Delft University of Technology

Editorial

Emerging on-demand passenger and logistics systems: Modelling, optimization, and data analytics

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Editorial

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1. Introduction

The proliferation of smart personal devices and mobile internet access has fueled numerous advancements in on-demand transportation services. These services are facilitated by online digital platforms and range from providing rides to delivering products. Their influence is transforming transportation systems and leaving a mark on changing individual mobility, activity patterns, and consumption behaviors. For instance, on-demand transportation companies such as Uber, Lyft, Grab, and DiDi have become increasingly vital for meeting urban transportation needs by connecting available drivers with passengers in real time. The recent surge in door-to-door food delivery (e.g., Uber Eats, DoorDash, Meituan); grocery delivery (e.g., Amazon Fresh, Picnik); and same-day courier services (e.g., Amazon Same-Day Delivery) has significantly enhanced both convenience and safety for customers, particularly during the COVID-19 pandemic.

Despite their rapid growth, on-demand transportation services bear several challenges for key stakeholders. The private sector, which includes online platforms, strives to optimize system efficiency and revenue through advanced artificial intelligence techniques and optimization methods. Meanwhile, the public sector aims to strike a balance between the interests of various stakeholders to create more sustainable, equitable, and eco-friendly mobility systems. As such, new mobility paradigms arise in which public authorities require decision support tools that offer realistic cost and benefit estimations for all parties involved. As these services continue to expand, researchers, operators, and policymakers can leverage the vast amount of data generated to better understand, model, analyze, and effectively coordinate both the supply and demand dynamics within these systems.

Over the past few years, a rich literature has targeted various challenges for on-demand transportation systems, including but not limited to pricing strategy and coordination (Taylor, 2018; Bimpikis et al., 2019; Karaenke et al., 2023; Bahrami et al., 2023); order matching and dispatching (Alonso-Mora et al., 2017; Özkan and Ward, 2020; Tafreshian et al., 2020; Lyu et al., 2023); fleet sizing and relocation (Braverman et al., 2019; Shehadeh et al., 2021; Benjaafar et al., 2022; Chang et al., 2022; Fan et al., 2024); external impacts on traffic congestion and environment (Henao and Marshall, 2019; Beojone and Geroliminis, 2021); integration with public transit (Masoud et al., 2017; Galkin et al., 2019; Salazar et al., 2019; Fayed et al., 2023); and travel behavior analysis (Rayle et al., 2016; Tirachini, 2020; Ashkrof et al., 2022). Nevertheless, as highlighted by several recent outline papers (Wang and Yang, 2019; Mourad et al., 2019; Agatz et al., 2024), many important and intriguing research questions warrant further investigation in the field of on-demand ride and delivery services and the broader concept of on-demand transportation systems. This motivates the call for this special issue.

Accordingly, we invited papers that examine new models, optimization algorithms, and data-driven analytical methods to address the challenges in planning, operations, management, and regulation of on-demand transportation services in both passenger and logistics transportation systems. After careful review, 18 papers were selected from more than 100 submissions. Fifteen of the 18 papers investigate on-demand passenger transportation services: regular ride-sourcing services (Jiao and Ramezani, 2022; Qin and Sun, 2022; Yu et al., 2023; Park et al., 2023; Liu et al., 2023a; Chen et al., 2023); electrified ride-sourcing services (Liu et al., 2023b); autonomous mobility on-demand systems (Tavor and Raviv, 2023; Yang et al., 2023); ride-sharing services for first-mile transport

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system (He et al., 2023); dial-a-ride services (Gao et al., 2023); demand-responsive buses (Ma et al., 2023; Abdelwahed et al., 2023; Li et al., 2023); and modular transit services (Tian et al., 2023). The three remaining papers attempt to solve optimization problems for on-demand logistics services: on-demand pickup and delivery problems (Zhang et al., 2023); dynamic truck–drone routing problems (Gu et al., 2023); on-demand meal ordering problems (Luo and Xu, 2023).

2. Research advances in this special issue

Jiao and Ramezani (2022) in their article "Incentivizing shared rides in e-hailing markets: Dynamic discounting" develop a dynamic discount pricing strategy to incentivize ridesharing, aiming to counteract the negative effects of ride-sourcing services on traffic conditions. The study demonstrates that this strategy benefits the platform economically, increases driver efficiency, and reduces vehicle fleet size needed for servicing passengers, ultimately benefiting all stakeholders involved.

Qin and Sun (2022) in their article "Ride-hail to ride rail: Learning to balance supply and demand in ride-hailing services with intermodal mobility options" discuss the potential of introducing intermodal mobility options to balance supply and demand in ride-sourcing services, using a Markov decision process (MDP) and reinforcement learning (RL) algorithms. The results demonstrate that the learned availability policy can significantly dissipate rider queues and improve service rates, ultimately achieving a more balanced supply and demand.

Yu et al. (2023) in their article "A high-order hidden Markov model for dynamic decision analysis of multi-homing ride-sourcing drivers" introduce a dynamic discrete choice framework using a high-order hidden Markov model (HO-HMM) to model ride-sourcing drivers' multi-homing behavior and labor supply decisions in a competitive market with multiple platforms. Their results demonstrate that the HO-HMM provides superior explanatory power and interpretability compared to other models. The model can help ride-sourcing platforms design pricing, reward, and personalized management strategies to improve driver income in a competitive ride-sourcing market.

Park et al. (2023) in their article "An optimization model of on-demand mobility services with spatial heterogeneity in travel demand" propose an optimization model to predict the required fleet size for on-demand mobility (ODM) services, considering customer waiting time, spatial heterogeneity in demand, and vehicle relocation. They also use the model to examine the effects of spatial demand patterns on fleet size requirements and the trade-offs between fleet size minimization and cost minimization. The findings offer valuable insights into ODM service design, investment decision-making, and policy design for governments or agencies.

Liu et al., (2023a) in their article "Effects of threshold-based incentives on drivers' labor supply behavior" investigate the impact of threshold-based driver incentives on ride-sourcing drivers' labor supply. Using a real-world shared mobility dataset, the authors reveal that threshold-based incentives positively affect drivers' labor supply along the intensive and extensive margin, but their effectiveness is limited by their design and drivers' working schedules. They also find that drivers' working decisions are only affected before the incentive threshold is reached.

Chen et al. (2023) in their article "Region-aware hierarchical graph contrastive learning for ride-hailing driver profiling" address the ride-hailing driver profiling problem by proposing a Hierarchical Graph Contrastive Learning (HGCL) framework that can automatically learn low-dimensional embeddings encoding driver behaviors from raw GPS data. The HGCL framework, which consists of a hierarchical graph neural network and a hierarchical contrastive learning strategy, proves effective in capturing regional features and learning high-quality representations, as demonstrated by its performance in three downstream tasks using a real-world large-scale dataset.

Liu et al., (2023b) in their article "Temporal equilibrium for electrified ride-sourcing markets considering charging capacity and driving fatigue" propose a time-expanded network equilibrium modeling framework to analyze the work schedules of electric vehicle (EV) and gasoline vehicle (GV) ride-sourcing drivers, considering factors like driving fatigue and limited charging infrastructure. The study develops a gap function-based method and customized multi-objective label correcting algorithm to solve the equilibrium problem. The study reveals that temporal equilibrium of the electrified ride-sourcing market is moderated by the charging capacity, EV penetration and the competition among drivers, while drivers' work schedules and market performance are significantly influenced by driving fatigue.

Tavor and Raviv (2023) in their article "Anticipatory rebalancing of RoboTaxi systems" examine the online decision-making process for vehicle dispatching and rebalancing to optimize fleet operations in a RoboTaxi system. The study develops an advanced rebalancing strategy that aims to minimize passengers' waiting time and total distance traveled by empty vehicles while assuming a simple yet effective dispatching policy. The proposed algorithm can well balance the trade-off between rebalancing efforts including various costs and service quality reflected by passengers' waiting time.

Yang et al. (2023) in their article "Fleet sizing and charging infrastructure design for electric autonomous mobility-on-demand systems with endogenous congestion and limited link space" present a discrete event simulation model that evaluates and designs electric autonomous mobility-on-demand (EAMoD) systems while considering the congestion effects caused by the operation of autonomous electric vehicles. The study integrates three mathematical models for optimal vehicle matching, relocation, and charging station assignment, and uses Bayesian optimization to jointly design the fleet size and charging facility configuration. It shows that a charging facility configuration aligned with the fleet size is vital for the improvement of service quality and vehicle utilization rate.

He et al. (2023) in their article "Optimizing first-mile ridesharing services to intercity transit hubs" propose a ridesharing approach for first-mile transport for travelers heading towards the intercity transportation hub and develops a mixed-integer linear programming (MILP) model aimed at minimizing total operating costs for ridesharing service operators. The MILP model takes into account factors such as large luggage, passengers' arrival and ride time requirements, and travel time uncertainty. A tailored adaptive large neighborhood search algorithm is designed to find out robust near-optimal solutions within a reasonable time. The study demonstrates the effectiveness of ridesharing in reducing overall travel costs and meeting first-mile travel demands.

Gao et al. (2023) in their article "A branch-and-price-and-cut algorithm for time-dependent pollution routing problem" develop an exact branch-and-price-and-cut (BPC) algorithm for the time-dependent pollution routing problem (TDPRP), which addresses the planning of a fleet of homogeneous vehicles to serve customers while minimizing total route costs under urban traffic congestion. The proposed algorithm employs a tailored label-setting approach to solve the pricing problem and uses valid inequalities and acceleration techniques to enhance performance. Extensive computational experiments demonstrate that the proposed algorithm outperform a commercial MIP solver by finding out the optimal solutions with less time.

Ma et al. (2023) in their article "Dynamic vehicle routing problem for flexible buses considering stochastic requests" address the dynamic bus-routing problem in the context of flexible buses, considering stochastic future passenger demand, and propose a two-stage stochastic programming model to minimize total vehicle travel time costs and penalties for rejecting requests. The study introduces a vector-similarity-based clustering and adaptive large neighborhood searching (VSC-ALNS) algorithm for effective vehicle and passenger matching, and demonstrates its effectiveness using Shanghai taxi order data, indicating that flexible buses are more suitable for moderate demand scenarios.

Abdelwahed et al. (2023) in their article "Balancing convenience and sustainability in public transport through dynamic transit bus networks" propose a dynamic public transit system that combines the convenience of on-demand services with the sustainability of public transport, aiming to attract more passengers by offering reduced walk-to-station distances and total travel times. The solution method splits the problem into four stages, including clustering, initialization, optimization, and merging. The results show that the proposed system provides a more sustainable option, reducing system-wide travel distance and attracting on-demand passengers with better service compared to fixed public transit routes.

Li et al. (2023) in their article "Frequency-based zonal flexible bus design considering order cancellation" study order cancellation behavior in a frequency-based flexible bus (FB) system, considering stochastic elastic demand volume and spatial distribution. The study develops a two-stage stochastic model together with a gradient descent solution algorithm to design the price, dispatching, and passenger assignment strategies of FB service while accounting for the probability of pre-booked order cancellations. Through a case study based on Chengdu's mobility data, the authors justify the importance of considering the impact of order cancellation and validate the performance of the proposed optimization algorithm in solving large-scale problems.

Tian et al. (2023) in their article "Joint scheduling and formation design for modular-vehicle transit service with time-dependent demand" present a mathematical model for the optimal scheduling and modular vehicle formation in a future public transit service adopting modular vehicles, considering time-dependent travel demand, limited module availability, and re-balancing costs. The model is formulated as a mixed-integer nonlinear program (MINLP) and then reformulated into an equivalent mixed-integer linear program (MILP) using exact reformulation techniques, while a two-step heuristic is developed for solving more practical problems with a longer planning horizon. Numerical studies validate the formulation and solution methods and show that modular transit services can significantly reduce both operator and passenger costs by dynamically adjusting vehicle formations based on time-dependent demands.

Zhang et al. (2023) in their article "A two-stage learning-based method for large-scale on-demand pickup and delivery services with soft time windows" develop a two-stage learning-based method, consisting of a clustering stage and a routing stage, to tackle the large-scale pickup and delivery problem with soft time windows. Experiments demonstrate that the model, trained on small-scale problems, generalizes well to larger-scale problems, outperforming heuristic methods and Google OR-Tools with significantly shorter computing time. In addition, a contract experiment proves the favorable transferability of the model, saving a significant amount of training time.

Gu et al. (2023) in their article "Dynamic truck–drone routing problem for scheduled deliveries and on-demand pickups with time-related constraints" investigate the dynamic truck-drone routing problem with scheduled deliveries and on-demand pickups (D-TDRP-SDOP) for an on-demand logistics system and formulate it as a Markov decision process (MDP). For solving this complicated problem, the authors develop a heuristic solution framework which consists of an offline enhanced construction algorithm (OECA) and a segment-based heuristic. The algorithm can improve total profits by 15 % and achieve a 50 % increase in acceptance rates for dynamic customer requests.

Luo and Xu (2023) in their article "Online-to-offline on the railway: Optimization of on-demand meal ordering on high-speed railway" develop a mathematical model to optimize on-demand meal ordering systems on high-speed railways, proposing a pre-ordering policy that cancels order deadlines while ensuring timely delivery through stocking up. The authors propose distributionally robust stochastic optimization models and cutting-plane algorithms for managing meal orders both the existing and the pre-ordering procedures. Computational studies on a real-world high-speed railway line in China demonstrate that the proposed policy can increase service availability, improve profits, and reduce delay rates.

3. Summary and future research directions

The emergence and evolution of on-demand passenger and logistics transportation services, including ride-sourcing, ride-sharing, bike-sharing, modular transit, on-demand logistics, and dynamic bus services, call for systematic approaches to model the complex interplay between demand and supply. This is crucial for devising optimal strategies concerning control, operations, management, and regulations. Despite prior efforts devoted to solving these problems, there is still a great need for more advanced and innovative models, theories, algorithms, and applications to enhance the efficiency and sustainability of these on-demand transport services. In what follows, we provide several potential future research directions in this field.

(1) Nowadays, on-demand mobility services have become increasingly integrated with other transportation systems, resulting in the emergence of massive interconnected public transit services and the like. It is thus of great interest to examine the complementary and substitution effects of on-demand transport services on other transport modes (e.g., Lanzetti et al., 2023), and develop optimal operational strategies to seamlessly combine on-demand services with other transportation services to enhance overall system efficiency and sustainability.
(2) The integration of optimization and artificial intelligence to solve real-time decision problems in complex on-demand passenger and logistics transport systems (e.g., Baty et al., 2024), including on-demand ride-pooling and crowd-sourcing delivery, warrants further examination.
(3) Recent advances in vehicle- and infrastructure-based technologies enable a single vehicle to simultaneously offer diverse services, such as passenger mobility, goods delivery, information acquisition, and mobile on-site service provision (e.g., Sun et al., 2023). We anticipate significant research opportunities for developing models, theories, and algorithms aimed at investigating and enhancing decision-making in the service strategy, design, operations, and evaluation of these innovative vehicle-based multi-services for future urban mobility.
(4) Integrating behavior models into planning and design optimization problems remains a significant challenge (e.g., Fan et al., 2023). The inherent non-linearity of these models demands careful mathematical treatment to accurately depict the equilibrium between supply and demand interactions.

CRediT authorship contribution statement

Jintao Ke: Conceptualization, Writing – original draft. **Hai Wang:** Conceptualization, Writing – original draft. **Neda Masoud:** Conceptualization, Writing – review & editing. **Maximilian Schiffer:** Conceptualization, Writing – review & editing. **Gonçalo H.A. Correia:** Conceptualization, Writing – review & editing.

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