國立陽明交通大學

運輸與物流管理學系

碩士論文

Department of Transportation and Logistics Management

National Yang Ming Chiao Tung University

Master Thesis

以深度強化學習演算法求解電動公車充電排程問題

Solving the Electric Bus Charging Scheduling Problem Using Deep Reinforcement Learning Algorithms

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中華民國一一四年六月

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摘要

本研究以市區電動公車營運業者為對象，考量單一車種、多條路線及單一場站的營運情境，在已知固定班表與車隊規模，且考慮時間電價與電網限制的條件下，規劃於公車各班次間之閒置時段，以及結束營運後之夜間時段進行充電排程。

本研究首先針對此電動公車充電排程問題建立數學規劃模式，為提升大規模問題之決策效率，本研究使用深度強化學習(Deep Reinforcement Learning, DRL)技術，並建構以深度 Q 網路(Deep Q-Network, DQN)為核心之代理人架構，透過模擬代理人與環境互動之獎勵學習的過程，自主學習最小化充電成本之最佳充電排程。

為了驗證與比較數學模式與深度強化學習演算法之求解績效，本研究以高雄港都客運與台北首都客運之實際營運班表資料進行範例測試。實驗結果顯示，深度強化學習演算法具備處理高維度決策問題的能力，能夠自主學習具成本效益的最佳充電排程，特別是在面對尖峰與離峰時段的電價波動時，能靈活調整充電決策，展現高度的應變能力。

本研究為文獻中首先應用深度強化學習於電動公車充電排程之研究，相關成果可作為客運業者於電動公車充電排程規劃之參考依據，且展現深度強化學習於電動公車營運管理最佳化之應用潛力，對市區公車電動化之發展具理論與實務價值。

關鍵字：電動公車充電排程、混合整數規劃、深度強化學習、深度 Q 網路

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Abstract

This study investigates the charging scheduling problem of urban electric buses from the perspective of public bus operators. The research considers an operational scenario featuring a single vehicle type, multiple routes, and a single depot. Under the constraints of a fixed timetable, known fleet size, time-of-use electricity pricing, and grid capacity limitations, the study aims to schedule charging operations during both the idle periods between bus trips and the nighttime period after daily operations.

To address this problem, a mathematical programming model is first developed as a baseline. In order to enhance decision-making efficiency for large-scale problem instances, this study adopts Deep Reinforcement Learning (DRL) and constructs an agent-based framework centered on the Deep Q-Network (DQN). Through a reward-based interaction process between the agent and the environment, the model is capable of autonomously learning cost-minimizing charging schedules.

To evaluate and compare the solution performance of the mathematical model and the DRL algorithm, real-world operational data from Kaohsiung Great City Life Bus and Taipei Capital Bus Company are used for numerical experiments. The results demonstrate that the DRL-based approach effectively handles high-dimensional decision-making problems and learns cost-efficient charging strategies. Notably, the proposed method exhibits strong adaptability in response to dynamic electricity pricing during peak and off-peak hours.

This research is the first known application of deep reinforcement learning to the electric bus charging scheduling problem. The proposed approach provides practical insights and theoretical contributions to the field. Furthermore, it demonstrates the potential of DRL in optimizing electric bus operations and supports the advancement of urban transit electrification.

Keywords: Electric bus charging scheduling, Mixed Integer Programming, Deep Reinforcement Learning, Deep Q-Network