ELECTRIC INTEGRATED DEMAND-RESPONSIVE SERVICE – A CASE STUDY

Yumeng Fang*
Luxembourg Institute of Socio-Economic Research, 11 Porte des Sciences, L-4366 Esch-sur-Alzette, Luxembourg, yumeng.fang@liser.lu

Tai-Yu Ma
Luxembourg Institute of Socio-Economic Research, 11 Porte des Sciences, L-4366 Esch-sur-Alzette, Luxembourg, tai-yu.ma@liser.lu

Francesco Viti
University of Luxembourg, 6 Avenue de la Fonte, L-4364 Esch-sur-Alzette , Luxembourg, francesco.viti@uni.lu

* Corresponding author

1. INTRODUCTION

Integrating demand-responsive transport (IDRT) services with transit systems is an effective strategy to mitigate the impact of standalone demand-responsive transport on traffic congestion and the environment (Kim et al., 2023). However, the inter-modal transfers can negatively impact customer experience, and the introduction of electric vehicles in IDRT (referred to as EIDRT) can further impact customer inconvenience.

While several studies have focused on developing optimization models and solution algorithms for IDRT services (Molenbruch et al., 2021; Posada et al., 2017), research on the real-world performance of EIDRT remains limited. Evaluating its implementation is crucial to essential to gain insights into its operational efficiency and user satisfaction.

Therefore, this study aims to fill that gap by conducting case studies based on real-world scenarios to assess the effectiveness of EIDRT. By comparing its performance with other transport modes, this research seeks to identify potential challenges and provide insights into its practical deployment.

2. EIDRT SERVICE

The studied EIDRT service combines three travel modes: walking, electric demand-responsive buses (referred to as "buses"), and fixed-route transit (referred to as "trains"). We assume that train services run independently on scheduled timetables with unlimited passenger capacity, while the bus fleet is managed by the service operator. The bus fleet varies in passenger capacity and battery size, with each bus starting and ending its service at a designated depot. Charging stations are privately owned by the operator and not shared with other vehicles.

Customers must book the service in advance, providing their origin, destination, and preferred pickup or drop-off time window. The operator then informs them of trip details, including bus and train departure and arrival times. Customer's trips from their origins to destinations can choose from one of the feasible combinations among taking the trains and/or buses and walking to the stations or meeting points selected to access the modes. When customers transfer between buses and transit, a pre-defined butter time (e.g. 10 minutes) before train departures (first mile) or arrivals (last-mile) to ensure a reasonable inter-modal waiting times.

The solutions provided in this study are based on an optimization model for the EIDRT service previously developed by the authors (Fang et al., 2024). The objective function minimizes the weighted sum of bus and customer travel times, plus a penalty for rejected customers. We proposed an efficient hybrid large neighbourhood search (LNS) algorithm tested on instances with up to 100 customers. The hybrid LNS is applied in the case study for the EIDRT service. The formulation and solutions algorithms will be detailed in the full paper and at the conference.

3. CASE STUDY AND DATA AQUISTION

To assess the performance of the optimised service, we conducted a case study using empirical ride data from Kussbus, a microtransit service operating in Luxembourg (Ma et al., 2021) and offering a service to the cross-border commuters from the neighbouring countries. Kussbus operates a meeting-point based service, i.e. customers are picked up or dropped off at nearby meeting points instead of their origins and destinations. We consider the Arlon (Belgium) to Luxembourg commuting travels during morning peak hours from 5:00 to 9:00 am. The ride data covers 70 working days in 2018 with 1143 requests.

As depicted in Figure 1, most customer origins are concentrated in Arlon, with only a few pickup points between Arlon and Luxembourg, while all destinations are around Luxembourg City centre. A train line in this corridor operates 3 to 4 departures per hour, including one express train with fewer stops, which is used for the proposed EIDRT service. The performance of EIDRT is compared against car, public transport (PT), EDRT (door-to-door service), and Kussbus (meeting-point-based service) using Kussbus demand data (same origins, destinations, and departure times).

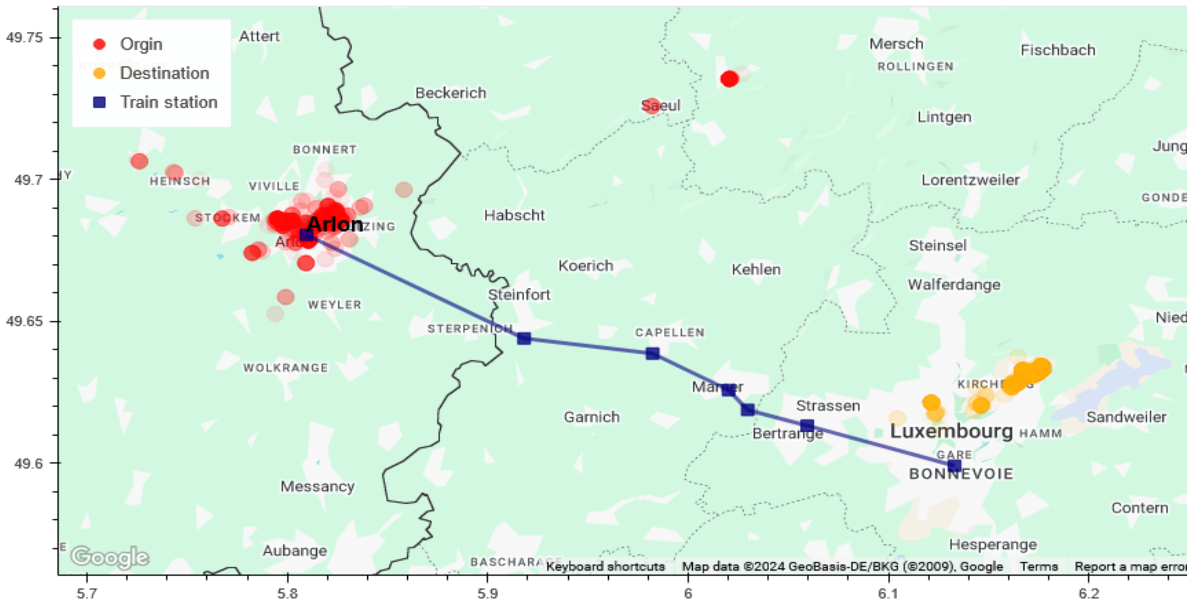

Figure 1. Arlon-Luxembourg case study

To obtain customer experience with different travel options, car and PT travel times are acquired from Google Map API, averaged over five weekdays in January 2025. PT travel times reflects the existing public transport network, including trains, buses, and trams. For the results of EDRT and EIDRT, we treated the 70-day demand as 70 instances of the corresponding optimization problems, solved using the hybrid LNS. The bus speed for EIDRT is estimated from the average speed from Kussbus data, while Kussbus results are taken from its empirical data.

4. RESULTS

We compare the performance of five different mode options (car, PT, Kussbus, EDRT, and EIDRT) from both customers' and on-demand bus operator's perspective.

4.1. Analysis based on customers' perspective

Figure 2 presents a density plot of 1143 requests' travel times across five transport options, calculated as the difference between their arrival time at destinations and the departure time at origins. The results show that car has the highest concentration with a prominent peak at less than 40 minutes of trip duration, followed by EIDRT and EDRT. The distribution of Kussbus, EDRT and EIDRT exhibit similar patterns but with wider dispersion compared with the other two. The peak of Kussbus distribution is slightly higher than that of EIDRT and EDRT, indicating longer customer travel times. PT has the longest customer travel times, with a peak around 80 minutes.

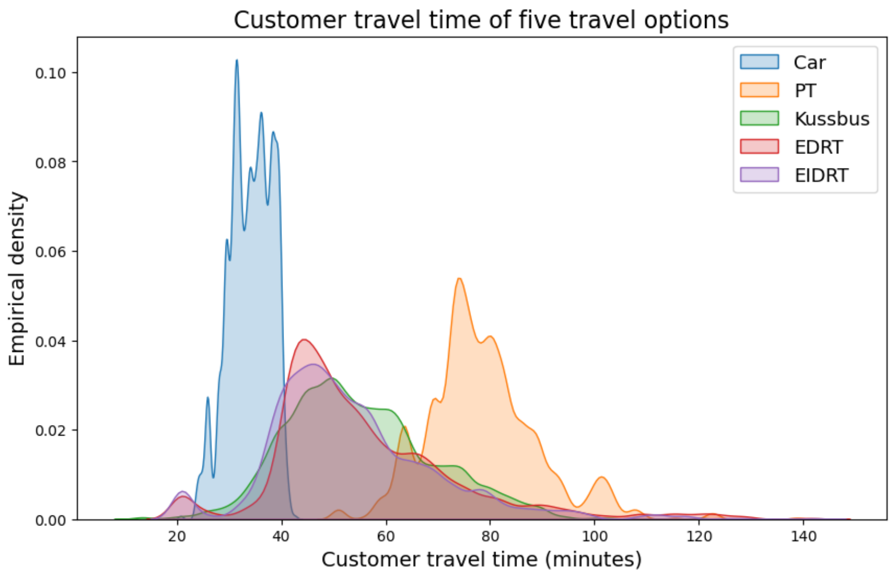

Figure 2. Density plot of customer travel time for four transport service options

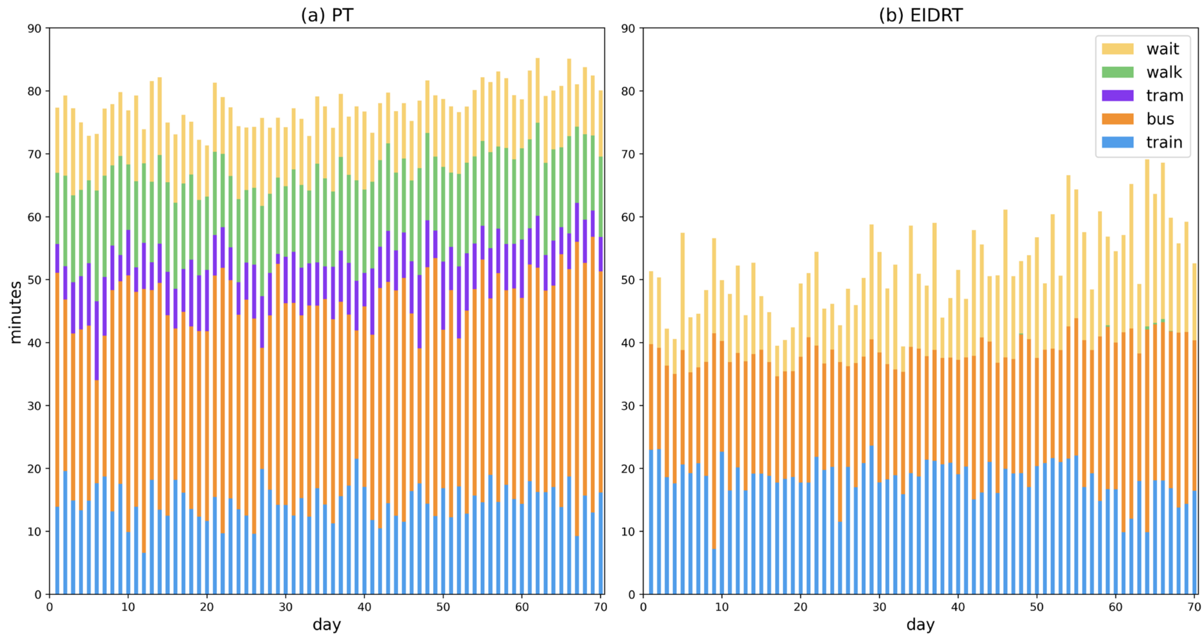

Figure 3. Average customer travel time per day and its decomposition for PT and EIDRT

As both PT and EIDRT involve multiple transport modes, Figure 3 presents the average customer travel time for each day and its composition on used transport modes. Similar to the results shown in Figure 2, the travel time of EIDRT is significantly less than that of the PT option. One main reason for such a difference is the effect of walking. The EIDRT limits the maximum walking distance of customers, and minimizes customer travel time. Bus service dominates overall travel time in PT, whereas EIDRT reduces customer in-bus travel time significantly and improves customer in-train travel time. The demand-responsive bus service in EIDRT is more efficient than existing fixed-route bus service within PT.

4.2. Analysis based on on-demand bus operator's perspective

As Kussbus, EDRT and EIDRT involve demand-responsive bus services, this section compares these three transport modes looking at the operator's perspective. Figure 4 (a) shows that the EIDRT demonstrates significantly lower VKT than Kussbus and EDRT, as some customers' trips are replaced by train services. The VKT distribution of Kussbus exhibits two distinct peaks due to frequent deadhead trips between Luxembourg and Arlon (see the empty VKT of Figure 4 (c)). In contrast, EIDRT buses rarely undertake long deadhead trips, with most below 20 km.

Due to the long empty VKT, Kussbus and EDRT operates fewer buses than EIDRT as depicted in Figure 4 (b). Another reason EIDRT requires more buses is that customers traveling by train need two buses—one for the first mile in Arlon and another for the last mile in Luxembourg City. Figure 4 (d) shows that EIDRT has higher occupancy, with a maximum of 21 customers per bus, compared to 14 for Kussbus and EDRT. The higher number of served customers per bus also explains the lower empty VKT for EIDRT.

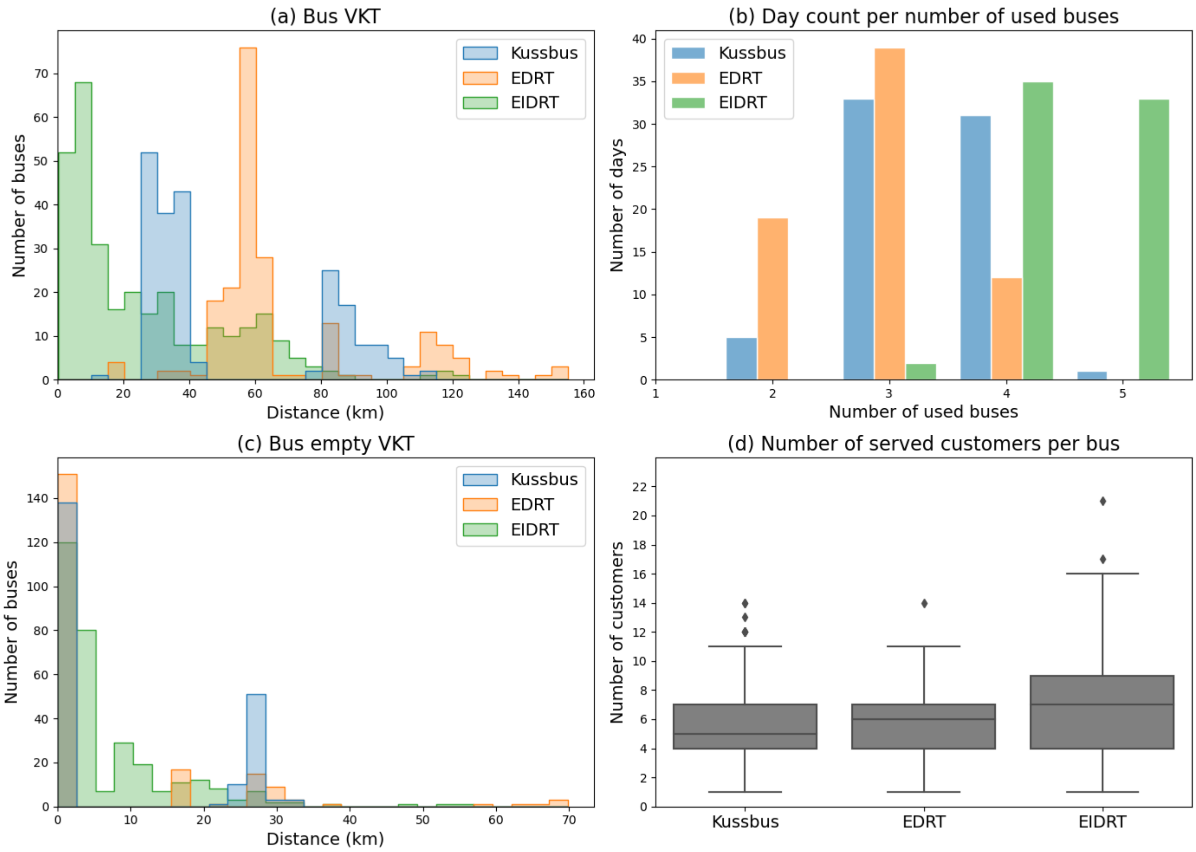

Figure 4. Key performance indicators from operator's perspective for Kussbus and EIDRT

5. CONCLUSIONS

This study investigates the EIDRT service through a case study in Arlon – Luxembourg corridor, using Kussbus ride data during morning peak hours. We compare the performance of EIDRT with cars, PT, Kussbus and EDRT. The results shows that EIDRT's offers significantly lower customer travel times compared to PT. From bus operator's perspective, EIDRT reduces VKT compared to Kussbus and EDRT, and EIDRT achieves a higher occupancy rate. Future research could apply EIDRT in more complex transit networks to verify its VKT reduction and better understand its optimal operating conditions. Exploring the impact of electric vehicles and incorporating uncertainties such as train delays or bus travel times are also promising research directions.

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