ENHANCING PUBLIC TRANSPORTATION SUSTAINABILITY: AN ECONOMIC FEASIBILITY FRAMEWORK FOR EFFECTIVE REGIONAL GOVERNANCE

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This research was supported by project number APVV-19-0263.

Abstract: This study seeks to address rural transportation sustainability by exploring the inclusion of demand-responsive transport (DRT) into the public transport system. To assess the feasibility of this approach, an agent-based model has been developed to calculate the costs and revenues and applied in case study of rural region of eastern Slovakia. While the DRT operations are generally unprofitable, under specific conditions, 31% of routes serviced by DRT recorded lower losses than bus transport, particularly in areas with low demand and during off-peak hours. These findings imply that DRT could serve as a viable option in enhancing rural transport accessibility and bolstering the cost-effectiveness of public transportation, however, it cannot entirely replace conventional bus transport.

Keywords: DRT, fixed-route transport, effectiveness, framework

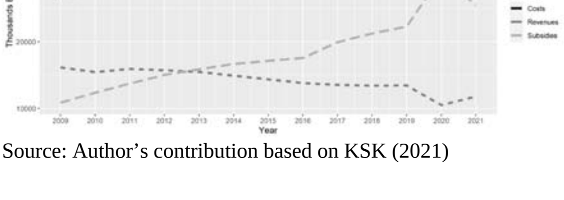
1 Introduction

Current society is marked by rapid urbanization, increasing environmental concerns, and growing demands for accessible transportation networks. The sustainability of public transit systems has emerged as a critical issue, especially questionable is the sustainability in rural areas. Among the currently available various modes of public transportation, bus transport has long been a cornerstone of rural mobility, providing essential connectivity for regions worldwide. However, as cities grow, the accessibility of rural regions while managing limited resources is coming under scrutiny. This paper delves into the challenges facing rural bus transport, with a particular focus on the economic aspects that make it a daunting proposition for regions seeking to sustain accessibility in their less densely populated areas.

In this context, it is essential to explore the challenges and opportunities posed by bus transport sustainability. This paper scrutinizes the economic implications of bus transportation, shedding light on the true cost of maintaining these systems and examining their impact on regional budgets. Moreover, it introduces alternative transportation solution and innovation that may provide more sustainable and cost-effective alternatives, ultimately aiming to contribute to the discourse on the future of urban mobility.

Similar challenges can be observed in Slovakia on the regional level. The Košice Self-Governing Region as the research area grapples with the pressing issues of increasing costs and diminishing transport demand, making the bus transport unsustainable for the future. During the lockdowns due to COVID-19 pandemic, the subsidies for bus carriers rose by a considerable margin due to the reduction in passenger traffic, as illustrated in Figure 1.

Figure 1 Costs, revenues of bus operators with subsidies received from Košice Self-governing Region



Source: Author's contribution based on KSK (2021)

As highlighted by Štofa et al. (2023), the decline in passenger traffic resulted in lower revenues for bus carriers, making it increasingly difficult to sustain their operations. At the same time, the carrier costs have remained high, and so they needed additional support from municipalities. Altogether, rising costs, decreasing number of passenger and the ecological impact are rendering this system of transport unsustainable.

This paper seeks to undertake an in-depth economic feasibility analysis of bus lines and aims to formulate a holistic approach for regions to proactively tackle the sustainability challenges of public transportation. The primary objective is to not only improve regional accessibility but also to concurrently mitigate the financial burdens associated with public transportation. While this approach is demonstrated using a specific region in Slovakia as a case study, its applicability and relevance extend beyond geographical boundaries, making it adaptable and transferable to various regions worldwide.

2 Literature review

The challenges inherent in sustaining accessible transportation networks in rural and remote regions represent one of the main issues of transportation. As the costs and logistical complexities of maintaining traditional bus transport systems in these areas continue to mount, alternative solutions have gained traction as potential remedies. This literature review seeks to explore the applicability of Demand-Responsive Transportation (DRT) as a solution to the pressing problems of accessibility and sustainability in rural and remote areas, as suggested by Liu & Ouyang (2021), Mortazavi et al. (2023) and Zhu et al. (2020). DRT is defined as a transportation system that adjusts to the current demand by either adapting the routes or schedules of the vehicles or by allowing passengers to pool their rides (Coutinho et al., 2020). Implementing DRT into public transport to combine multiple modes or to supplement public transport by using DRT as feeder service could increase the sustainability of public transport. However, as Gomes et al. (2015) suggest, the success of DRT projects is not always guaranteed. The previous projects implementing DRT systems have faced challenges, including high operating costs, as highlighted by Currie and Fournier (2020) and Enoch et al. (2006). Košice Self-governing Region meets several preconditions for successful DRT survival as lower employment density, less densely populated region, poor connectivity to road networks and increasing problems with parking mentioned by Wang et al. (2023) and Wang et al. (2015).

Despite the aforementioned challenges, DRT offers a more flexible transport option than traditional fixed-route bus transportation. In particular, DRT can be implemented as a door-to-door service, which provides passengers with greater convenience and reduces the need for additional transfers. In addition to reducing costs, implementing DRT can result in several secondary benefits, such as lower travel times (Caulfield, 2009), lower greenhouse gas emissions (Caulfield, 2009; Jacobson & King, 2009; Yu et al., 2017), and increased accessibility for individuals with reduced mobility. These benefits are supported by Coutinho et al. (2020) and Wong et al. (2020).

In some studies the DRT has been considered as a direct competition to public transit service (Sadowsky & Nelson, 2017; Zhu et al., 2020). Studies usually use a grid structure as network topology or a hub structure (Newell, 1979) or a hybrid topology as used in Daganzo (2010). In this paper, the primary intention was to replace inefficient bus routes rather than create an entirely new DRT network. To achieve this, we have modified the existing network of fixed bus service providers in the region by including DRT in specific cases. The proposed framework also takes a different approach by analyzing each bus route separately, as suggested by Ryley et al. (2014). While DRT services are rarely financially viable, the main objective of this paper is to reduce regional subsidies for transportation companies. Thus, while financial viability is a desirable outcome, it is not the primary goal. The proposed implementation of DRT system into bus transport system must create lower losses than the current mode to be considered a viable alternative. In low population density areas with low occupancy rates, a lower DRT service standard than in urban areas may be necessary. Viergutz and Schmidt (2019) suggest that a less flexible DRT service, characterized by fixed schedules, fixed routes, and the necessity of pooling, may be appropriate in such cases. Additionally, passengers may need to order tickets at least a few hours in advance to enable adequate trip planning.

One of the commonly applied methodologies to evaluate feasibility of implementing DRT is by utilizing agent-based simulation as stated by Ronald, Thompson, and Winter (2015) or Fagnant and Kockelman (2018). Agent-based models simulate demand and supply behavior. While this study expects the demand will be similar to that of fixed bus with fluctuations throughout the day in accordance with the actual occupancy of fixed transport. Additionally, the supply aspect of DRT can accommodate demand by dispatching more vehicles, with each DRT vehicle ready in accordance with the bus schedule and serving specific bus stops. The DRT route can be dynamically altered based on demand, allowing for efficient navigation by avoiding empty stops and selecting the quickest path. This paper adopts simple agent-based model to simulate the movement of passengers based on the real-world data from bus transport.

The aim of this paper is to introduce a framework for the integration of DRT into fixed-bus transportation and subsequently applying it in a case study within the rural areas of the Košice Self-governing Region in Slovakia. Considering previously mentioned challenges associated with DRT, this paper endeavors to identify the most feasible integration of DRT within the existing bus transport system, while the profitability has been employed as a main metric to quantify the suitability and extent of such an integration.

3 Research Methodology

In this study, the primary source of information used to model the demand for transportation within the Košice self-governing region was the data from the purchase of standard day travel tickets. This dataset provided crucial information, including the number of passengers traveling on specific bus routes, the origin and destination of each passenger, fares, and the route itself. It is important to note that the dataset used for this analysis represents only one day of travel. While this dataset may offer valuable insights into travel patterns on that particular day, it may not accurately represent travel patterns on other days or over a longer duration.

As a secondary source of information, a list of bus routes operated by bus transport companies in the region for the year 2018 was obtained. This data was utilized to gain insight into the existing fixed-route bus transport system in the area, facilitating a comparison of its performance with that of Demand-Responsive Transit (DRT). In total, 3,643 bus routes were analyzed, serving more than 600 towns, with each bus route being served multiple times throughout the year. Descriptive statistics for these bus routes, covering the entire year, are presented in the following table. These bus lines can be served by multiple buses a year, and all the essential descriptive statistics as distance traveled in km and passenger-kilometers (PKM), occupancy of buses, costs and revenues are presented in Table 1.

Table 1 Descriptive statistics of bus routes for the year 2018

variable	mean	sd	median	min	max
Bus lines per year	240.85	44.70	249	80	365
Distance traveled	5438.74	4614.89	4312.7	94.50	35955.60
Max bus capacity	50.62	13.51	49.82	3.94	104.55
Occupancy	20.30	16.22	16.81	0.01	101.2
PKM	68018.79	89808.01	36574	0	874086
Route revenues	3080.11	3539.12	1926.67	0	31893.20
Route costs	7032.56	5952.35	5510.40	115.07	48363.88
Route subsidies	3952.45	3733.22	3149.76	-5546.26	30021.82

Source: Author’s contribution

Due to the significant decline in mobility caused by the COVID-19 pandemic, pre-pandemic occupancy levels and other relevant data have been used. This approach is supported by the study conducted by Campisi et al. (2021) which highlighted the need to consider the pre-pandemic levels of transportation demand when analyzing the performance of public transport systems.

The proposed DRT system has a fixed schedule but partially adaptive routes, based on pooling a few hours earlier. The demand for DRT was modelled by analyzing the occupancy rates of real buses in the Košice Self-governing Region. While König and Grippenkoven (2020) suggest DRT services are often underutilized, the proposed DRT system will replace the non-viable bus routes and therefore we assume the same level of demand for DRT and buses. On the other side, the supply is made of network of private carriers, operating private fleet, and organized by one joint system. Considering that buses offer higher passenger capacity than DRT vehicles, this paper tries to analyze the distance travelled by one or multiple DRT vehicles, to ensure all passengers reach their destination. Therefore, it is expected, that economically viable routes served by DRT will be those in only low-demand areas during off-peak hours.

To overcome the challenges associated with identifying and locating all bus stops, the simplification of bus stops has been introduced where the bus stops have been replaced by individual towns along the bus route. While this approach helps to simplify the computation process, it also brings with it potential inaccuracies in estimating the route lengths between towns, especially in cases where the bus serves only crossroads before villages.

Given the challenges associated with accurately estimating the costs of implementing a DRT system, the market research was conducted to understand the current costs of private transport. It is expected that private carriers set prices that cover all costs associated with providing the service, while also generating a reasonable profit margin. Therefore, we assume that all costs associated with operating a DRT system can be part of these prices.

Additionally, due to low demand for transportation on some bus lines and the need to provide service to all passengers, we have selected microbuses as the primary vehicle type for DRT implementation. These vehicles have a maximum capacity of 8 passengers and are more suitable for low-demand areas where larger buses would be uneconomical.

According to the source data for costs and distance travelled, the standardized operating costs per km for buses have been identified and denoted by c^{buskm}, which is subsequently used to evaluate the costs of bus route for one day. Utilizing the information regarding ticket sales, it is possible to analyze the revenue generated by a particular bus route. Consequently, the costs of operating the buses, c_i^{bus}, the revenues generated by the buses r_i^{bus} and bus route profitability π_i^{bus} have been calculated as follows:

$$c_i^{bus} = c^{buskm} * d_i^{bus} \quad (1)$$

$$r_i^{bus} = \sum_{j=1}^{n} p_{ij}^{bus} \quad (2)$$

$$\pi_i^{bus} = r_i^{bus} - c_i^{bus} \quad (3)$$

where

i is i-th route
c_i^{bus} is daily fixed-route transport costs for i-th route
c^{buskm} is standardized costs of fixed transport per km
d_i^{bus} is distance travelled by i-th route
r_i^{bus} is daily fixed-route transport revenues for i-th route
j is j-th passenger on i-th route

n	is number of passengers in bus route i
p_i^{bus}	is ticket price for i-th route for j-th passenger in bus
π_i^{bus}	is profitability of i-th route

Subsequently, a distance matrix of all towns in the Košice Self-governing Region was generated for analysis. This matrix was utilized to analyze the distance that the DRT vehicles must cover in order to fulfil the estimated demand for a standard day to identify cost-effective way of meeting local transportation needs, as applied in Davison et al. (2014).

In this paper, an agent-based model has been designed to replicate the passenger transportation network, replacing buses with DRT vehicles. Each passenger is represented as an agent in the model. These agents possess attributes such as origin, destination, and departure time. On the other side, DRT vehicles are introduced as mobile agents which follow route of the buses. These vehicles have a fixed capacity of 8 passengers and are capable of dynamically editing their routes, if no demand is on the way. When a DRT vehicle reaches full capacity or if a passenger's request cannot be accommodated due to vehicle occupancy, a new DRT vehicle is dispatched to continue serving the route. The primary metric of interest is the total kilometers traveled by DRT vehicles, which is calculated as the sum of distances covered for all trips made by the vehicles.

As the initial location of DRT vehicles cannot be predetermined, this model takes into account the return journey of DRT vehicles, while allowing them to start from either the starting or ending town of the bus route. Therefore, two distances for DRT vehicles have been calculated, which represent the total mileage of DRT vehicles required to serve all passengers on i-th bus route based on the demand and distance matrix, starting from either the first or terminal bus stop of the specific bus route.

Standardized costs of DRT vehicles have been determined by market research and set on level 0.738 EUR/km. By analyzing the starting and ending locations on the tickets, an estimate of the ticket price based on the distance travelled d_{ij}^t by passengers on a specific route could be made. As the passengers are willing to pay more for better services and accessibility, we have decided to set the price per km p^{drtkm} on the level of willingness to pay 0.09 EUR/km, based on the Čopová (2022) research. This value is 34.12% higher than average fare of bus transport in Košice Self-governing Region, which also corresponds to the recommendations of Kim, Moon, and Kim (2017), who suggest an optimum price strategy for DRT that takes into account the cost of operation and the fares charged by other modes of transport, such as buses.

It is anticipated that the fares set for DRT will not be sufficient to cover all the costs associated with its operations. Therefore, the remaining costs would need to be subsidized by the government, in this case, the Košice self-governing region. However, the goal is to achieve at least the same level of accessibility of rural areas while utilizing a lower number of subsidies. Based on the previous assumptions and simplifications, the costs and profitability of DRT can be calculated as follows:

$$d_i^{drt} = \frac{d_i^{drt\ start} + d_{2i}^{drt\ end}}{2} \tag{4}$$

$$c_i^{drt} = d_i^{drt} * c^{drtkm} \tag{5}$$

$$r_i^{drt} = \sum_{j=1}^{n} d_{ij}^t * p^{drtkm} \tag{6}$$

$$\pi_i^{drt} = r_i^{drt} - c_i^{drt} \tag{7}$$

where

i	is i-th route
d_i^{drt}	is average distance travelled by DRT on i-th route
$d_i^{drt\ start}$	is distance travelled by DRT for i-th route starting from first route stop
$d_i^{drt\ end}$	is distance travelled by DRT for i-th route starting from terminal route stop
c_i^{drt}	is daily DRT transport costs for i-th route
c^{drtkm}	is calculated costs of DRT per km
r_i^{drt}	is daily DRT revenues for i-th route
j	is j-th passenger on i-th route
d_{ij}^t	is distance travelled by j-th passenger on i-th route in DRT transport
$p^{drt\ km}$	is price of DRT ticket per km
π_i^{drt}	is DRT profitability of i-th route

Subsequently, the costs of DRT and buses have been compared for each bus route. Since fully occupied bus requires to be replaced by multiple DRT vehicles, the costs of DRT transport can be substantially higher than those of bus transport. However, DRT transport is expected to generate higher revenues than fixed-route bus transport, therefore the profitability of DRT vehicles has been compared for every route. Therefore, the savings for each route have been computed.

$$s_i = \left(\pi_i^{drt} - \pi_i^{bus}\right) * b_i \tag{8}$$

where

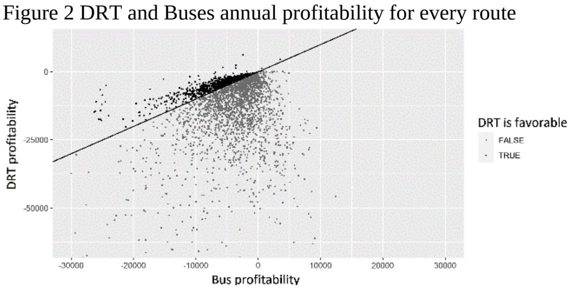
s_i	represents yearly savings for i-th route
b_i	represents number of bus connections

If the profitability of the DRT transport exceeds that of the bus transport, it implies that DRT is generating higher revenues and/or incurring lower costs than buses for that particular route. As a result, the route is deemed favorable for DRT transport, as it would result in cost savings or increased profitability.

4 Results of case study

The designed framework has been subsequently applied to the data Košice Self-governing Region, encompassing 3643 bus routes with the data collected for a standard day. Notably, a majority of bus routes and nearly all DRT routes resulted in losses, which have to be subsidized from the budget of Košice self-governing region to ensure the sustainability of transport services. Out of these, 1135 bus routes served by DRT exhibited a higher profitability, respectively lower losses, than fixed-bus transport, as evidenced in Figure 2. Hence, it is more advantageous for these routes to be serviced by Demand-Responsive Transit (DRT) transport.

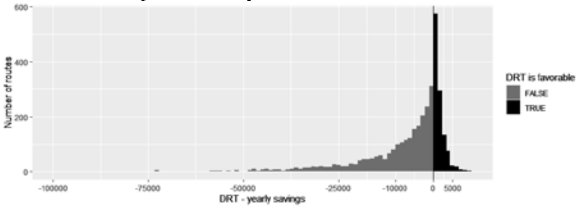
Figure 2 DRT and Buses annual profitability for every route



Source: Author's contribution

Municipalities could implement cost-saving measures on these routes in form of DRT application, and despite the fact that DRT routes will result in losses in most cases, these losses are still lower than those incurred with fixed-route bus transport, making the adoption of DRT transport a viable option. As illustrated in Figure 3, the potential annual savings can reach up to €10,000 per bus route. However, for bus routes with high passenger demand, the negative savings may be significantly higher due to the limited capacity of the microbuses utilized in this framework. Unlike buses, microbuses cannot exceed 100% occupancy as standing passengers are not permitted. Consequently, multiple microbuses must serve a single bus route, leading to substantially higher losses when employing DRT.

Figure 3 Histogram of annual savings using DRT instead of fixed-route transport for every route



Source: Author’s contribution

To ensure that DRT implementation is economically viable, it is essential to consider the fluctuations in demand that can occur throughout the year, which was not part of this paper. In some cases, it may be more appropriate to use a larger vehicle, such as a minibus, that can serve the entire route in less trips in case of high demand. In the analysis of Košice Self-governing Region, we found that the median of positive savings was only 1137.11 EUR. Therefore, it is important to carefully select the most economically viable routes for DRT implementation. In general, it can be asserted that DRT has the potential to alleviate the financial burdens of municipalities, as underscored by Park & Jung (2019).

It is important to consider that demand for bus routes can fluctuate over time, and so, the savings may not be consistent throughout the year. In the following figure, we have identified all the routes with savings over 2000 EUR a year. In total 324 bus routes identified are represented with the figure below.

Figure 4 Bus routes identified for replacement by DRT with estimated savings over 2000€ a year

Source: Author’s contribution

It is important to consider the potential fluctuations in demand and the need for a more detailed analysis of individual buses' economic viability. Other external factors may also impact the savings identified in this analysis, highlighting the importance of ongoing evaluation and adjustment. Therefore, in the next step, we propose conducting a Willingness to Pay and conjoint analysis. To facilitate this, we have pinpointed seven recurring settlements where the possibility of substantial savings becomes apparent when transitioning from bus to DRT.

Table 2 Selected settlements for WTP and Conjoint analysis

Settlement	Bus routes replaceable by DRT	Yearly savings (EUR)	Average occupancy in persons	Bus Fare (EUR)	Distance to district city (km)
Hažín	14	46779	7.9	1.10	11
Spišské Vlachy	46	79996	6.8	1.70	22
Jasov	23	52514	7.8	1.90	29
Mlynky	12	42413	10	2.50	42
Nižná Hutka	12	23200	11.1	1.10	13
Jablonov n.Turňou	14	36698	7.4	1.30	17
Závadka	8	46876	10.4	1.30	15

Source: Author’s contribution

As evident from Table 2, the average occupancy of the identified bus lines replaceable by DRT is notably low, underscoring the viability of replacing routes with lower demand. In the context presented in this paper, DRT is almost always not profitable, however, the combination of higher fares and reduced associated costs results in significant savings for selected routes in comparison with bus transport. This implies that DRT can be a viable option as a bus replacement, especially in areas with low demand or during off-peak hours, aligning with the findings of Mortazavi et al. (2023). However, this significantly depends on passenger counts, and sudden peaks can pose a challenge. The utilization of larger vehicles through advanced transport booking could effectively address this issue.

5 Conclusions and Policy implications

This study proposes a novel framework for evaluating the feasibility of implementing DRT transport in a specific region and applies it for the Košice Self-governing Region. The methodology involves agent-based model to predict costs and revenues for DRT transport through distance and demand matrix, to calculates occupancy and distance travelled for DRT vehicles. The costs and revenues of DRT transport are then compared with those of fixed-route bus service, considering the higher willingness to pay for DRT transport. In addition to cost comparison, profitability is also assessed to determine whether DRT implementation is economically feasible. A separate comparison of each route is proposed since it is not expected that replacing all bus transport with DRT would be possible or feasible. Therefore, DRT should be considered as an additional integrated transport service within public transportation systems, with the aim of reducing government subsidies while maintaining or enhancing accessibility wherever feasibility is established.

To test the applicability of the proposed framework, we conducted a case study on the Košice Self-governing Region in Slovakia, using the data from one standard day. The results indicated that even after implementing DRT transport, the majority of routes remain unprofitable. While the achieved cost savings were not consistently substantial and some DRT routes exhibited considerable losses, it is noteworthy that DRT outperformed fixed-route bus transport in 31% of cases. These superior outcomes were predominantly observed in low-demand areas and during off-peak hours suggesting the usability of DRT vehicles. However, it is essential to acknowledge that as demand escalates, the efficiency of traditional bus services experiences a notable upturn, whereas the efficiency of DRT starts to diminish. In a long term the savings could be even bigger, because a portion of the subsidies provided to private carriers is allocated for the renewal of their vehicle fleet and this cost could theoretically be avoided in the case of DRT. Therefore, our framework could be considered as a viable option for municipalities looking to reduce transportation costs and increase efficiency in their public transport systems. By rigorously evaluating each bus line for replacement, decision-makers can pinpoint routes where DRT offers substantial economic advantages, balancing the need for cost reduction with the commitment to maintaining high-quality service. Pilot programs should be initiated to test the feasibility and public acceptance of DRT on select routes, providing valuable insights to inform broader implementation strategies. Moreover, seamless integration with existing public transport options should be embraced to ensure DRT remains a viable and cost-competitive alternative while effectively addressing high subsidies for public transport in the region.

This paper has several implications for the improvement of rural transportation systems. First, it demonstrates that DRT can be integrated into the existing fixed-route bus transport system in rural areas to reduce costs and increase accessibility. Second, it provides a scientific framework and a simple agent-based model to evaluate the feasibility and performance of DRT for each bus route. Third, it offers insights into the conditions and factors that affect the viability of DRT, such as demand, occupancy, fares, and subsidies. Fourth, it contributes to the literature on DRT and rural transport by applying the framework in a case study of a rural region in Slovakia.

However, it is important to note that the study has several limitations that may affect the generalizability and validity of the results. For instance, the study assumed stable demand and included DRT costs in the prices of private carriers, which may impact the results. Moreover, further research is necessary to evaluate the long-term benefits and drawbacks of implementing DRT transport in different regions with varying transportation needs and demographics. Despite these limitations, the framework provides a valuable tool for decision-makers to evaluate the potential benefits and drawbacks of implementing DRT transport in a given region.

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Primary Paper Section: A

Secondary Paper Section: AH, AP