A Survey on Demand-Responsive Transportation for Rural and Interurban Mobility

Pasqual Martí[1], Jaume Jordán[1], Angélica González Arrieta[2], Vicente Julian[1,3] *

[1] Valencian Research Institute for Artificial Intelligence (VRAIN), UniversitatPolitècnica de València, Valencia (Spain)
[2] Department of Computer Science and Automation, University of Salamanca,Salamanca (Spain)
[3] Valencian Graduate School and Research Network of Artificial Intelligence, Universitat Politècnica de València, Valencia (Spain)

Received 26 February 2023 | Accepted 24 July 2023 | Published 31 July 2023

Abstract

Rural areas have been marginalized when it comes to flexible, quality transportation research. This review article brings together papers that discuss, analyze, model, or experiment with demand-responsive transportation systems applied to rural settlements and interurban transportation, discussing their general feasibility as well as the most successful configurations. For that, demand-responsive transportation is characterized and the techniques used for modeling and optimization are described. Then, a classification of the relevant publications is presented, splitting the contributions into analytical and experimental works. The results of the classification lead to a discussion that states open issues within the topic: replacement of public transportation with demand-responsive solutions, disconnection between theoretical and experimental works, user-centered design and its impact on adoption rate, and a lack of innovation regarding artificial intelligence implementation on the proposed systems.

Keywords

Artificial Intelligence, Demand-Responsive, Intelligent Transportation, Optimization, Rural Areas.

DOI: 10.9781/ijimai.2023.07.010

I. Introduction

Access to public transportation (PT) should be generalized, as its name implies. Rural communities are often marginalized, with citizens only accessing low-quality PT. Some of the characteristics associated with rural PT are old vehicles, long and infrequent routes, and inconvenient stops. Therefore, it is common to observe higher ownership of personal motor vehicles in rural settlements (2 per household versus 1 in cities) [1].

The demand for transportation in rural areas differs from that in urban areas. It is characterized by more scattered transport requests, both in time and space, which makes the economic viability of higher-quality services more difficult. Consequently, with this shape of demand, it seems difficult to justify deploying a transport that continuously offers service, with or without passengers. Because of that, the on-demand transportation paradigm shows potential for reducing costs while increasing service quality in rural areas.

Demand-responsive transportation (DRT) systems offer displacement services adapted to the needs of their users. Initially conceived as a mobility option for impaired people and inhabitants of isolated areas [2], this mode of transport is again attracting PT providers' interest thanks to technological advances that allow users to be connected most of the time. DRT systems count on two main characteristics: on-demand mobility and adaptable flexibility. According to the specific configuration, DRT can resemble transportation ranging from high-capacity interurban buses to dial-a-ride urban taxis [3]. Thus, given a use case, it is necessary to analyze which implementation best fits the needs of the potential customers. In practice, however, implemented DRT services have a relatively high failure rate, caused by high economic costs [4], [5] and low customer acceptance, among others. In addition, the success of a concrete DRT deployment depends on the characteristics of the area it services, its population density, demand, and current transportation trends. The implementation of demand-responsive mobility has been highly studied in recent years, although mostly applied to urban contexts [6].

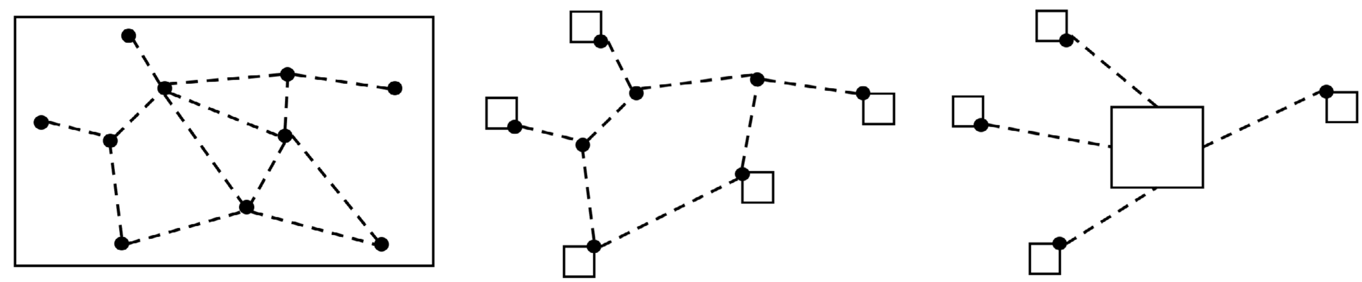
In this review article, we bring together papers that discuss, analyze, model, or experiment with DRT systems applied to rural areas and interurban transportation, with the intention of discussing their general feasibility as well as the most successful configurations. Political authorities from different parts of the world have shown their interest in the improvement of rural transport with a sustainable perspective. The Spanish government, for example, has presented within its "mobility strategy" the Rural Mobility Roundtable[1] where it highlights, among others, the importance of demand-driven transport and the creation of dynamic routes to work towards the goal of generalized access to PT in rural areas.

The rest of the paper is structured as follows. Section II describes DRT systems and their components, introducing the challenges its

* Corresponding author.

E-mail addresses: pasmargi@vrain.upv.es (P. Martí), jjordan@dsic.upv.es (J. Jordán), angelica@usal.es (A. González Arrieta), vinglada@dsic.upv.es (V. Julian).

[1] https://esmovilidad.mitma.es/mesa-de-movilidad-rural (Accessed on 01/12/2022)



(a) Within a rural settlement (b) Between rural settlements (c) Between rural and urban settlements

Fig. 1. Observed operational patterns for rural demand-responsive transportation systems. Boxes indicate rural/urban settlements. Black dots represent stops. Dashed lines represent demand-responsive lines. Pictures (a) and (b) are cases of many-to-many transportation, while (c) represents a many-to-one model.

implementation involves. Section III classifies the state-of-the-art work dividing it into analyses and proposals and summarizing each of the cited works. Section IV discusses the results and insights of the reviewed publications, with a particular fixation on the observed open issues. Finally, Section V concludes the review article by summarizing the state of DRT research and stating the main takeaway points of the present work.

II. Definitions and Problem Description

This section describes DRT and provides the necessary definitions for the posterior classification of rural-DRT publications. First, we characterize demand-responsive systems according to their configuration. Then, the modeling and optimization techniques that are classically applied to works in the area are commented. Finally, some insight is given regarding the optimization perspective that different DRT researchers follow.

A. Demand-Responsive Transportation Characteristics

DRT systems have a series of standard elements present in all of them. Different authors apply different labels to those elements. For the current work, we have followed the terminology described in this survey [7].

In a DRT system, a *service* is the departure of a vehicle to serve the transportation requests it has assigned. One service is generally tied to a concrete area or line assigned to the transport. In contrast, a *route* is the specific path the vehicle follows connecting all the pickups and drop-offs. A route does not necessarily include all existing stops in a line or area. Customers are picked up and dropped off in a predefined set of *stops* within the serviced area or line. Alternatively, a *door-to-door* service can be offered, in which any user-specified location within a particular area may act as a stop. This type of mobility is thought to be *shared*; i.e.: multiple customers are served by the same vehicle. Typical vehicle choices for demand-responsive services include a taxi-like car with a capacity of 4 passengers, mini-vans with 9 to 12 seats, and mini-buses or buses with 20 to 30 seats, respectively.

Many operational patterns exist for DRT. Specifically, for rural-DRT, we find the following: transportation within rural settlements, transportation between rural settlements, and transportation between rural and urban settlements. In practice, these cases can be reduced to two systems: *many-to-many*, with a set of multiple origins and destination locations, and *many-to-one*, where origin and destination locations share a unique pick-up or drop-off point. The last type is usually the so-called feeder line, where a flexible transportation service is used to move passengers to a different, less accessible service (for instance, communications from rural settlements to an airport). Fig. 1 shows a schematic representation of the commented used cases.

If the customer is required to send a *request* to access transport the service is provided *on-demand*. The time between sending a request and the customer's pick up is the *lead time*, and it is used to adapt the fleet operation or *planning* to include such a request. In a stop-based operation, the customer will be assigned a stop from which it will be picked up. On-demand systems can operate in real-time, accepting last-minute bookings, or with a hybrid approach, accepting bookings in advance too. DRT systems which are not on-demand are also possible. These systems consider current demand or demand predictions for service planning but do not require requests to run.

The period of time for which the DRT service is planned and optimized is referred to as *planning horizon*. The duration of planning horizons is usually a whole day. In addition, the operator may plan for a few hours to adapt to high/low demand periods. According to the influence of the demand data on the service planning, the system will be *fully-flexible* if routes are planned from scratch according to current demand or *semi-flexible* if a predetermined plan exists but vehicles are allowed to modify it influenced by demand.

B. Modeling and Optimization Techniques

Once the specific type of DRT system has been chosen, it must be modeled and tested to check its performance and adjust its attributes. We discuss below the different steps this involves, citing relevant research and the methods their authors employ. Please be aware that not every paper cited in this section explores rural-DRT.

Most DRT works are set in a specific settlement or area. In general, the main transportation network (roads, highways) of the area is mirrored thanks to services like Open Street Map (openstreetmap.org) or Open Sourcing Routing Machine (OSRM, project-osrm.org) [8]. Ideally, the actual organization of the area, its types of districts, population, or socio-economic reality, among others, should also be considered. Authors in [9] describe a seven-step analysis method for the optimization of any transportation system, based on reproducing the features of the currently implemented transport service (that would potentially be replaced). Alternatively, some works employ grid-like modelings of the area where the system will run [10]. The actual routing of each fleet vehicle represents one of the main challenges of DRT services, as it must be performed in real time. Innovative heuristic algorithms [11], [12] aid in this respect.

Demand modeling is also crucial. Passenger demand has two main aspects: (1) frequency and intensity and (2) shape (location of origin-destination pairs). Demand attributes can be extracted from datasets of different transportation modes and extrapolated, as in [13], where taxi data is used. Moreover, real data of pilot DRT services [14], [15] can be reproduced when available. However, the most observed technique is the use of synthetic demand data that can be generated statistically [10], based on socio-demographic information [16], via surveys [8], [15], [17] or generated in a (semi-)random [18] way according to the properties of the reproduced area (population, age, occupation, vehicle ownership). Finally, if traffic intensity data is available, it is useful to include it in the model, although not as relevant for rural areas with respect to city-centered studies, since the former tend to have lower intensity.

The operation of the DRT system requires automated planning and scheduling of vehicle services. At the same time, these tasks need information on the time and traveled kilometers that any detour would imply, which makes routing algorithms also necessary. In addition, since it is common to find online systems that accept real-time requests, the computation time for detours and new request insertions must be kept low. The use of multimodal planning [8] is common to solve the scheduling of vehicle services. Moreover, some simulation platforms, such as MATSim [19] include their own implementations of the algorithms mentioned above. These implementations usually employ (meta)heuristic techniques [16] that optimize vehicle-passenger assignments (insertion heuristics [20], for instance) or vehicle routing in a short computational time. Besides that, other less exploited techniques such as automated negotiation could be used to decide assignments from a decentralized perspective [21].

Finally, to observe the system's dynamics and its operation and adjust its attributes, it is necessary to simulate it. This can be performed through mathematical modeling [9] provided detailed data is available. However, a more popular way of achieving this is through multi-agent simulation (MAS). Among the observed choices we find NetLogo [22], used in [23], the already mentioned MATSim, and even custom simulators [8], [24].

C. Optimization Goals

The main goal of people transportation services is to supply the displacement needs of its users. Ideally, the operation of the service shall be performed by optimizing three factors: (1) the economic viability of the service; (2) the customer's experience (or quality of service); and (3) the environmental impact of the service. These three factors are translated into scopes when it comes to transportation research, and thus we can find works that asses one (only operator perspective [25]), or many of them from a multi-objective perspective (passenger and operator perspectives [26]). Optimizing customer experience implies reducing passenger travel times, whereas economic viability is ensured by reducing operational costs. Finally, optimizing sustainability requires reducing vehicle traveled kilometers (VTK).

The greatest challenge of demand-responsive transportation systems is finding the equilibrium among the above factors to offer a competitively-priced, economically viable, and flexible mobility alternative to private cars and traditional public transportation. For the case of rural-DRT, economic viability is especially difficult, taking into account the relatively low demand.

III. State of the Art Classification

This section presents a classification of the relevant literature found while researching the topic. Given the heterogeneity observed among the articles, they have been grouped by two criteria. On the one hand, the first group encapsulates studies, surveys, and analyses on the implantation of DRT solutions for rural areas. On the other hand, the second group presents papers that include at least an explicit DRT system proposal and experimentation to evaluate it. Both types of work offer reflections and insights into the viable application of on-demand mobility to areas with scattered populations and low demand.

A. Literature Retrieval and Overview

The Google Scholar and Scopus search engine were used to retrieve articles and book chapters relevant to the topic. The results were filtered applying the following rules: 1) the term "demand-responsive" had to be present in the title, abstract, or keywords of the publication, and 2) at least one of the terms "rural", "rural area" or "interurban" had to be present in the title, abstract, or keywords of the publication. Using the above criteria, the first search yielded 34 articles. Of these, 9 were discarded because the algorithms or systems they described did not fit the rural perspective of our review paper. The keywords "rural" and "interurban" could be present in the abstracts, but that did not guarantee that the characteristics of the systems researched by the authors matched those of rural or interurban mobility. Therefore, only papers that explicitly modeled low demand with scattered residents or assessed a rural interurban scenario were retained. Once filtered, the batch of relevant publications had a relatively small size of 25 publications. The fact is that rural-DRT solutions are less explored than their urban counterparts, probably because of factors such as scarce data availability and a lack of general interest until recent times.

In addition to the few publications, the degree of detail regarding the DRT systems described in them varied considerably. In general, all authors describe at least the operation of the basic components of any transportation system. However, just a minority explicitly state their system's constraints, the objective function(s), or the technology employed to build their proposals. Finally, it is worth mentioning that each proposal is tailored to the rural area it serves, which also differs for each work.

Given the described situation, we have chosen to summarize the publications on this topic one by one, giving as much relevant detail for each of them as possible. Nevertheless, two main classification criteria have been applied to divide the publications: analytical works, discussing challenges and studying the implementation of DRT in a specific context (Section III.B); and experimental works that explicitly model, implement and simulate a DRT system (Section III.C).

B. Analyses and Surveys

This subsection groups the state-of-the-art literature which assesses the challenges, potential benefits and contributions of implementing DRT for rural mobility. Most of the cited works develop their analyses around a main topic, which is shared among some, but present their own methods and conclusions. Following, we present the contributions grouped by the main topic they discuss.

1. Success and Failure of DRT Systems

One of the most historically studied topics in DRT history is the success and failure of deployed systems. Works in this line give important insight that PT providers must consider when designing a system. Enoch et al. assess the failure of DRT systems in [5]. The authors concluded that DRT projects are often not realistically costed or designed with a full understanding of the market they are to serve. A pattern was observed in which providers offered too flexible a service, including costly technological systems, when they may not be needed. In contrast, the authors recommend an incremental approach as a more sensible option. Compared to conventional PT operations, DRT requires more marketing effort and skills, but above all, it requires new skills in working in partnership. The failure in partnerships is where the root of DRT failure is often found.

G. Curry and N. Fournier [4] review DRT and Micro-Transit implementations to assess their performance. High failure rates stand out in their findings. 50% of the systems last less than 7 years, 40% last less than 3 years, and about a quarter fail within 2 years. In the UK, 67% of DRT services have failed, and in Australasia, 54%. The results indicate that simpler operations (e.g., many-to-few or route deviation) had lower failure rates compared to more complex many-to-many services. The authors develop a cost analysis that shows a strong and definitive link between DRT failure and higher service costs.

2. Replacing Classic PT With DRT

Many analyses focus on a particular rural settlement and aim to replace or optimize the currently implemented means of PT. Ryley et al. [2] investigate the contributions of DRT to sustainable PT. Their study surveys the public of both urban (Rochdale, Manchester) and rural (Melton Mowbray, Leicester) areas of the UK. Six DRT service variants are explored using mixed logit models; from those, a rural hopper service linking a number of rural settlements to a market town fits our research. Regarding that system, authors find the in-vehicle time of passengers is longer than normal, as the alternative to the DRT service is private motorized vehicles. Longer times are mainly caused by the dispersion of the served population, and the need for door-to-door as opposed to stop-based services, necessary due to the predominantly elderly and/or mobility-impaired users.

Coutinho et al. [15] assess replacing a fixed public bus line with a DRT system to service the rural surroundings of Amsterdam, the Netherlands. Their analysis focused on indicators such as distances, ridership, costs, greenhouse gas (GHG) emissions and the population's perception of DRT. Their results expect a drop in ridership which is compensated by mileage and operating time-frame reductions. There is better overall efficiency with DRT compared to the fixed service. The number of traveled kilometers, operational costs and GHG emissions per passenger were smaller.

C.-G. Roh and J. Kim [27] analyze and propose an optimization for six small bus routes in the rural city of Yangsan-si, South Korea. Geographic Information Systems (GIS) were used to compare and review the planned routes and operation status of each route, while improved DRT operation methods were studied based on these operations patterns. A more suitable DRT small bus operation model for each route was proposed as a conclusion.

3. DRT Systems' Adoption Rate

The adoption rate of newly deployed DRT systems is tightly related to their success. Some authors center their assessments on this topic. Wang et al. [28] discuss the DRT adoption rate in the rural area of Lincolnshire, England. The authors argue that car ownership, the aging population, and cuts in public spending threaten the traditional public bus services that operate in rural settlements. DRT, however, faces a series of challenges for its successful implementation. Through the analysis of various factors, it is determined that people with disabilities, those traveling for work, and those who live in less densely populated areas are more likely to travel by DRT. In addition, a gender-based analysis reveals females have a higher propensity to use DR services compared to males below retirement age. However, the trend vanishes upon reaching retirement age. This, for the authors, indicates an emerging market potential from the retired male market segment, and thus service providers should design their systems considering it.

Anburuvel et al. [29] run a survey to explore the willingness to accept a DRT service for the spatially scattered population of a rural region of Sri Lanka. The survey pointed towards economic attributes (income and vehicle ownership), sociocultural attributes (age, gender, and education), and mobility needs (travel frequency and access distance/cost) as the primary factors which decided the choice of a transport mode, thus begin more relevant in the decision of the deployment of a new service.

Schasché et al. [30] elaborate a review on the conflicting expectations and weak user acceptance of rural-DRT systems. Their paper creates an overview of the development in the research field, focusing particularly on user-oriented research, detects conflicting performance expectations towards DRT services that complicate their success, and identifies discrepancies between perception and empirical design studies. The findings suggest a need for more focus on rural areas when attempting to reduce the use of private combustion engine vehicles in favor of public transport and successfully establish DRT services as well as further research into specific user groups. The main take-away points are the following: In rural areas, personal factors such as age, gender, and private car access are found to be of stronger influence on user acceptance than in urban areas. Service-related factors like time reliability and booking methods have a higher impact on rural transport mode decisions than in urban settings. Finally, knowledge of DRT service and information provision also appears more influential for users in sparsely populated regions.

4. Reviews on Smart and Sustainable Mobility for Rural Areas

Some of the most useful theoretical contributions come from those works that group relevant publications, much like the present paper. The perspectives and criteria for the grouping are what differentiated one review on a concrete topic from another. Agriesti et al. [31] aim to build the case for a renewed research effort about smart mobility in low-density areas. The authors perform a wide surveying effort across Estonian municipalities, focusing on the outputs from rural and small suburban centers. The results report the main mobility challenges across the region and what hindering factors are preventing envisioned solutions. Tracking social behavior, changing travel patterns, and social inclusion stand out among these challenges. Technology implementation is also identified as a key priority, particularly regarding traffic management and planning practices.

Poltimäe et al. [32] present a review of papers dealing with inclusive and sustainable mobility systems for rural areas. After analyzing many proposals, the authors group them into four categories: semi-flexible DRT, flexible door-to-door DRT, car-sharing, and ride-sharing. The main conclusion of their study is that single mobility solutions are rarely applicable to all rural travelers. Therefore, the future lies in multimodal mobility, considering that strong spatial and temporal synergies exist when combining different solutions. Success factors for sustainable rural transportation are identified, among which accessible and easily understandable information on routing, booking, and ticketing systems, as well as cooperation, shared values and trust between various parties, stand out. Finally, the importance of integrating the needs of various user groups for implementing environmentally, socially, and economically sustainable mobility solutions in rural areas is emphasized.

5. Other Analytical Contributions

Given the strong relationship between transportation systems and the area they service, some authors focus their surveys and proposals on specific topics which are relevant in their case. Abdullah et al. [33] assess the service quality of two DRT bus services operating in Lahore, Pakistan, through a questionnaire. The surveyed data reflected service attributes and bus ambiance as significant predictors of overall customer satisfaction.

F. Heinitz [34] approaches the improvement of rural mobility through incentives for private vehicle drivers to share their vehicle with other passengers for a concrete journey. The author builds a framework that defines steps to take when considering the introduction of DRT elements to a rural mobility scenario. His case study, set in the Schmalkalden-Meiningen area, Germany, takes into account German legislation. The author's conclusions show he understands as a mistake the proposal of a whole DRT solution from scratch for a certain rural area. Instead, he bets on modal integration and the development of high-adoption ridesharing among citizens, as private vehicles are the best approach to the mobility patterns of rural inhabitants.

F. Cavallaro and S. Nocera [35] study the novel concept of integrating passenger and freight transportation in flexible-route vehicles for rural areas. The developed case study is centered in the municipality

(a) Interurban stop-based operation

(b) Within settlement door-to-door operation

Fig. 2. Graphic representations of demand-responsive transportation systems operating with different configurations. Passenger demand is depicted by green human icons, whereas vehicles are portrayed by yellow buses. Vehicle routes are indicated with red dashed lines. Picture (a) reproduces an interurban operation, where settlements, indicated with white boxes, act as stops to travel from/to. Picture (b) depicts a door-to-door operation within a rural settlements, in which passengers can ask for a ride from any location within the town.

of Misano Adriatico, Italy. The performance of the service is evaluated through a selection of financial, operational, environmental, and social key performance indicators. The results of the analysis revealed a reduction in kilometers traveled, fuel consumption, and air pollutants, together with an increase in the area covered by the service, an increase in potential daily deliveries (for freight transport), and an increase in the occupancy rates of vehicles (for passengers).

C. Proposals and Experimental Work

This subsection groups the state-of-the-art literature which explicitly describes either a complete DRT system or some crucial part of it, including proposals that seek to optimize the system's operation or that simply test a particular approach for modeling, scheduling, or simulation.

Two main criteria have been used to divide the publications according to the system's proposed features. On the one hand, systems following many-to-many locations' operational patterns are separated from those using a many-to-one scheme. On the other hand, within each operational pattern, systems are split into those with fully-flexible routing and scheduling and those with semi-flexible ones.

Fig. 2 illustrates different DRT configurations that were found among the proposals analyzed in this section.

1. Many-To-Many Operational Pattern

Fully-flexible scheduling

Among the analyzed works that implement and validate concrete proposals, a few aim to enhance a commonly used technique or define approaches that deviate from the norm. Van Engelen et al. [18] propose an enhancement to insertion heuristics by including demand anticipation. Their algorithm is tested over the Tata Steel IJmuiden area in the Netherlands. The demand forecast is considered when a new request arrives in the system and is used to filter the number of fleet vehicles that can serve it. Generally, a vehicle will have enough free seats to serve passengers (demand) at the next stop on its route. Demand forecasting is applied to decide the probability that the next stop will have more demand than what the system currently considers. A vehicle may be rerouted to a stop with an expected demand greater than its current seat availability if the operator has "low confidence" in the demand forecast; this implies taking a risk. Conversely, when there is high confidence in the prediction, vehicles with a higher number of available seats than the current demand are rerouted, thus making room for the estimated demand as well. The authors compare their method to traditional insertion heuristics. The results show that by combining their proposal with empty vehicle rerouting 98% of the baseline rejected requests are eliminated, and travel and waiting times are reduced by up to 10 and 46%, respectively.

K. Viergutz and C. Schmidt [16] propose a case study on the rural town of Colditz, Germany, comparing conventional public transportation against DR services. The conventional transportation consisted of a bus line, whereas for the DRT two proposals were tested. Both DR proposals were on-demand, many-to-many, and fully-flexible. However, one of them operated stop-based with 5 automobiles and the other door-to-door with 10 vans. Their system declared constraints on the number of fleet vehicles, vehicle capacity, the maximum waiting and passenger travel time, and walking distance to the nearest stop. The scheduling of services was performed by a heuristic algorithm that allocates the nearest idle vehicle to each new request. The authors used surveyed and statistical data to reproduce realistic demand for the experimentation. Then, multi-agent simulations were run for each fleet configuration. Their findings revealed that, for the stop-based scenario, the number of passengers increases compared to conventional PT, but also does the fleet necessary to keep a good level of service (four vehicles vs one). Moreover, dynamic, real-time vehicle assignment requires hard-and software, which involves additional expenses to already financially limited rural PT providers. An excess of dynamism in PT (absence of lines and timetables), according to the authors, may be a strain on customers, leaving them at the mercy of their technical capabilities for managing booking applications. The work concludes that ultra-flexible DRT services are not the panacea for the rural PT sector, especially not in the case of a free-floating, DR, door-to-door service. Economically speaking, the authors remark on the importance of autonomous vehicles for a more efficient DRT.

Dytckov et al. [8] explore by means of simulation the benefits of replacing existing bus lines in the rural area of Lolland, Denmark, with a DRT system that better fits the low mobility demand. Authors build their own microsimulator joining together many open-source tools: a multimodal travel planner for scheduling (OpenTripPlanner), a library for solving vehicle routing problems (jsprit), OSRM to prepare data for the routing solver, and finally a custom event-driven simulator. Their proposal consists of an on-demand, fully-flexible, many-to-many, stop-based DRT system served by eight-seat minibusses. During the experimentation, constraints on request lead time, time window, trip time, driving time, and vehicle capacity are defined and modified. In addition, authors consider penalties for rejected requests and for the dispatching of new vehicles. The main assumption of their study is that transportation demand does not change when changing from buses to a DRT system. The simulation results show the potential to reduce costs and CO_2 emissions.

Morrison and T. Hanson [36] explore the concept of volunteer driver programs (VDPs) to replicate a door-to-door DRT service in rural areas. A rule-based system was developed to describe the operation of a VDP. The system was calibrated and validated with one year of New Brunswick (Canada) Volunteer Driving database data. Then, the multi-agent simulator Netlogo was used to implement and study a simple agent-based VDP. The system operation was simulated and stressed through many scenarios that posed challenges. Finally, VDPs were understood as a viable solution, although the authors remark on the need for additional research regarding actor (users, drivers, dispatchers) interactions.

Matsuhita et al. [37] propose two methods for promoting tourism use of a demand transportation system operated in the rural town of Aizumisato, Fukushima Prefecture, Japan. These proposed methods are a hybrid operation of both conventional on-demand transportation and scheduled transportation which is compatible with Google Map route search and the posting of times and routes using virtual stops. The effect of the proposals is studied utilizing the SUMO microscopic traffic simulator. The results show that the proposed system can operate on time without any problems, although the waiting time for passengers increases compared to the current method. The average maximum number of passengers that can be picked up and dropped off within 30 minutes is 12.3, which means that the system can operate with an increase of about four passengers compared to its current maximum capacity during peak hours.

Semi-flexible scheduling

Bruzzone et al. [38] explore the implementation of a DRT solution for the rural town of Velenje, Slovenia, given the poor performance of its current transit system. The researchers surveyed a focus group to establish the faults of the current transportation and the citizen's attitude towards on-demand mobility and cycling. The authors had the parallel objective of moving demand away from private motorized transports. Their final proposal combines two new DR bus lines and an electric bike-sharing system (e-BBS). The main DR line offers a semi-flexible, many-to-many service with a scheduled route and several on-demand stops; meanwhile, the secondary line operates in a fully-flexible manner, feeding the main line with a many-to-one[2] service. The e-BBS has two roles; feeding both DRT bus lines and offering accessible transportation for short displacements within the town's neighborhoods. Cost analysis reveals the proposal would achieve better service quality with the same financing the current public transportation is getting, reaching a higher percentage of the population.

Li et al. [39] propose a method for transit scheduling of DRT systems based on optimizing urban and rural transportation stops. Their method clusters passenger reservation demand through a DK-means clustering algorithm, identifying later fixed and alternative stops for the transportation system. Then, a genetic simulated annealing algorithm is proposed to build the bus schedule, obtaining a flexible-route DRT service that promotes urban-rural connections. Their proposal is validated in the northern area of Yongcheng City, Henan Province, China. Comparing their final model against the existing regional flexible buses, results show the optimized bus scheduling reduced the operating cost by 9.5% compared with that of regional flexible buses while reducing the running time by 9%. In addition, the authors compare their final proposal to that obtained merely after the DK-means clustering of stops and observed a 4.5% reduction in operational costs and 5% reduction in run times, thus proving the genetic simulated annealing step crucial to improve the service further.

2. Many-To-One Operational Pattern

Fully-flexible scheduling

Vehicle dispatching (from the current stop to the following one) in DR services is generally computed as a function of time, ensuring early service to boarded customers and waiting at stops only when there is enough slack time. Marković et al. [25] propose a threshold policy to dispatch vehicles according to the number of onboard passengers. For the experimentation, a flexible, one-to-many, door-based DR service is implemented, transporting the customers from a terminal to their homes. The authors adjust their proposal through numerical simulations set in a rural context, with demands ranging from 21 to 30 passengers per hour. They aim to find the threshold that reduces hourly costs as well as the adequate fleet size. The results indicate that the optimal threshold is a function of time-varying demand and thus must be adjusted for different times of the day. In contrast, the fleet size must be adjusted accordingly.

J. Bischoff and M. Maciejewski [20] propose an optimization for the operation of a DR fleet based on balancing vehicles according to the expected trip demand. Their method ensures that the spatial availability of vehicles follows the spatial distribution of demand in the (near) future. To test their proposal, the authors implement a feeder service that connects inhabitants of rural areas to other high-capacity means of transportation. The system operation is simulated with MATSim. The passenger-vehicle allocation is done through insertion heuristics where, given a request, each feasible insertion point is assessed and the best one is chosen. The balancing of the fleet is done as follows: First, rebalanceable (with enough slack time) and soon-to-be-idle vehicles are grouped. Then, the amount of demand per zone is estimated according to historical data. With that, the surplus (extra) vehicles in each zone are computed, and vehicles are dispatched from routes with a positive surplus to those with a negative one. Such dispatching aims to incur the shortest possible movement of the empty dispatched vehicle. The results show that customer waiting times can be cut up to 30% with no increase in VTK, meaning the rebalancing improves service quality at barely any monetary cost.

Schlüter et al. [17] assess the impact an autonomous DRT system would have in the specific case of linking an urban and a rural area. Specifically, their work is centered in the city of Bremerhaven, Germany, and its surrounding rural settlements of Lengen, Schiffdorf and Loxstedt. This constitutes a fairly wide area, leading the authors to two different assessments, centering one of them in the rural area. For that, an on-demand, door-to-door, many-to-one, fully-flexible service is established. As for the implementation, authors use the multi-agent simulator MATSim [40] with DRT modules. The road network is created with Open Source Routing Machine (OSRM), reproducing the real one. The system optimizes the operation through insertion heuristics, and the demand is generated following population statistics and surveys. The experimentation studies the replacement of the MIT (motorized individual transport). Results show that at least 1800 vehicles with a capacity of 6 passengers are necessary to provide a service rate of above 95%. Passenger waiting time values are below 13 minutes in this manner and decrease with an increasing number of DRT vehicles. The average travel time of the agents increases by around 66% when switching from a car-based scenario to pure DRT. Their results distill the following assessments: the number of vehicles can be reduced by more than 90%. By that, several negative side

[2] Bruzzone et al. use the term few-to-one, which would be a variation of a many-to-one operation with a relatively small number of origin stops.

effects such as congestion, noise, fragmentation, or land sealing can be mitigated, allowing new perspectives for urban planning and regional management. The replacement of human drivers with an autonomous driving system leads to a significant reduction in operational costs. However, the authors state that without the use of fully automated driving systems, DRT cannot compete economically. Finally, the limitations of this work come from the available data, which does not provide sufficient depth, the exclusion of public transportation from the simulated baseline framework, and the replacement of the entire MIT of a region, which is a radical theoretical approach. Authors remark that the adoption rate of new mobility, such as DRT systems, and the acceptance of fully automated vehicles determine the realistic percentage of MIT that can be replaced.

Calabrò et al. [10] explore the benefits of DRT feeder services with respect to a fixed-route (FR) service. Even though their experimentation takes place in a virtual road network, feeder services are one of the go-to DR modes in rural settlements, and thus we consider them relevant for the present review. The authors model a stop-based, many-to-one, fully-flexible, on-demand service. Their implementation employs basic insertion heuristics and a demand generation based on Poisson distributions. The system operated on a node-joint network. The simulations reveal that DRT is preferred in peripheral areas where the space between stops is high and during off-peak demand periods. In contrast, FR service performs better during peak demands. The recommendation for a transport operator is, therefore, to switch services according to the demand.

Semi-flexible scheduling

Lakatos et al. [9] explore the substitution of a regular bus line operating between 11 “dead-end” villages in rural Hungary. They describe a seven-step analysis method for the optimization of any transportation system. Such a method attaches particular importance to the characteristics of the current transport service (the one that would potentially be replaced). Their study is conducted through mathematical modeling fed by surveyed data. The study proposes three different DRT solutions. All proposals are on-demand and stop-based but vary in operational pattern and flexibility. Their first system (1) completely replaces all bus connections with a DRT service, modeling a many-to-many, semi-flexible operation. The second one (2) aims to replace only the detours that the bus has to do from the main line with a DRT service, keeping the regularly scheduled bus service just along the main line, describing a many-to-one, semi-flexible operation. Finally, the last proposal (3) introduces DRT just as an extra service connecting settlements with the present main route, therefore establishing a feeder for the main bus service. In this case, the operation would be many-to-one and fully-flexible. After analyzing all three proposals, the main bus line is kept for four of the settlements and the connection among all of them, whereas the other seven villages implement a DRT service, with one minibus each, connecting the stops within them to the main line. This configuration feeds the main line and avoids bus detours. The new configuration’s cost does not exceed that of the traditional transportation system but increases the level of service with better frequencies and more connections. The authors emphasize the importance of developing policies with the public services for the viability of the rural-DRT system as well as the limitations of their method, which mainly considers ridership as an influencing factor.

IV. Discussion

The cited works have been summarized in a series of tables. Table I gathers the works from Section III.B whereas Table II collects those described in Section III.C.

A. Summary of Results

Observing Table I, certain topics stand out as the most investigated. DRT systems’ failure as a general public transportation service has been widely studied. Such a topic is closely related to the adoption rate these systems have once deployed; the number of users that switch from their current transportation alternatives to the new DRT system. In addition, many authors aim to replace or improve the current PT of a rural area with a DRT solution. This is also the case for most of the assessed system proposals. Regarding the observed challenges for a viable and successful DRT system deployment, these can be grouped into economic challenges: unrealistic or excessively flexible operation, lack of partnerships, and poor adoption rate; and social challenges: scattered population, disparity among technological skills, low income, different social behaviors and travel patterns, and high ownership of MIT. Both analytical (Table I) and experimental works (Table II) acknowledge the potential of DRT to improve service quality and thus passenger satisfaction, and reduce vehicle mileage and operating hours, thus reducing the system’s environmental impact too. Besides that, a series of factors increment the chances of a successful deployment of DRT: semi-flexible operations, user-focused design, user-group research, partnerships with public and private institutions, and the integration of different modes of transportation.

Regarding experimental works, Table II shows the most popular trend in terms of DRT systems’ configuration: a many-to-many operational pattern with a fully-flexible routing, servicing a series of stops with an on-demand shared mid-capacity vehicle. The proposals mainly aim to replace or improve the operation of the current means of PT in a concrete rural area. In some cases, a new system is proposed from scratch to serve a specific unfulfilled displacement need. Among the observed used cases, most of them serve a series of locations freely, whereas a minority propose feeder systems that bring passengers to a higher-capacity, less flexible transportation network. Finally, it is usual that authors aim to optimize, at least, the passenger’s perspective. Most of them also include an operator perspective, which is closely related to the economic viability of the service. Finally, a minority explicitly comments on the environmental improvements their system brings.

B. Open Issues

Following, the open issues and key insights distilled from our classification are discussed, providing a basis for reflection on the challenges and indicating possible solutions and recommendation.

1. Replacement and Optimization of Existing PT With DRT

The reviewed literature shows the difference among authors’ insights regarding the performance of their proposed systems. For a fair assessment of a DRT proposal’s performance, we must consider the context in which the system is proposed and thus its intended goals. The metrics that the authors will give importance to in their research depend on those goals. For instance, when it comes to public transportation optimization, usual metrics are passenger waiting and traveling time, vehicle traveled kilometers (VTK), and greenhouse gas (GHG) emissions. If a DRT system is proposed to replace or complement the current public transportation system, the research will focus on reducing passenger waiting and traveling time, VTK and GHG emissions. In contrast, a DRT service may be planned to introduce public transportation in an area where there are no mobility alternatives besides motorized individual transports (MIT). In such a case, the research will focus on the level of adoption rate of the new service and the reduction of MIT in favor of public transportation. Most of the cited works propose a partial or a complete replacement of the traditional means of transportation already implemented in a chosen rural area in favor of a new DRT solution. Those aiming for total replacement usually keep elements of the old transportation system (such as stops) in the DRT service. This approach eases the

TABLE I. Cited Survey and Analysis Works Classified by Main Topic, Data-Gathering Method, and Identified Challenges and Potentials. Acronyms: DRT (Demand-Responsive Transportation), MIT (Motorized Individual Transport), PT (Public Transportation), VTK (Vehicle Traveled Kilometers)

	Topic	Method	Challenges	Potentials
[5]	Success and failure of DRT systems	Analysis of failure factors	Unrealistic design, excessive flexibility, lack of partnership, high service costs	Simpler operations (in pattern and flexibility)
[4]		Review of DRT database		
[2]	Replacement/ optimization of public transportation with DRT	Citizen survey	Financial viability, institutional barriers	Mileage reduction, operating time-frame reduction, improved passenger load
[15]		Historical overview of DRT systems	Population's perspective, drop in ridership	
[27]		Modeling	Populations' aging and decline	
[28]	Adoption rate	Factor analysis	Ageing population, cuts in public expense	Market for commuters and retired population User-focused deployment of services Specific user group research
[29]		Citizen survey	Scattered population, low income, high vehicle ownership	
[30]		Literature review	Disparity among perception and empirical design	
[31]	Smart, sustainable mobility for rural areas	Citizen survey	Social behav. tracking, changing travel patterns, technology implementation	Multimodal mobility Cooperation among parties User group integration
[32]		Literature review	Mobility solutions tied to specific travelers	
[33]	Service quality	Questionnaire	High costs, institutional barriers	Customer satisfaction given by vehicle ambiance
[34]	Incentivized shared mobility	Modeling	Excess of MIT in rural areas, uneven travel patterns	Modal integration, citizen cooperation
[35]	Passenger-freight transportation	Modeling	Limited resources to guarantee access to main territorial hubs, underutilized PT	Higher area of service, higher occupancy, reduction in VTK

TABLE II. Cited Experimental Works Classified by Operational (Op.) Pattern, Route Flexibility, Stop Configuration, Booking Necessity, Fleet Size and Capacity, and Optimization Perspective (Persp.). Acronyms: E-BBS (Electric Bike-Sharing System)

	Op. pattern	Flexibility	Stops	Booking	<# vehicles>x<# seats>s	Optimization persp.
[18]	many-to-many	fully-flexible	stop-based	on-demand	100x5s	passenger
[16] (1)			stop-based	on-demand	5vx4s	operator passenger
[16] (2)			door-to-door	on-demand	10x6-14s	
[8]			stop-based	on-demand	29x8s, 19x8s	operator passenger environment
[36]			door-to-door	on-demand	4s (private cars)	passenger
[37]			door-to-door	on-demand	1x9s + 2x4s	passenger
[38] (1)		semi-flexible	stop-based	not needed	1 bus + e-BBS	passenger
[39]			stop-based	not needed	1x20s	operator passenger
[9] (1)			stop-based	on-demand	11x8s	operator passenger
[38] (2)	many-to-one	fully-flexible	stop-based	on-demand	1 bus + e-BBS	passenger
[25]			door-to-door	not needed	6x10s	operator
[20]			door-to-door	on-demand	100x4s	operator passenger
[17]			door-to-door	on-demand	1800x6s	operator passenger
[10]			stop-based	on-demand	3x20s, 5x8s, 10x4s, 20x2s	passenger
[9] (3)			stop-based	on-demand	1x50s + 11x8s	operator passenger
[9] (2)		semi-flexible	stop-based	on-demand	1x50s + 7x8s	operator passenger

comparison between new and previous transportation systems. However, it also facilitates results with lower VTK and, therefore, GHG emissions, as generally with DRT some of the stops along a vehicle line are optional. If the DRT is implemented as a door-to-door service, VTK and GHG may increase with respect to the existing means of PT, and thus an improvement in service quality through time reduction and the servicing of a wider area gain more relevance.

The substitution and improvement of preserved elements of the current PT of an area should also be assessed when aiming to improve its operation. As in [39], demand distribution and stop location can be studied and modified to fit the new proposal's characteristics better.

2. Disconnection Between Analysis and Proposals

From a general perspective, comparing the potentials that DRT offers (Table I) with the most popular system configurations (Table II), there appears to be a disconnection between theoretical and practical works. Even though surveys conclude on the benefits of simpler, less flexible operations and the inclusion of multimodality, the proposals present mostly fully-flexible services, and only some of them [38] consider a different transportation mode (electric bike-sharing) to complement DRT. Some authors [4], [5] agree that an excess of dynamism in demand-responsive operation can be too economically costly for the system's long-term sustainability, especially when the level of demand does not justify such a level of dynamism. The general conclusion of analytical works seems to favor semi-flexible systems, with elements from scheduled transportation (non-flexible) combined with on-demand, dynamic operation.

As a relatively new field, DRT lacks standardized systems, leading to a plethora of proposals, each with its own unique "name". Despite the abundance of ideas, a closer examination reveals that most systems are strikingly similar, varying only in minor details. Furthermore, there are few works that delve into the attributes of these models. Although it is expected to explore various algorithms and techniques in a field with many open issues like DRT, authors should focus on the specific contributions their algorithms and system models bring to passengers, operators, and drivers. It is crucial to adjust configurable components such as stops, assignments, and vehicle capacity to suit the specific real-world use case of the system.

Authors in [32], [34] comment on the importance of the integration of different modes of transportation to truly match the rural area inhabitants' mobility requirements. In addition, partnerships between the transportation provider and other entities have been identified as a factor contributing to DRT success. One of the many ways multimodal transportation and partnerships can be promoted is through mobility hubs [41], physical locations where different modes of transportation are integrated. Mobility hubs provide travelers with options for transfers between various transport systems in order to facilitate the exchange from one mode of travel to another. Moreover, they can also include amenities like shops and restaurants, making them attractive places to visit while traveling. Given the high percentage of failed DRT systems, we consider the implementation of mobility hubs must be studied together with the topic at hand.

3. User-Centered Design and Adoption Rate

It seems evident that a transportation system has to adapt to the area it serves. Elements such as routes, stops and vehicles take into account the geography and spatial-temporal demand of the area. However, when it comes to classic transport systems, the way they operate remains the same regardless of where they are implemented. In the case of DRT, generalist solutions have no place, even less so in rural areas. Their necessary flexibility, combined with the low and distributed demand, forces an operation tailored to the reality of the system's potential users.

How well a system is adapted to its potential users determines the number of final users it will have. This is even more evident for systems that compete with other alternatives, such as transportation systems. Therefore, user-centered design is closely related to the final DRT system's adoption rate. The adoption rate of DRT is one of the key issues leading to its failure. The number of passengers that may switch from existing PT or MIT to DRT depends on the service quality and the ease of interaction with the service. The latter concept refers to the booking of services, which is generally done through a call center, web, or smartphone application. Because of all the aforementioned, when simulating a DRT operation, the demand intensity must be adapted accordingly and not simply copied from the existing PT or MIT displacements. In addition, by including findings on human behavior in such simulations, further research could simulate the estimated depth and speed of user transition from their preferred transportation method to the new DRT solution.

Works such as [28]–[30], [32] conclude on the importance of adapting the design, operation, and deployment of DRT solutions to specific user groups. The displacement requirements of potential users should be at the center of the development of a mobility system. In rural areas, where demand is low, and the gap between users is widening, it is especially crucial to consider their characteristics, such as social and travel patterns and technological skills. However, it would be unrealistic to propose a system that adapts to each and every one of its users. Because of that, user-group research is advisable to determine the best operation for the system. Moreover, we consider hybrid operations that adapt to different user groups in various periods of the day as a potential solution to increase a system's adoption rate.

4. Artificial Intelligence for Rural-DRT

Regarding rural-DRT research, we can establish a baseline of commonly discussed topics and commonly applied technologies for modeling and simulation. Regarding the latter, most proposals are modeled through mathematical or agent-based approaches. The demand for the system's validation is synthetically generated according to surveys and population, vehicle ownership, and other relevant statistics from the serviced area. The system counts with routing algorithms and insertion heuristics to assign passengers to vehicles and schedule the service. Finally, numerical or agent-based simulations are run according to the modeling, and conclusions about the proposal are drawn.

Recently, rural areas have attracted the interest of artificial intelligence researchers, in order to apply in them the type of techniques which are already being developed for smart cities [42], [43]. Still, there is a noticeable lack of innovation regarding rural-specific transportation. Certain aspects of transportation research, such as autonomous vehicles [44], enjoy a high level of popularity and therefore a high level of articles. For the case of DRT, most of the proposed systems do not implement new algorithms for allocating the demand or scheduling operations. On the contrary, the authors assess the viability of specific proposals. The few improvements for the classic algorithms that have been reviewed present general optimizations and do not consider the characteristics of the rural demand to further improve the system. Because of that, we wish to highlight those contributions which innovate regarding research topics.

The works in [34]–[36] present unexplored topics which tie their proposals to specific characteristics of the serviced area. These topics are incentive-driven shared mobility, integrated passenger-freight transportation, and volunteer driving programs, respectively. In addition, some authors innovate with the optimization techniques applied to their systems. In [18], demand anticipation is used to improve the classic insertion heuristic. In [25], the authors propose a dispatch policy based on a threshold of passengers onboard a vehicle.

In [20], vehicles are rebalanced based on expected demand. Finally, the authors in [39] employ generally unused techniques for their proposal: DK-means to group stops and a genetic algorithm (global optimization) combined with simulated annealing (local optimization) to define the system's operation. These works, regardless of their relevance, bring freshness to the field of research and, as analyzed in this paper, follow the line necessary to apply real solutions that work in concrete rural areas.

The DRT paradigm facilitates resource savings and transport adaptability. Hand in hand with artificial intelligence (AI), the potential for improving rural mobility increases considerably. Machine learning and pattern recognition techniques can be used for demand prediction and generation, both historically and in real time. This, in turn, may optimize vehicle deployment and passenger balancing. AI can also identify and group potential customers of a future DRT service according to their social behavior and travel patterns. Regarding the adoption rate of DRT, AI can be implemented to analyze data about the needs of rural populations and identify ways to increase the demand for transportation services, such as gamification: creating incentives for people to use public transportation or offering discounts to those who carpool. Additionally, as mentioned throughout the paper, heuristic optimization can improve transportation conditions, identify the best routes, and create more efficient routes that reduce the amount of time and money spent on displacement. There are myriad approaches that can be leveraged to the topic at hand, from agent negotiation to evolutionary computation, and most are worth exploring to build original solutions for a research field in need of innovation.

V. Conclusions

This survey has reviewed relevant works that assess the viability and potential of improvement that the DRT paradigm can bring to rural mobility. Such a task included the description of transportation problems, the characterization of DRT, and the enumeration of the techniques that computer science brings to implement and experiment with transportation systems. Both analytical and experimental works have been described and classified. Finally, the open issues of the matter, gathered from the reviewing process, have been discussed.

The main takeaway points of the present work are the following. Practical research needs to be more in touch with its theoretical counterpart. Works that apply the knowledge of transportation research must favor the approaches which are economically viable. The problem of low adoption rate and implementation that does not adapt to the potential users of the rural area has to be considered in every step of the formulation of the transportation system. PT providers must understand those issues and adapt their expected ridership amount accordingly. It is smart to begin with a somewhat less flexible operation and increase the flexibility if factors such as demand justify it. Finally, one should always keep in mind the potential of multimodal transportation; study the application area to try and create partnerships with other actors that facilitate the transition to the new transportation method.

From the point of viewof computer science research, there is a need for rural-specific works that use the deployment area's features to find innovative and creative optimization solutions. There are a series of unexplored algorithms that could bring new perspectives to synthetic data generation, mobility modeling, and simulation.

The present research inspires two logical follow-up works. On the one hand, the results of this work could be applied to the definition of a framework describing the series of steps that both PT providers and researchers in the area should follow when considering the design and implementation of a DRT system, giving the necessary importance to user-centered design, multimodality, and innovation in modeling and optimization. On the other, we would like to take advantage of the latest advances in AI to study the best way to implement and improve rural-DRT.

Regarding the latter, we have plans to develop a general framework for transportation fleet optimization. Employing agent-based modeling to reproduce public transportation and other types of fleets, and integrating different algorithms to optimize aspects such as task allocation and vehicle coordination from both a centralized and a distributed perspective. A few examples of algorithms we have been researching would include insertion heuristics, distributed negotiation and task allocation through auctions, or distributed planning of the fleet's operations [45]. With the aforementioned ideas, a first approach on demand-responsive systems can be found in [46].

Machine learning techniques are also a powerful tool to innovate in the improvement of the operational area and further optimize transportation operations. For instance, in [47] demand-prediction models are developed to test and optimize a public bus service. Finally, we would use massive multi-agent simulation techniques, such as those illustrated in [48], to validate the different systems and identify potential partnerships with other means of transport or actors in the rural area.

Acknowledgment

This work is partially supported by grant PID2021-123673OB-C31 funded by MCIN/AEI/ 10.13039/501100011033 and by "ERDF A way of making Europe". Pasqual Martí is supported by grant ACIF/2021/259 funded by the "Conselleria de Innovación, Universidades, Ciencia y Sociedad Digital de la Generalitat Valenciana". Jaume Jordán is supported by grant IJC2020-045683-I funded by MCIN/AEI/ 10.13039/501100011033 and by "European Union NextGenerationEU/PRTR".

References

[1] R. Choudhary, V. Vasudevan, "Study of vehicle ownership for urban and rural households in india," *Journal of Transport Geography*, vol. 58, pp. 52–58, 2017, doi: https://doi.org/10.1016/j.jtrangeo.2016.11.006.

[2] T. J. Ryley, P. A. Stanley, M. P. Enoch, A. M. Zanni, M. A. Quddus, "Investigating the contribution of demand responsive transport to a sustainable local public transport system," *Research in Transportation Economics*, vol. 48, pp. 364–372, 2014.

[3] S. C. Ho,W. Szeto, Y.-H. Kuo, J. M. Leung, M. Petering, T.W. Tou, "Asurvey of dial-a-ride problems: Literature review and recent developments," *Transportation Research Part B: Methodological*, vol. 111, pp. 395–421, 2018.

[4] G. Currie, N. Fournier, "Why most drt/micro-transits fail–what the survivors tell us about progress," *Research in Transportation Economics*, vol. 83, p. 100895, 2020.

[5] M. Enoch, S. Potter, G. Parkhurst, M. Smith, "Why do demand responsive transport systems fail?," in *Transportation Research Board 85th Annual Meeting*, Washington DC, USA, 22-26 Jan 2006.

[6] L. Butler, T. Yigitcanlar, A. Paz, "Smart urban mobility innovations: A comprehensive review and evaluation," *IEEE Access*, vol. 8, pp. 196034–196049, 2020, doi: 10.1109/ACCESS.2020.3034596.

[7] P. Vansteenwegen, L. Melis, D. Aktaş, B. D. G. Montenegro, F. S. Vieira, K. Sörensen, "A survey on demand-responsive public bus systems," *Transportation Research Part C: Emerging Technologies*, vol. 137, p. 103573, 2022.

[8] S. Dytckov, J. A. Persson, F. Lorig, P. Davidsson, "Potential benefits of demand responsive transport in rural areas: A simulation study in lolland, denmark," *Sustainability*, vol. 14, no. 6, 2022.

[9] A. Lakatos, J. Tóth, P. Mándoki, "Demand responsive transport service of 'dead-end villages' in interurban traffic," *Sustainability*, vol. 12, no. 9, 2020.

[10] G. Calabrò, M. Le Pira, N. Giuffrida, G. Inturri, M. Ignaccolo, G. Correia, "Fixed-route vs demand- responsive transport feeder services: An exploratory study using an agent-based model," *J. of Advanced Transportation*, vol. 2022, 2022.

[11] H. B. Demir, E. Pekel Özmen, S. Esnaf, "Time- windowed vehicle

routing problem: Tabu search algorithm approach," *ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal*, vol. 11, p. 179–189, Oct. 2022, doi: 10.14201/adcaij.27533.

[12] E. Osaba, F. Diaz, "Design and implementation of a combinatorial optimization multi-population meta-heuristic for solving vehicle routing problems," *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. 4, pp. 89–90, 12/2016 2016, doi: 10.9781/ijimai.2016.4213.

[13] M. Hyland, H. S. Mahmassani, "Operational benefits and challenges of shared-ride automated mobility-on- demand services," *Transportation Research Part A: Policy and Practice*, vol. 134, pp. 251–270, 2020.

[14] S. Vallée, A. Oulamara, W. R. Cherif-Khettaf, "Maximizing the number of served requests in an online shared transport system by solving a dynamic darp," in *Computational Logistics*, Cham, 2017, pp. 64– 78, Springer International Publishing.

[15] F. M. Coutinho, N. van Oort, Z. Christoforou, M. J. Alonso-González, O. Cats, S. Hoogendoorn, "Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in amsterdam," *Research in Transportation Economics*, vol. 83, p. 100910, 2020.

[16] K. Viergutz, C. Schmidt, "Demand responsive - vs. conventional public transportation: A matsim study about the rural town of colditz, germany," *Procedia Computer Science*, vol. 151, pp. 69–76, 2019.

[17] J. Schlüter, A. Bossert, P. Rössy, M. Kersting, "Impact assessment of autonomous demand responsive transport as a link between urban and rural areas," *Research in Transportation Business Management*, vol. 39, p. 100613, 2021.

[18] M. van Engelen, O. Cats, H. Post, K. Aardal, "Enhancing flexible transport services with demand- anticipatory insertion heuristics," *Transportation Research Part E: Logistics and Transportation Review*, vol. 110, pp. 110–121, 2018.

[19] M. Balmer, M. Rieser, K. Meister, D. Charypar, N. Lefebvre, K. Nagel, "Matsim-t: Architecture and simulation times," in *Multi-agent systems for traffic and transportation engineering*, IGI Global, 2009, pp. 57–78.

[20] J. Bischoff, M. Maciejewski, "Proactive empty vehicle rebalancing for demand responsive transport services," *Procedia Computer Science*, vol. 170, pp. 739– 744, 2020.

[21] C. Bertelle, M. Nabaa, D. Olivier, P. Tranouez, "A decentralised approach for the transportation on demand problem," in *From System Complexity to Emergent Properties*, Springer, 2009, pp. 281–289.

[22] S. Tisue, U. Wilensky, "Netlogo: A simple environment for modeling complexity," in *Int. conference on complex systems*, vol. 21, 2004, pp. 16–21, Boston, MA.

[23] G. Inturri, N. Giuffrida, M. Ignaccolo, M. Le Pira, A. Pluchino, A. Rapisarda, *Testing Demand Responsive Shared Transport Services via Agent-Based Simulations*, pp. 313–320. Cham: Springer International Publishing, 2018.

[24] J. Palanca, A. Terrasa, C. Carrascosa, V. Julián, "Simfleet: a new transport fleet simulator based on mas," in *International Conference on Practical Applications of Agents and Multi-Agent Systems*, 2019, pp. 257–264, Springer.

[25] N. Marković, M. E. Kim, E. Kim, S. Milinković, "A threshold policy for dispatching vehicles in demand-responsive transit systems," *Promet - Trafficamp;Transportation*, vol. 31, pp. 387–395, Aug. 2019.

[26] S. Liyanage, H. Dia, "An agent-based simulation approach for evaluating the performance of on- demand bus services," *Sustainability*, vol. 12, no. 10, 2020.

[27] C.-G. Roh, J. Kim, "What are more efficient transportation services in a rural area? a case study in yangsan city, south korea," *International journal of environmental research and public health*, vol. 19, no. 18, p. 11263, 2022.

[28] C. Wang, M. Quddus, M. Enoch, T. Ryley, L. Davison, "Exploring the propensity to travel by demand responsive transport in the rural area of lincolnshire in england," *Case Studies on Transport Policy*, vol. 3, no. 2, pp. 129–136, 2015.

[29] A. Anburuvel, W. Perera, R. Randeniya, "A demand responsive public transport for a spatially scattered population in a developing country," *Case Studies on Transport Policy*, vol. 10, no. 1, pp. 187–197, 2022.

[30] S. E. Schasché, R. G. Sposato, N. Hampl, "The dilemma of demand-responsive transport services in rural areas: Conflicting expectations and weak user acceptance," *Transport Policy*, vol. 126, pp. 43–54, 2022.

[31] S. A. M. Agriesti, R.-M. Soe, M. A. Saif, "Framework for connecting the mobility challenges in low density areas to smart mobility solutions: the case study of estonian municipalities," *European Transport Research Review*, vol. 14, no. 1, p. 32, 2022.

[32] H. Poltimäe, M. Rehema, J. Raun, A. Poom, "In search of sustainable and inclusive mobility solutions for rural areas," *European transport research review*, vol. 14, no. 1, p. 13, 2022.

[33] M. Abdullah, N. Ali, S. A. H. Shah, M. A. Javid, T. Campisi, "Service quality assessment of app-based demand-responsive public transit services in lahore, pakistan," *Applied Sciences*, vol. 11, no. 4, p. 1911, 2021.

[34] F. Heinitz, "Sustainable development assessment of incentive-driven shared on-demand mobility systems in rural settings," *European Transport Research Review*, vol. 14, no. 1, p. 38, 2022.

[35] F. Cavallaro, S. Nocera, "Flexible-route integrated passenger–freight transport in rural areas," *Transportation Research Part A: Policy and Practice*, vol. 169, p. 103604, 2023.

[36] R. Morrison, T. Hanson, "Exploring agent-based modelling for car-based volunteer driver program planning," *Transportation research record*, vol. 2676, no. 11, pp. 520–532, 2022.

[37] S. Matsuhita, S. Yumita, T. Nagaosa, "A proposal and performance evaluation of utilization methods for tourism of a demand-responsive transport system at a rural town," in *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)*, 2022, pp. 2920–2925, IEEE.

[38] F. Bruzzone, M. Scorrano, S. Nocera, "The combination of e-bike-sharing and demand-responsive transport systems in rural areas: A case study of velenje," *Research in Transportation Business & Management*, vol. 40, p. 100570, 2021.

[39] P. Li, L. Jiang, S. Zhang, X. Jiang, "Demand response transit scheduling research based on urban and rural transportation station optimization," *Sustainability*, vol. 14, no. 20, p. 13328, 2022.

[40] A. Horni, K. Nagel, K. Axhausen Eds., *Multi-Agent Transport Simulation MATSim*. London: Ubiquity Press, Aug 2016.

[41] T. Rongen, T. Tillema, J. Arts, M. J. Alonso-González, J.-J. Witte, "An analysis of the mobility hub concept in the netherlands: Historical lessons for its implementation," *Journal of Transport Geography*, vol. 104, p. 103419, 2022.

[42] G. Mariammal, A. Suruliandi, S. P. Raja, E. Poongothai, "An empirical evaluation of machine learning techniques for crop prediction," *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. In Press, pp. 1–9, 12/2022 9998, doi: 10.9781/ijimai.2022.12.004.

[43] V. K. Solanki, M. Venkaesan, S. Katiyar, "Conceptual model for smart cities: Irrigation and highway lamps using iot," *International Journal of Interactive Multimedia and Artificial Intelligence*, vol. 4, pp. 28–33, 03/2017 2017, doi: 10.9781/ijimai.2017.435.

[44] M. Qader Kheder, M. Aree Ali, "Iot-based vision techniques in autonomous driving: A review," *ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal*, vol. 11, p. 367–394, Jan. 2023.

[45] P. Martí, J. Jordán, V. Julian, "Best-response planning for urban fleet coordination," *Neural Computing and Applications*, pp. 1–20, 2023.

[46] P. Martí, J. Jordán, F. De la Prieta, H. Billhardt, V. Julian, "Demand-responsive shared transportation: A self- interested proposal," *Electronics*, vol. 11, no. 1, 2022, doi: 10.3390/electronics11010078.

[47] A. Ibáñez, J. Jordán, V. Julian, "Improving public transportation efficiency through accurate bus passenger demand," in *Highlights in Practical Applications of Agents, Multi-Agent Systems, and Cognitive Mimetics. The PAAMS Collection*, Cham, 2023, pp. 18–29, Springer Nature Switzerland.

[48] P. Martí, J. Llopis, V. Julian, P. Novais, J. Jordán, "Validating state-wide charging station network through agent-based simulation," in *Highlights in Practical Applications of Agents, Multi-Agent Systems, and Cognitive Mimetics. The PAAMS Collection*, Cham, 2023, pp. 158–169, Springer Nature Switzerland.

Pasqual Martí

Pasqual Martí is a Ph.D. student and researcher at the Valencian Research Institute for Artificial Intelligence (VRAIN) of the Universitat Politècnica de València. He finished his degree studies in Computer Engineering in 2019 and continued his education with a master's degree in Artificial Intelligence, which finished in 2020. During the development of his master, he began his career in research through a scholarship, participating in 2 R&D projects related to Multi-Agent Systems and Urban Fleets. From such work, he has published several articles in indexed journals and international conferences.

Jaume Jordán

Jaume Jordán is a postdoctoral researcher at the Valencian Research Institute for Artificial Intelligence (VRAIN) of the Universitat Politècnica de València. He finished his Ph.D. in 2017 with a grade of Outstanding Cum Laude and international mention. He has participated in more than 10 R&D projects (1 as principal investigator) related to Artificial Intelligence, particularly in the lines that integrate Multi-Agent Systems, Planning, Game Theory, Genetic Algorithms, and Urban Fleets. He has more than 35 works published in relevant international conferences and JCR journals, and he collaborated as an organizer, committee, editor, and reviewer of different conferences and journals.

Angélica González Arrieta

Received a Ph.D. in Computer Science from the University of Salamanca in 2000. She is currently a Lecturer at Salamanca's University Department of Computer Science and has attended several Masters courses. She is also a UNED professor and tutor (Universidad Española de Educación a Distancia, Spain's Open University). Previously, she carried out relevant administrative tasks, such as Academic Secretary of the Science Faculty (1996-2000) and Chief of Staff for the University of Salamanca (2000-2003). Since 1990, she has cooperated with the Home Ministry, and from 2008 with the Home and Justice Counsel of the local government (Junta de Castilla y León). She is a member of the research group BISITE (http://bisite.usal.es) and has led several research projects sponsored by both public and private institutions in Spain. She co-authors several works published in journals, workshops, meetings, and symposia.

Vicente Julian

Vicente Julian holds the position of Full Professor of Computer Science at the Universitat Politècnica de València (UPV) where he has taught since 1996. He is a member of the Valencian Research Institute for Artificial Intelligence (VRAIN), and the Coordinator of the Computer Science Ph.D. Program at the UPV. Four international projects, two international excellence networks, twenty-five Spanish projects, and four technology transfer projects have covered the research on Artificial Intelligence. He has more than 300 works published in journals with outstanding JCR positions or in relevant conference proceedings. Vicente Julian has supervised 10 Ph.D. Thesis.