTag</code>	Integer	Custom metadata tag.
<code>metaValue</code>	String	Value associated with the metadata tag.
<code>pointBaseType</code>	Integer	Internal point type used by the system.

3.1.4 Size and Coverage

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3.1.5 Limitations

Missing Values: GPS gaps etc, useless trackings etc.

With a lot of data, also comes a lot of unfurnished and faulty data. Through communication with *infeo GmbH* and through visual examination, it is clear that many trackings are not collected properly. Since the tracking devices installed on the garbage collecting vehicles are operated partly manually, some trackings showed GPS tracks only on the parking facility and not in operation, while others showed that the tracking device being turned on over night, while no operation was taking place either.

3.2 Big Picture

Formatvorlage für den Fließtext.

3.3 Dataset Analysis

Formatvorlage für den Fließtext.

3.3.1 Sample Analysis

A small, manually selected sample of 8 tracking routes was selected for initial exploratory data analysis. Each route was inspected on the AWM-Map-Tool and then categorized into one of the four area type labels: RURAL, SUBURBAN, TOWN or URBAN. Each Label is represented by 2 tracking routes in the sample data to ensure a balanced representation.

Feature extraction was performed to calculate route-level metrics such as length, duration, bounding box area, point density, number of stops and average distance between points.

The goal of this sample is to explore patterns, validate assumptions, and identify features useful for future automatic classification.

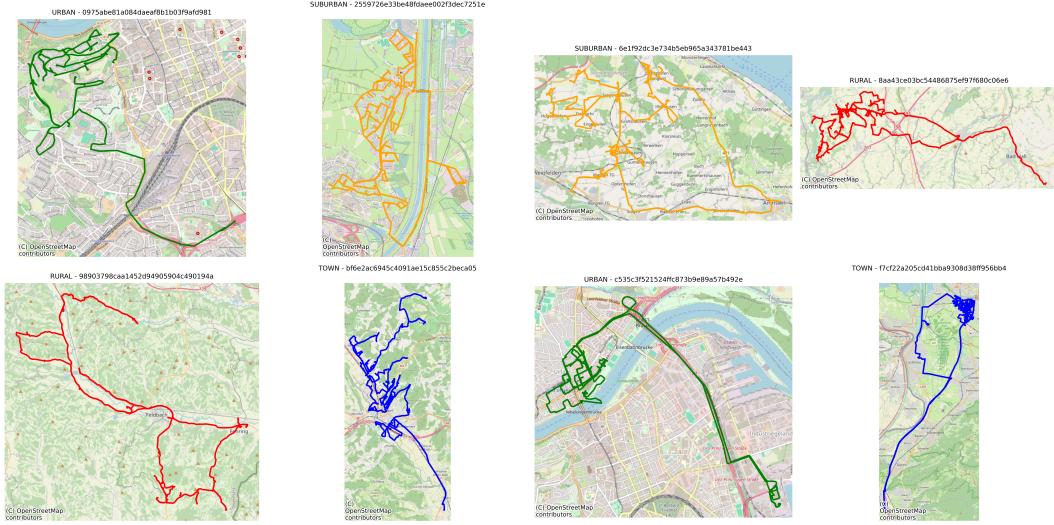


Figure 3.1: Mapgrid for selected sample trackings

The mapgrid shows spatial layout of each tracking route overlayed on a visual map. Each subplot corresponds to a single tracking and is colorcoded with the assigned lable (RURAL=Red, SUBURBAN=Orange, TOWN=Blue, URBAN=Green). This visual representation clearly shows the difference in route shapes and sizes between the four different area types.

Urban:

- Routes are geographically compact and highly localized.
- Movement appears dense with short travel distances between stops.
- Often confined to a small cluster of city blocks or neighborhoods.

Town:

- Coverage is slightly more dispersed than urban routes.
- Still relatively compact but less tightly packed.
- Serves a central area and nearby residential surroundings.

Suburban:

- Routes extend farther and cover wider areas than town routes.
- Show transitional behavior between urban and rural structures.
- Less dense stop distribution, indicating more spaced-out residential zones.

Rural:

- Routes are long and span large geographical areas.
- Stops are widely spaced, often connecting small, isolated settlements.
- The shape and path vary significantly, often following main roads between distant collection points.

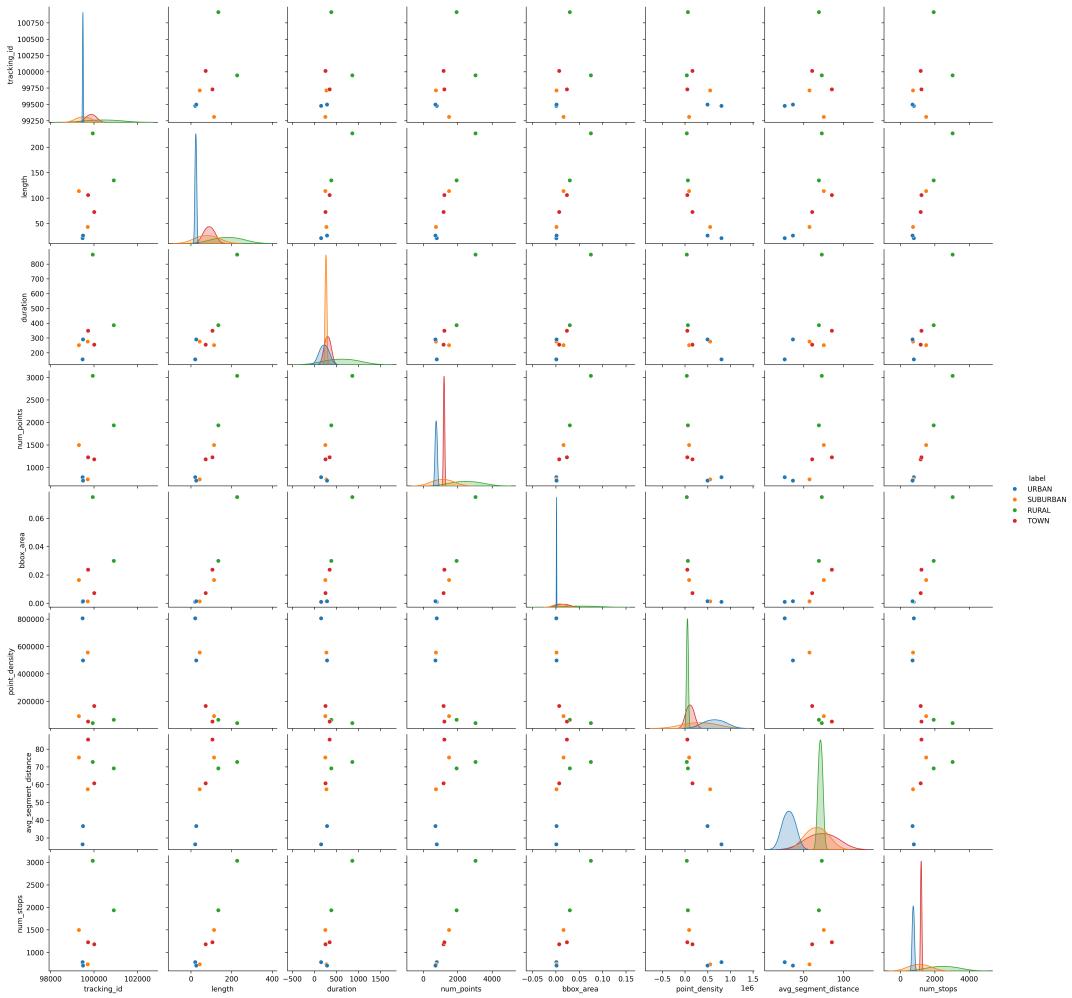


Figure 3.2: Pairplot of selected GPS route features grouped by area label

The pairplot compares the relationships between the extracted features (eg., length, duration, number of points, bounding box area, point density, average segment distance and number of stops). Rural and urban trackings show a

clear difference in multiple features. Point density and average segment distance are especially good discriminators. Suburban and town trackings show more variance and occasionally overlap with eachother, giving a not so clear distinction.

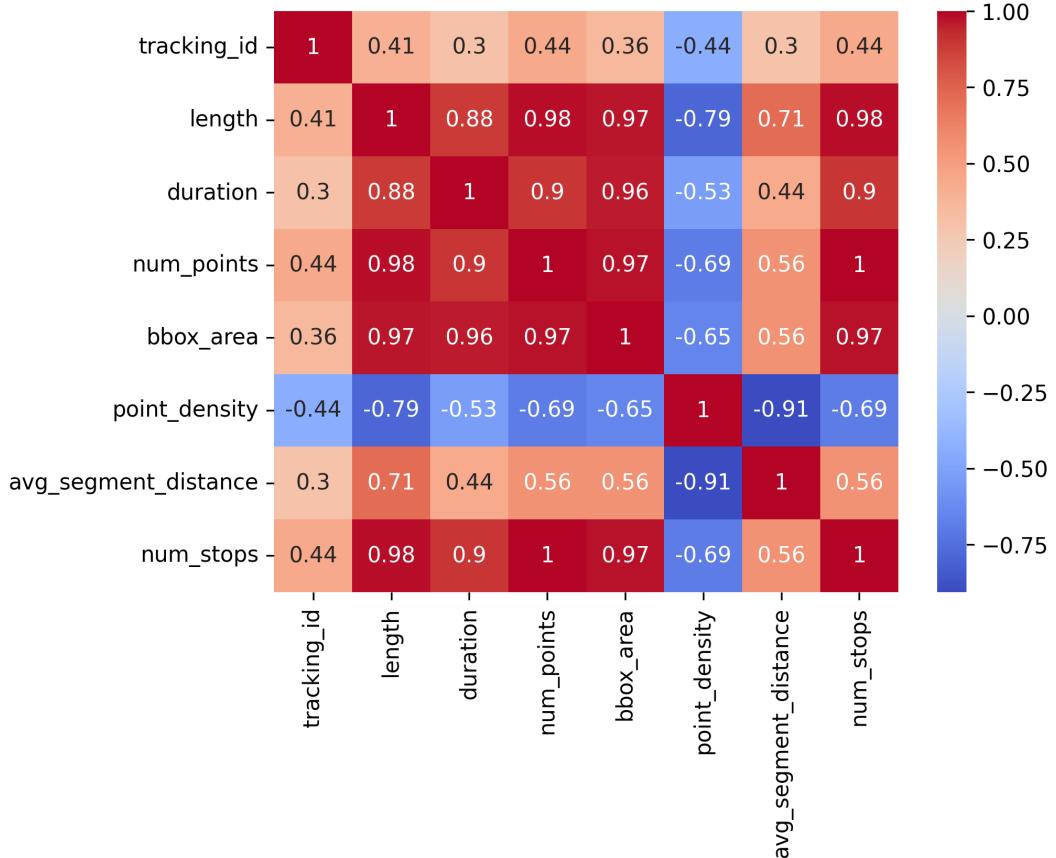


Figure 3.3: Correlation Matrix of selected GPS route features grouped by area label

The Correlation Matrix highlights the strong correlations between features in the selected sample. A high positive correlation between length, duration and number of points can be observed. Additionally the point density has a strong negative correlation with the tracking length, number of points and average segment distance.

This correlation is to be expected and confirms the consistency of the data, since the points (GPS coordinates) are recorded in uniform intervals. This plot also indicates the possible redundancy of features such as number of points and number of stops.

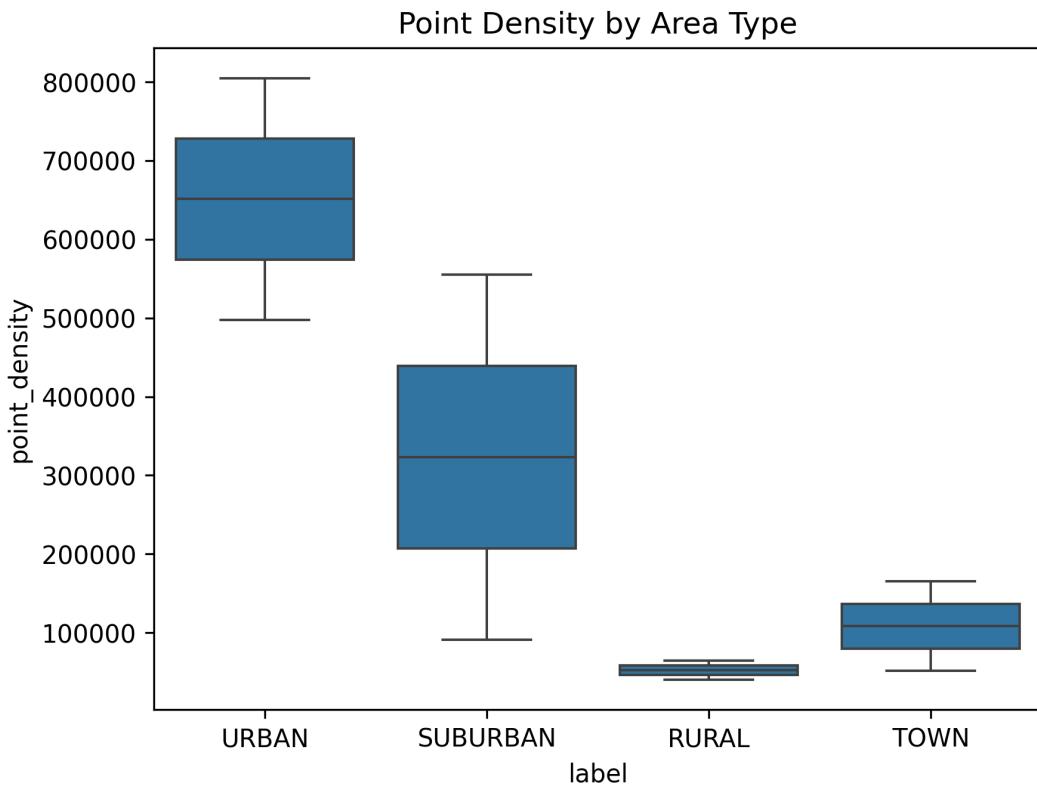


Figure 3.4: Boxplot of point density grouped by area label

The point density boxplots for each label shows a clear difference between the labels. Urban trackings appear to have the highest density and rural trackings the lowest, with suburban and town trackings falling in the middle with a wider variability.

This validates that the point density is a strong feature for classifying trackings to the four labels.

3.4 Solution Approach

3.4.1 Exploratory Data Analysis

The foundation of this thesis is the dataset provided by *infeo GmbH*. It contains anonymized GPS track data collected by waste collection vehicles during real world operation. Due to its large size of more than 100.000 GPS tracks and its anonymization, a clear picture of the data needed to be established as the first step. With visual examination of different random trackings a sample of eight

manually labeled trackings was gathered. The selected trackings were labeled to four categories, two trackings per category.

- Urban (Dense building structures, complex road networks, and minimal spacing between stops)
- Suburban (Moderately spaced residential areas with organized street layouts)
- Town (Smaller clustered settlements with simpler road structures)
- Rural (Sparse housing, long roads, large distances between collection points)

With the manually selected trackings varying in geographical structure, a exploratory data analysis helped transfer the visual distinction to clear differences found in the data of each tracking category.

3.4.2 Feature Extraction from Sample Dataset

3.4.3 Filtering and Preprocessing the Full Dataset

3.4.4 Clustering and Pattern Discovery

Notes: First i used kmeans (specifically kmeans++ from scikit-klearn python) to cluster the data into four clusters, but soon found out that cluster two in particular was only contained of outliers. I then refined my notebook to first use dbscan clustering to detect outliers and remove those from the dataset. Then afterwards use kmeans clustering to cluster into the four category clutsers, which gave a way better results than without dbscan clustering.

3.4.5 Training a Classification Model

3.4.6 Comparison with OSM Geofences

3.4.7 API Integration

3.5 Structure of the Work

4 Implementation

4.1 Implementation of the Big Picture

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4.2 Integration with existing systems

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5 Evaluation and Discussion

5.1 Definition of the data sets used for the evaluation

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5.2 Evaluation of the results

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5.3 Reflection on the results

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6 Conclusion

6.1 Future Directions

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6.2 Limitations

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Affidavit

I hereby declare in lieu of oath that I have written this Bachelor thesis independently and without the use of aids other than those specified. The passages taken directly or indirectly from other sources directly or indirectly from other sources are marked as such. The thesis has not been neither in the same nor in a similar form to any other examination authority nor has it been published.

Dornbirn, on 15. May 2025

Matthias Hefel