

# Integrating Elevation Data in SUMO models for detailed estimation of Energy consumption by Electric Vehicle in large networks

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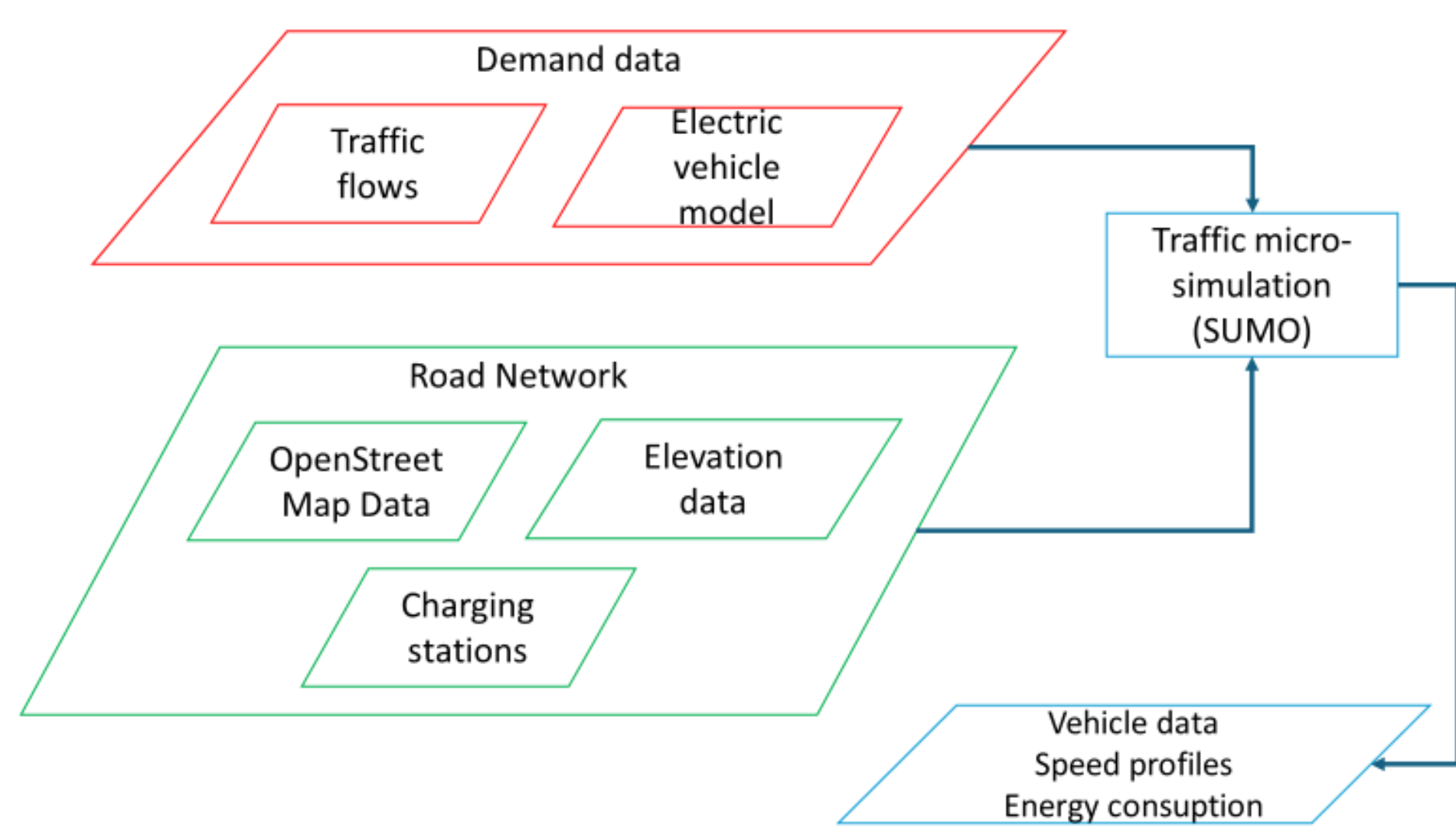
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To adequately describe the operating conditions of electric vehicles across different usage patterns, it is necessary to generate representative speed profiles. EV usage conditions are influenced by several factors, including battery size and range, driving style, charging behavior, area of use (urban, extra-urban, or mixed), and prevailing traffic conditions.

This study aims to identify a set of driving scenarios that meaningfully represent EV operating conditions from the perspective of road layout characteristics. These include road functional class, number of lanes, maximum permitted speed, and the presence of traffic-lighted intersections, all of which influence vehicle speed profiles and driving dynamics.

Trip length, charging opportunities, temperature, and the spatial distribution of charging infrastructure further affect EV energy usage. Road gradient plays a key role in EV energy consumption and performance, particularly in mixed-terrain networks combining urban and extra-urban roads. However, the datasets used in microscopic traffic simulations often neglect elevation information, limiting their ability to reproduce realistic EV trips beyond flat environments.

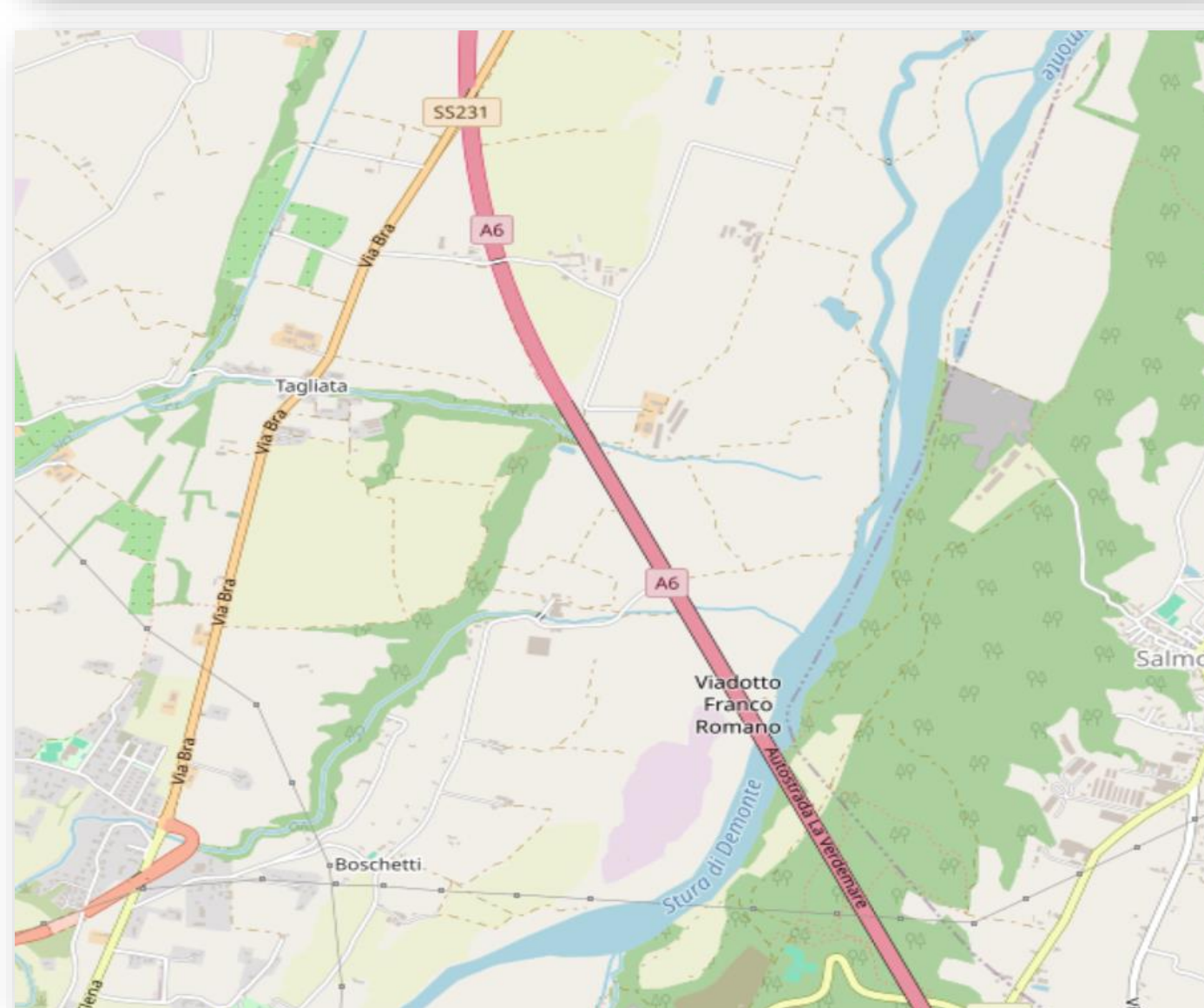
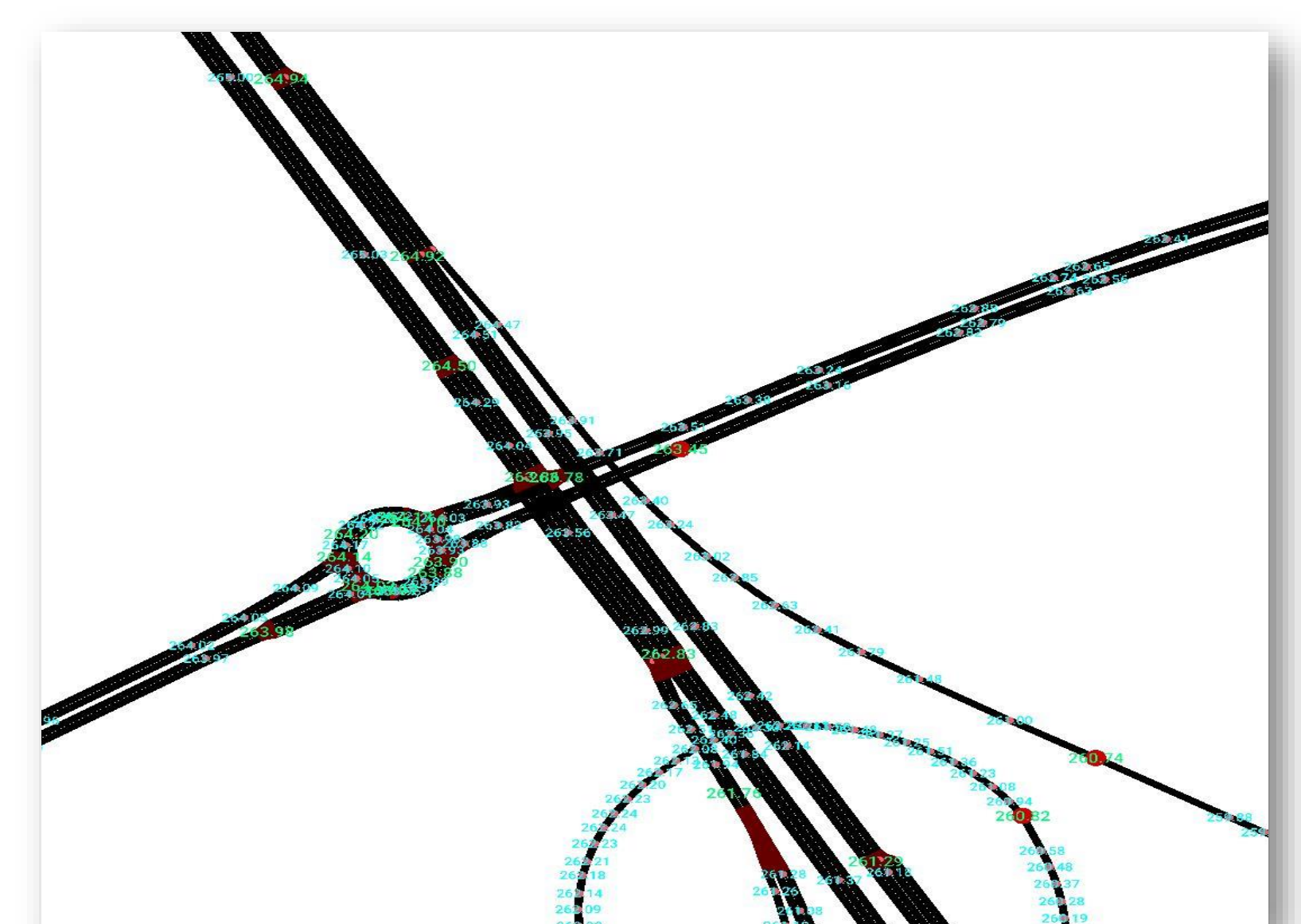
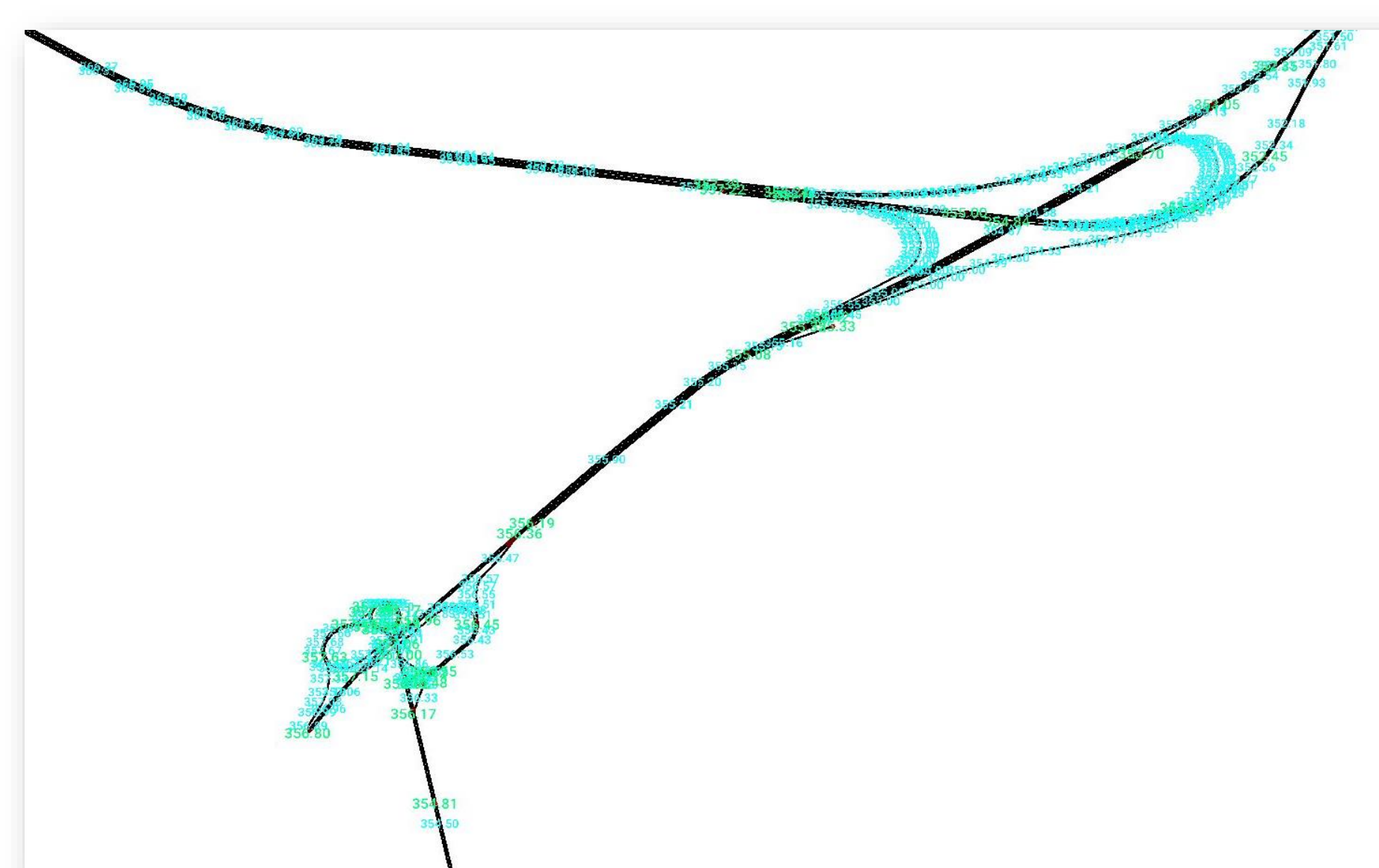
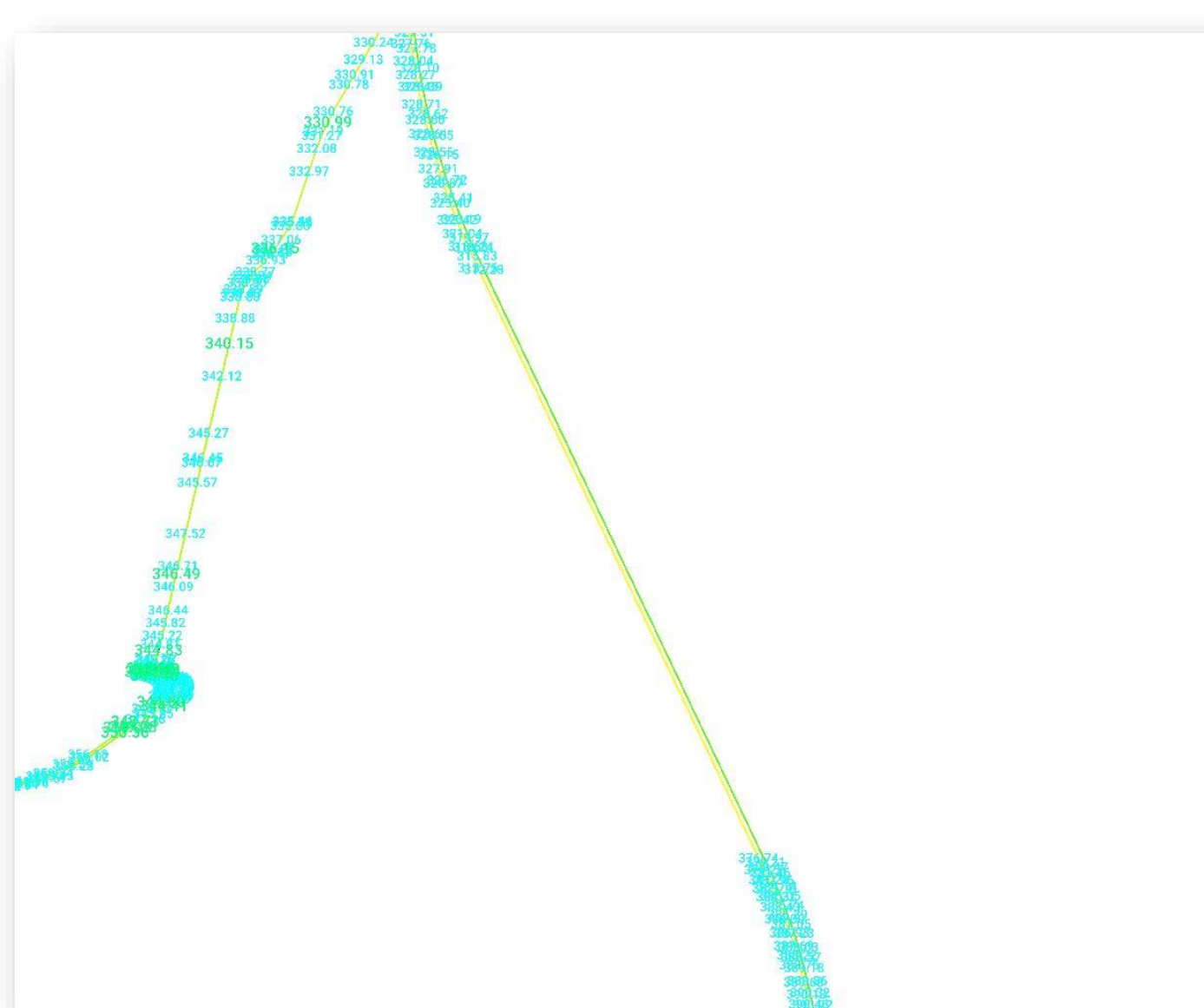
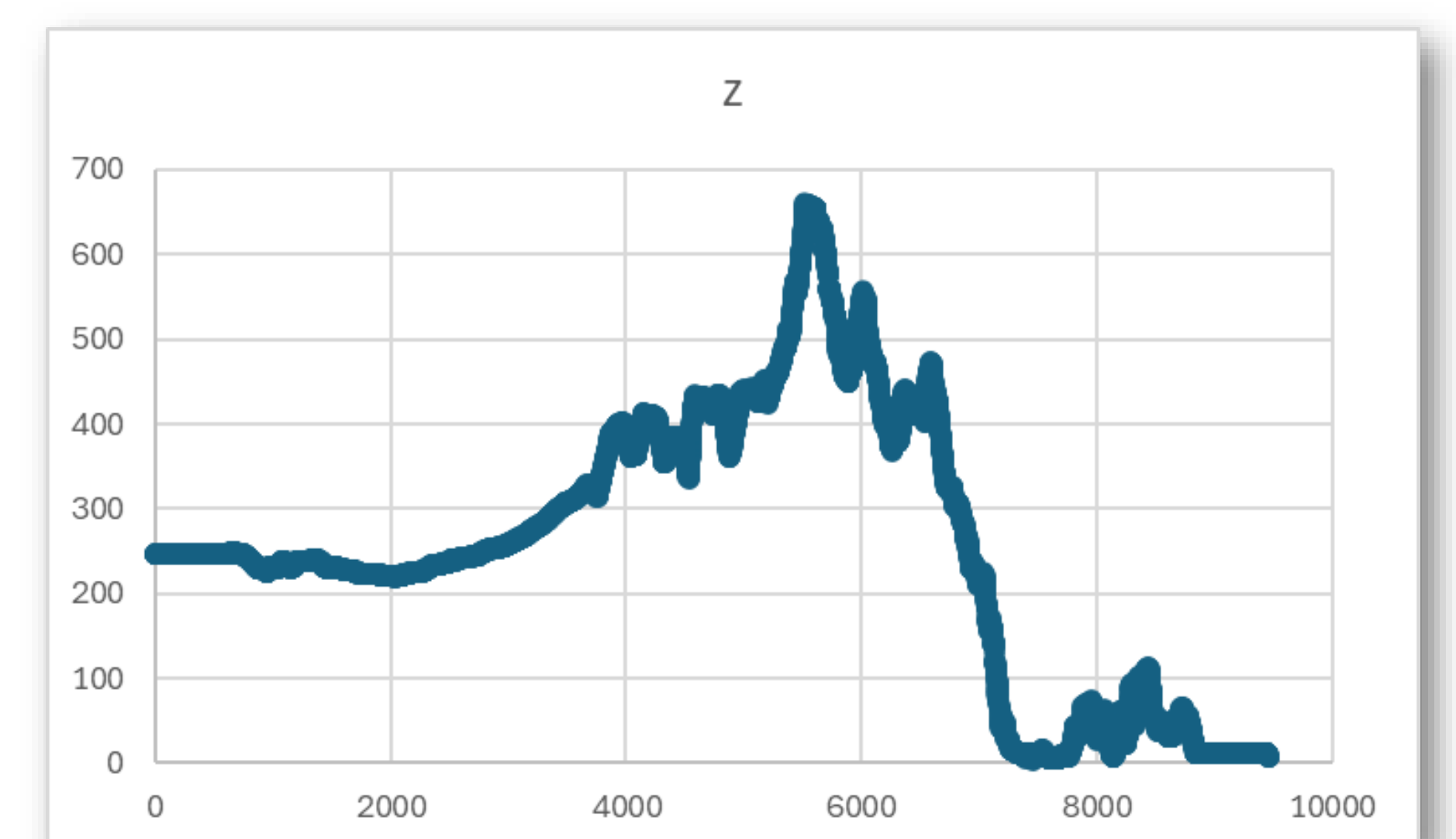
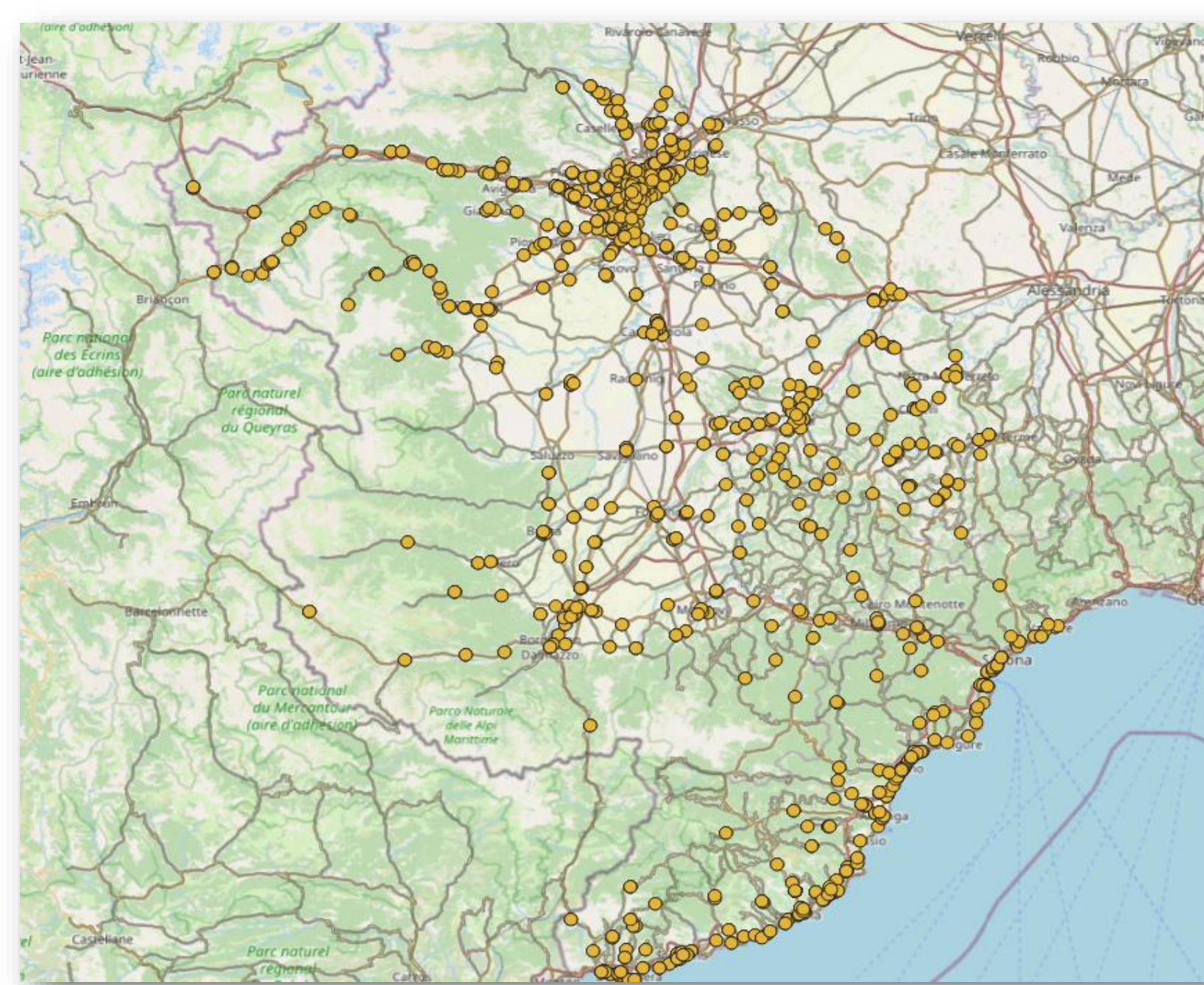


To address DEM limitations — such as the lack of representation of viaducts and multi-level intersections — high-resolution elevation data are collected through field surveys. Using a GNSS+RTK positioning device on a vehicle, centimeter-level 3D trajectories are recorded to refine edge elevation profiles. The workflow is applied to a large-scale regional road network in northwestern Italy characterized by mixed terrain.

## Integrating elevation data into SUMO road networks to enable terrain-aware EV trip simulation.

The proposed methodology follows a two-step approach. First, an open-source Digital Elevation Model (DEM), obtained from OpenTopography, is combined with OpenStreetMap-based road networks using SUMO's netconvert tool. By parsing both the road network and DEM data, elevation information is added to network edges through the vertical (z) coordinate in edge geometries.

During the simulation focused on energy consumption, an electric vehicle will follow a specific route, encountering different slopes, with eventual recharging operations during the trip.



- Simulated a realistic network representing a large part of north-west Italian territory, requiring a refinement process of road geometry.
- Integrated traffic simulation results and energy consumption related to realistic road characteristics to quantify charging operations.
- Explored alternative solutions for gathering data to refine the model accuracy with on-field observations.