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POLICY BRIEF

Multimodal Strategies for Mitigating Congestion from Urban Parcel Delivery

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BACKGROUND AND OBJECTIVES

In the high-growth parcel delivery market, dramatically increased traditional truck deliveries are contributing to traffic congestion, air pollution, noise, road deterioration, and safety concerns. With rapid technological change in urban parcel delivery system, conventional truck delivery is shifting to new classes of vehicles such as drones, autonomous robots, electric cargo bikes and combined with new delivery models featuring crowdsourcing, and parcel lockers. Multiple modes can be operated synergistically to improve delivery service quality and manage road congestion. One option of particular interest is drone, which shifts traffic from the ground to the air. Replacing the last-mile truck delivery with drones helps mitigate traffic congestion results from truck traffic and double-parking activities. In order to attain the full potential of multimodality, it is necessary to develop efficient delivery strategies. The benefit of integrating multiple types of delivery vehicles has been explored recently, especially new types of vehicles including electric bikes, drones, auto-robots, crowdsourcing, etc. Delivery by these non-motorized vehicles and Unmanned Aircraft Vehicles (UAVs) is increasingly perceived as an integral part of the future solution for urban freight movement to provide fast, point-to-point deliveries. As part of the parcel delivery demand shifting to non-motorized vehicles and drones in the air, delivery by new vehicle types helps mitigate the traffic congestion in the road transportation system. In this project, we develop a suite of multimodal, congestion-sensitive strategies for urban delivery, by integrating traditional motorized vehicles, non-motorized modes, and UAVs. Building on prior research for modelling and managing urban road congestion as well as logistics studies for UAV route optimization and scheduling, we develop new models that combine UAVs with other modes for integrated and coordinated urban package delivery. The impacts of the new multimodal strategies on roadway operations and safety are evaluated.

METHODOLOGY

Building on prior research on logistics studies for UAV route optimization and scheduling, the new models combine UAV with other modes for coordinated package delivery. We introduced two-echelon delivery network with local transshipment centers as the parcel transfer facilities between the first and second echelon. We conceptualize and optimize several different multimodal strategies, including traditional truck-only delivery, truck or drones operating separately from warehouse, truck with drones on board, two echelon operations with truck for first echelon and either cargo bikes or drones for the second echelon. We focus on strategic same-day parcel delivery instead of instant food or grocery delivery. Thus, the delivery time window is not introduced to the models. We designed the delivery models in both ring-dial networks and grid-based networks. Different mode combinations are considered and compared. We apply Continuous Approximation Methods (CAs) to evaluate costs and formulate Integer Linear Programming (ILP) models to optimize routing, scheduling and mode assignment for different strategies. The proposed multimodal last-mile delivery strategies leverage untapped potential of non-traditional modes to balance demand and capacity on urban road networks. Importantly, we also incorporate congestion effects into multimodal delivery strategies, which has rarely been done in existing research. We developed a congestion model to evaluate congestion effects from delivery traffic and double-parking activities by conducting traffic simulations based on Macroscopic Fundamental Diagram (MFD). In our congestion model, we will capture both the road congestion impacts on delivery traffic, and the congestion externalities of delivery traffic imposed on the road system. For road congestion impacts on delivery traffic, we focused on the delay cost of delivery traffic that results from the reduced truck speed in congested situations. For congestion externalities by delivery traffic, we evaluate the impacts through calculating the additional total system delay of non-delivery traffic. Analytical formulations of congestion costs for different delivery strategies are fitted and integrated to the ILP models.

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RESEARCH FINDINGS

Multimodal delivery models with different combinations of vehicles are summarized and compared in this work. Especially two-echelon delivery network with truck, cargo bikes and drones are proposed. We consider both the facility assignment and mode decisions under scenarios. The results show that considering congestion cost, two-echelon multimodal strategies outperform all other strategies by significantly reducing truck traffic and double-parking activities. It reveals how alternative delivery strategies can alleviate traffic congestion in urban areas and can reduce congestion impacts on the activities themselves as well as other urban vehicles. We explicitly calculate the delivery costs mainly including parcel handling cost and vehicle operational costs. From our specific experiments, we found that single echelon delivery model generates less cost than that of two-echelon. Considering the benefit of reducing road traffic congestion, the two-echelon network may be more efficient. In addition, delivery models with multiple vehicles modes in both single- and two- echelon networks are more efficient in terms of total delivery cost than truck only scenario. The results suggest that we can take advantage of synergistic operation among emerging vehicle types, especially nonmotorized vehicles, and drones for more efficient parcel delivery. Then, we propose congestion models that analytically evaluate the congestion impact of different multimodal delivery strategies. Macroscopic Fundamental Diagrams (MFD) and simulations are used to develop the congestion models. Simulations are performed under various scenarios and the results are fitted to analytical expressions with high goodness of fit. The developed multimodal delivery models and analytical congestion models can be the basis of future studies. By integrating the analytical congestion models into multimodal delivery models, we are able to reduce costs and increase the efficiency of the delivery systems. This work provides delivery service providers and public transportation sectors with benefits of cooperations among different vehicles modes and the importance of congestion sensitivity. For future research, one direction can be performing sensitivity analysis with different parameter settings and network design, and compare delivery models under various scenarios. Besides, it would be interesting to apply the delivery models to real-world case studies, and compare the multimodal delivery efficiency with idealized situations. In addition, we can improve the current multimodal delivery models considering congestion effects results from delivery traffic, and evaluate the benefit of integrating multiple vehicle modes.

POLICY AND PRACTICE RECOMMENDATIONS

Online delivery has become a global market worth more than $150 billion. Especially during the Covid-19 pandemic, the market has more than doubled in the United States (Ahuja et al., 2021). Delivery service providers have said they are optimistic the expansion will continue despite a gradual return to normality from coronavirus restrictions because Covid-19 has changed people's dining habits (Liu, 2022). To meet the enormous delivery demand, efficient delivery operations are necessary in transportation systems. The delivery system has incorporated new types of vehicles, including drones and auto robots. Amazon first proposed drone delivery in 2013. Wing operated drone deliveries on three continents. And Walmart is backing several drone startups to experiment with delivering its products. Meituan started to offer drone delivery in very challenging environments: dense urban neighborhoods (Yang, 2023).

The project developed efficient system operations and planning strategies for multimodal delivery by utilizing recent advances in operations research and data analytics. Such operations and planning strategies provide delivery service providers with a rigorous plan for vehicle routing, scheduling, mode assignment, and facility location problems. So that the delivery service providers can manage and operate delivery trips more efficiently to reach an optimal system. Our project team invited stakeholders (e.g., delivery companies like Walmart) to review the proposed system operations and planning strategies to enhance their pertinence and applicability for real-world implementation by arranging a board meeting. In addition, the theoretical framework for delivery system optimization and solution approaches can be tailored to solving similar service planning problems.

In long-term, as part of the transportation systems, delivery traffic causes problems, including generating air-polluted emissions and contributing to road congestion. Systematic strategic planning helps the city and government promote an efficient and green transportation system. The strategic planning strategies helps provide not only the delivery service provider but also the city planner with efficient infrastructure design and planning in transportation systems. Proper land use and infrastructure design help improve system efficiency and sustainability.

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