

[Achtung: Verwenden Sie einen Sperrvermerk nur in sehr gut begründeten Fällen]

[evtl. Sperrvermerk]

Die vorliegende Arbeit ist bis zum [DATUM] für die öffentliche Nutzung zu sperren. Veröffentlichung, Vervielfältigung und Einsichtnahme sind ohne meine ausdrückliche Genehmigung nicht gestattet. Der Titel der Arbeit sowie das Kurzreferat/Abstract dürfen veröffentlicht werden.

Dornbirn,

Unterschrift Verfasser*in



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

Supervised by
Dipl.-Ing. Dr. techn. Ralph Hoch

Submitted by
Matthias Hefel
Dornbirn, May 2025

Dedication

*Dedicated to my younger self, who never stopped chasing his dream and never
will!*

And to my parents, who 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]

Contents

List of Figures	11
List of Tables	12
List of Abbreviations	13
1 Introduction	14
1.1 Motivation	14
1.2 Problem Statement	15
1.3 Solution Approach and Goal	15
2 Problem Definition and Solution Approach	16
2.1 Description of the Dataset	16
2.1.1 Overview	16
2.1.2 Source and Collection Method	16
2.1.3 Structure of the Data	16
2.1.4 Size and Coverage	18
2.1.5 Limitations	18
2.2 Big Picture	18
2.3 Dataset Analysis	18
2.3.1 Sample Analysis	18
2.4 Solution Approach	22
2.4.1 Exploratory Data Analysis	22
2.4.2 Feature Extraction from Sample Dataset	23
2.4.3 Filtering and Preprocessing the Full Dataset	23
2.4.4 Clustering and Pattern Discovery	23
2.4.5 Training a Classification Model	23
2.4.6 Comparison with OSM Geofences	23
2.4.7 API Integration	23
2.5 Structure of the Work	23
3 Background and Related Work	24
3.1 Technical Background	24
3.2 Related Work	24
3.2.1 Comparison of GPS-Routes	24

4 Implementation	25
4.1 Implementation of the Big Picture	25
4.2 Integration with existing systems	25
5 Evaluation and Discussion	26
5.1 Definition of the data sets used for the evaluation	26
5.2 Evaluation of the results	26
5.3 Reflection on the results	26
6 Conclusion	27
6.1 Future Directions	27
6.2 Limitations	27
Literaturverzeichnis	28
[evtl. Anhang]	29
6.3 Use of AI tools	29
Affidavit	31

List of Figures

2.1	Mapgrid for selected sample trackings	19
2.2	Pairplot of selected GPS route features grouped by area label	20
2.3	Correlation Matrix of selected GPS route features grouped by area label	21
2.4	Boxplot of point density grouped by area label	22

List of Tables

2.1	Structure of a Tracking Entry	17
2.2	Structure of a GPS Point Entry	17
6.1	Use of AI tools during the creation process	30

List of Abbreviations

GPS Global Positioning System

AI Artificial Intelligence

ML Machine Learning

API Application Programming Interface

CSV Comma-Separated Values

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 Problem Definition and Solution Approach

2.1 Description of the Dataset

2.1.1 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.

2.1.2 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.

2.1.3 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 2.1: 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 2.2: 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.

2.1.4 Size and Coverage

Formatvorlage für den Fließtext.

2.1.5 Limitations

Missing Values: GPS gaps etc, useless trackings etc.

2.2 Big Picture

Formatvorlage für den Fließtext.

2.3 Dataset Analysis

Formatvorlage für den Fließtext.

2.3.1 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.

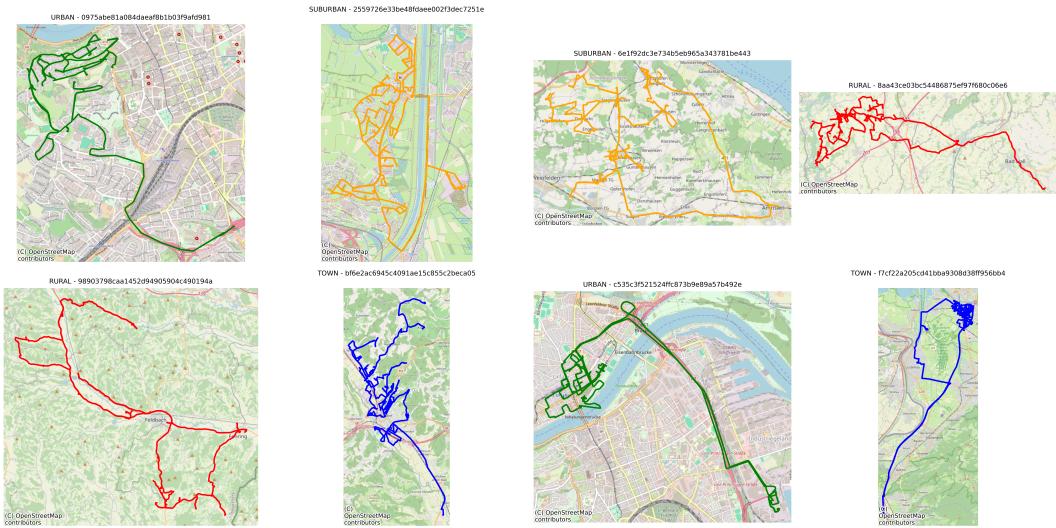


Figure 2.1: Mapgrid for selected sample trackings

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, UR-
BAN=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.

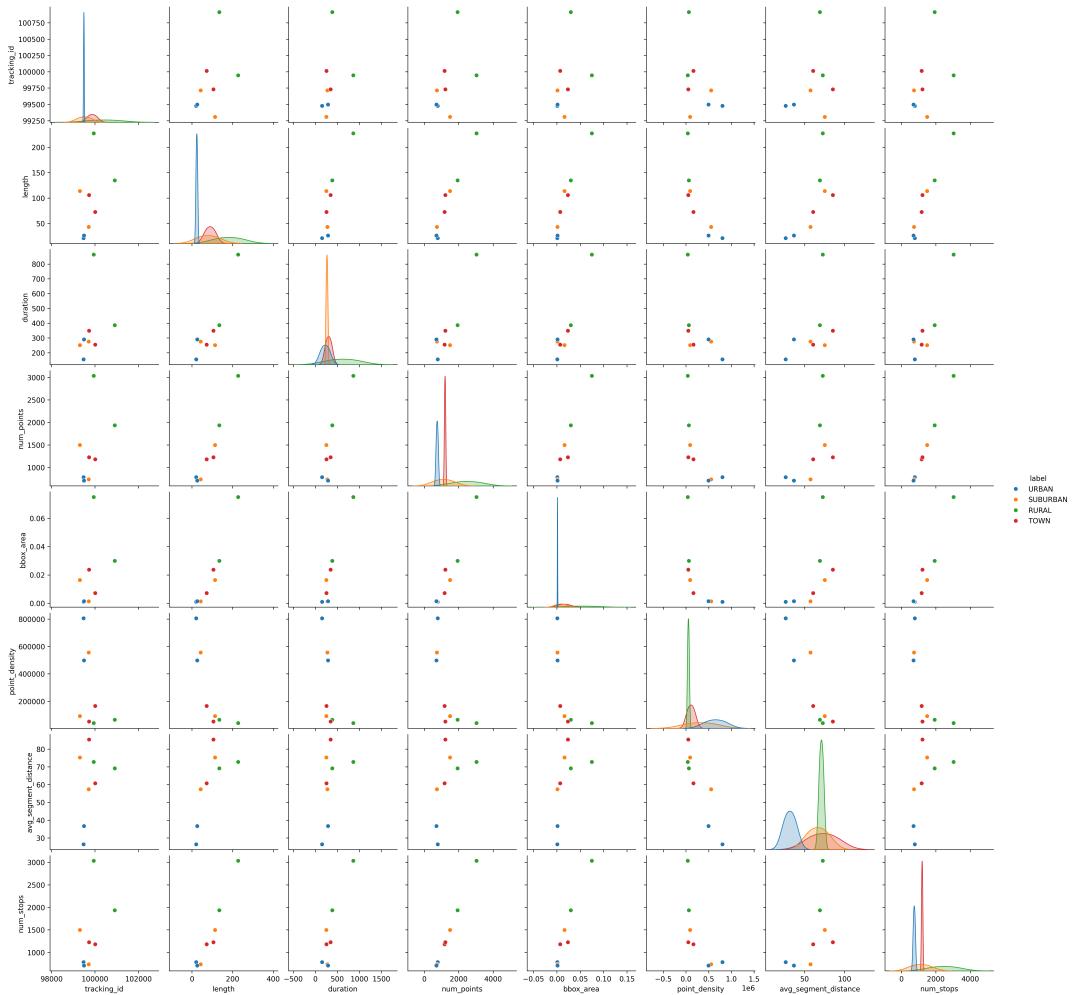


Figure 2.2: Pairplot of selected GPS route features grouped by area label

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.

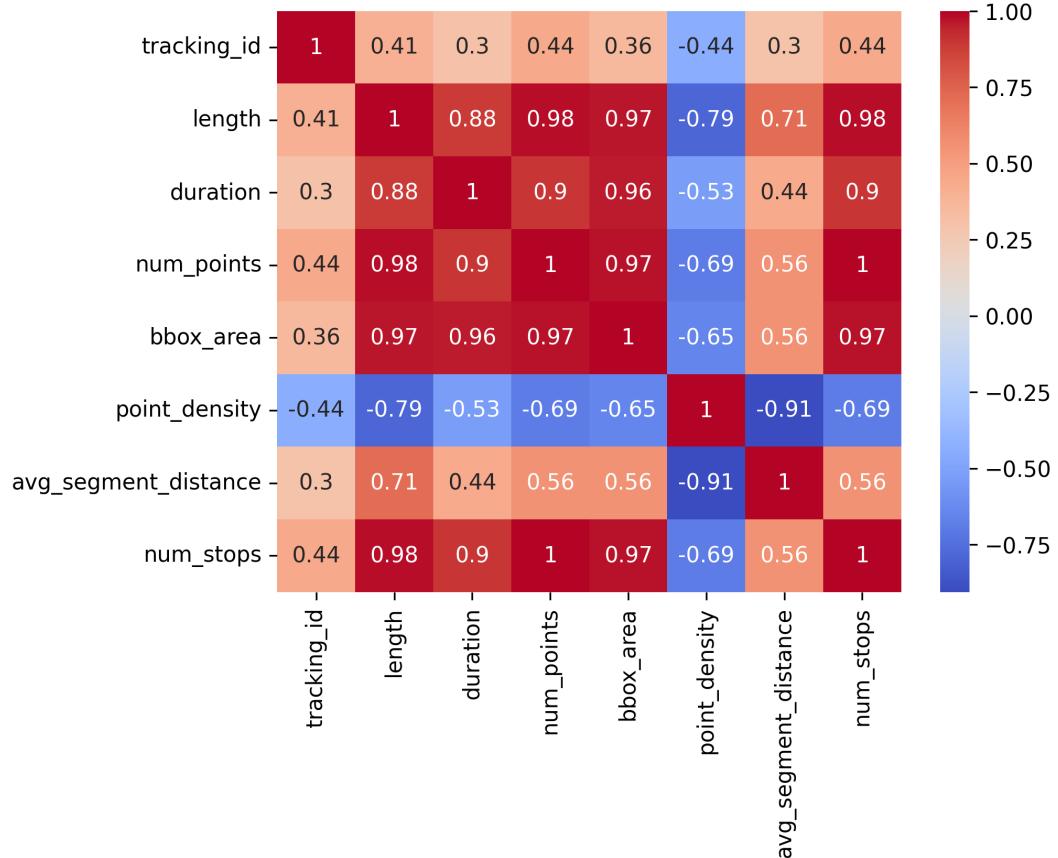


Figure 2.3: Correlation Matrix of selected GPS route features grouped by area label

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.

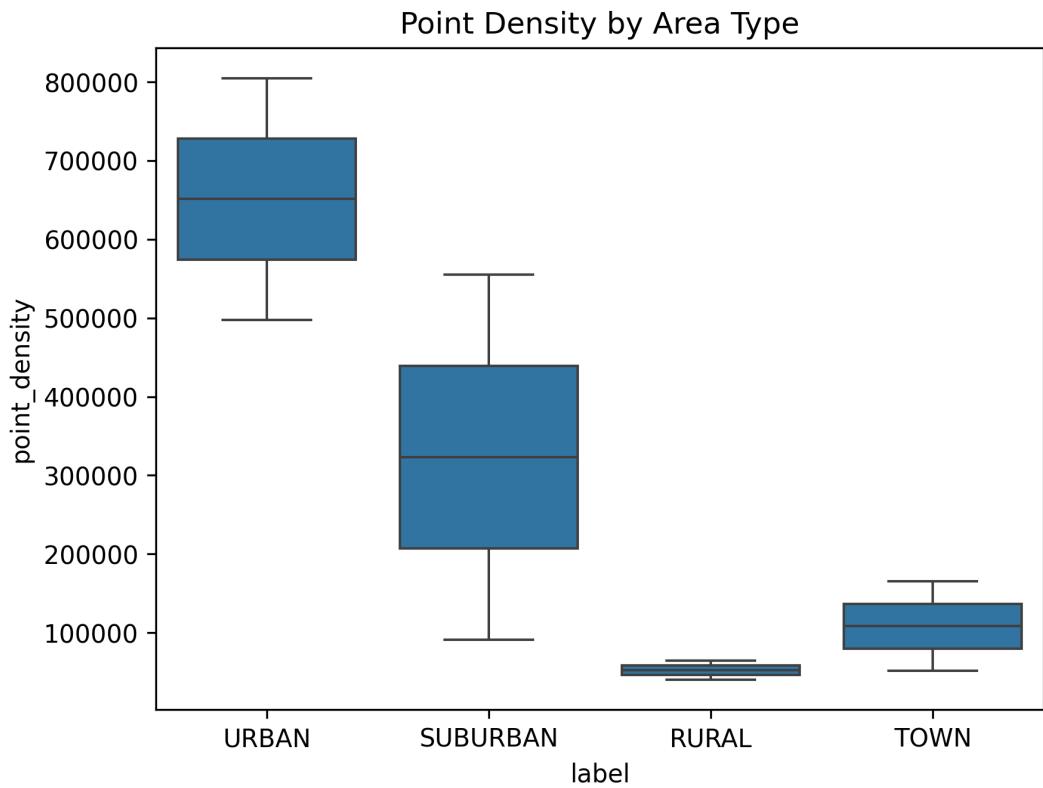


Figure 2.4: Boxplot of point density grouped by area label

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.

2.4 Solution Approach

2.4.1 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.

2.4.2 Feature Extraction from Sample Dataset

2.4.3 Filtering and Preprocessing the Full Dataset

2.4.4 Clustering and Pattern Discovery

2.4.5 Training a Classification Model

2.4.6 Comparison with OSM Geofences

2.4.7 API Integration

2.5 Structure of the Work

3 Background and Related Work

3.1 Technical Background

3.2 Related Work

3.2.1 Comparison of GPS-Routes

4 Implementation

4.1 Implementation of the Big Picture

Formatvorlage für den Fließtext.

4.2 Integration with existing systems

Formatvorlage für den Fließtext.

5 Evaluation and Discussion

5.1 Definition of the data sets used for the evaluation

Formatvorlage für den Fließtext.

5.2 Evaluation of the results

Formatvorlage für den Fließtext.

5.3 Reflection on the results

Formatvorlage für den Fließtext.

6 Conclusion

6.1 Future Directions

Formatvorlage für den Fließtext.

6.2 Limitations

Formatvorlage für den Fließtext.

Bibliography

- [1] “The world’s most valuable resource is no longer oil, but data,” *The Economist*, ISSN: 0013-0613. [Online]. Available: <https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data> (visited on 04/06/2025).
- [2] T. Petroc, *Data growth worldwide 2010-2028*, en. [Online]. Available: <https://www.statista.com/statistics/871513/worldwide-data-created/> (visited on 04/11/2025).
- [3] *Europe Waste Management Market Size and Share Analysis 2030*, en. [Online]. Available: <https://www.nextmsc.com/report/europe-waste-management-market> (visited on 04/24/2025).
- [4] *Solid waste management*, en. [Online]. Available: <https://www.eib.org/en/projects/topics/energy-natural-resources/solid-waste/index> (visited on 04/24/2025).
- [5] *Gemeinsam mit unseren Kunden revolutionieren wir die digitale Kreislaufwirtschaft*, de-AT. [Online]. Available: <https://infeo.at/index.php/revolution/> (visited on 04/24/2025).

[evtl. Anhang]

Formatvorlage für den Fließtext.

6.3 Use of AI tools

Table 6.1: Use of AI tools during the creation process

Working step	AI used	AI tool(s)	Experiences / recommendations / irritations
Find a topic idea	no	-	-
Narrow down topic / Formulate question	no	-	-
Find sources	yes	OpenAI GPT-4o	Helped identify relevant keywords and topic clusters.
Explain terms	yes	OpenAI GPT-4o	Useful for quick definitions and simple explanations.
Design text structure	yes	OpenAI GPT-4o	Good for outlining sections. Required manual adjustments.
Have content read aloud	no	-	-
Translate content	no	-	-
Dictate content	no	-	-
Paraphrase content, summarise	yes	OpenAI GPT-4o	Helpful to generate concise summaries of long text.
Write introduction	yes	OpenAI GPT-4o	Provided inspiration but required rewording.
Write main chapter	yes	OpenAI GPT-4o	Used for structuring and rephrasing, not full writing.
Write a summary	yes	OpenAI GPT-4o	Used to condense main points effectively.
Obtain text feedback	yes	OpenAI GPT-4o	Used to review tone, clarity, and consistency.
Revise text statement	yes	OpenAI GPT-4o	Helpful for reformulating statements.
Revise text formulation	yes	OpenAI GPT-4o	Polished sentences and improved flow.
Correct text formally	yes	OpenAI GPT-4o	Assisted with grammar and punctuation checking.
Code generation	yes	OpenAI GPT-4o, Github Copilot	Assisted with generating code and fixing bugs

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