Design of Wireless Charging Lane Infrastructure

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The transport industry represented 27% of all UK greenhouse gas emissions in 2017, with 90% of which being attributed to road transportation. Despite improvements in technology over the last three decades, emissions only decreased by 4%, compared to a 47% decrease in the industrial sector. These increases took place despite improvements in automotive technologies, motor efficiency and policy efforts, and are attributed to increased road traffic.

Extensive efforts are currently underway in the UK to promote the electrification of transport. In terms of public transport, buses constitute about 60% of all trips and particularly in London, where about half of bus trips take place, the number of journeys has increased by 20% since 2005, illustrating that electrifying the bus network offers a significant opportunity to reduce emissions.

Even though the implementation of electric buses is a promising solution, there are some aspects that confine their usage, such as the limited driving range and the long recharging times which translates into a requirement for larger fleets to compensate for the downtime due to charging. An alternative solution is the adoption of wireless charging lane (WCL) technology. This technology allows the bus to charge while on the move, increasing the driving range and reducing the downtime for recharging. This results in a reduction in demand for fixed charging infrastructure as well as fleet sizes. Network optimisation, combined with reduced battery size, can also reduce bus procurement and battery renewal costs through increased utilisation and other cost-savings.

To date, the studies carried out to estimate the infrastructure requirements to implement WCL have severe limitations that preclude their realistic application. As an example, energy consumption is generally assumed constant and independent of traffic congestion, which simplifies the relationships between velocity, emissions, and start-and-go traffic. Several studies do consider some of these aspects, but seldom incorporate them simultaneously

Neglecting these relationships may lead to serious operational consequences, such as buses running out of electricity, or requiring shutting down on-board services such as heating and air conditioning.

The aim of this study is to optimize the deployment of wireless charging infrastructure for the electric bus system. The main contribution of this study is the formulation of a stochastic model where variations in traffic, temperature, and passenger loading are considered. A two-stage stochastic programming model has been established to identify the best location of the WCL along with the optimal on-board battery size for every bus route while also considering all the possible energy consumption scenarios. The objective of the model is to minimize the total cost requirements of the WCL set up. The total cost is the summation of the following three major components:

- The cost of building the WCL,
- The cost of on-board battery for the entire bus fleet
- A penalty attributed when the battery level falls below the designated threshold.

Associated with the said objective function, there are three main constraints:

- The buses are assumed to be fully charged at the beginning of the route,
- The buses will never run out of power while in operation,
- The battery is only charged when the bus is using a WCL lane,
- Energy consumption continuity is maintained throughout the bus route.

The battery discharge rate is calculated considering five sources of energy loss, namely: energy loss due to friction or rolling resistance, aerodynamic resistance, road gradient, vehicle acceleration, and energy loss due to auxiliary systems usage.

The developed two stage-stochastic programming model was used to carry out an analysis using public domain data for the area of London. At an initial stage, 22 London central bus routes have been considered. To determine the benefits of WCL, two different scenarios have been studied: one with WCL-base recharge and another with only stationary charging facilities installed at the two ends of each bus route. The scenario where WCL has been used resulted on average in 36% reduction of battery size requirements, and over £300,000 savings in procurement costs in comparison to the scenario where WCL have been neglected.

A more extensive sensitivity analysis is carried out with additional considerations to the model. This instance incorporates the bus fleet size as a decision variable and can be used to jointly determine the optimal operational requirements in terms of battery size, WCL infrastructure, and bus fleet size. Due to the larger size of the problem caused by the greater number of decision variables, the analysis is carried out to optimize a single route in central London (line 43). An optimal battery capacity of 348.8 kWh is required, reducing annual costs for the operation of this route by 24% during the 10-year period considered.

Further modifications to the model have taken place to improve speed prediction of the bus, as speed is one of the main sources of uncertainty in our model. Machine learning framework has been used for the development of vehicular speed prediction in an urban context with heterogeneous traffic states. For this study, London bus route 9 has been used as a case study. From the studied models, the best accuracy was obtained by the random forest classifier, correctly predicting the speed class in 53.3% of occasions, while in 86.6% of the occasions the model predicts the correct speed class or only misses it by one class (either the immediately faster or slower class). The random forest classifier resulted in the lowest mean average error (MAE) of 1.94 mph.

Future work will focus in applying the improved model to the full London bus network. Such an endeavor will require the development of bespoke heuristic algorithms to overcome the dimensionality problem caused by several non-linearities, stochastic components, and large number of decision variables that describe the system.