Shared Passenger-Freight Transport in Automated Bus Systems: Optimization Model and Solution

Mohammad Sadrani (a,*), Ramandeep Singh (a), Constantinos Antoniou (a)

([a]) Chair of Transportation Systems Engineering, TUM School of Engineering and Design, Technical University of Munich, Munich 80333, Germany

m.sadrani@tum.de *Corresponding author

ramandeep.singh@tum.de

c.antoniou@tum.de

Extended abstract submitted for presentation at the Conference in Emerging Technologies in Transportation Systems (TRC-30)
September 02-03, 2024, Crete, Greece

Keywords: Automated bus; Public transport; Integrated passenger freight transport; Optimization.

1. Introduction

Integrated passenger freight transport (IPFT) is a tactical solution that can potentially reduce travel demand and the costs of first- and last-mile services. While scholarly interest in IPFT has grown over the past decade, research contributions are still mainly related to defining a general framework (Antoniou et al., 2023). The IPFT concept has received limited attention within bus transportation systems. Specifically, its exploration within the context of automated bus systems has remained unexplored, despite the new dimensions and operational flexibility that automated buses can bring to public transportation operations. Furthermore, the potential challenges for passengers resulting from the simultaneous accommodation and transportation of parcels alongside passengers have not yet been examined in this context.

In this research, our objective is to develop and optimize the scheduling of automated bus systems to facilitate IPFT. We will also consider users' perceptions (experience) of trip comfort within vehicles, considering potential inconveniences arising from parcel transportation inside buses. These effects can be delineated as follows:

- **Crowding externalities:** Freight load accommodation requires a portion of the vehicle's capacity. This reduces the available space for passenger seating and standing, potentially leading to increased discomfort due to crowding, particularly in crowded public transport systems. Moreover, it may result in passengers being left behind due to capacity limitations.
- **Extra trip times:** Loading and unloading freight at stops may lead to additional dwell times for passengers beyond the time required for boarding and alighting.

2. Literature and gap analysis: IPFT studies

2.1. IPFT in railway systems

Passenger and freight transport integration has received increasing attention in recent literature (Cavallaro and Nocera, 2022; Qu et al., 2022; Cheng et al., 2023a). Studies have explored the integration of freight transportation into various systems, such as public/mass rapid transit systems (Hu et al., 2022), metro systems (Zuo et al., 2023), last-mile deliveries (Bruzzone et al., 2021; Nocera et al., 2021), and passenger and parcel share-a-ride problems with drones (Cheng et al., 2023b).

In the context of operations research, the integration of passenger and freight transport has been mostly studied in the railway mode (Liu and Dessouky, 2017; Behiri et al., 2018; Li et al., 2021; Sahli et al., 2022; Xu et al., 2022; Behiri et al., 2023). Behiri et al. (2023) used an Ant Colony Optimization (ACO) algorithm to address urban freight transport on passenger rail networks and demonstrated its efficiency in finding near-optimal solutions. Xu et al. (2022) presented an optimization framework for train capacity allocation in high-speed rail systems, considering the integrated transportation of passengers and freight. They formulated optimization models for deterministic and stochastic demand cases and introduced an approximate linearization technique to solve the model with stochastic demand. Li et al. (2021) presented an optimization framework for designing train services that combine passenger and freight transportation in urban rail systems, focusing on maximizing total profits. They formulated the problem as a Mixed-Integer Nonlinear Programming (MINLP) model and used linearization techniques to transform it into a linear form, solving it with iterative scheduling approaches and heuristic algorithms.

2.2. IPFT in bus systems

Beyond the railway mode, Peng et al. (2021) proposed a bus-pooling system that combines passenger and freight transportation, giving priority to passengers. Pimentel and Avalos (2018) investigated the integration of urban freight into bus networks. Fatnassi et al. (2015) explored the benefits of integrating personal rapid transit (PRT) and freight rapid transit (FRT) systems in urban areas, and their results demonstrated the applicability and benefits of this integrated mode compared to other transportation options.

2.3. Research gap analysis

As evident from the literature review, compared to railway systems, the IPFT concept has received little attention within bus transportation systems. Specifically, to our knowledge, it remains unexplored in the context of automated bus systems. Moreover, the potential trip inconveniences that can be experienced by passengers in such systems, posed by the simultaneous accommodation/transportation of parcels alongside passengers, have not yet been investigated in this context.

3. Optimization model

We present the formulation of the Integrated Passenger and Freight Transport with Automated Buses (IPFTAB) problem by developing a novel MINLP formulation. The objective function of the model is designed to minimize the total costs of the system, encompassing passenger trip time costs (including waiting and crowding-sensitive in-vehicle time costs) and parcel time window penalty costs (related to the timeliness of delivery tasks). We detail the constraints of the IPFTAB problem, which include passenger flows, capacity limitations of passenger and parcel accommodation areas, and vehicle arrangements, aiming to depict real-life operational conditions accurately.

The following decision variables are considered and optimized in the proposed IPFTAB problem:

- Vehicle size (selected from available options, such as 12, 15, and 18-meter long buses)
- Fleet size (the total number of vehicles required)
- Vehicle dispatching times
- Vehicle dwell (stopping) times for parcel loading and unloading

4. Solution methodology

Due to the computational complexity of the IPFTAB problem, characterized by nonlinearities and mixed integer and continuous decision variables, solving large instances using exact methods within reasonable computing times is challenging. To tackle this issue, we employ efficient metaheuristic algorithms and develop hybrid versions, combining genetic and simulated annealing approaches. By designing a diverse range of experiments using various-sized test problems, we widely benchmark and validate the accuracy of the developed metaheuristics by comparing their solutions with the optimal solutions obtained from off-the-shelf solvers like GAMS/BARON solver.

5. Numerical experiments and results

This section is finalized following the execution of the model and algorithms to assess the potential of IPFTAB systems in total cost savings. Furthermore, we examine the planning and design aspects of an IPFTAB system by conducting a thorough sensitivity analysis of our proposed model. This analysis considers various factors, including cost parameters, the value of passengers' travel times, and time-dependent passenger and freight demand levels, to provide comprehensive insights into the system's performance under different scenarios.

References

Antoniou, C., Nocera, S., Susilo, Y., 2023. Special Issue: Integration passenger-freight. Editorial. Transp Res Part A Policy Pract 173 (July, art. n. 103724).

Behiri, W., Belmokhtar-Berraf, S., Chu, C., 2023. A robust ant colony metaheuristic for urban freight transport scheduling using passenger rail network. Expert Syst Appl 213, 118906.

Behiri, W., Belmokhtar-Berraf, S., Chu, C., 2018. Urban freight transport using passenger rail network: Scientific issues and quantitative analysis. Transp Res E Logist Transp Rev 115, 227–245.

Bruzzone, F., Cavallaro, F., Nocera, S., 2021. The integration of passenger and freight transport for first-last mile operations. Transp Policy (Oxf) 100, 31–48.

Cavallaro, F., Nocera, S., 2022. Integration of passenger and freight transport: A concept-centric literature review. Research in Transportation Business & Management 43, 100718.

Cheng, R., Jiang, Y., Nielsen, O.A., 2023a. Integrated people-and-goods transportation systems: from a literature review to a general framework for future research. Transp Rev 1–24.

Cheng, R., Jiang, Y., Nielsen, O.A., Pisinger, D., 2023b. An adaptive large neighborhood search metaheuristic for a passenger and parcel share-a-ride problem with drones. Transp Res Part C Emerg Technol 153, 104203.

Fatnassi E., Jouhaina Chaouachi, Walid Klibi (2015). Planning and operating a shared goods and passengers on-demand rapid transit system for sustainable city-logistics. Transportation Research Part B: Methodological 81-2, Pages 440-460.

Hu, W., Dong, J., Hwang, B.-G., Ren, R., Chen, Z., 2022. Is mass rapid transit applicable for deep integration of freight-passenger transport? A multi-perspective analysis from urban China. Transp Res Part A Policy Pract 165, 490–510.

Li, Z., Shalaby, A., Roorda, M.J., Mao, B., 2021. Urban rail service design for collaborative passenger and freight transport. Transp Res E Logist Transp Rev 147, 102205.

Liu, L., Dessouky, M., 2017. A decomposition based hybrid heuristic algorithm for the joint passenger and freight train scheduling problem. Comput Oper Res 87, 165–182.

Nocera, S., Pungillo, G., Bruzzone, F., 2021. How to evaluate and plan the freight-passengers first-last mile. Transp Policy (Oxf) 113, 56–66.

Peng Z., Rui Feng, Chenyu Wang, Yonglei Jiang, Baozhen Yao (2021). Online bus-pooling service at the railway station for passengers and parcels sharing buses: A case in Dalian. Expert Systems with Applications 169, 114354

Pimentel C., Filipe Alvelos (2018). Integrated urban freight logistics combining passenger and freight flows – mathematical model proposal. Transportation Research Procedia 30, Pages 80-89

Qu, X., Wang, S., Niemeier, D., 2022. On the urban-rural bus transit system with passenger-freight mixed flow. Communications in Transportation Research.

Sahli, A., Behiri, W., Belmokhtar-Berraf, S., Chu, C., 2022. An effective and robust genetic algorithm for urban freight transport scheduling using passenger rail network. Comput Ind Eng 173, 108645.

Xu, G., Zhong, L., Wu, R., Hu, X., Guo, J., 2022. Optimize train capacity allocation for the high-speed railway mixed transportation of passenger and freight. Comput Ind Eng 174, 108788.

Zuo, T., Li, B., Zhang, F., Yin, Y., 2023. Analysis of a collaborative transport model mixing passengers with freights in metro system. Journal of Rail Transport Planning & Management 25, 100358.