A Multi-Objective Constraint Programming Approach for Route and Garage Allocation of Electric Buses

Uğur Eliiyi[1], Özgür Akgün[2], Emine Zehra Akgün[3], and Deniz Türsel Eliiyi[4]

[1] *Department of Computer Science, Dokuz Eylül University, Türkiye*
ugur.eliiyi@deu.edu.tr

[2] *School of Computer Science, University of St Andrews, United Kingdom*
ozgur.akgun@st-andrews.ac.uk

[3] *Transport Research Institute, Edinburgh Napier University, United Kingdom*
e.akgun@napier.ac.uk

[4] *Department of Industrial Enginering, Yaşar University, Türkiye*
deniz.eliiyi@yasar.edu.tr

Keywords: Electric Bus, Charging Station, Constraint Programming

Maintaining a sustainable public transportation system is one of the key tasks for metropolitan city administrations. In order to provide such systems, cities have to implement recent advances in fuel technology for both reducing operating costs and emission levels incurred by the vehicles. Electrification of urban transit fleets by adding full or hybrid electric vehicles with different types of battery systems is one of the effective solution approaches. Careful planning is needed to utilise these vehicles effectively - including the route allocation for electric buses, and the optimal placement of the necessary charging stations. This study aims to identify the optimum bus route allocation and charging station placement, through a case study in the city of Izmir in Turkey.

İzmir, the third largest city of Turkey, is operating a multimodal transit network comprising bus, metro, ferry and tram systems. Around 62% of all the daily boardings (1.7 million) are served by the public bus transportation system, with a fleet of around 1500 buses. In an effort to reach the goals mentioned above, the city administration procured 20 full electric buses and had put them into service since April 2017. They operate these buses in 20 different routes that belong to five different managerial districts of the public bus authority. Moreover, the buses are charged at five different garages of those districts, from where they begin their daily services.

The main reason for selecting totally distinct routes for each bus is for maximising the public exposure to this new bus type, and testing the performance of the vehicles and their battery systems for future investments. Currently, the buses are charged to 100% once daily through their overnight parking periods, and their trip schedules are planned loosely to avoid the risk of power failures due to insufficient charging. Therefore, it is observed that the bus operator cannot fully attest the capabilities and limits of these new vehicles with respect to representativeness, regarding actual passenger load, traffic congestion, and different route topologies. Moreover, the mid charging station units mounted at major route terminals are idle for long periods of time. Thus, a more thorough approach is required to fulfill both the economic goals for justifying the high levels of initial investments, and the social expectations of the administration.

In this study, we develop a multi-objective constraint programming (CP) formulation which performs the bus route allocation simultaneously with charging station placement. We use the constraint programming toolkit developed at the University of St Andrews which include Conjure and Savile Row. In combination, these tools allow us to state a CP model at a very high-level of abstraction and without making ad-hoc modelling decisions. Instead, the high-level model we develop is automatically converted to a low-level model in an efficient way before it is solved using a standard constraint solver. We used Minion as the solver in our experiments.

We identify two objectives corresponding to the two requirements of the public bus authority in our model: cost minimisation and exposure maximisation; the former being an operational goal and the latter for gathering public support for the electric buses which will, in turn, boost support for future investments. We use very detailed micro-data made available to us by the CANBUS system of the public bus authority. The data includes timestamped information about passenger numbers, geographical location, and the state of the battery for each electric bus. We calculate the optimal Pareto frontier and present a number of strategic schedule options with different amounts of cost and exposure. We also evaluate the current schedule with respect to these optimal schedules and demonstrate the possible gains.