# Evolution of Public Transport in Rural Areas - New Technologies and Digitization

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**Abstract.** Public transport in rural areas is currently often characterized by inadequate services, so that motorized private transport dominates these areas. This situation is considered to be unsatisfactory from an economic and social policy perspective, as it has considerable negative environmental effects. The main problems here are a decline in economic performance and an aging population as well as an increasing rural exodus. With the development of autonomously driving vehicles, it is now possible to achieve fundamental changes in the design of public transport services especially in terms of cost structures and attractiveness. However, this does not mean that the current structures of line-based service should be eliminated and completely replaced by new, quasi-individual forms of services. Rather, the objective is to extend the existing structures in order to significantly improve mobility provision through more flexibility and thus more attractiveness. The technical basics required for this exist or are already very advanced in the developments. In addition to the necessary vehicles, it is in particular the information and communication systems required for extensive interconnected network structures. However, to make the transformation successful, new organizational concepts and in particular a fundamental rethinking are required. It is not only the technical design of transport, but also to ensure the mobility needs of the population. The related developments and future tasks are outlined and discussed below.

**Keywords:** Public transport in rural areas · Autonomous vehicles · Quasi-individual mobility

## 1 Introduction

Public transport is on the way to a comprehensive redesign. The reasons for this far-reaching transition result from the changed requirements in mobility services, the necessary reduction of current individual motorized traffic and the simultaneous growth in public transport, especially from an ecological point of view. Within the (technical) framework in the last years, however, there have been substantial limits that, together with a strong focus on (private) individual mobility, have led to a situation that is not politically desirable for a number of reasons.

However, a structural differentiation must be made here. In urban areas, public transport has steadily increased in importance due to the existing settlement structures and


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the framework conditions of the existing traffic infrastructure. The focus here is on rail-based transport systems with high capacities as well as efficient *bus rapid transit* (BRT) *systems* both in connection with established busses (standard and articulated busses) with varying capacities for feeder and distribution services. The reason for using these types of vehicles are primarily the limitation of the available traffic area and the resulting inner-city traffic congestion problems. However (especially in urban areas) there is an increasing change in personal attitudes towards individual mobility as well as a greater awareness of traffic-related environmental pollution.

The current weaknesses in public transport, on the other hand, are evident in rural areas (see, e.g., Petersen 2016; Šipuš and Abramoviś 2017; Berg and Ihlström 2019). Individual mobility dominates here, primarily in developed countries. The reasons for this are the very low volume of demand in these regions (apart from commuter traffic) and the higher costs associated with a better service level. The revenue that can be achieved on the basis of socially justifiable fares cannot be cost-covering in anyway, that means, there is a high need for subsidies which, under realistic assumptions, cannot generally be met by the public budgets.

With the technological developments of the past few years, especially here due to autonomous driving, completely new possibilities to organize public transport arise. A necessary prerequisite for this, however, is comprehensive digitization, which is imperative to develop attractive service structures and to control the associated processes as well as to communicate the offered services to (potential) users. The last point is of considerable importance for the realization of new service structures, because a fundamental rule from marketing says that a customer will not buy a product he do not know.

In the following description, the current situation of public passenger transport in rural areas is outlined first. This is followed by a brief summary of the current developments in autonomous vehicle techniques for passenger transport in the field of road transport. Afterwards, the general conditions for an area-wide use of autonomously driving vehicles are discussed as well as the main advantages for their operational use. Based on this, quasi-individual forms of mobility are described, with the help of which public passenger transport in rural areas can be made more efficient and more attractive. Then the necessary technical and organizational requirements are explained, in particular with regard to the required information and communication structures. Finally, there are a short outlook and some comments on the further developments.

## 2 Public Transport in Rural Areas

Public transport in rural areas is a problem that has been repeatedly discussed for decades. Before the beginning of the expansion of wide-ranging individual mobility through the availability of private cars for a broad share of the population, regional rail and interurban bus transport in the (developed) countries was of considerable importance for ensuring mobility services. With the evolving changes in mobility behavior, the demand and with it the importance of these services decreased considerably, so that they currently only play an essential role in commuter traffic and local and regional school traffic.

In terms of transport volume in passenger transport, especially in developed countries, the demand in rural areas is often very low. This means that the existing mobility demand is largely covered by the use of private cars, with corresponding negative effects regarding to traffic-related environmental pollution. In the Federal Republic of Germany, the share of private car transport in rural area is up to 70%, with a public transport share of 5%, (see, Nobis and Kuhnimhof 2018, p. 40) which is to be regarded as completely unsatisfactory. Also with a view to the increasingly propagated climate policy objectives, it is necessary not only to make the appropriate changes in the long term, but as soon as possible.

In the developing and emerging countries, the available services in rural areas are often insufficient due to the framework conditions there. Even if regional rail and bus transport networks exist to a certain extent, in most cases the line network structure and the range of services offered are not suitable to meet existing demand (see, e.g., Sonderegger et al. 2019). Parallel to these there exist flexible and (partly) demand-dependent services with an often individual vehicle design, also known as *paratransit* (see, e.g., Cervero 1991; Cervero and Golub 2007; Phun and Yai 2016), but also in urban areas (see, the examples in Wicaksono et al. 2015). Examples from the rural area can be found around the world. These are usually less structured services operated normally by micro-entrepreneurs applying smaller vehicles (mainly mini and midi busses, but also different types of converted trucks), which run worldwide under different names, e.g., Camiones (Cuba), Camioneta (Guatemala), Dolmuş (Turkey) Marschrutka (in countries from the former Sowjet Union), Porpuesto (South American countries), Tanka tanka (Gambia) and Taxi pirata (Costa Rica) (see, e.g., the examples in Fig. 1).

**Fig. 1.** Paratransit vehicles operating in Cuba (l) and Colombia (r).

In recent years, however, new technical developments have emerged in many fields that can form an essential basis for disruptive changes. For public passenger transport in rural areas, two developments are in the foreground, the availability of autonomous vehicles for use in the public road network and the (almost complete) digitization of information management. In the medium and long term, these can offer the opportunity to develop and introduce new and more attractive public transport service structures.

## 3 Developments in Autonomous Driving

The estimations regarding future developments in the area of autonomously driving vehicles in road transport can be seen very clearly in the changes in market participants in the automotive sector. It is no longer just the traditional car manufacturers (e.g., BMW AG, Daimler AG, Toyota Motor Corporation and Volkswagen AG) and also new car manufacturers who enter the market (e.g., Tesla, Inc.), but also companies from the internet industry (e.g., Alphabet Inc.) and from the electronics industry (e.g., Sony Corporation). From this, however, it can be seen that this is a long-term important sales market, in which, however, it is still open who will ensure market leadership with which (technical) focus. In any case, the decisive development steps for the introduction of autonomously driving vehicles in road traffic have been successfully implemented in recent years (see, e.g., Fagnant and Kockelman 2015; Chan 2017; Haboucha et al. 2017; Meyer et al. 2017; Ainsalu et al. 2018; Martínez-Díaz and Soriguera 2018; Hulse et al. 2018; Schwarting et al. 2018; Martínez-Díaz et al. 2019; Soteropoulos et al. 2019; Doerr and Romstorfer 2020).

The technical basics for autonomous driving are largely in place. These are primarily the components that are already available or in the process of further development from the field of *Advanced Driver Assistance Systems* (ADAS) (see, e.g., Ainsalu et al. 2018; Kukkala et al. 2018; Arnold et al. 2019; Haas et al. 2020). Another field is a sufficient performance of location and environment recognition techniques, which is also available (see, e.g., Bresson et al. 2017; Chindhe 2018; Kuutti et al. 2018). This includes satellite-based positioning, for example based on the *Differential Global Positioning System* (DGPS) or the (European) navigation system *Galileo*, as well as a continuous and real-time environmental detection based on *Simultaneous Localization and Mapping* (SLAM) *technologies*, the components of which some are also integrated into the ADAS structures. But the information and communication structures for connected driving, such as *vehicle-to-vehicle* (V2V) *communication*, *vehicle-to-infrastructure* (V2I) *communication,* and *vehicle-to-everything* (V2X) *communication* have not yet been sufficiently developed (see, e.g., Arena and Pau 2019; Montanaro et al. 2019; Tiwari and Akhilesh 2020).

Associated with the discussions about the introduction of autonomous driving in the political environment is often the question of the form of drive of the vehicles, even if this does not play a role with regard to the conceptual design. The reason for this is the close connection of the vehicle development with ecological objectives, also with a view to the negative environmental influences of road traffic. This has led to that, despite of significant technical developments, the diesel drive is often considered to be an undesirable technique. As an alternative, other fuels with comparatively lower emissions were also tested for use but could not prevail. Biodiesel proved to be a very controversial solution due to the lack of sustainability in terms of production, especially with regard to the competition with the food sector. Also in the last decades the use of *Liquefied Natural Gas* (LNG) was ultimately unsuccessful for technical and economic reasons.

At present, therefore, electric traction is the preferred solution, although this technology is not uncontroversial (see, e.g., Piatkowski and Puszkiewicz 2018). At a first view, it seems to be an appropriate step in order to reduce emission loads. However, this effect only occurs locally in the affected urban areas. It is not taken into account that there exist negative environmental effects in the manufacturing processes, amongst other things, in connection with the procurement of raw materials for the production of the required batteries. Therefore, long-term sustainability of electro mobility will ultimately depend on longstanding ecological and economic benefits. In addition, it must be waited whether in the next years with the fuel cell a better alternative will be available (see, e.g., Alaswad et al. 2016; Miotti et al. 2017; Moriarty and Honnery 2019; Tang et al. 2019), especially in the commercial vehicle sector.

Regardless of the question of the drive technology used, which is currently still often based on diesel engines, the developments in autonomous vehicles show a clear market expansion. Worldwide, there are more and more applications in the field of public road transport networks that go beyond a test operation, both in freight and in passenger transport. Even if the “learning phase” of the vehicles, that means, the training of the software for autonomous control and monitoring of the vehicles, has not yet been completed, the transition to real operation begins in a number of cases.

A significant increase in the use of autonomous vehicles in passenger road transport is forecast for the coming years (see, e.g., Möller et al. 2019). It is assumed that the traffic volume (in passenger kilometers) will triple from 2018 to 2040, based on the situation in major cities worldwide. In 2040 the share that is generated by autonomously driving vehicles is assumed to 66%, with 83.3% being public transport services in different forms. At the same time the share of mobility volume with private cars will decrease from 90% to 39%. With a view to the (politically prescribed) climate policy objectives, it must be assumed, however, that these forecast developments will only be possible on the framework condition that emission-free drive techniques can prevail on the market in the long term (see, e.g., Martínez-Díaz et al. 2019).

The use of autonomously driving vehicles is also associated with an expansion of individual mobility (see, e.g., Kaplan et al. 2019). The present access restriction to defined groups of people (age, driving license, physical aptitude) can be dropped. In this way, under-aged, elder, and handicapped people in particular also have their own access, which will have very significant positive effects on the design of social structures (see, e.g., Milakis and van Wee 2020). This applies in particular to rural areas, where there are significant mobility restrictions due to the undersupply in public passenger transport, especially for the mentioned groups of people.

In the development of autonomous driving, a number of vehicles have also been developed in recent years which are intended for use in *public passenger transport*. These are essentially three basic types with different capacities (*passenger cars* and *vans*, *small*, *mid-sized* and *greater minibuses* as well as *standard* and *articulated busses*), which can be used in accordance with the existing spatial based demand structures (see, e.g., López-Lambas and Alonso 2019). This applies to urban areas (see, e.g. Ainsalu et al. 2018) but much more to rural areas (see Sect. 2).

## 4 Advantages and Framework Conditions for the Use of Autonomous Vehicles

The acceptance of vehicle systems does not only depend on the technical performance, but also to a considerable extent on economic and increasingly also on ecological advantages. Adequate market penetration and thus economic viability can only be achieved under these conditions (see, e.g., Acheampong and Cugurullo 2019).

Looking at the advantages of autonomous driving a focus is on personnel costs (see, e.g., Tirachini and Antoniou 2020), because these are reduced to a considerable extent, apart from the costs for service, maintenance and repair personnel. This has a particular impact on the transport of people in the area of road traffic, because here, in comparison with other modes of transport, there is the most unfavorable relation between personnel costs and transport capacity. In addition, there are no longer any restrictive labor law regulations (e.g., working time, driving time, mandatory breaks, minimum duration of rest periods, etc.), through which both the service and the operations design can take place in a completely new framework.

By eliminating the human factor when driving a vehicle, emotionally influenced behaviors are eliminated. This causes significant fuel savings between 15% and 30% and thereby also a reduction of traffic-related emissions. With an increasing of $CO_2$ pricing, this also results in additional savings in operational costs.

Further, also very considerable cost savings result from the reduction of road traffic accidents (see, e.g., Ilkova and Ilka 2017). On the one hand it is a *quantitative cost reduction*, relating to the number of accidents and on the other hand it is a *qualitative cost reduction* in terms of severity. Taking the number of accidents recorded by the police of the Federal Republic of Germany in 2018 as an example, it shows that 88.4% of all road traffic accidents (of 2,636,468) were caused by vehicle drivers (and 3.2% by pedestrians), that means, 91.6% of accidents are caused by human error (see, Destatis 2020, p. 49). This is not a specific German situation because the share for all countries of the European Union is about 90% (see, e.g., Martínez-Díaz et al. 2019). In the case of accidents with personal injuries (a total of 15% of all accidents), the causes lies in human errors when turning, turning around, reversing as well as entering and exiting (15.5%), disregarding the right of way and priority (13.8%), inadequate distance to other vehicles (13.4%), driving at inappropriate speed (11.0%), as well as when driving under the influence of alcohol (3.2%) (see, Destatis 2020, p. 50).

The data show the importance of the human factor in the occurrence of traffic accidents in road traffic (see, e.g., Ainsalu et al. 2018; Grunwald 2019; Martínez-Díaz et al. 2019) and thus in the direct accident-related costs as well as the long-term follow-up costs. However, autonomous driving will not make it possible to completely avoid accidents in the future, especially if the traffic infrastructure is shared with conventionally used vehicles (see, e.g., Grunwald 2019). In addition, there are accidents caused by pedestrians or cyclists, which cannot be prevented (or only to a limited extent) by a high level of performance in situational detection in autonomous vehicles. However, halving the number of accidents, not only in the Federal Republic of Germany, would lead to considerable (short-term) savings at the operational level and also to a reduction in (long-term) economic costs, particularly in the health care system and in accident-related (public) care services.

The elimination of the human factor not only has an impact on the cost structures, but there are completely new possibilities in the design of the operational service processes in both freight and passenger transport. Only technical restrictions can influence these processes, but for example, not labor law regulations. In addition to the advantage of greater flexibility with regard to serving customer requirements, there are also cost advantages that result from more efficient and more customer-oriented process design for the operational procedures.

However, not only economical and technical aspects are important at this point, but also the question of adapting the legal framework conditions (see, e.g., Gasser 2016; Schreurs and Steuwer 2015; Bartolini et al. 2017; Ainsalu et al. 2018; Stender-Vorwachs and Steege 2018). The main legal problem is the ban that the public traffic area is used simultaneously by manually operated and autonomous vehicles. The basis for this is the *European Agreement*, *Supplementing the 1968 Convention on Road Traffic*, in conjunction with the national traffic laws. The regulation for ADAS-supported operation that has been in force in the European Union since 2016 continues to require a driver who can or may have to intervene. This clearly clarifies the legal responsibility. Apart from a few examples, test projects can currently only be carried out with exceptional permits. Another question to be discussed is which legal regulations are necessary for the use of the data collected, especially by third parties (see, e.g., Stender-Vorwachs and Steege 2018).

For the future use of autonomous driving, a suitable legal basis must be created for damage cases. That means, the question of the culpability of machines must ultimately be clarified within the legal framework (see, e.g., Stender-Vorwachs and Steege 2018; Grunwald 2019; Lenk 2019; Martínez-Díaz et al. 2019). For example, the vehicle manufacturer, a software or component supplier, the owner or the respective user is liable or there is another form of claim settlement. The critical point here is the occurrence of dilemma situations in which serious consequences of an accident for individual road users depend on situational decisions made by machines (see, e.g., Stender-Vorwachs and Steege 2018; Grunwald 2019; Lenk 2019). In conventional driving, people decide, in autonomous operation the designer of the corresponding software systems makes the rules for the decision. Relating to this critical problem there are very controversial discussions regarding ethical acceptability, but these have not yet led to a satisfactory solution.

Another legal problem field is the question of responsibility for traffic offences (see, e.g., Gasser 2016), which must be examined. An important step here can be a complete recording of all processes via black box systems, which (but then for all vehicles in public road traffic) would have to be prescribed by law.

In addition, the question of public acceptance is of considerable importance for future market penetration (see, e.g., Fraedrich and Lenz 2016; Acheampong and Cugurullo 2019; López-Lambas and Alonso 2019; Avermann and Schlüter 2020; Bissell et al. 2020). The focus here is on the discussion of possible uses and any risks that may arise, but these must also be seen in a changing environment. With the decline in the importance of one's own private car as a social status symbol and an increasing spread of the sharing economy, some changes in the societal framework are associated. It follows, for example, that a renouncement of the individual mobility that has been propagated for decades as a symbol of individual freedom. This is accepted much more strongly in urban regions, depending on the offered public transport services. In contrast, due to insufficient services in rural areas, its use is low. For this purpose, the use of private cars is seen as necessary, and viewed less critically due to the greater availability of space and less traffic problems. Furthermore, the fundamental position towards questions on environmental protection also plays a role, as well as consistent rejections of technological developments, partly due to the uncertainty regarding unpredictable negative consequences.

## 5 Re-design of Public Transport in Rural Areas

The availability of autonomous vehicles for passenger transport in rural areas is of particular importance. This opens up completely new possibilities for the design of an efficient and attractive public transport system that has never been possible before (see, e.g., Sonderegger et al. 2019; Soteropoulos et al. 2019). The far-reaching elimination of the personnel cost as a substantial factor and the detachment of the service planning from labor law restrictions is the essential basis. In principle, individual customer demand can be the decisive basis for planning public transport services. The main objective must be to ensure a basic mobility, especially regarding to services of public interest. In the foreground is, for example, an extension of service periods, also with an orientation to seven days with a 24-h service.

In addition to the (regional) rail passenger transport systems as well as the regional bus and school bus systems, which must continue to form a basic network with timetable-based services, new forms can be included that enable *quasi-individual mobility* (see, e.g., Saeed and Kurauchi 2015) that lead to a transition from a technical oriented (traditional) passenger transport to connected mobility services (see, e.g., Jittrapirom et al. 2018; Mulley et al. 2018; Utriainen and Pöllänen 2018). The main forms of such *mobility as a service* (MaaS) *concepts* are innovative taxi services, modified carsharing concepts, ridesharing concepts and on-demand transport services based on autonomous vehicles (see. e.g., Kamargianni et al. 2016; Shaheen and Cohen 2020; Tyrinopoulos and Antoniou 2020).

*Autonomous Taxis:* This is a cost-effective extension of the classic range of individual transport services (see, e.g., Tussyadiah et al. 2017). The main aspects are the cost savings due to the elimination of the driver as well as the possibility of an unrestricted service time.

*Modified Carsharing Concepts:* The classical (station-based) carsharing services (see, e.g., Lenz and Fraedrich 2016; Namazu et al. 2018; Perboli et al. 2018; Webb et al. 2019; Shaheen et al. 2020), where vehicles have to be returned at defined locations, are only applied in urban areas usually. This is possible here due to the existing demand structures, but not in rural areas. However, if autonomously driving vehicles are available, an assignment to determined stations after finishing a trip is no longer necessary and a transition to free floating carsharing (see, e.g., Shaheen et al. 2020) is possible. Here, the vehicles can either be sent to the location of a next customer, or they can be made available at a specified location, close to expected customers. In a long-term view such a service may be a chance to reduce the high level of private car ownership (see, e.g. the current situation from the Federal Republic of Germany in Nobis and Kuhnimhof 2018, p. 40) and therefore the number car trips (see also, Kaplan et al. 2019 and Liao et al. 2018).

*Ridesharing:* This form, in which several customers use a vehicle together on different sections of a route, is not new from the basic approach (see, e.g., Najmi et al. 2017; Dong et al. 2018; Farhan and Chen 2018; Hyland and Mahmassani 2018; Richter et al. 2019; Shaheen et al. 2020). Such carpooling has been taking place for many years, mostly in rush hour transport, where a time and direction-related bundling of trips is possible, or within the framework of informal structures at the local level (see, e.g., Meyer 1982). However, there are also limitations due to various restrictive conditions that have previously prevented widespread applications. With the use of autonomously driving vehicles, ridesharing can be made much more flexible and integrated as an additional component in public passenger transport.

*On-Demand Public Transport Services:* These are primarily *dial-a-bus concepts* or *demand-responsive transport* (DRT) *concepts* mostly based on minibuses. Characteristic of these types of services is a demand-dependent transport, which is ordered by customers, either ad hoc in connection with an immediately intended departure, or in advance for a specific date or time slot. The aim here is to try to counteract existing supply deficits, whereby different organizational forms can occur. The services can be organized *line-based*, *corridor-based* and *area-based* (as the variant with the most flexibility). Such types of services have been discussed for several decades and have been operationally tested in various forms, including as group-specific services (for example handicapped persons or elder people) (see, e.g., Schiefelbusch 2016).

However, such concepts were implemented successfully in practice only in a few cases but then often discontinued. The main reasons for this were the high costs of conventionally operated vehicles (see, e.g., Meyer 1982; Ryley et al. 2014), the lack of suitable information and communication systems, an inadequately accurate description of the road network structures, and an unreasonable range of services, especially due to restrictive working time regulations. In addition, there were also politically desired restrictions to avoid competition with existing public transport services, as well as resistance from the trade unions regarding the reduction of jobs when volunteer drivers were deployed in locally oriented on demand services (see, e.g., Meyer 1982).

With the availability of autonomously driving minibuses and the technical developments in the context of digitization, new operating options have emerged worldwide in recent years. There are currently various applications, especially in urban areas (see, e.g., Ainsalu et al. 2018), which are still predominantly in test operation. Similar developments are also increasingly evident in rural areas such as in the Federal Republic of Germany, but not across the whole country and not very structured (see, e.g., Hänsch et al. 2019). In some cases, however, the transition to regular operation has already taken place, for example, in the Bad Birnbach area (see, e.g., Barillère-Scholz et al. 2020; Kolb et al. 2020). Such services will be an essential element in the redesign of public transport, especially in rural areas (see, e.g., von Mörner and Boltze 2018) due to the operational framework and the significant quality improvements.

The core problem of the design is the connection of these four outlined forms of quasi-individual mobility based on autonomous vehicles with the traditional public transport services. Due to the existing demand structures, these are still mandatory for the operation of commuter traffic in rural areas (see, e.g., Robson et al. 2018). A substitution with the new services is not possible, neither organizational nor traffic related (see, e.g., Metz

2018). A major restriction is that especially in the cities the availability of traffic space is limited, and this is also to be reduced more and more in connection with an inner-city redesign.

The convergence of transport systems in public passenger transport towards a dominance of quasi-individual mobility outlined by Ennoch (2015) seems to be unlikely under these framework conditions. A displacement of buses from the transport services in the cities (see also Hannon et al. 2019 and Sonderegger et al. 2019) is not realistic due to the existing demand structures. However, a substitution of underutilized standard buses in rural areas or in smaller cities (see, e.g., Winter et al. 2018) can be possible and also be useful. This applies to public transport access at local level and to a certain extent on regional level as well as feeder and distribution traffic (on the last mile) for the connection to higher-level traffic systems (see, e.g., Scheltes and de Almeida Correia 2017). Figure 2 shows a basic concept of such an interconnected service structure for public passenger transport in rural areas.

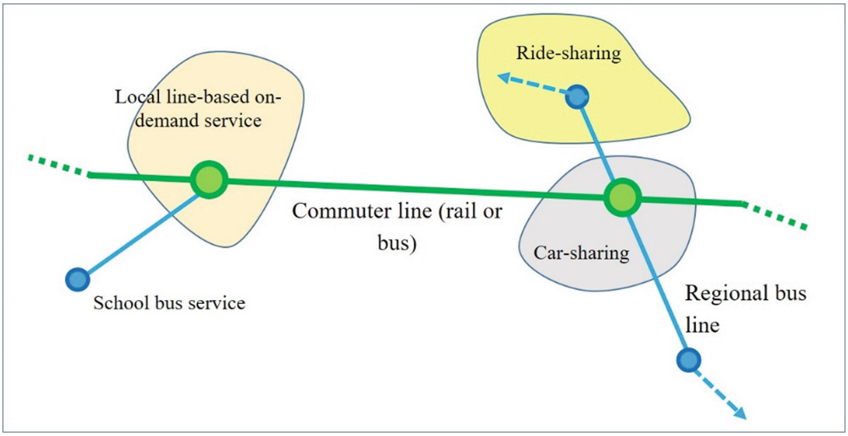


**Fig. 2.** Interconnected service structures for public passenger transport in rural areas.

A sufficiently qualified transport infrastructure, the availability of the required vehicle systems and (largely) comprehensive digitization of the transport sector are necessary for the operational implementation of novative transport services. Even if the technical developments mentioned have not yet been completed, it is still necessary to design the conceptual structures in a targeted manner so that corrections do not have to be made later. This applies in particular to road traffic infrastructure and an efficient digital infrastructure.

## 6 Planning and Control of Passenger Transport Processes

A mandatory prerequisite for the successful integration of quasi-individual mobility services in public transport in rural areas is their interconnection with the actual existing services, but not their substitution. However, this requires a profound change in the planning processes as well as in the control and monitoring of operations. In addition, continuous online communication between provider and customer must be guaranteed on the basis of planned data as well as on real-time data. Perhaps the most difficult part of the implementation is the development of a suitable tariff structure and the revenue sharing system among the service providers involved. With regard to the planning and control measures, the tasks outlined below result.

*Network and Service Planning:* There are no significant changes when planning the conventionally designed transport services (for train and standard busses), since the functional tasks remain the same. For this area, on a centralized level there will continue the planning of area-based line networks and timetables as well as the timetable synchronization. Afterwards, a coordinated vehicle and personnel requirements planning for the participating transport companies follows. With regard to the quasi-individual parts of the services, only transfer points to the higher-level network can be defined and an estimation of the vehicle requirement based on expected demand volumes, apart from the cases in which a line or corridor-based operating structure is intended. Applying line-based services the route and stops must be defined and in the case corridor-based services in addition the size of the corridors must be fixed.

*Operative Planning:* In this area, too, not any fundamental changes for the network and timetable-based part of the services is necessary. On the one hand, appropriate computer-aided planning tools are available here, with the help of which the needed vehicle blocks, duty schedules, and duty rosters can be calculated for the transport companies involved. For the quasi-individual parts of the services, on the other hand, only the number of required vehicles can be planned.

*Operational Control and Monitoring:* These tasks require new concepts, since all operations in a complex interconnected network structure must be monitored simultaneously in real time. This is imperative in order to be able to handle the on-demand customer requests even at short notice, especially when connecting to conventional transport services. The autonomous vehicles are scheduled dynamically at this level, where short-term changes in demand, for example, additional customer requests, have to be permanently included.

*Passenger Information:* The currently available passenger information systems based on *stationary* or *mobile devices* (smartphones, tablet computers, etc.) are only suitable to a limited extent for the integration of on-demand services within the framework of quasi-individual mobility structures. They are based on line network and timetable data that are known, partly including actual deviations that are recorded and made available with the help of *Intermodal Transport Control Systems* (ITCS) or, for example, real-time data based on information from *automated fare collection systems* (see, e.g., Jevinger and Persson (2019) as the basis for *dynamic passenger information* (see, e.g., Papangelis et al. 2016; Viergutz 2016; Corsar et al. 2017; Harmony and Gayah 2017). These are generally suitable to display multimodal connections based on classical transport modes, but not for including on-demand trips. Only information regarding the fixed transfer options to on-demand services can be integrated into the existing systems, which is not a sufficient solution to offer attractive information services from customer's point of view.

This means that new information systems with a significantly higher scope of performance are required (see, e.g., Lathia et al. 2012; Beutel et al. 2016; Szigeti et al. 2017), which are based on a communication platform through which a constant communication between the service provider and the customer is guaranteed. The provision of information must include, among others, two variants of queries. On the one hand, it is about querying information regarding an immediately intended (also multimodal) trip and then booking when a suitable offer is suggested. However, interactive communication processes may also be necessary until an offer is accepted. On the other hand, there must be the option of ordering a trip for a later date and, if desired, also reserving it, whereby a certain flexibility must remain possible for the on-demand trips involved, until a customer actually starts his trip.

In addition, a fundamental structural change to the information systems is necessary. These must be uniformly designed and operated systems in which all the transport providers involved are integrated. These must be connected to the higher-level communication platform mentioned above, regardless of the used communication devices. The underlying service areas should be large and overlap with neighboring areas in the peripheral zones to enable an attractive offer.

*Tariff Structure and Revenue Allocation:* The development of a suitable tariff structure is a very complex problem because it is a decisive factor for the acceptance of public passenger transport services. It must base on a clear and understandable concept and thereby the principle "*one trip - one price*" must be adhered to. In the case of multimodal trips with very different means of transport, however, the question then arises as to how the isolated trip segments of the different transport companies are to be valued in monetary terms and how a total price (which is acceptable for the customer) can be calculated from this. If the distance traveled is taken as a basis, the price is comparatively easy to calculate and also understandable for a customer. However, in this case another problem arises, the revenue allocation among the companies involved.

The development of a solution that is acceptable from the point of view of all those involved presents a complex problem, especially when public transport is seen as a service of public general interest or other political objectives are also included in the discussions (e.g., special tariffs for elder and handicapped people). For this reason, it can only be case-specific decisions that should not be considered here. Regardless of this problem, the determination of permissible payment systems, which can also have an impact on a tariff system, is independent of the fundamental questions to be solved.

In addition to these largely technical and process-related discussions, the question of organizational structures and responsibility for the design and implementation of services is a central point for a successful restructuring and further development of public passenger transport in the rural area. Since multimodal trips are usually provided by different operating companies, it is necessary to have a superordinate level for planning and implementation of central tasks. In connection with the discussions about the developments of service structures in the sense of MaaS, private sector solutions are proposed. However, if the mobility of people is seen as part of a service of public general interest and is also financed accordingly, as it is often the case, the primacy of politics applies.

Ultimately, this excludes a form of private business organization. However, the question must also be asked whether an integration of such organization into the public administration can make sense. A cooperative organizational form can therefore be a better solution, for example within the framework of a *Public Private Partnership* (PPP) *concept*. If public passenger transport is viewed as a private service, there are various organizational models that should not be discussed further here, as these are usually very strongly influenced by the respective national legal framework and the different interests of the involved parties.

## 7 Outlook and Further Developments

The need to improve and expand public transport in the rural area is uncontroversial. The main reasons for this are the reduction in traffic-related environmental pollution, the improvement of mobility, also with a view to under-aged as well as elderly and handicapped people (see, e.g., Milakis and van Wee 2020), as well as the reduction in rural exodus and thus the resulting increase in urbanization. In addition the demographic change has to be seen (see, e.g., Kaplan et al. 2019; Avermann and Schlüter 2020). The use of autonomously driving vehicles in public transport is seen as an essential approach to the implementation of these goals (see Sect. 4). Even if these developments are just beginning, the operational and financial advantages of autonomous driving are obvious. This is also evident worldwide through a large number of ongoing test projects and the first realizations in practice, as well as comprehensive political support, also with regard to the necessary adjustments in international and national traffic law.

However, some (partly supposed) negative effects that result from autonomous driving must also be seen. The focus is on the loss of jobs that will come (see, e.g. the forecasts of Frey and Osborne 2017 as well as Grunwald 2019 and Bissell et al. 2020). On the other hand, looking at the age structure of the current population development, a different valuation is possible. The again and again discussed lack of vehicle drivers, for example, may be compensated by such a technical solution. Moreover, there is of course a risk for autonomously driving vehicles to be attacked electronically, but the question arises as to how the comparison with manually operated vehicles currently looks. The problem of external interventions in vehicle electronics is not a system-inherent problem of autonomous driving, this also applies to manually operated vehicles with appropriate on-board electronics, for example when using ADAS components. In addition, it may be in the first few years a problematic situation applying driverless vehicles in public road networks. It is necessary to get used to the changing conditions in road traffic if there is a shared use of the traffic space by autonomous and manually controlled vehicles.

For the future it must be assumed that it is not a question of whether autonomous driving will prevail, but how quickly and with what market penetration. The essential factors are the progress of the qualification of the technical systems (vehicle technology, electronic components, information and communication technology) as well as the speed of the "learning" of the vehicles, whereby an extensive database can be generated by sufficient mileage (in kilometers driven). This is the crucial basis to ensure adequate security in daily operation.

Public passenger transport in rural areas can be an important field of application in order to demonstrate in a first step suitability for everyday of use autonomous vehicles, since the general traffic conditions are less critical here. In addition, the achievable improvements in the operating structures are clearly visible, not only on the technical level, but in particular also with regard to an improvement in living conditions in an area that was previously largely undersupplied with regard to public transport. This can significantly influence the choice of means of transport in rural areas, combined with a corresponding reduction in traffic-related environmental pollution as well as cost savings for customers by eliminating fixed costs (for owning a car) and replacing them with usage-dependent variable costs.

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