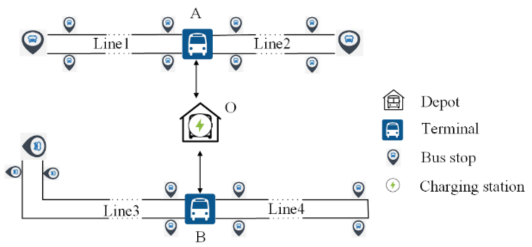
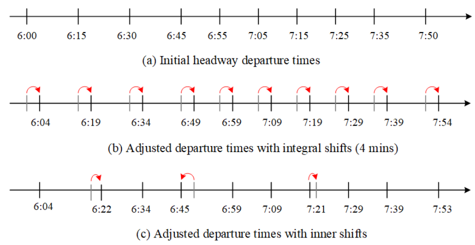
Integrated optimization of electric bus scheduling and charging planning incorporating flexible charging and timetable shifting strategies

It has been reported that the transportation sector accounts for about one-quarter of the global carbon dioxide emissions due to the wide use of carbon-fueled vehicles, which is one of the main causes of climate change. This proportion is even higher in developed economies, for example, one-third in the European Union. Therefore, it is necessary to find substitute mobility options to reduce emissions and secure a more sustainable environment. Electric mobility has proven to be instrumental in the decarbonization of the transportation sector. Amongst, electric public bus systems are considered an important pillar that offers affordable and environmentally friendly mobility. Local governments in many countries implement a series of policies, such as financial incentives, customer subsidies, and taxation on petroleum, to promote the deployment of battery electric buses (BEBs). Despite the advantages of BEBs, they still face challenges in large-scale adoption. The high capital investment, including the costs of embedded battery packs and auxiliary charging facilities, makes BEBs less appealing than traditional diesel buses. The Battery capacity of the BEBs gradually decreases during the charging and discharging cycles, resulting in the degradation of battery performance. Furthermore, due to the complex planning processes for a BEB system, inefficient charging strategies and fleet schedules are usually adopted by BEB operators.

In a battery electric bus (BEB) network, buses are scheduled to perform timetabled trips while satisfying time, energy consumption, charging and operational constraints. Increasing research efforts have been dedicated to integrated optimization of multiple planning tasks to reduce system costs. At a high integration level, this study determines the BEB scheduling and charging planning with flexible charging and timetable shifting strategies to minimize the total operational costs including the fixed fleet, charging, and battery degradation costs and meanwhile reduce the peak power demand. We first formulate an arc-based model for this problem and subsequently reformulate it into a path-based model, for which we develop an effective two-stage solution method. The first stage minimizes the total operational costs based on the column generation technique, and the second stage minimizes the peak power demand by two timetable shifting strategies. It is found through numerical experiments that the proposed integrated optimization model and solution method can achieve significant improvement in the utilization rate and reductions of the fleet size, operational costs, and peak power demand compared to two baseline models.



(a)



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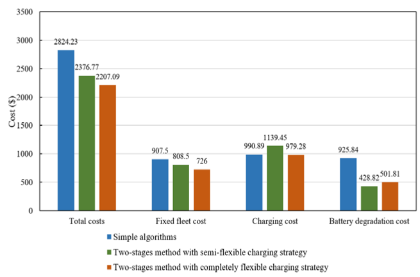
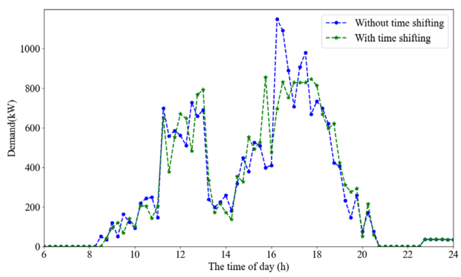


(c)



(d)

Figs. (a) A general transit network; (b) Illustration of timetable shifts; (c) Comparison of the cost components between three solution methods; (d) Comparison of the power demand.