

EVMapSim: A Network-level Electric Vehicle Charging Simulator

Demonstration Track

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ABSTRACT

Long-distance electric vehicle (EV) travel depends critically on charging infrastructure reliability. When stations fail or queues form unexpectedly, drivers face increased range anxiety and risk of getting stranded. In this demonstration paper, we present EVMapSim, a discrete-event simulator for modelling EV navigation and charging behaviour at a national scale. We demonstrate 10,000+ vehicles traversing the UK road network, each making real-time charging decisions while encountering infrastructure failures. EVMapSim supports three failure scenarios, enabling analysis of how infrastructure resilience affects driver outcomes, including wait times, route deviations, and stranding rates.

KEYWORDS

EV charging; agent-based simulation; road network; resilience

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1 INTRODUCTION AND BACKGROUND

Range anxiety, the fear of depleting battery charge before reaching a charging station, remains a significant barrier to electric vehicle (EV) adoption [13, 14, 16]. While EVs offer substantial environmental benefits, including lower emissions and reduced dependence on fossil fuels, prospective buyers consistently cite concerns about charging availability and journey reliability as key deterrents [4, 16, 17]. This anxiety is acute for long-distance travel, where drivers must plan multiple charging stops and trust that the infrastructure will be operational upon arrival. Surveys confirm that station availability and reliability significantly influence driver behaviour [6, 7]. Yet, existing simulations assume static networks,

overlooking the stochastic nature of real infrastructure where failures are inevitable [5, 9]. Empirical studies show that a significant fraction of public chargers may be non-functional due to hardware faults and payment errors, undermining reported availability rates [2, 4, 8, 15, 20].

Within the UK, these challenges are visible. The public charging network has grown rapidly in recent years, with tens of thousands of charge points installed, including rapid and ultra-rapid chargers [1, 3, 19, 21, 22]. Despite this, driver confidence remains fragile. Reports of out-of-order chargers and slow repairs undermine trust in reliable inter-city travel [4, 20]. Infrastructure reliability is not merely installed capacity but sustained operational performance.

We present EVMapSim, a UK-level EV navigation and charging simulator modelling infrastructure failures and large-scale multi-agent interactions to quantify impacts on driver experience. It simulates 10,000+ EVs in a shared resource environment as autonomous agents, making decentralised decisions under uncertainty. EVMapSim captures how stochastic outages and agent interactions drive emergent effects, allowing researchers to study multi-agent phenomena such as resource competition and infrastructure resilience. It provides a scalable experimental platform for infrastructure planners to compare failure patterns and resilience, policymakers to evaluate reliability standards and researchers to test coordination mechanisms and how battery capacity influences stranding risk.

2 EVMAPSIM SIMULATOR

EVMapSim simulates thousands of EV journeys across the UK to answer: *how do charging station failures affect drivers' ability to complete long-distance trips?* The simulator tracks each vehicle's State-of-Charge (SoC), recording when drivers experience anxiety, encounter failed stations, face unexpected queues, or become stranded. By aggregating outcomes across the network, EVMapSim reveals how infrastructure reliability translates into driver experiences. A demo video is available here: <https://www.youtube.com/watch?v=MTIZAShsqrE>.

2.1 System Components

Network and Data. The simulator constructs a UK road network from ONS geographic data [11], representing 344 wards as graph nodes with distance-weighted edges. Charging station data from OpenChargeMap [12] (27,423 points) is assigned to nearest nodes, including connector types, power, and capacity.



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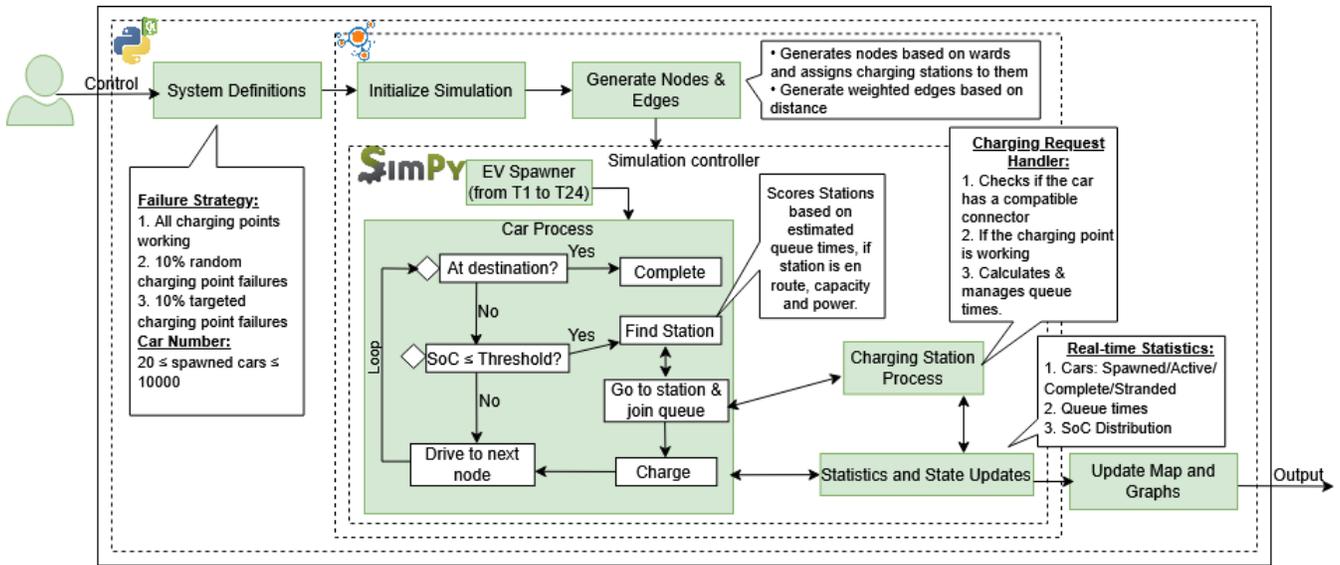


Figure 1: System Architecture of the EV charging simulation framework

Simulation Engine. EVMapSim uses SimPy for discrete-event simulation [10]. Heterogeneous vehicles are spawned as shown in Figure 1, in a 24-hour demand distribution with randomised origin-destination, initial SoC, battery capacity, patience threshold, and connector type (UK distribution). A 10,000 EV simulation run completes in 8 minutes on a 14-core CPU machine with 16 GB RAM.

Driver Behaviour and Charging. Vehicles navigate using shortest-path routing and threshold-based charging decisions. Station selection considers queue length, wait time, charger power, and route deviation. Upon arrival, drivers discover the actual equipment status. Charging duration is based on realistic physics models, accounting for battery capacity, SoC, and efficiency.

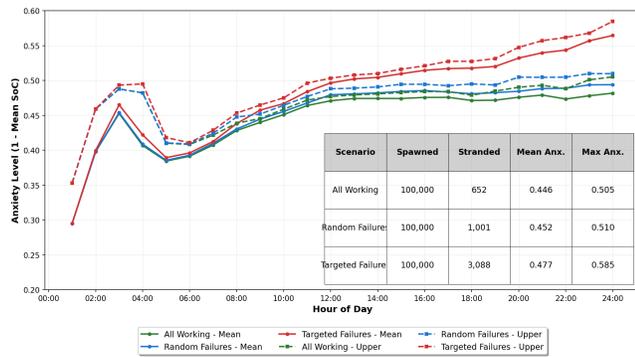


Figure 2: Anxiety levels under different failure scenarios.

2.2 Failure Scenarios and Analysis

EVMapSim supports three failure scenarios: (1) baseline with all charging points operational, (2) 10% random failures distributed uniformly, and (3) 10% targeted failures disabling high-traffic hubs using betweenness centrality.

Figure 2 shows how failure scenarios affect driver anxiety through a 24-hour simulation with 10,000 vehicles over 10 simulation runs with different seed values. We adopt a simple anxiety proxy, $Anxiety = 1 - SoC$ [18, 23]. Targeted failures (red) consistently produce higher anxiety than random failures (blue) and baseline (green), and the gap widens as vehicles encounter failed stations at critical nodes and as the number of vehicles increases.

2.3 Visualisation and Statistics

The interface provides real-time visualisation with vehicles colour-coded by SoC and live analytics. The status bar displays live statistics: active vehicles, driving count, charging count, completed journeys, and stranded vehicles. Hover tooltips show individual vehicle details, including current SoC, origin, destination, and personal charging threshold. This provides intuitive evidence for public engagement and policy discussions.

3 CONCLUSIONS AND FUTURE WORK

We presented EVMapSim, a network-level EV charging simulator modelling 10,000 vehicles navigating the UK road network under charging infrastructure failures. EVMapSim quantifies how reliability impacts driver anxiety, route deviations, and stranding risk, providing evidence for resilience planning and reliability standards.

Future work will extend EVMapSim to other countries by adapting charging and geographic datasets, add reinforcement-learning agents that adapt to outages and weather-driven range loss, and study multi-agent coordination via shared station availability, alongside policy experiments comparing charging incentive schemes.

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