Maybury L
Cardiff University
School of Engineering

Corcoran P
Cardiff University
School of Engineering

SUSTAINABLE ENERGY

Mathematical Modelling to Optimise an Urban Electric Vehicle Charging System

Many countries are embracing the adoption of electric vehicles for private transportation as a key measure in decarbonising their transportation sectors. In the UK, the Industrial Decarbonisation Strategy provides a blueprint for industry players to reduce carbon emissions, aligning with the nation's commitment to reach net zero emissions – a state where human generated greenhouse gases are balanced by their removal from the atmosphere. In line with this commitment, the UK is transitioning from conventional vehicles to electric vehicles, with a ban on the sale of new petrol and diesel vehicles slated for 2030. This transition underscores the need for reliable charging infrastructure and systems to support the growing demand for electric vehicles. In this article, a charging system for urban areas is proposed. An integer linear program model based on queuing theory is developed with the goal of minimizing congestion in the charging system. In the results section, a case study of Cardiff's urban centre, with a street network obtained from Open Street Map [1] is used to demonstrate the model's application of creating an assignment of apartment blocks to charging stations with the goal of minimizing the congestion of the charging stations in the urban area.

Keywords:
Electric vehicles, sustainable mobility, mathematical modelling, assignment problem, decarbonisation.

Corresponding author:
MayburyLE@cardiff.ac.uk

L. Maybury and P. Corcoran, 'Mathematical Modelling to Optimise an Urban Electric Vehicle Charging System', *Proceedings of the Cardiff University Engineering Research Conference 2023*, Cardiff, UK, pp. 173-175.

doi.org/10.18573/conf1.am

INTRODUCTION

Many countries, including the UK, prioritize decarbonisation and have implemented policies such as the Net Zero Strategy [2] to decarbonise all sectors of the economy by 2050. The UK government's Road to Zero policy [3] specifically targets cleaner road transport as part of this effort.

The UK has banned the sale of new petrol and diesel cars by 2030, prompting the transportation sector to transition towards electric vehicles (EVs) with the aim of achieving net zero emissions. This is a costly and ambitious transition that must be achieved with minimal expense and disruptions. Mathematical modelling can help optimise this transition.

As such, the approach presented in this paper is to mathematically optimise an urban EV charging system, with a specific focus on apartment blocks where residents typically lack designated parking spots in which to charge their vehicle. The optimisation problem incorporates an assignment problem and queuing theory to minimise the average wait time in the system by optimally assigning users to shared charging stations. By implementing the optimal solution, we believe congestion in the system can be reduced, as each urban resident is assigned a priority charging station that serves as their home station without incurring extra fees, with an assignment based on minimising queue times.

MATERIALS AND METHODS

The charging system proposed in this article is based on the assumption that those living in apartment blocks do not have access to individual home EV charging. As such, they will have priority access to a *shared home charging station*, which is a public charging station near the residence.

The model is formulated as an assignment problem where apartment blocks are assigned to charging station queues , which correspond to charging stations of fixed locations. This assignment is obtained using an ILP (integer linear program) optimisation model. The objective of the model is to minimise the average queue time over the set of charging station queues Q, whilst ensuring that users are not assigned to a charging station that is too far away from their residence. The ILP is solved using Gurobi Optimization, LLC [4].

RESULTS

In this section, the ILP described above is demonstrated using a simple example, and also applied to a street network of Cardiff City Centre.

Simple Example
In the simple example shown in Figure 1, the set of charging station queues is and the set of apartment blocks is . The edges represent the shortest path between each apartment block and each charging station.

Then the optimal assignment of apartment blocks to charging station queues is shown in Figure 2.

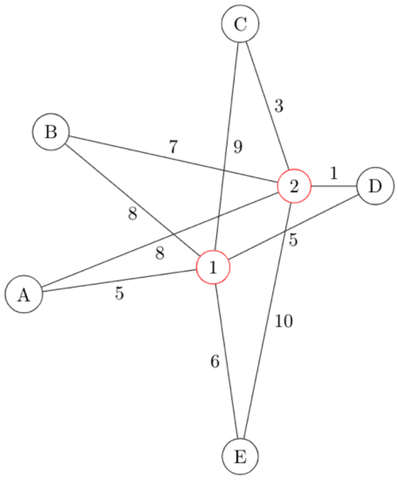

Fig. 1. Simple network of apartment blocks and charging stations.

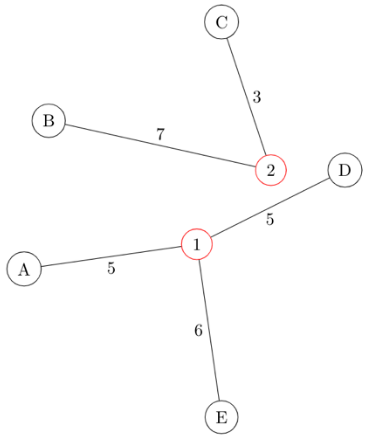

Fig. 2. Optimal assignment of apartment blocks to charging station queues.

Case Study: Cardiff City Centre
The method is applied to Cardiff's urban centre. For the purpose of the study, a street network is modelled using a graph, where nodes are locations and edges are paths between the locations. As such, a street network of Cardiff is obtained from OpenStreetMap [1] using Python package OSMnx [5] which can be seen in Figure 3.

This street network is a bounding box of size 1100m containing the city centre.9 apartment blocks are identified, along with 6 potential placements for charging stations to be installed. The apartment blocks are located at: Churchill Way, The Hayes, Westgate Street, Caroline Street, Bute Terrace and Cathedral Road. The carparks are located at St David's Shopping Centre, Capitol Shopping Centre, Dumfries Place, Westgate Street, Adam Street, Sophia Gardens, Queen Street and Newport Road. These locations can be seen in Figure 3, with apartment blocks in blue and potential charging stations in red.

Fig. 3. Cardiff City Centre street network with apartment blocks and potential charging stations in blue and red points respectively.

The assignment ILP is applied to the street network shown in Figure 3, and the optimal assignment of apartment blocks to charging stations is calculated, and displayed in Fig. 4.

Fig. 4. Optimal assignment of apartment blocks to charging stations.

DISCUSSION

The method proposed in this article provides an optimal assignment of apartment blocks to charging station queues based on the constraints and parameters input, and has a number of applications, such as informing city planners how many charging points to install at different charging locations. It can also be used to compare overall system congestion for different charging station locations, by varying these locations in the model.

The method also has limitations. For example, the users are considered at an aggregated apartment block based level. Future research may employ household level data to complete the analysis at a finer scale.

Acknowledgments
This study is partly funded by an EPSRC DTP PhD studentship.

Conflicts of interest
The authors declare no conflict of interest.

REFERENCES

[1] M. Haklay and P. Weber, 'Openstreetmap: User-generated street maps', *IEEE Pervasive Computing*, vol. 7, no. 5 pp. 12-18, Oct. 2008. doi.org/10.1109/MPRV.2008.80

[2] HM Government, 'Net zero strategy: Build back greener', 2021[online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf.

[3] HM Government, 'The road to zero', 2021 [online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf.

[4] Gurobi Optimization, LLC, 'Gurobi Optimizer Reference Manual', 2022 [online]. Available: https://www.gurobi.com

[5] G. Boeing, 'OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks', *Computers, Environment and Urban Systems*, vol. 65, pp. 126–139, Sep. 2017 doi.org/10.1016/j.compenvurbsys.2017.05.004

Cynhadledd Ymchwil Peirianneg Caerdydd
Cardiff Engineering Research Conference

Proceedings of the Cardiff University Engineering Research Conference 2023 is an open access publication from Cardiff University Press, which means that all content is available without charge to the user or his/her institution. You are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles in this publication without asking prior permission from the publisher or the author.

E. Spezi and M. Bray (eds.) 2024. *Proceedings of the Cardiff University Engineering Research Conference 2023.* Cardiff: Cardiff University Press.
doi.org/10.18573/conf1

Cardiff University Engineering Research Conference 2023 was organised by the School of Engineering and held from 12 to 14 July 2023 at Cardiff University.

The work presented in these proceedings has been peer reviewed and approved by the conference organisers and associated scientific committee to ensure high academic standards have been met.

Cardiff University Press | Gwasg Prifysgol Caerdydd

First published 2024

Cardiff University Press
Cardiff University, PO Box 430
1st Floor, 30-36 Newport Road
Cardiff CF24 0DE

cardiffuniversitypress.org

Editorial design and layout by
Academic Visual Communication

ISBN: 978-1-9116-5349-3 (PDF)