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Demand-responsive transit systems in areas with low transport demand of "smart city"

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Abstract

The development of modern telecommunications allows the concept of a "smart city" to increase the flexibility of public transportation significantly and, thus, improve population mobility. In this regard, public transportation represents a demand-responsive transit (DRT) system. This system occupies an intermediate position between route systems and taxi services and ensures flexibility in providing on-demand transport services. The article describes the main technologies that can be used in the DRT system, including those with fixed routes (Flexible-Route Segments, Request Stops) and without fixed routes (Demand-Responsive Connector, Feeder Service, Zone Route, Point Deviation). Despite the wide international experience in implementing DRT in practice, there are no clear criteria to determine the conditions, under which it is reasonable to introduce a particular technology of flexible service for passengers. The article systematizes the factors that determine the feasibility of transferring a bus route to the DRT system in particular time intervals and also determines a sequence of actions for the introduction of flexible modes of public transport services. The considered technologies to manage public transportation on demand show that it is possible to combine regular traffic and demand-responsive service, using these modes at different times. Such an approach allows reducing the carrier's costs while maintaining or even improving the quality of public transportation compared with systems implementing only flexible service modes.

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Keywords: demand-responsive transit system; smart city; route network; public transport; demand for transportation; bus route; flexible service mode; passenger traffic.

1. Introduction

A few years ago, the concept of a "smart city" was perceived with skepticism, but due to the rapid development of telecommunications and the Internet of Things the concept has made it into everyday practice (Anthopoulos 2015, Benevolo et al. 2016, Chourabi et al. 2012, Saba et al. 2020). End-to-end technologies that should integrate all areas

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of urban life in the concept of a “smart city” are developing with different intensity, and if, for example, the progress is slow in the field of housing and utilities, new technologies are changing the usual approach to mobility in the field of transportation (Evtiukov et al. 2018, Marusin et al. 2018, 2019, 2020, Danilov et al. 2020, Soo et al. 2020, Trombin et al. 2020).

Within the concepts of a “smart city”, a wide variety of new approaches to using cars based on the peer-to-peer economy and telematics, such as carsharing, carpooling or ridesharing, etc., is observed (Mlayah et al. 2020, Molenbruch et al. 2017). However, practice shows that they do not lead to a decrease in the number of vehicles and, consequently, do not solve the problems related to the road network congestion, growing accident rate and environmental pollution — without which it is impossible to create a favorable urban development environment and improve mobility (Gorev and Solodkij 2013). An analysis of territorial and economic opportunities of cities shows that the development of public transport remains the main direction of mobility development (Popova et al. 2018). Due to “smart technologies”, this transport can provide flexible service, being used, among other things, for single trips (on demand) (Potts et al. 2010).

Thus, the purpose of this article is to systematize and study the possibilities of implementing demand-responsive transit systems based on public transport in Russian cities.

2. Introduction

Demand-responsive transit (DRT) systems provide transport services in response to a passenger’s request. Modern telecommunications technologies are used to receive demands (via websites, SMS, mobile apps, less often phone calls). These systems occupy an intermediate position between route systems and taxi services and differ little from those in extreme implementations. DRT systems provide flexibility in transport services rendered according to demand, by using various technologies and organizational principles (Crainic et al. 2012, Daganzo and Ouyang 2019, Zheng and Li 2019).

Fig. 1 shows a typical diagrammatic map of a bus route serving dense urban areas and suburban areas. The use of an average fixed mode of service on the route leads to overcrowding of a bus in the area of dense development and poor occupancy in the suburbs. Decreasing or increasing the traffic interval either deteriorates the service quality or increases the carrier’s costs. The use of DRT systems seems an obvious solution (Perera et al. 2018).

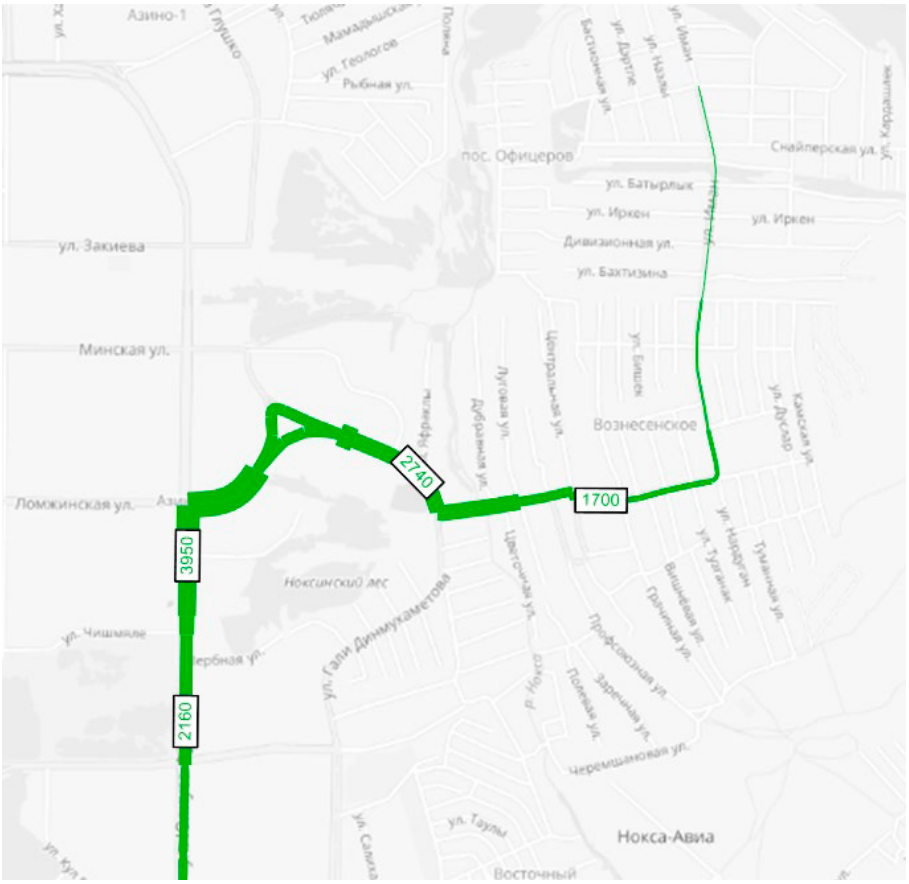

Fig. 1. Typical diagrammatic map of a bus route serving dense urban areas and suburban areas.

Let us consider the main technologies that can be used in DRT systems (Archetti et al. 2018, Bellini et al. 2003).

Feeder Service (Demand-Responsive Connector, Feeder Service) is organized in a particular service area within a certain time interval to transport passengers to the existing route network (Lee and Savelsbergh 2017, Lu et al. 2018). One or more stops are allocated in the route network, from which or to which transportation can be ordered. Passengers can use the DRT system to arrive at or depart from stopping points arranged in the service area. During the period of low demand, requests can be accepted for transportation not only to a stopping point on the route network but also to or from a shopping mall, medical institution, etc. In this case, it is advisable to use the DRT system when 2–8 passengers demand transportation per hour.

Zone Route is used within a particular area, from any point of which (within the reach of the road network suitable for bus traffic) an order for transportation to a specific destination can be made (Lee et al. 2018). The time of departure or arrival at this point is usually fixed (e.g. corresponds to the schedule of passenger trains, etc.). Zone Route is typically used to provide transport services for people traveling to some point of attraction (a district center or a railway or bus station) and living in underpopulated areas. Zone Route can also be used for public transport services during the night. Its organization is reasonable when the demand is 3+ passengers per hour.

Point Deviation does not involve the use of a predefined route network and can be performed in a certain area as well as between certain stopping points (Flusberg 1976). This type of DRT system is typically used to serve urban areas at night or underpopulated areas. Its organization is reasonable when the demand is 2.5–4 passengers per hour.

Route Deviation is used on fixed routes with the possibility of deviation from those within certain limits (Zheng et al. (2018). The service can be provided with stops either only at designated stopping points or at any location. Route deviations can be limited either by a fixed list of points that a passenger may enter or by the maximum distance to

deviate from the route. The number of deviations is limited by the need to comply with the bus schedule. Route Deviation is the most common DRT option, which is often used in areas with low population density and in rural areas. In practice, the service is provided when the demand is 2.5–20 trips per hour. The higher the demand, the more stringent limitations are applied to route deviations. The possibility of route deviation can be used as a separate service or in combination with service within a fixed route network. Then, some runs are performed on fixed routes, and others are performed with the possibility of route deviation. Changing a part of a route can be used when serving the public within a fixed route network. Depending on demand, a limited part of a route network may be modified to include places with low traffic demand in the transport service zone. This service can be used when the demand for route deviations is 2.5–3 trips per hour.

Request Stops are used within a fixed route network that is served according to a fixed schedule. This type of DRT differs from the common option with on-demand stops in that passengers can enter or exit a vehicle at any point along the route while respecting safety requirements. In most options, the number of such stops is limited. The use of this service allows expanding the pedestrian accessibility zone for areas with low population density and providing direct transportation to particular destinations. The service is usually used during low-demand hours when extra stops do not disrupt the bus schedule.

Flexible-Route Segments mean servicing on regular fixed routes with a fixed schedule, but with the opportunity to switch to work on demand within a limited part of the route. It allows serving sections of the route only if there is a demand for getting on or off (Atasoy et al. 2015).

Even though DRT options are being implemented in the activities of organizations responsible for public transport services in Europe and the United States more widely, we still have no clear criteria to determine the conditions necessary to consider the introduction of a flexible service option for passengers. DRT systems often cease to operate due to the large carrier's losses and the refusal of municipalities to pay significant subsidies. In this regard, it seems most effective to combine fixed-route service with on-demand service (Cats and Haverkamp 2018, Charisis et al. 2018).

Fig. 2 shows an analysis of demand for bus transportation with a division into dense urban and suburban areas. This analysis allows identifying time intervals that may be suited for the transfer of the route service mode to the DRT system. This analysis should be performed for all days of the week and by seasons to identify the possibility of introducing flexible service for particular periods or days of the week, e.g. only on weekends.

The relevance of bus route switching to the DRT system in the selected time intervals depends on the following factors:

- the ratio between the length of the route sections running in dense urban areas and the length of the route section running in the suburbs;
- duration of the time intervals when the route can be switched to the DRT system;
- the ratio between the values of demand in dense and suburban areas.

This may reduce the transport work and, consequently, the costs of the carrier. The quality of public service is not deteriorated because the bus service is maintained and the waiting time may even decrease. With flexible route changes, the transport service zone expands, i.e. the time for pedestrian access to the route is reduced. Maintaining or even improving the quality of public transport services increases the municipal authorities' rating.

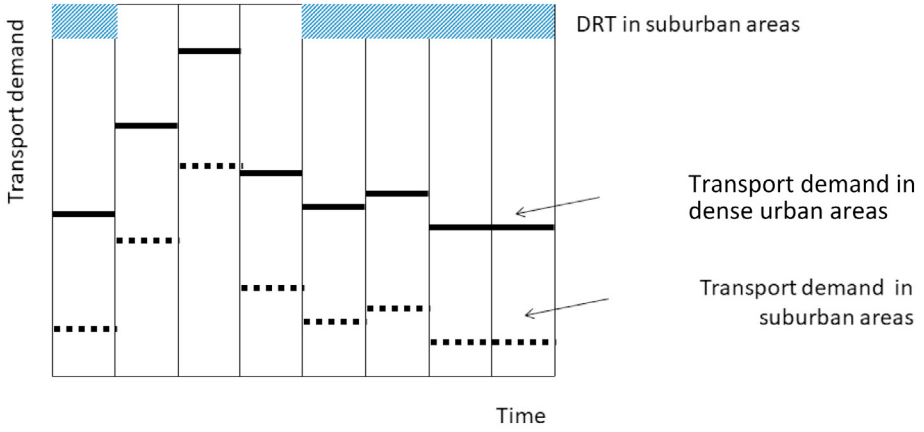

Fig. 2. Analysis of demand for bus transportation in dense urban areas and in the suburbs.

In the case of DRT system operation without fixed routes, it is necessary to use a more complex management system. Fig. 3 shows the operation algorithm of such a system in a simplified form.

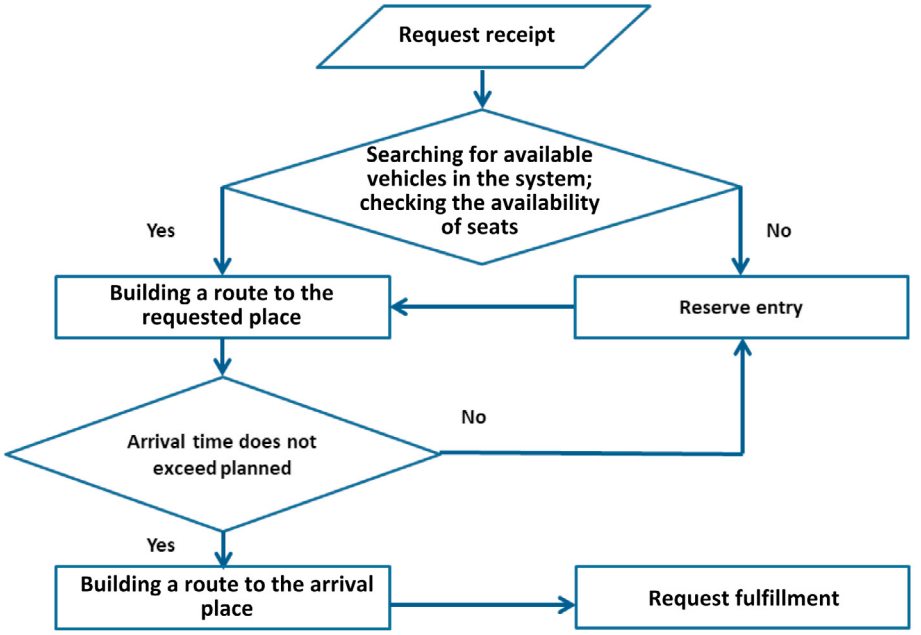

Fig. 3. DRT system operation algorithm without fixed routes.

When a service request is received, the system searches for the nearest vehicle and checks for available seats. After creating a route to the requested place, the system checks whether it is possible to arrive there meeting the following criteria: the request completion time and the maximum duration of the trip for the passengers in the vehicle. If these criteria are met, the driver receives a command to fulfill the request with instructions for changing the route (if required). If the criteria are not met, the possibility to fulfill the request using available vehicles is analyzed, or the request is declined (put on the queue).

3. Results and discussion

The analysis of the possibilities to introduce flexible modes of public transport services has shown that the following sequence of actions is recommended for the implementation of the DRT system:

- the analysis of the service area in terms of demand for public passenger transport services (population and job density, complicated transport communication, road network condition, population age structure, income level, motorization level);
- the forecast of passenger traffic intensity and identification of areas with low demand;
- the analysis of the demand structure, identification of factors negatively affecting the DRT system, such as time-dependent demand (seasonal demand, etc.);
- the development of an organization plan and a DRT technology, selection of the service type;
- the analysis of the possibility to combine the service with social services for people with limited mobility;
- the calculation of costs;
- the determination of the possibility to receive subsidies from local authorities;
- the development of a detailed service plan, including a business plan and a marketing policy.

Since the DRT system requires significant subsidies from municipal authorities to cover the significant difference between the carrier's costs and revenues, it is advisable to use combined solutions for existing routes that provide for the use of DRT in particular intervals, which can be beneficial for all entities (carrier, municipal authorities, passengers).

4. Conclusion

1. The development of modern telecommunications technologies within the framework of the "smart city" concept can significantly increase the flexibility of public transportation.
2. The considered DRT technologies allow choosing the service option that best corresponds to the specifics of settlement and the service area geography.
3. In terms of economic efficiency, it is most appropriate to combine the regular mode and the DRT node in the existing route network with the possibility of flexible route changes in the suburban area.

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