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The journey of demand responsive transportation: Towards sustainable services

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The concept of Demand Responsive Transport (DRT) describes a technology-enabled shared mobility service that has a flexible operating schedule and/or provides virtual stops and/or flexible routes. While these on-demand services are not new, the developments in communication and tracking technology (vehicle positioning systems) have revived these services in the past decade. The benefits of adopting demand responsive transport services for intra-community and FLM travel needs are widely accepted, but there is still a cautious approach towards their implementation due to the failure of many promising demand responsive transport schemes in the past. This article 1) creates an overview of the various on-demand services introduced across the world, to understand the factors that may have contributed to the failure of these services in the past 2) identifies the progress made towards sustainable demand responsive transport ventures through analysis of global case studies 3) provides an overview of the flexibility of vehicle and deployment technologies in the demand responsive transport sphere. A bibliometric analysis, where the top keywords were further categorised using VOSviewer's default clustering algorithm, highlighted the importance of sustainability in demand responsive transport ventures. By the progress made towards sustainable demand responsive transport ventures, it can be concluded that environmentally sustainable demand responsive transport ventures can be achieved through the adoption of electric and autonomous vehicles for demand responsive transport services, by reducing mileage of the vehicle and/or adjusting the length of route. The study concludes by reviewing existing research gaps regarding performance expectation, and recommending policy and practice implications, based on the case study of the Bus-on-Demand in Dubai, UAE.

KEYWORDS

demand responsive transport (DRT), sustainability, public private partnership (PPP), public transportation, integrated public transport

1 Introduction

The world is experiencing rapid urbanisation today. Over 66% of the world's population will reside in cities by 2050, creating 80% of global wealth, and consuming 60% of the world's energy (Gerardo 2018). As urban mobility is the lifeline of modern cities, one of the most pressing issues for cities across the globe is the planning and development of smart cities that provide an effective, equitable and sustainable mechanism for moving people. Over the past few decades, both public transportation (including buses and railway/metro) and personalised vehicles have facilitated urban mobility. Although conventional public transportation is more affordable and environmentally sustainable than personal vehicles, the latter trumps mass transportation when it comes to comfort and convenience. To this end, governments across the world have tried to improve accessibility, service quality, frequency, network expansion, financial incentives, and several other methods to attract citizens towards public transportation. However, only a handful of public transportation systems globally are profitable (Canales et al., 2017). The rest are only making enough to keep the system going or more often sustain losses and still function. With urban areas becoming increasingly denser, the provision of mass transit to urban dwellers has become an expensive proposition to the city authorities. Moreover, with the growing earning/car ownership levels and the ensuing dispersal of activity centres and ride styles (Khattak & Yim, 2004), conventional public transportation (including buses and railway/metro) which operate with fixed stops, routes, and schedules, can no longer meet the travelling needs of large sections of society.

Innovations in mobility, such as ride-hailing (Feigon and Murphy, 2016; Erhardt et al., 2019) have paved the way for the concept of shared mobility, which combines the advantages of public transport and personal transport (Marković et al., 2016). Shared mobility can be achieved either through vehicle-sharing (car sharing or peer to peer car sharing), ride-sharing (taxi sharing or carpooling) (Balcombe et al., 2004), or flexible-transit (micro-transit or Bus-on-Demand) (Feigon and Murphy, 2016). The use of mobility-on-demand services has been shown to improve transportation efficiency, user satisfaction, and the environment (Greenblatt and Shaheen, 2015; Beiker, 2016; Djavadian and Chow, 2017). With recent developments in communication and sensor-based ICT technology, as well as the necessity to integrate shared mobility with other public transportation modes (inter-modal journeys), demand responsive transportation (DRT) systems have been developed (Marković et al., 2016). These systems are characterised by flexible routes and small vehicles that operate in a shared-ride mode along routes consistent with passenger needs (Ambrosino et al., 2003).

A well-designed DRT system strikes the right balance between the dependability of conventional public transportation and the flexibility of private vehicles (Kamargianni et al., 2016), and at prices far below that of taxis (Rodier et al., 1998). Therefore, demand responsive public transportation is becoming the preferred solution for today's fast growing cities. It complements the city's mass transport networks and provides new travel options that reduce congestion air pollution, while also increasing ridership and customer happiness (Bürstlein et al., 2021).

While the benefits of adopting DRT services for intra-community and FLM (first-mile last-mile) travel requirements have been well documented (Shu et al., 2021), there still remains a cautiousness towards the implementation of DRT services, with many examples of promising DRT schemes that have failed (Pettersson, 2019). The steep fares for DRT services in comparison with fixed-route public transport was cited as the main reason for the failure of these systems (Enoch et al., 2004). Currie and Fournier (2020), reported the failure of Bridj which shut down its U.S. operations in 2017 (Marshall, 2017; Schmitt, 2018) and Chariot (Marshall, 2019), and attributed the "success" of the DRT ventures to the "media hype," and the lack of documentation relating DRT failures to the high costs. In spite of this, the fact that the pilot projects have been deployed in over 900 cities globally over the last four to 5 years (Foljanty, 2020) is a testimony that DRT services may well be able to bridge the gap between an efficient public transportation system and convenient individual mobility.

In this paper, we examine the various on-demand services introduced across the globe to learn from past initiatives and understand the major roadblocks that led to their failure. While the resurgence of interest in these services can be seen from the publication trend over the years, a bibliometric analysis of the keywords indicated a keen interest by researchers on sustainability aspects. Therefore, an assessment of the progress made towards sustainable DRT ventures is carried out, focusing specifically on the DRT ventures in the past decade. Through the lens of sustainability, DRT services can be beneficial for internal community transport as well as first-mile last-mile (FLM) requirements.

2 Towards sustainable DRT services

DRT was first experimented with in Atlantic City in 1916 when jitneys were used to respond to public requests for rides (O'Leary, 1982; Strobel, 1987). However, as these services provided stiff competition to the existing trolley systems, they were throttled by the conventional transit authorities and regulated to operate on fixed routes, thereby reducing their relevance by the 1920s (Eckert and Hilton, 1972). The DRT's made a come-back much later in the 1960s, with the spread of the low-density areas in the United States (Cole, 1968). The CARS project of the Massachusetts Institute of Technology, aimed at the development of a "many-to many" origins and destinations algorithm to efficiently assign demand, reducing the workforce necessary to provide the offer, making a door-to-door transit system affordable (Wilson et al., 1969).

The high operating costs associated with DRT prior to 1980 (Wilson and Simpson, 1975), the lower speeds (Murphy et al., 1975) and the higher ticket prices (Enoch et al., 2004) led to the failure of many of these ventures. While the 1980s and 90s saw the improvement of different technologies that enhanced communication and data collection, most paratransit services were characterised as either low-tech or high-tech. As internet technology developed in the early 2000s (Lasdon et al., 2000), this concept did not meet much acceptance as a replacement for regular transportation, and it was deemed inefficient (Davison et al., 2012; Mulley et al., 2012), and not economically viable (Davison et al., 2014).

The DRT services have evolved over the decades, from the 'traditional' paratransit service, paving the way for the demand-responsive modes today, being launched in urban/metropolitan areas for the general public (Pettersson, 2019). The development of communication technologies (smartphones) and tracking technologies (global positioning systems) has greatly increased the popularity of these services in recent years. From a review of Scopus-indexed publications (Pirola et al., 2020), 169 documents addressing demand responsive transportation have been identified since the first papers on the topic in 1973, following the elimination of irrelevant documents. Only 22 publications were published between 1973 and 2003, while 24 publications were published in 2020 itself. This trend has been reflected on the ground, with on-demand transportation growing 3 times globally from 2009 to 2017 (Goldman Sachs Annual Report, 2017) and many of the world's cities either exploring or in the initial stage of running of pilot DRT projects, to understand the possibility of using a suitable on-demand technology that can complement or replace traditional public transport services (Barrett et al., 2019).

The high failure rate of previous DRT services (before 2000) underscores the importance of learning from the past deployments to ensure the success of the DRT services. Based on the approach suggested by Petticrews' Practical Guide to Systematic Reviews in the Social Sciences (2006), a systematic review of the DRT development over the years have been carried out.

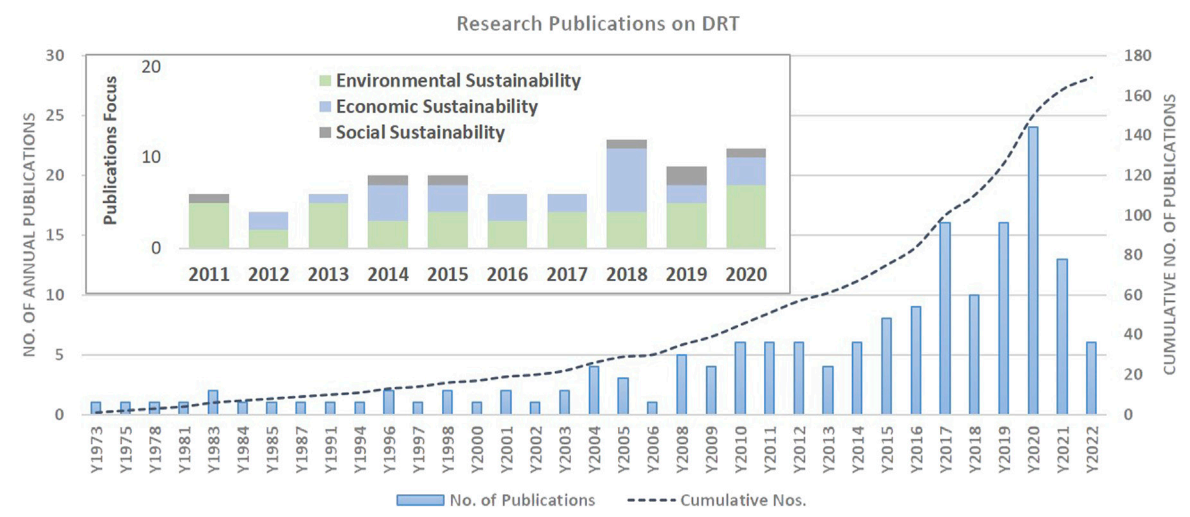

FIGURE 1
DRT research publications trend (as of April 2022).

DRT systems contribute to social sustainability by merging the advantages of public transportation with the conveniences of private vehicles (Brake et al., 2004). According to a review of journal publications (Scopus) over the last decade, there has been an increasing interest in sustainable DRT ventures, as illustrated in Figure 1 above. The focus during 2011 was on environmental sustainability. However, the research focus was also equally shifted to economic sustainability from 2012 onwards and during 2018, majority of the sustainability related publications were focused on economic aspects of DRT development.

The research focus on economic sustainability could potentially be attributed to the practical implementation of DRT pilot programs all across the world cities indicating importance of financial sustainability of such deployments.

2.1 Commercial sustainability

In the period between 2000 and 2010, nearly all the wider proposals for DRT adoption were premised on receiving public monetary support (Mulley and Nelson, 2009). Researchers (Tsubouchi et al., 2010; Davison et al., 2014) have suggested that getting aid from local authorities or even the government to start-up the project would aid in resolving the first big obstacle any DRT project would face. Stating that DRT projects may fail, especially when they are not realistically priced or designed with a full understanding of the market they are to serve, Gomes et al. (2015) proposed an approach integrating simulation and optimization to balance the envisaged costs and service efficiency.

As developing a DRT system with adequate software and labour does not come cheap, and researchers (Furuhata et al., 2014; Ryley et al., 2014) claim that it is very difficult to earn back the investments made and to make the system financially stable. Another main challenge faced is how the operating costs and profits are to be shared fairly among the passengers.

As driver costs and scheduling constraints are the main reasons why introduction of large-scale DRT may not be feasible (Bösch et al., 2018; Lioris et al., 2018; Winter et al., 2018), DRT services with autonomous vehicles (AVs) were proposed as a solution as they are claimed to be economical, as they minimise or absolutely deduct the cost of labour for transportation.

Experiences across the world have indicated that a DRT system can be long lasting only if it is economical for the passenger when compared to a private or other public transports. A study by Ryley et al. (2014) explained that changing the competitor makes it easier for DRT to succeed. Competing against railway or airline modes of transportation will make it easy for a DRT system to be preferred over the former.

3 Case study: Bus on demand in Dubai, UAE

Since February 2020, Dubai Bus on Demand (DBOD) has been operating in the United Arab Emirates (UAE) as a technology-enabled shared bus service. A third-party service provider operates the services under a 3-year Public Private Partnerships (PPP) Contract. For a service fee based on service kilometres, the service provider brings the standard-sized (12–14 seat capacity wheelchair accessible vehicles), the drivers, the technology, and the marketing of the services. Figure 2 illustrates a month by month comparison of the capacity utilisation i.e., riders per vehicle per hour in 2020 and 2021 as well as the average hourly cost recovery ratio (CRR) of the DRT operation. During 2021, the average monthly utilisation level increased by 23.5% from 2020. During August 2020 (peak COVID-19), the capacity utilisation had reached its peak, requiring the deployment of additional vehicles. The system's hourly utilisation reaches 8+ making the Dubai BOD one of the most efficient micro-transit deployments of its kind. These numbers are comparable with the best cities that has provision of FLM & intra-community DRT services with similar capacity vehicles internationally that varies between 1.69–5.5 riders/vehicle/hour.

The data set used for case study analysis is collected and re-organised with approval from Roads and Transport Authority, Government of Dubai which are based on actual operational data of DBOD over three consecutive months during 2021 that includes week days and week ends in one of the operational area (Al Barsha).

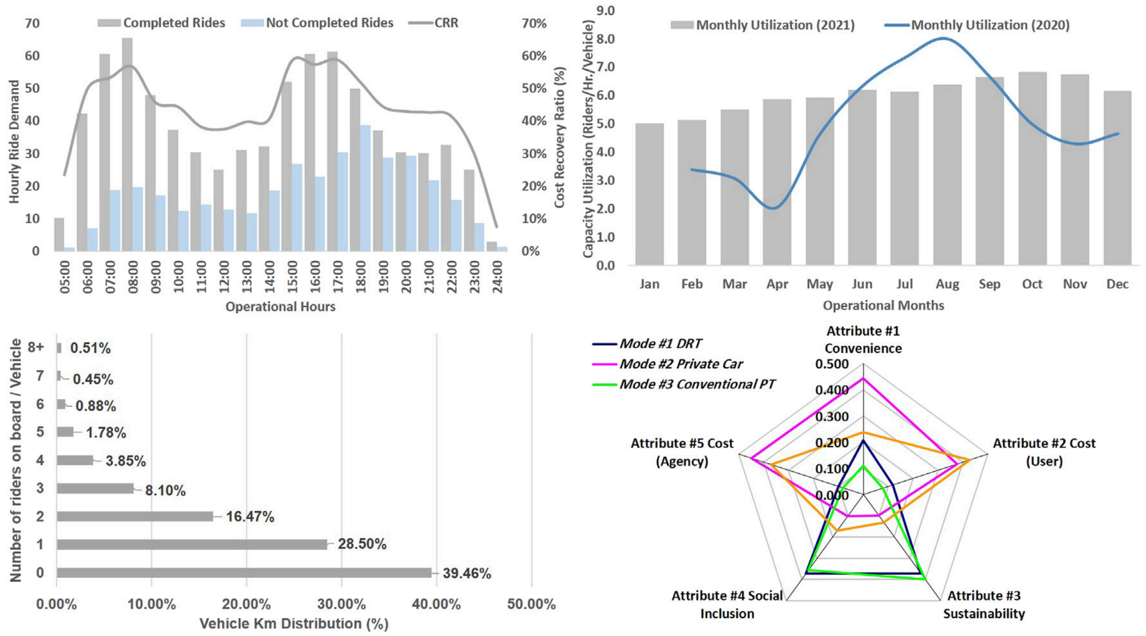

FIGURE 2
Operational parameters of DBOD (Source: DBOD operational data).

3.1 Key factors for DRT commercial sustainability

From the first author's experience, the authors' recommend the following factors that need to be considered for sustainable DRT ventures:

3.1.1 DRT mode choice

From a basic Analytic Hierarchy Process (AHP) model (see Figure 2), based on the results of stated preference survey of users of DBOD, sustainability and social inclusion are seen to be the two main attributes to be considered for DRT. Despite the launch of these on-demand services in many cities, there are still many misgivings regarding the commercial sustainability of these ventures.

3.1.2 Integrated planning for cost recovery

Cost Recovery Ratio (CRR), which is the percentage of operating costs covered by fares, often depends on the route (feeder, urban, and intercity). Normally the intercity routes with more frequent service and faster journey times tend to carry more passengers with higher fare level thereby having a higher return on investment, while other routes (feeder or urban) servicing first mile/last mile or serving the outskirts of the city or newly developing communities often carry fewer passengers and therefore have lesser CRR. Lesser cost recovery inevitably leads to significantly higher public sector budgetary subsidies. Moreover, longer distances covered during off-peak hours without optimal passenger on-board can significantly impact the mileage and reduce cost recovery.

From the experience of BDOD, while planning for the vehicle deployment during the operational hours, there is significant additional capacity required during the morning and evening peak hours in order to meet the key performance criteria (ETA, pick-up walk distance) of the service deployment. As the number of riders increases during the peak hours, Vehicle-Kilometres travelled with riders on-board also proportionately increases. Another important aspect that can be observed from Figure 2 is the distribution of Vehicle-Kilometres with no riders on board even during the peak hours of operation. This is due to the nature of the on-demand services, but it is also apparent that aggregation of riders plays a crucial role in determining the commercial rigour of the services. The CRR of the service operation is the single most indicator for commercial sustainability of DRT, and the DBOD operations highlights the need for optimal fleet deployment for higher cost recovery.

A balance between the fare level that can be levied on the riders versus the cost of operation covering both revenue and non-revenue kilometres need careful consideration by keeping in mind the public transport users economic profile.

From Dubai's Bus on Demand experience (refer Figure 2), approximately 40% of the vehicle mileage consists of vehicle travel without any passenger on board and the balance 60% distance travelled with passengers on board, 28.5% boarded km distribution consists of one rider, 16% has two riders, and 4% has three riders on-board, indicating the need for additional aggregation of riders for achieving the desired commercial rigour with optimization of service planning. Accordingly, a successful DRT venture should be flexible enough so as to minimise the mileage with no passengers on board, thus minimising the non-revenue mileage (Bellini et al., 2003).

3.1.3 Service efficiency

A key lesson from the pilot run of DBOD was that the larger vehicles (Mercedes Sprinters) had difficulty making U-turns. By introducing smaller vehicles (Toyota Hiaces), both Expected Time of Arrival (ETA) and mileage have improved. The operational data averaged over a month for both large vehicles (Mercedes Sprinter) and small vehicles (Toyota Hiace) indicates a reduction of 22.5% in case of pickup ETA time with an average reduction of 14% travel duration for each passenger. Accordingly, accommodating smaller vehicle sizes skews the scale in favour of optimal vehicle utilisation compared to traditional public transport buses. This result is in accordance with the guidelines suggested by Wright (2013), who concluded that the product of the demand and the average trip distance provides a very strong indicator of the suitable vehicle type.

4 Discussion and recommendations

Despite the potential barriers, the popularity of DRT services has been increasing exponentially since 2017, with the highest number of on-demand shared mobility pilot services till date, launched in Europe, followed by North America (Foljanty, 2020). One of the likely reasons behind these initiatives were due to the early experiences of long-existing DRT services in various countries in Europe, e.g., Germany, France or the United Kingdom. During 2019 and 2020, there have been multiple deployments all across Asian cities like Singapore, Japan, India, Indonesia, Korea, Israel, and UAE, closely following the market dynamics of Europe and North America. Thus, there are many DRT operators and technology platform providers working in silos in many parts of the world. However, a comprehensive approach for the commercial sustainability of a citywide DRT System, that addresses the urban mobility requirements of a city in an integrated manner with a multi-modal approach, is lacking.

5 Conclusion

The main purpose of Demand Responsive Transport is to address the citizens' travel demands at the most basic level by creating an integrated platform for journey options and modal choices. While the system can run independently, taking over the traditional modes, there is also a possibility of integrating DRT with the traditional public transit modes in the city. FLM solutions including DRT foster end-to-end "door-to-door" mobility, enabled by new technology, which is critical to provide alternatives to individual private transport. Making the services customer friendly with flexible timings play a factor in a successful DRT service though there is significant additional capacity required during the peak hours necessitating extra capacity that can meet the key performance criteria and customer satisfaction. However, the cost recovery ratio of the service operation is the single most indicator for commercial sustainability determination of a DRT system. A balance between the passenger fare and the cost of operation considering both capital investment and operational expenses (vehicle type, fuel type, seating capacity) covering both revenue and non-revenue kilometres requires careful policy considerations by keeping in mind the public transport users economic profile.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

UD—conceived the study, drafted manuscript, visualization of key word matrix and conducted assessment of case study. VV and DD—were involved in data collection, provided key information and revised the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2022.942651/full#supplementary-material

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