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Technological and Environmental Challenges of On-Demand Transportation Systems: A Systematic Literature Review

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On-demand transportation is a mobility service that adapts to the passengers, including the route, location of picking-up and dropping-off, and time. In general, an area with less travel demand is highly suitable for its operation as it moves according to the request only, unlike the typical public transit that operates within a fixed route leading to an inefficient operation and environmental burden. Although the system introduction seems appealing, the operation possibly encounters technical or organizational problems. Therefore, detailed consideration of system operation is mandatory for stakeholders to maintain operation sustainability while simultaneously satisfying the passengers. In this paper, the authors aimed to highlight various challenges of the service and the implemented technologies in the demand-responsive transportation (DRT) system. A systematic literature review with the help of mapping studies was conducted to give broader insights into these research questions: What problems does the already-existing DRT system have and how do researchers propose the solution? What are the main technologies used within the DRT services? What are the possible improvements or innovations for the system? The study will collect and evaluate related papers from the Scopus database to answer the research questions. With the presented information, the paper simultaneously aims to provide insight for other stakeholders on DRT systems for policy consideration and present literature for researchers in this field. In relation to the development opportunities, the study revealed that the integration of DRT systems with micro-mobility services such as bike-sharing and scooters, integration between existing transport services, and autonomous vehicles may elevate the current DRT system.

1. Introduction

On-demand transportation is a mobility service in which the passengers can define the primary operation, including its travelling and boarding time, route, and destination definition. With the mixed characteristics of private and public transit, the system can satisfy individual mobility requests while simultaneously serving many people. Besides, the system promotes environmental conservation by producing less pollution with less unnecessary mobility of unoccupied vehicles.

Demand-responsive transportation (DRT) is a flexible public transportation system that adapts routes and schedules in real time based on passenger requests and needs, providing on-demand service. DRT systems could run as the feeder system for other typical traditional public transit services, elevating accessibility for people in rural areas to the primary mobility service and simultaneously escalating the service (Freiberg et al., 2021). DRT systems also offer mobility services for specific passengers, including the elderly living in remote areas where public transit operation seems hard to introduce, elevating social inclusion, or within the city centre. People with disabilities who require special assistance may also benefit from the service since the driver is specially assigned to help them or even patients to reach the hospital. Besides, the introduction of the DRT service may coexist with existing transit such as taxi services (Yang et al., 2022). Also, customers have the willingness to pay for this service to some extent as a result of the value of their saved time, indicating the sustainability of this business activity (Grau et al., 2022), which is an important factor towards eco-friendly city transportation (Ku et al., 2021), as Bencekri et al. (2021) also highlighted.

Although the system introduction seems appealing, the operation possibly encounters technical or organizational problems. The possible challenges may be in which area should be added with more optional

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stops or how large the area is covered by door-to-door service to optimize the operation cost and customer satisfaction and sustainability. Therefore, detailed consideration of system operation is mandatory for stakeholders to execute prior to system implementation. Although there are several related articles regarding a specific problem encountered by the system, studies that discuss the broad overview of the system implementation are few. Therefore, this study aims to highlight various challenges the existing DRT system has or may encounter with the proposed methods by researchers, what technologies the system uses and the possible future innovation. Simultaneously, the paper intends to present different development stages for policy consideration and present literature for researchers of DRT system by conducting a systematic literature review. The paper presents the descriptive analysis of the method and result and then describes the findings in detail.

2. Materials and Methods

A systematic literature review is a method for identifying and evaluating relevant studies and simultaneously collecting and analyzing data (Snyder, 2019). It aims to answer specific research questions or hypotheses by identifying and presenting the evidence (Moher et al., 2009). With the elimination of references and relevant journal searching, a rapid systematic review accelerated the process. Besides, the arrangement of inclusion/exclusion criteria, data extraction and quality evaluation does not involve many parties (Reynen et al., 2018). This study implemented a rapid systematic review to answer the following research questions:

- RQ1: What problems are encountered by a demand-responsive transport system, and how do researchers propose the solution?
- RQ2: What are the main technologies used within the demand-responsive transport system?
- RQ3: What are the possible improvements or innovation opportunities for the system?

To answer the research questions, the Scopus database was used to collect the relevant studies published in various sources, including journals, conference proceedings, book chapters, reviews, and short surveys. During the search process, several keywords, including the common synonyms of the demand-responsive transport system, were implemented to widen the data collection. The used keywords in the advanced search were “on-demand transportation” or “demand-responsive transportation” or “flexible transportation system”.

During the data collection process, the following inclusion and exclusion criteria were applied: 1. The articles are freely accessible. 2. The articles are written in English. 2. The articles are related to the research question. The initial number of collected data from Scopus databases was 914 articles. After selecting the papers with the first criteria, freely accessible, there were 643 removed documents, resulting in 271 remaining documents. Further, eight studies were eliminated as not written in English. An initial short analysis based on the abstract is performed to define whether papers were relevant to the research question, avoiding unnecessary irrelevant paper reading. As a result, there are 96 remaining articles whose content will be further analyzed.

The 96 collected articles were then categorized according to the publication year and publication type. All selected papers were published between 2004 and 2022. A relatively low number of selected articles were found between 2004 and 2016, with a range of 1 to 5 studies. Afterwards, the increasing trend started to emerge with a peak of 24 papers in 2021. There are only 5 collected articles in 2022 as the search was conducted at the beginning of the year. The collected articles are dominated by the Journals, accounting for 77, followed by the Conference Proceedings with 18. Only a mere 1 study was obtained from a book chapter.

3. Results and Discussion

Demand-responsive transportation services might have a more flexible schedule but high complexity compared to conventional public transit as serving dispersed passengers’ requests. As a result, scheduling while simultaneously optimizing the operational cost is a challenge. A study by (Torkjazi and Huynh, 2019) proposed the concept of picking up unscheduled passengers within a defined area while driving the scheduled customers using an agent-based simulation. Furthermore, research by (Liu et al., 2022) studied the scheduling optimization of customized buses using mixed-integer linear programming (MILP) with static demand. Customized buses offer mobility service to the passengers after they gather enough people to be picked up and driven to the destination point.

3.1 DRT Challenges

The challenge is how to schedule the customized buses and transfer them to the next trip request considering the trade-off between dwell time (waiting time of the bus to start the trip) and idle time (travelling time of bus without passengers). In terms of scheduling issues, a study of regional demography could be connected to the system. The different occupation of the society may shape their unique travel pattern, especially including the time and duration. It will be interesting to understand the influence of employment type on the scheduling strategy after assessing its correlation according to several demography data.

Another problem encountered by the DRT system is defining the operating fleet number, especially considering the unpredictable and dispersed passenger number. Thus, a study by (Shehadeh et al., 2021) recognized the challenges and implemented two consecutive models to optimize the fleet size, specifically the last-mile transit system. Research by (Markovic et al., 2019) studied fleet sizing by considering the threshold policy of one-to-many on-demand transportation services, only dispatch after reaching the minimum level of passengers which the optimal Q numbers might vary depending on the time period. In case of combination between classical public transit and DRT service, (Zhao et al., 2021) addressed the fleet optimization issue considering the total travel time. In context of fleet sizing, the studies are essential with the trade-off analysis between the fleet size, total cost, passenger waiting and in-vehicle time. Regarding the fleet number and size, a study of road topography is beneficial to identify what type of vehicle and how many fleets are required to cover the area. Although the number of travel request are many, it does not necessarily refer to the bigger fleet, but a smaller fleet with more number and frequency may help, particularly in an area with narrow or bumpy road.

DRT usually costs more than the traditional one as it offers specialized service to the passengers. However, finding the optimal fare policy is challenging to remain competitive in the transit market. Pei et al. (2019) studied the flexible transit routing scheme with the consideration of willingness to pay from customers. The proposed model presented two levels of bus stops, A level for fixed-stop and B level for flexible ones which will only be served with a strong willingness to pay. Pricing strategy for on-demand transportation services was also studied by Egan et al. (2019). The authors attempted to optimize the service provider's revenue by proposing a new pricing scheme, hybrid mechanisms, combining the posted-price mechanism for the passengers' side and auctions for the drivers' side.

As the DRT service operates without a fixed route, it is crucial for system to find the optimal route while picking-up and transporting the dispersed passengers. Additionally, the flexible route is intended to promote the sustainability, as the bus does not have to run on the fixed route with unoccupied passengers. Li et al. (2022) proposed the eco-routing concept for on-demand transportation as the shortest or fastest paths are not always promoting environmental sustainability, especially when the fleet mobilizes through a congested area or road with geometric terrain. Wang et al. (2021) presented an incentive scheme for passengers of customized bus to reduce the total running kilometers, onboard time and elevate the operator's profit.

Bus routing definition also set according to the previously defined customers (static) or immediate request from the user (dynamic). Maciejewski et al. (2017) presented a review of dynamic vehicle routing problems for on-demand transportation services. Unlike the static vehicle routing problems in which basic parts were determining the minimal cost for vehicle routes, starting from the depot, serving passengers and returning back to the depot, dynamic routing not only covers the dynamically changing demand and supply of the service but also the traffic flow and other existing transit services. Carotenuto et al. (2014) presented a two-stage algorithm to solve optimal service paths and time, simply called the dial-a-ride problem, with dynamic travel-demand mode. In the case of the static system, Parragh and Schmid (2013) studied a dial-a-ride problem with a static demand scheme, in which all requests are known in advance of the planning.

3.2 DRT Technologies

One of the main managerial issues faced by the stakeholder is defining the possible market for the DRT service. Saxena et al. (2020) studied the market uptake of the DRT system as a feeder service for public bus transportation in the low population density area of Northern Beaches, Sydney, Australia. To address the problem, the authors used a stated preference (SP) survey experiment to understand user preference for multiple-option scenarios. Davison et al. (2012) identified potential development opportunities at different marketing framework levels, including the micro, meso and macro to achieve successful DRT market niches. Khattak and Yim (2004) explored the possible services attributes of Personalized Demand Responsive Transit (PDRT) in the San Francisco Bay Area which would attract travellers to use the service. Another managerial issue which should be managed by the stakeholder is DRT service assessment. The assessment is crucial as a tool to properly understand how the system performs, specifically in the perception of the user. Kersting et al. (2021) identified user satisfaction, primarily the entry system and vehicle equipment, of EcoBus DRT system, fully flexible door-to-door service, in rural areas in Germany, from the younger and elderly passengers' perspective. Macfarlane et al. (2021) analyzed user perception of DRT service in south Salt Lake County, a low-density suburban area with already existing fixed route and route deviation services. The authors used an electronic preference survey before and immediately after the introduction of the service.

One way to assess the DRT service except for user satisfaction consideration is the performance evaluation or system assessment. This analysis is more based on the actual performance of the system rather than subjectivity evaluation derived from the customer. Liyanage (2020) attempted to evaluate the performance of DRT service using an agent-based simulation, specifically the microscopic traffic simulation approach. As the study aimed to assess the viability of the new DRT service and to compare its performance with traditional scheduled bus transit service, the authors designed two simulation scenarios, including the scheduled regular

bus service and DRT service. The comparative analysis according to essential performance indicators, including the waiting and travel times, vehicle occupancy rate, utilization and emissions production are presented. To assess the system performance, a comparative study of either similar or different systems in different areas could assist the stakeholder in understanding better what are the key characteristics in defining the system.
Although the DRT concept seems beneficial, stakeholders have to comprehend that not all situations require this service system, thus the consideration of the timing or circumstances to implement the service is essential. Pira et al. (2022) compared the DRT service as a feeder system of mass rapid transit (MRT) with the fixed-route feeder scheme to figure out which service is preferable under some specific conditions. The authors used an agent-based modelling system to simulate the operation process of both services with a set of detailed output indicators, including the total unit cost (TUC), passenger unit cost (PUC) and the operator unit cost (OUC). Gorev et al. (2020) highlighted the possibility of changing the fixed public transit service into the DRT service under several considered conditions, such as during the weekend. The switching system based on interval time depends on several factors, including the ratio between the length of the route sections in urban and suburban, the duration of time interval when the route could be switched, and the ratio between the values of demand. Badia and Jenelius (2020) studied the applicability of fixed-route public transportation (FR) and door-to-door DRT services as first/last-mile transportation solutions in suburban areas. An analytical model was implemented to figure out which service is more suitable under different scenarios.

3.3 DRT Opportunities

As the operation of DRT highly depends on the information technology, from booking activities to the routing algorithm, this section presents several implemented technologies within DRT system. One of the fascinating technologies is the implementation of autonomous DRT service as the architecture of information systems and management was modelled by Szigeti et al. (2017). The study presented a detailed top-down approach architecture showing the components and connections between each of them, including the passengers, operational control centre, traffic control centre, autonomous road vehicle, smart stop and maintenance. Additionally, the beneficial role of big data in the DRT service is highlighted by Cai (2013). The authors proposed a real-time demand-responsive bus transit system (RTDRBTS) benefitting from the big data concept to collect the passengers' requests, to suggest an adaptive dispatch plan for the bus, to update the bus information on passengers' phones, and more. In line with the real-time context, Iqbal et al. (2011) studied real-time synchronization of Flexible Bus Systems using short-range wireless technology called Zigbee as communication tools for the Bus and Control Centre through the Bus stop. The Bus stops were equipped with RFID card readers, touch screens and other information devices for the user to get recognized by the system and book the service. With the aim of having a sustainable business operation, the improvement activities and possibilities are one of the essential issues to manage. Otherwise, the business might only operate for the short term and decrease in profit and operation over time. There are two primary opportunities discussed by the researchers, including the integration with other modes of transport and autonomous vehicles.
Bruzzone et al. (2021) presented the potential integration of DRT services with an electric bike-sharing system in Velenje, Slovenia, to solve the poor performance of traditional public transit services. Steiner and Irnich (2018) studied the integration of DRT service as first-/last-mile transportation with the existing fixed transit services. Posada et al. (2017) also explored the possibility of integration between dial-a-ride service with the existing traditional public transportation, as the flexible services were used for certain legs of passengers' journeys.
Repoux et al. (2021) presented the idea of a semi-autonomous DRT service called Multi-Layered Personal Transit System, in which the essential components are privacy, convenience, and flexibility. In this system, transportation service is conducted by convoys of small-capacity electric vehicles, consisting of lead vehicles driven by humans which is followed by several autonomous trailers. Autonomous vehicles in DRT service were also studied by Zhai et al. (2020), specifically the autonomous bus-on-demand (ABoD) system. The authors proposed the ABoD system in Fukayang, Zhejiang, China to replace the existing inefficient bus route operation.

4. Conclusion

The article aims to present a systematic literature review to address several issues related to on-demand transportation, including the specific problems or challenges that may be encountered by the service, several implemented technologies within a system, and the opportunities to improve the current system. To the best of the authors' knowledge, this is the first systematic literature review paper that discusses the three specific questions which may arise on demand-responsive public transport schemes. This study particularly attempts to identify the different stages of the DRT system realization process. First pre-implementation with defining possible market and switching time ideas. Second, implementation with bus scheduling, fleet sizing, fare policies and routing problem solutions. Third, post Implementation, which covers the system assessment by

performance and user satisfaction, and opportunity exploitation with the possible implementation of the latest technologies and integration with existing public transportation systems.

According to the stages, there are four primary technical problems including the bus scheduling, fleet sizing, fare policy and routing policy, and four managerial problems, namely market definition, system assessment based on passengers' satisfaction, system assessment based on performance evaluation, and switching condition from conventional to flexible transit service. Further, the authors found several implemented technologies within the DRT system, including the short-range wireless technology (Zigbee), RFID card reader, an autonomous road vehicle, smart stop, smart maintenance, sensors, advanced artificial intelligence, relational database, voice commands, machine learning. In relation to the development opportunities, the study revealed that the integration of DRT systems with micro-mobility services such as bike-sharing and scooters, integration between with existing transport services, and autonomous vehicle may elevate the current DRT system.

For future research recommendations, autonomous vehicle implementation for DRT systems seems appealing as the emergence of the system is continuously increasing as new opportunities arise such as driverless vehicles, automated lifting ramps for passengers with disabilities, real-time algorithms to shift the vehicle movement and others. From the organizers' perspective, studies regarding the cost-benefit analysis of autonomous vehicles, or the investment analysis are required for detailed consideration. Furthermore, a future study may focus on implementing technologies to enrich the technological literature of DRT services, especially because the effectiveness of this system highly depends on it.

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