MIT Portugal Project Report

Demand Responsive Transit - Why Do They Fail, and How (and If) Can They Succeed?

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Abstract

This report presents the findings of our study on Demand-Responsive Transit (DRT) within the MIT Portugal Program. Our research evaluates the feasibility of DRT services and examines the role of autonomous vehicle technology in improving their efficiency and viability in low-density areas. The study employs a three-step methodological framework: demand estimation, high-level service optimization using integer linear programming, and performance evaluation from key stakeholder perspectives. Conducted in collaboration with the University of Coimbra's Civil Engineering research group, this work benefits from their expertise in transportation planning and access to regional mobility data.

Our findings indicate that while human-operated DRT services enhance consumer surplus compared to conventional public transit, they remain financially unsustainable due to high operational costs and heavy dependence on subsidies, ultimately resulting in a net loss. Automation presents a promising alternative, substantially reducing costs and improving economic feasibility; however, it may still require higher subsidies than existing services. While driverless DRT improves social welfare, policymakers must anticipate increased public funding requirements. We conclude that integrating automation with strategic fare optimization offers a practical pathway to a more sustainable, cost-effective DRT model.

Introduction

Public transport is essential for ensuring mobility, particularly in high-demand urban areas. However, in rural and low-density regions, fixed-route transit often proves inefficient due to low passenger volumes and high per-trip costs. Demand-Responsive Transit (DRT) has been proposed as a flexible alternative, yet many implementations have struggled with economic inefficiencies and limited adoption. This study, conducted under the MIT Portugal Program, evaluates the viability of DRT services and explores whether automation can enhance their feasibility, efficiency, and long-term sustainability.

Methodology

Our research follows a structured three-phase methodology that integrates demand modeling, optimization, and performance evaluation:

1. **Demand Estimation:** We developed a demand model to evaluate the effectiveness of existing transit services by quantifying the impact of fare levels, travel times, and service frequency on ridership. This model incorporates price and time elasticities derived from empirical studies and is calibrated using real-world transit data from the Coimbra region. The mobility patterns in the region are based on the most comprehensive available survey, conducted in 2009, which provides detailed insights into travel behavior and mode choices.

2. **Optimization:** To optimize fleet operations, we implemented a time-space flow network formulated as an integer linear programming (ILP) model. Instead of modeling individual vehicle routes, our approach uses flow variables to represent vehicle movements, providing strategic insights into system-wide operations. This time-flow algorithm captures three key vehicle states: passenger transport, repositioning of empty vehicles, and idle waiting periods. By optimizing fleet size and staffing allocation, the model seeks to maximize operator profit while ensuring service feasibility. For autonomous vehicle deployments, the optimization constraints are adjusted to reflect reduced staffing requirements and lower operational costs, further enhancing efficiency and economic viability.

3. **Performance Evaluation:** We assessed the economic and operational sustainability of DRT services by analyzing key performance indicators (KPIs) from multiple stakeholder perspectives. Consumer surplus was evaluated based on generalized travel costs, including fare, in-vehicle travel time, and waiting time. From the operator's perspective, profitability was measured by balancing revenue, operational costs, and required subsidies. The regulator's viewpoint was incorporated by analyzing overall social welfare, which considers both consumer surplus and public funding requirements.

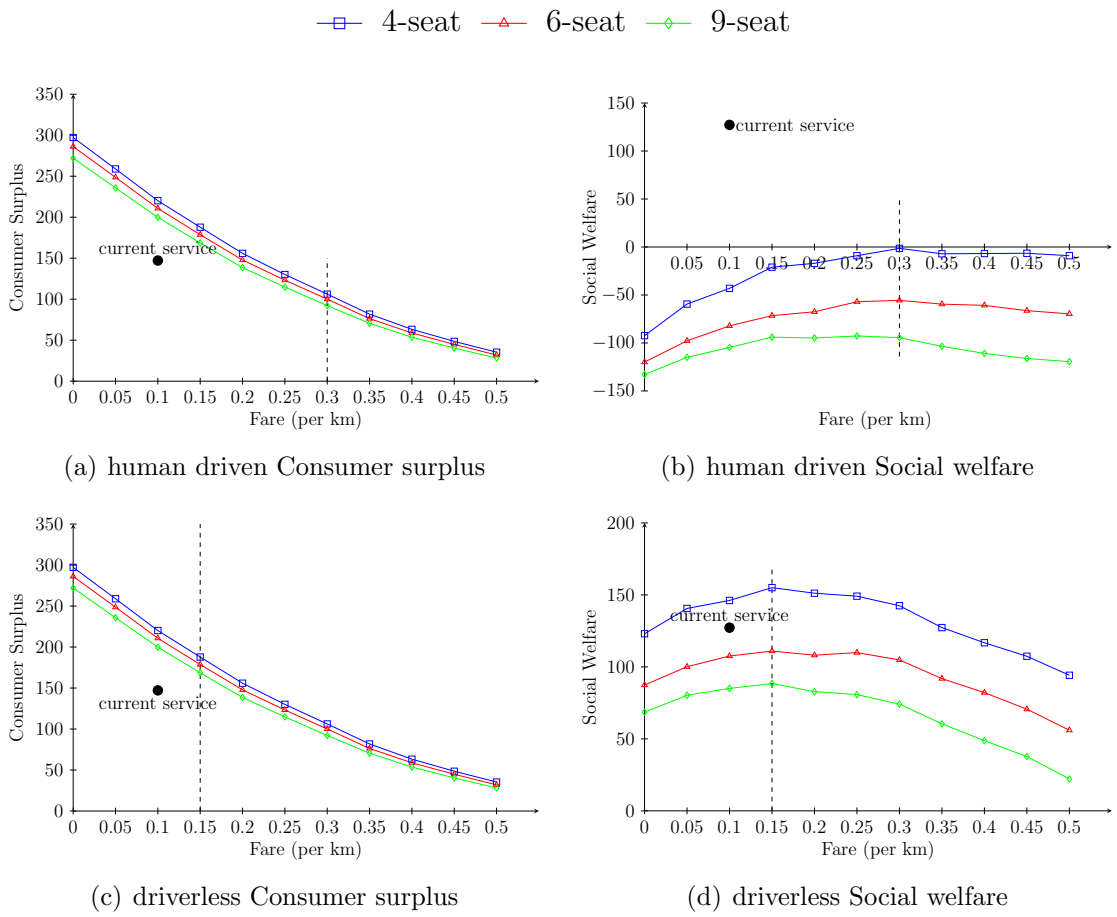
Findings

Our primary findings indicate that a proposed human-driven DRT service could, without adjusting the fare, accommodate approximately 20% more travelers than the existing fixed-route service while significantly increasing consumer surplus (see Figure 1(a)). However, higher operational costs and necessary subsidies for human-driven DRT lead to a net reduction in social welfare compared to the current system (see Figure 1(b)). Even fare optimization designed to maximize social welfare would require tripling the fare, yet this would still result in lower social welfare compared to the current service and a decline in consumer surplus, highlighting the inefficiency of human-driven DRT in this context.

In contrast, an evaluation of driverless DRT services, which significantly lower operational costs, suggests that automation enhances economic viability. Implementing a driverless DRT service with optimized fares, resulting in a 50% increase over the current fare, can improve social welfare by 10-30%, particularly when using smaller vehicles (4-seaters) that are better suited for low-density areas (see Figures 1(c) and 1(d)). Although higher subsidies are anticipated, the considerably lower operational costs make them more manageable, providing a more balanced trade-off between cost efficiency and service quality.

Policymakers and transit agencies should explore the potential of driverless technology in rural and low-density regions, where traditional fixed-route services fail to adequately

meet demand. Further research should focus on refining economic models and conducting pilot implementations to validate these findings and ensure the long-term sustainability of automated DRT solutions.



(a) human driven Consumer surplus

(b) human driven Social welfare

(c) driverless Consumer surplus

(d) driverless Social welfare

Figure 1: Overview of human-driven vs driverless fleet (in thousand euros per day).

Collaboration with Portuguese Partners

This project was conducted in close collaboration with researchers from the University of Coimbra's Civil Engineering research group, led by Professor Antonio P. Antunes and including Dr. Anne S. Patricio and Dr. Gonçalo Gonçalves Duarte Santos. Our partnership was characterized by regular meetings on a weekly basis, facilitating continuous knowledge exchange and iterative improvements in our models and analyses. Key aspects of this collaboration included:

- The exchange of data and expertise in regional transportation systems.
- The development and validation of demand and optimization models using real-world mobility data from Portugal.
- Joint research efforts on the sustainability of automated mobility solutions.

As part of this collaboration, Dr. Patricio, a Phd student at the time, joined MIT as a visiting researcher for three weeks, further strengthening the connection between

our institutions and contributing to the refinement of our optimization models and economic assessments. Even after the completion of the core research phase, we continue to meet regularly to finalize our paper and prepare presentations for conferences, including the Institute for Operations Research and the Management Sciences (INFORMS) and the Transportation Research Board (TRB) Annual Meetings. These ongoing discussions ensure that our findings are thoroughly reviewed and effectively communicated to the broader research and policy community.

Presentations and Publications

The results of this research have been presented at two important conferences in the field of operations research and transportation:

- INFORMS Annual Meeting, Seattle, WA. October 2024. `https://submissions.mirasmart.com/InformsAnnual2024/Itinerary/PresentationDetail.aspx?evdid=8676`
- TRB Annual Meeting, Washington DC, January 2025. `https://annualmeeting.mytrb.org/OnlineProgram/Details/23071`

Additionally, a full-length paper titled *How Driving Automation Will Save Demand Responsive Transit* is being prepared for submission to a peer-reviewed journal within the next month. A working version of the paper has been uploaded to SSRN at this link: `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4961593`