Transportation (2020) 47:811–826
https://doi.org/10.1007/s11116-018-9920-5

Establishing car sharing services in rural areas: a simulation-based fleet operations analysis

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Published online: 28 August 2018

Abstract
Today, car sharing represents a generally accepted and widespread mode of individual transport. Car sharing providers operate their fleets effectively in many cities around the world. Surprisingly, rural areas don't seem to have been considered in provider's current expansion strategies. However, studies suggest that car sharing would have the greatest impact on improving sustainability and reducing traffic if it were offered nationwide. In this paper, we analyze the factors that prevent car sharing enterprises from developing their services in rural regions. Supported by a simulation model, we elaborate strategic implications on how to deal with potential hindrances such as lower demand or longer driving distances. For this purpose, a symbiosis of urban and rural car sharing services was analyzed. Our findings indicate a certain feasibility of rural car sharing development, while highlighting the positive effect it could have on car sharing demand in urban areas.

Keywords Car sharing · Rural · Transportation · Mobility · Simulation

Introduction

Since the first commercial implementation of car sharing (CS) in 1948 (i.e. the SEFAGE project in Switzerland), the concept has undergone significant change. Alternative mobility concepts that included CS were established in different countries as a result of the oil crises of the 1970s (Cepolina and Farina 2012; Millard-Ball 2005). However, from its beginnings to the present day, CS enterprises have concentrated almost exclusively on urban areas, with very few exceptions. In rural regions, only occasional instances of peer-to-peer CS have been realized. The core issue during the foundation or expansion of CS services is the huge amount to be invested in relation to the (likely) poor initial performance and low profit margins. Large numbers of regular users are required for a CS network to become profitable. However, a broad user base can only be attracted by a widespread and well-situated

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CS network offering high availability right from the beginning (Efthymiou et al. 2013). These factors are mutually dependent, which significantly complicates the development of new CS services. The foundation of a small network with a few vehicles and further upscaling from time to time may not attract enough users to ensure financial survival during the initial stages of the new CS service. Instead, enterprises are forced to invest in relatively large networks from the start. It seems certain that this strategy would be more viable in cities, where demand figures are more predictable. Rural areas, on the other hand, do not offer such initial attractiveness for a variety of reasons. However, many cities today are fully exploited CS markets, so CS enterprises have started to turn their attention to rural areas. The situation is comparable to some extent with broadband expansion, which focused initially on profitable urban zones before eventually expanding into rural areas. Moreover, vehicle sharing generally works best when offered as a service nationwide, which encourages people to give up private car ownership, according to de Luca and Di Pace (2015). This includes people traveling from rural areas into cities as well as from cities to rural areas, e.g. for leisure activities or tourism (Wappelhorst et al. 2014). Our own work addresses a potential development strategy for CS in rural areas. We aim to solve the central research question of how to deal with lower initial demand for CS services in these regions. For instance, exploiting the scale effects that result from region-wide CS networks could potentially increase demand across the whole network, thus compensating for or even making viable investments in less profitable rural regions. Furthermore, urbanization and centralization in most industrial nations will change life in rural areas fundamentally in the coming years. Some well-known examples of the rural exodus are the movement of public institutions, medical care, and recreational activities as well as the reduced availability of local public transportation (Velaga et al. 2012). This situation offers great potential for growing CS demand as an individualized, fast and affordable mode of transportation and as an alternative to private car ownership in rural areas. Our paper broaches a promising field of research with respect to future CS development: CS in rural areas is currently excluded from the outset in almost all recent publications that address CS. Specifically, our research question examines manifold effects when attempting to overcome lower demand occurrence for CS services in rural areas.

Literature

As shown above, solid initial demand is crucial for the successful establishment of any CS service. There are several approaches in demand modeling, e.g. the realistic CS demand simulation of Ciari et al. (2012). Unfortunately, input data are required to determine the expected demand—data that are difficult to obtain for rural areas. Another demand forecast model dedicated to urban areas is provided by Zhou et al. (2017). One approach to using key characteristics of a potential CS user group to determine CS demand is presented by Dias et al. (2017). Alternatively, available data for similar transportation modes could be used for CS, e.g. information extracted from taxi trips (Brandstätter et al. 2017). Along with the difficulties in applying demand modeling, there are multiple empirical studies that survey the reasons behind CS success (Juschten et al. 2017). It is observed that vehicle owners living in the countryside are less likely to participate in CS (Kim et al. 2015). However, most of the papers known to us focus on CS in urban areas, with rural regions omitted from the scope from the beginning. Although there are no publications that address in detail the specific field of CS in rural areas, some of the following articles provide promising results that offered a good starting point for our work. Key success factors of an inter-urban CS network—including the bridging of rural areas between cities—are surveyed by de Luca and Di Pace (2015). The authors identify multiple dimensions, including the rate of house ownership, household income, education, characteristics of the neighborhood (walkability/transportation availability, congestion), familiarity with CS, willingness to experiment as well as concern for the environment and characteristics of the CS program, e.g. scheduling reliability, convenience and cost. A comparison between two CS case studies (with one in a larger city and one in a more rural area) is provided by Wappelhorst et al. (2014). The survey points to the likely future success of rural CS if the right user groups are targeted by marketing actions and if tourism provides additional CS demand. Factors that determine demand could also include the rate of vehicle ownership and the population density (Celsor and Millard-Ball 2007). Moreover, a detailed study of sociodemographic factors is conducted by Prieto et al. (2017). The authors find that compared to public transport use or private vehicle ownership, high usage frequency is a more important driver of CS membership. Another noteworthy study is conducted by Kim (2015), and it highlights the potential of CS to replace privately owned vehicles—which might also be applicable to rural populations. Required preconditions include higher proportions of singles, users with lower income levels, older people, and people who use or require the use of cars infrequently. Finally, women are more likely to participate than men. Kim et al. (2017) also found that other factors that help secure the success of CS include the time pressure of users and high parking costs at destination. Of course, both factors could be stimulating for rural CS—and especially when users travel to nearby cities frequently. Additionally, local and municipal law-making provides a significant opportunity for CS in rural regions. The important role of politics for CS services is examined by Lindloff et al. (2014). A different approach on improving transportation in rural areas is autonomous driving, which can be integrated in vehicle sharing (Steck et al. 2018). So called driverless taxies allow customers to order automated vehicles over longer distances and resolve the current issue of small demand within walking distance around a car sharing station in thinly populated areas. However, autonomous driving is not fully market ready yet and relies also on wireless broadband internet technology which will be mostly established in urban areas first (Seif and Hu 2016).

Background

CS modes applicable for rural areas

This article focuses on CS as a special form of vehicle sharing: namely, it concentrates on station-based one-way and two-way systems, and both forms of organization are considered. Two-way CS means that vehicle pick-up and drop-off occur at the same station, while one-way CS allows cars to be dropped off at any desired station. This allows users to avoid prolonged and, thus, costly vehicle occupation during shopping trips or working periods. The more costly nature of one-way CS from the operators perspective may, of course, act as a hindrance to its implementation (Shaheen et al. 2015). Free-floating systems for rural areas are also not generally excluded from the study e.g. if they are organized as hybrid systems offering some stations at strategical important locations or clear defined drop-off zones. Another mode, so called peer-to-peer CS, has proven its competiveness against commercial CS (Prieto et al. 2017). While it represents a possible sharing opportunity in rural areas, it falls outside of the scope of this paper.

Defining rural CS

Before more detailed simulation investigations are conducted, an examination of the term 'rural' should be provided insofar as it pertains to CS. Unsurprisingly, there are no comprehensive or standardized definitions of the terms 'urban', 'suburban' or 'rural'. To illustrate the diverging views, the definition used by the U.S. Census Bureau and the Scottish government are presented (National Statistics 2010; Ratcliffe et al. 2016). See Table 1 for details.

However, as these two examples illustrate, local differences hamper a global definition. The definition approaches of the OECD, for instance, highlight the need for significant local adaption (Organisation for Economic Co-operation and Development 2011, 2016). The fact that short distances to urban centers potentially classify rural areas (somewhat inaccurately) as urban areas is an important finding for transportation issues. Indeed, it highlights the enhanced role of individual mobility in surrounding areas. On the other hand, it marginalizes more distant regions with otherwise similar characteristics. This major finding qualifies the distance factor as an important parameter in our simulation model.

Challenges and potential benefits

As introduced in the literature section, CS success in rural areas may be determined by multiple sociodemographic characteristics (Celsor and Millard-Ball 2007). Firstly, a high rate of vehicle utilization is required for cost coverage, which seems impossible to realize outside of cities (Nair and Miller-Hooks 2014). This includes the costs incurred for vehicles as well as for support and maintenance staff. Price increases to overcome these higher costs could decrease the competitiveness of the CS service (Xu et al. 2017). Therefore, the following demand-reducing factors need to be considered in characterizing the current situation. The accessibility and availability of vehicles is crucial (de Luca and Di Pace 2015). Due to lower population densities in rural areas, less people

Table 1 Two exemplary definitions of the term 'rural' (National Statistics 2010; Ratcliffe et al. 2016)

	U.S. Census Bureau	Scottish Government
Geographical settlements	Less than 2500 residents	Less than 3000 residents
Distance	No urban area within 2.5 miles	Remote: no settlement of more than 10,000 people within 30 min drive Accessible: settlement of more than 10,000 people within 30 min drive
Density	Less than 500 people per square mile	–
Land use	No shopping centers, no airports with more than 2500 passengers annually	–

live within walking distance of a potential CS station. Moreover, typical user groups for CS—e.g. singles and students—represent only a small proportion of the population of rural areas (Dax and Fischer 2017). Finally, the psychological factor of owning a car might be more important in rural areas. At the same time, people in cities regularly rely on public transportation and may see less symbolic wealth in private car ownership (Bardhi and Eckhardt 2012).

Along with the aspects presented that are directly related to CS demand, other factors also exert an indirect influence on transportation and, thereby, on CS success in rural areas. This includes, for instance, the accessibility of community facilities, grocery stores, shopping centers or medical facilities. A small town with 50,000 residents, for example, may offer many such sites of public interest within walking and/or cycling distance for large proportions of the population. Moreover, a certain level of public transportation might be available as well. There is obviously a more limited demand for CS and cars in general in environments where schools, worksites and leisure activities are fully accessible without individual modes of transportation. On the other hand, there may be villages in rural areas with less residents but with a greater need for transportation options if all of the sites of social, cultural and commercial interaction listed above are further away and public transportation has been abandoned. Therefore, people living in such rural areas are in much higher need of cars or CS services.

Another important factor is the distance between rural areas and the nearest city. One of the fundamental assumptions in this study is the capability of profitable urban CS systems to expand into surrounding rural areas. Shorter distances to urban areas may appear promising for CS establishment at first. On the other hand, shorter distances mean shorter rental times for customers to reach their desired destination in the city. Low CS demand frequency in rural areas, combined with short rental times for typical trips, leads inevitably to poor utilization of CS vehicles. Longer distances combined with the same low demand frequency result in increased utilization through longer trip times. However, price models need adjustment in this case so that they can maintain their competitiveness against private car ownership.

Further interaction of urban and rural CS services address expeditiousness and urban parking issues. CS is, in many cases, faster than public bus systems with respect to waiting times and the choice of shortest routes. Furthermore, parking is often reserved for CS vehicles, while parking fees and parking space reservations in some cities are automated in the CS system. These two factors promote CS as an alternative for both users of public transportation and for private vehicle owners—a phenomenon examined in detail by Kim et al. (2017). A parking fee reduction for CS is also proposed by Engel-Yan and Passmore (2013). Finally, synergy effects also operate in the opposite direction, and the pursuit of leisure activities may encourage urban residents to rely on CS when traveling to rural destinations. It becomes possible to drop off the CS vehicle there and, also, to have CS vehicles available (for return trips, etc.) if required. The tourism factor for rural CS is surveyed by Wappelhorst et al. (2014) and is presented as a future driver of CS by Zhou et al. (2017). Figure 1 illustrates the correlations between the factors mentioned.

Definition of research questions

Summarizing the major aspects from the chapters above, some interesting research questions arise—which we aim to address based on our proposed simulation tool.

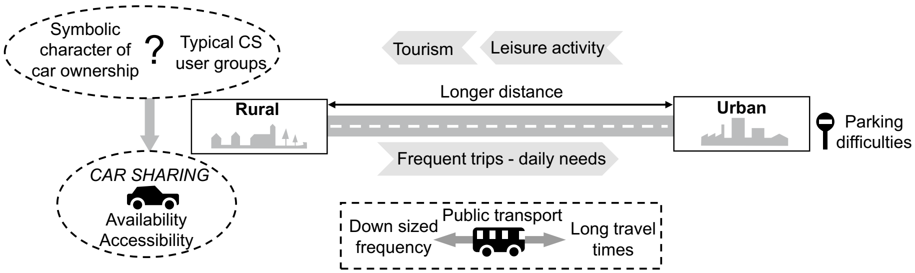


Fig. 1 Factors determining CS success in rural rreas

- Might a potential demand increase in urban areas overcome low demand situations in rural areas? How large would this required increase in demand be, and could it be provided by some of the following points?
- What role is played by the driving distances between urban and rural areas?
- What benefit is generated by urban CS users traveling to rural areas and dropping off their vehicles at a rural CS station?
- Does the rural CS system also benefit and facilitate urban CS?
- Do these issues encounter any limitations when upscaling rural CS services?

Modeling a CS network connecting urban and rural areas

The methodological guideline for our present work was the CS growth strategy and simulation approach provided by Fassi et al. (2012) and the vehicle simulation in Fagnant and Kockelman (2018). We utilized the queue-based discrete event simulation software Rockwell Automation Arena, version 15.00 (academic license/academic lab package). The proposed simulation model was based on a simplified generic urban CS network connected to a generic rural CS network (see Fig. 2). Both area networks were viewed as enclosed sub-model units with certain individual characteristics. They were equipped with independent vehicle stocks ready to satisfy the stochastically occurring demand. The number of rural sub-models could be scaled up to any desired network size by adding multiple rural simulation threads. The overall structure of the model was therefore able to simulate the expansion of an existing urban CS network into surrounding rural areas in a simple and reproducible manner.

Furthermore, the model was capable of simulating one-way trips with relocations, thus connecting the otherwise isolated CS networks. This setup seemed to be the most promising one for future development. The vehicle relocation problem applies in this case. Therefore, we utilized a demand-driven relocation system, which triggered a relocation operation if the overall vehicle stock level in the rural area was zero but reservations or demand occurred. The effect of two-way trips and one-way trips without relocations could be illustrated by deactivating both the relocation routine and the choice of drop-off location. Vehicle relocations within the urban or rural areas were not considered: both were handled as one unit, as indicated above.

Trip times in the urban area of the model were taken from Clemente et al. (2013) along with findings from Costain et al. (2012) and Kim et al. (2017). Trip times were based on a triangular distribution with associated parameters (min = 13, med = 20, and max = 30 min).

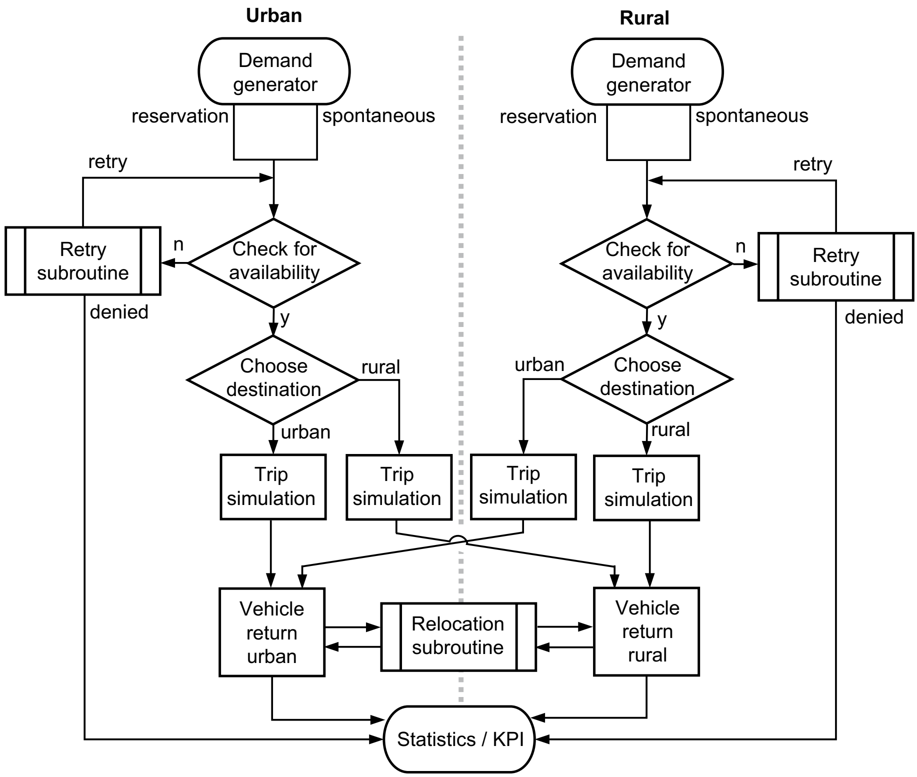


Fig. 2 Simulation flow chart for one-way configuration

Trip times in rural areas were assumed to be identical, but could be adjusted slightly to account for the distances used in the simulation experiments. The number of trips between urban and rural regions was also altered in deriving the simulation results (see next chapter).

The allocated demand data (see Fig. 3) originated from real-world investigations from the online reservation systems of free-floating and station-based CS networks. The observed daily and weekly demand patterns were adjusted in accordance with the charts presented by He et al. (2017), Li et al. (2016), Schmöller et al. (2015) and Schreier et al. (2015).

Along with the deterministic base load, which offered a basic demand curve for 1 week, a stochastic component was added to account for additional random demand. To this end,

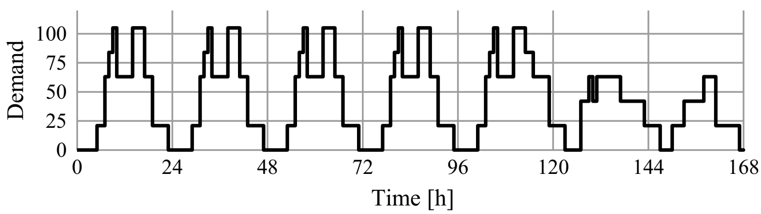


Fig. 3 Arena base level demand schedule for the urban area

the simulation model utilized separate so-called ‘create modules’, randomly generating demand based on two uniform distributions with 30 and 120 min (as min/max) determining the interarrival time. Rural demand followed the same pattern but was reduced in some experiments by scale factors. The system utilized five cars in the rural part of the model region and 40 cars in its urban component, thus representing a fleet size typical for a smaller town. Average CS fleet sizes per city are surveyed by Münzel et al. (2017). The basic performance indicators obtained are shown in Table 2. This applied for the theoretical case with 100% demand, where rural demand per car was approximately equal to urban demand per car. The β service level in this regard is calculated by dividing the satisfied demand proportion by total demand. Furthermore, the daily vehicle-to-trip ratio is a load factor primarily developed by Barth and Todd (1999) for the evaluation of vehicle sharing model utilization. It is defined as the ratio between the number of vehicles in the system and the total count of daily trips. A vehicle-to-trip ratio of 0.041 equals 24 trips per day in our model.

Due to the uncertain nature of the expected demand, it was further analyzed as a variable in the simulation experiments described in the next chapter. The lower demand likely in the rural region became an adjustable variable in the simulation. The slight divergences of performance measures between both areas could be explained by the general disadvantage of the smaller car pool with respect to the efficient allocation of trips and cars. The run-time set-up was calibrated as follows:

- Warm-up time: 1 week
- Run-time: 4 weeks
- Number of replications: 10

Run-time had to be an integer of full weeks in order to cover the demand situations on weekends and weekdays. The number of replications decreased the volatility of the average results. Based on ten replications and a 4-week run-time, the maximum variation of the results fell below 5% in all experiments, thus maintaining a 95% confidence interval. The warm-up time allowed vehicle stocks to balance out.

Simulation experiments and discussion

The following experiments were conducted to study the challenges and potential benefits presented in chapter “Challenges and potential benefits”—vehicle utilization represented a key performance indicator that was relatively easy to obtain from the simulation reports. In a real-world application, this metric would determine the profitability of a single car or network because almost all CS enterprises rely on distance- and time-related usage fees. Vehicle utilization is differentiated into urban utilization, rural utilization and total utilization in order to identify various impacts. It is always the average of all simulation runs with the

Table 2 Initial simulation model characteristics

Territory	Vehicle utilization (%)	Vehicle-to-trip ratio	β service level (%)
Urban	35.9	0.041	95.2
Rural	35.1	0.042	81.0

presented run-time settings. The utilization value is calculated as a quotient of the operation time of a car and the total time of the simulation run. This includes customer trips with waiting times while being occupied and relocation trips carried out by the operator.

Required demand increase in urban areas

The first experiment tested the impact of a potential demand increase within the urban CS system if it expanded into surrounding rural areas. As introduced in chapter "Challenges and potential benefits", the enhanced attractiveness of an increased operation area may lead to higher demand among urban residents. The question is simulated of how much of an increase in demand is required to compensate for low demand situations in rural areas. The subsequent increase in the overall average utilization meant that the same revenue may be achievable from the point of view of an operator. In this regard, only two-way trips were allowed in order to prevent mixing of cars and varying vehicle stock levels. Two-way trips also avoided any influence arising from the target destination decision of users. Figure 4 illustrates the impact on vehicle utilization of low-demand scenarios in rural areas. Starting with the worst case and zero demand in a newly opened CS service, the average utilization naturally dropped across all 45 vehicles. This drop could be balanced if the utilization of the 40 cars operating in the urban area increased. The chart in Fig. 4 can be interpreted as follows: the utilization of the vehicles stationed in rural areas (A) was determined by the demand for CS services in that area (x-axis). The average total utilization of urban and rural cars (B) was therefore lower than of the urban cars alone (C). If (C) is seen as an average target utilization level for profitable operation, a desired demand increase in the urban area (D) was required to compensate for (A) and hit target (C).

The required demand increase required to force the expected utilization increase is illustrated in Fig. 5. If demand in the rural area was higher, the required urban demand increase then became lower. This referred only to the minimum demand increase necessary to hit the desired utilization target. It was obvious that the total vehicle utilization could potentially overshoot the initial level, thus increasing overall revenue for the operator.

Influence of the distance between urban and rural areas

The next experiment reviewed the impact of the driving distance between the urban and rural service areas with respect to the importance of the distance factor in the latest rural definitions (see chapter "Defining rural CS"). This test was conducted in the one-way

Fig. 4 Total vehicle utilization as a function of the rural demand situation

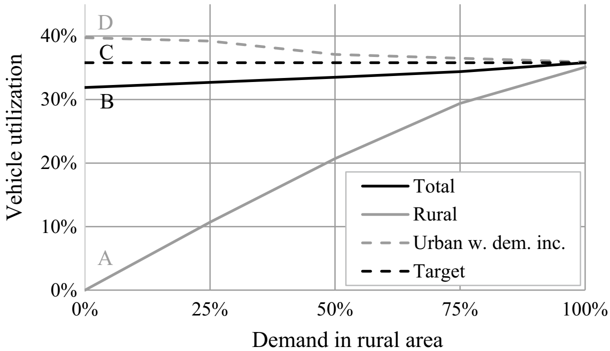
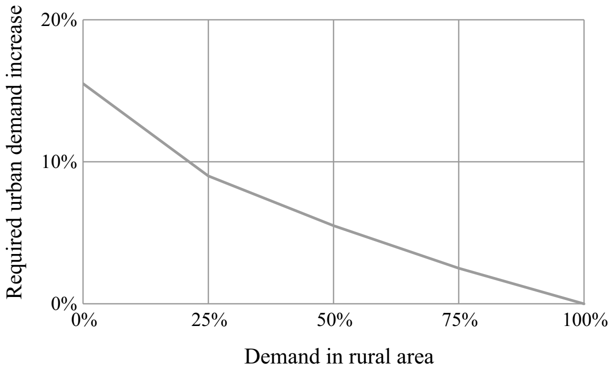


Fig. 5 Required urban demand increase to compensate for low rural demand



configuration of the model, thereby allowing customers to begin a trip in the rural area but to drop the vehicle off in the urban area and vice versa. The greater driving distances between stations forced customers to adopt longer rental times. This effect was tested with a demand scenario of 50% in the rural area, and with its subsequent lower level of vehicle utilization (see also Fig. 4 for reference). The chart in Fig. 6 illustrates the correlation of both parameters. If it is assumed that customers rented a CS vehicle for both covering the distance and doing something else while in possession of the car, shorter distances bore a larger relative influence on total trip time.

It should be noted that longer travel times decreased availability in the rural area, thus reducing the service level achievable. To overcome this effect, longer distances would require more vehicles at a certain point. It was found that a travel distance of 55 min between city and countryside allowed for vehicle utilization comparable to urban-only CS. The need for a reservation policy in real-world applications is highlighted in this regard. If longer distances are travelled and the car is dropped off, users require a guarantee that they will be able to find an available vehicle for their return trip.

Urban CS users traveling to rural areas

Of course, the longer distance also affected users making trips from the urban to the rural area, but their assumed destination choice more often lay within the urban CS network. Figure 7 visualizes the effect in more detail. For this purpose, the third experiment offered great insight into the effect of urban CS users taking advantage of the newly extended CS

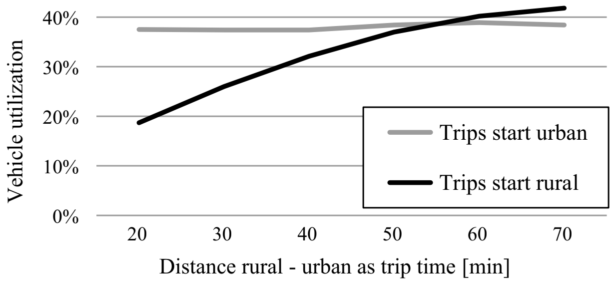


Fig. 6 Average vehicle utilization over average trip time chart

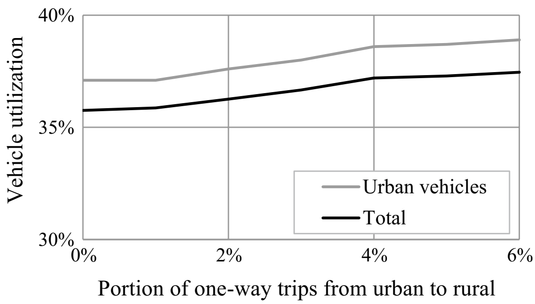


Fig. 7 Average vehicle utilization over destination choice rate of urban CS users

service area. These users now traveled the longer distance to the rural area, which they couldn't do before. The reasons for this are elucidated in chapter "Challenges and potential benefits". This behavior increased average total vehicle utilization. Again, an average of 30 min travel time represented the distance between rural and urban service areas, and the total utilization was again based on steady 50% demand for the rural CS service. Utilization of the vehicles operating in the rural area equaled some 26% in this situation. In this case, the simulation results indicated the following: If 3.5% of the trips starting in the urban area ended in the rural area, the total vehicle utilization compensated for low demand situations in the rural region. In absolute numbers, at least 35 of the nearly 1000 inner-urban trips per day also need to go to the countryside.

It was clear that the effects explained occurred only in the one-way configuration, which inevitably led to vehicle imbalances due to uneven destination choice rates. Vehicle relocations became necessary to prevent vehicle shortages in the rural area, or even in the urban area (Gavalas et al. 2015). Even though the vehicle and staff relocation problems were outside of the scope of this paper, our simulation model offered a sophisticated relocation routine. Based on actual demand (reservations or spontaneous bookings) and vehicle stock levels, our model executed (on average) between 21 and 33 relocations per day—depending on the demand scenario in the rural area. This equaled 2–3% of the total daily trip volume in the entire model. Relocations lowered the availability of vehicles to customers and raised operational costs. This factor must be considered for pricing strategies in practical applications. Another potential alternative to avoid expensive relocations can be seen in the dynamic pricing strategies presented by Chow and Yu (2015), Waserhole et al. (2013), and Ma et al. (2017).

Impact on urban CS performance

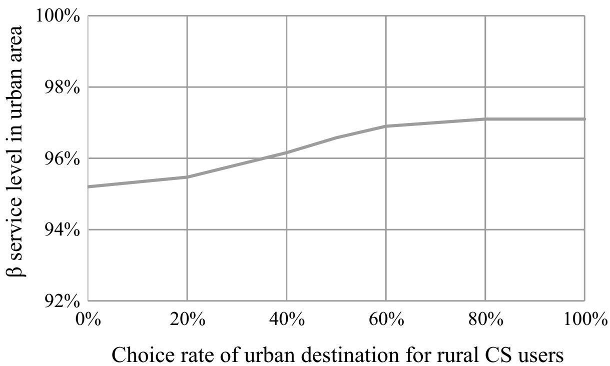
The final simulation experiment illustrated another important advantage in switching the CS service to the one-way mode of organization. During peak demand times, e.g. in the evenings, additional cars originating from the rural network are pushed into the urban CS network by rural CS users. This facilitated the satisfaction of more of the spontaneous demand proportion in the city. Some of the five cars assigned to the rural CS stations would be available in the urban area, depending on the destination choice. The reason for this behavior was that customers traveled to the urban area and dropped off their car where it could then be occupied by urban CS users for spontaneous trips. The experiment was conducted without relocations in order to avoid overlapping of the effects. During high demand peaks, the urban network would otherwise request relocations—which would increase the vehicle stock level and, thus, render the desired effect invisible. Instead, overall vehicle balance was maintained by adjusting the destination choice rate in the urban network. This meant that everyone travelling to the urban area was leaving it later, so that the same vehicle stock was restored at the end of each day. Figure 8 illustrates the impact of this on the β service level in the urban CS network. A small proportion of the demand spikes that previously could not be facilitated could now be satisfied. This increased the average β service level in the experiment by 1.9% if at least 80% of the trips starting in the rural area ended in the urban area. This increased the profitability of the entire network.

Upscaling of rural CS networks

It became clear that most of the effects observed also depended on the relation between urban and rural vehicle stocks. Therefore, we surveyed the effect of multiple separate rural areas connected to an urban CS area. Demand was again assumed to be 50% in the rural areas. This test represented a typical CS development strategy. Unfortunately, the impact of the described effects decreased with the number of additional rural areas. A given number of efficiently operating urban vehicles could only support a certain number of rural CS vehicles operating on a less profitable basis. Figure 9 visualizes the drop in average total vehicle utilization (left ordinate) and, exemplarily, the urban demand increase required to compensate for this drop (right ordinate).

However, it should be noted that average fleet sizes in urban areas are often much larger than the 40 cars assumed in our simulation model. The average CS fleet size for one urban area in Belgium, France, or the Netherlands is typically larger than 100 vehicles, and in Germany even larger than 200 (Münzel et al. 2017). These higher numbers then allow for larger fleets of rural cars to be supported. However, increasing the number of vehicles in our simulation model mostly affects utilization and leads to similar outcomes as indicated by the variation of demand. If demand is also increased proportionally in order to hit the desired daily vehicle-to-trip ratio the results approach the ones presented above. Still minor increases in β service level can be observed due to more flexibility in demand satisfaction from the larger car pool. This observation aligns with findings in Barth and Todd (1999), Cepolina and Farina (2012) and Clemente et al. (2013).

Fig. 8 Urban β service level in the urban CS area



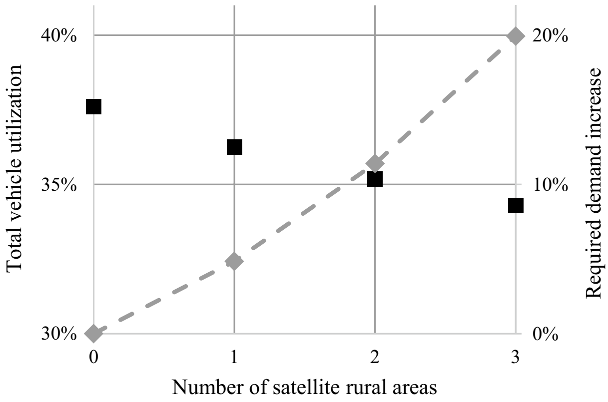


Fig. 9 Increase in the number of rural CS units

Conclusion

As expected, extending CS services into rural areas offers some challenging issues. If a CS enterprise runs a profitable urban CS network, this can serve as a development base for rural areas nearby—as simulated in our model. The experiments conducted showed some promising results, and led to the following strategic implications.

- If the enhanced attractiveness of a more widespread CS service increased CS demand in existing urban CS areas, this compensated for the lower utilization of CS vehicles operated in rural areas. The average vehicle utilization across all of the vehicles operated eventually exceeded the former utilization levels of urban-only CS.
- Longer distances between urban and rural areas increased the overall vehicle utilization rate and may compensate for lower demand. Typical travel distances of between 30 and 55 min offered good utilization values.
- Additional trips from urban to rural areas also had a noteworthy impact on total vehicle utilization. The urban area had the suitable user groups and better predictable demand, which correlated with longer travel times than for inner-city trips—with this factor increasing the profitability of the entire network. This only applied if the rural area represented, for example, a valuable tourist destination (Wappelhorst et al. 2014).
- If organized as a one-way trip system, the CS vehicles in rural areas could temporarily increase the vehicle pool in urban areas during peak demand times. This slightly increased the service level achievable in the urban CS network. A reservation system will be required to ensure reliability for users.
- Each well-functioning urban CS network had only a limited capability to support additional CS vehicles in surrounding rural CS services. It seemed to be fruitful to add fewer new service areas per city and to repeat this for multiple cities, instead of overburdening a single urban CS network.

Considering all of the factors together can ensure that CS development in rural areas may be profitable. It was proved that the factors leading, unquestionably, to lower demand in rural areas can be compensated to a certain degree. However, transportation demand in rural areas remained a great unknown (Abenoza et al. 2018), though it determined whether a minimal required vehicle utilization level could be realized. Demand numbers could be taken from demand modeling approaches or transferred from other transportation modes, e.g. taxi trips (see Brandstätter et al. 2017). The eminent fear of CS further cannibalizing the public transportation services remaining in rural areas must be analyzed for each case individually (Stathopoulos and Sener 2017). However, public busses with only one or two passengers are more ecologically harmful and more expensive to run than individual trips in CS vehicles. This can be important for municipal financial support of various transportation modes, thus further increasing the attractiveness of CS.

The aim of this study was to support vehicle sharing expansion strategies into rural regions. The applied simulation study provided experiments that illustrated potential opportunities to overcome low-demand situations. The study focused not only on the performance of stand-alone sharing services for rural regions, but for networks that included urban areas. This approach did not exclude far-off and less accessible rural areas from any future CS development. Instead, newly established CS networks—according to the strategy presented—may function as new bases for further network developments. At a certain point, current urban vehicle sharing markets will be fully exploited, and rural areas will become a contested market. The promising findings of our simulation study can help in finding the most profitable region for the initiation of future expansion strategies. Furthermore, CS offers the potential to help arrest rural exodus in some regions. Nonetheless, this would require more detailed insights and the filling of existing research gaps. Vehicle and staff relocations were not considered in our model, but may require more time and incur higher costs than in inner-city CS networks. Therefore, future research should consider actual costs and revenue in order to compare achievable profit from various network configurations. In addition, dynamic pricing can help to address the vehicle relocation problem. Some fruitful approaches examine the modeling of optimal CS station locations for rural regions, or survey the development of future rural populations (e.g. the number of residents holding driving licenses and possessing internet skills). One major topic will likely be the development of a dedicated CS demand modeling approach for rural areas. Finally, different CS pricing models need to be compared and modified for rural services in order to maximize profits for the CS operator—and to minimize cost for the customer.

Acknowledgements The authors would like to thank the anonymous reviewers for their constructive remarks.

Author's contribution Stefan Illgen reviewed the literature, designed the simulation model and performed and analyzed the simulation experiments. Michael Höck supervised the research and provided critical feedback. Stefan Illgen and Michael Höck wrote the manuscript.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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