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Article

Sustainable Business Models for Innovative Urban Mobility Services

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Abstract: Any sharing mobility service aims to make urban mobility sustainable to help reduce environmental impacts and improve the quality of life for all in cities. Many transport services are not currently self-sustainable. The Life for Silver Coast (LifeSC) opened its mobility services on 22 May 2021 and offered electric mobility services during the summer for a few cities in Tuscany. E-bikes and e-scooters can be financially neutral, and even profitable, thanks to the low costs of the vehicles, but they only see a high utilization rate in winter. Shared electric cars, meanwhile, are not profitable. A new shared service that is viable must be profitable to become widely adopted and significantly contribute to sustainability. A few key characteristics have been identified, and one has been tested with a new business model that combines ride-sharing and car-sharing. The innovative Ride Sharing Algorithm (RSA) has been tested based on data from a potential city, Monterondo, where many commuters travel daily to Rome by train. The Italian census and local survey data allowed for the simulation of the scheduling of vehicle rides and an evaluation of the economic results, which could be positive if enough interest for such a system exists among the people, as at least 400 commuters from Monterotondo go to the train station daily in the morning and return in the afternoon. Such a transport demand would justify a new commercial sharing service by using the model tested with the RSA algorithm.

Keywords: shared mobility; transport services; business model; sustainability; ride-sharing; car-sharing; transportation

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1. Introduction

The transport sector, as the largest carbon emitter ([1,2]), is central to the climate crisis and the transition to a Net Zero economy [3], yet it has shown no clear emissions reduction. This implies a rapid and radical action is needed to decarbonize transport. More intensive use of fewer vehicles can effectively cut emissions, but there is currently no coherent national or local policy framework for the integration of shared car use with other mobility options. This lack of integration, especially where public transport is limited, hinders progress. Resistance to sharing is due to the wrong questions being asked; the focus should be on enabling greater levels of sharing and innovations that make not owning a car more accessible [4].

This article is an extended version of a conference paper presented at the EVS37 Symposium (COEX, Seoul, South Korea, 23–26 April 2024) [5]. The paper aimed to review the literature on sharing vehicles (mostly electric). Then, it analyzed the Life for Silver Coast (LifeSC) results, which involved the authors through direct design and experimentation, survey, data collecting, and results evaluation. The results promise positive benefits for commuters, entrepreneurs, and, last but not least, the environment. However, the economic results of e-car sharing are still negative.

This article suggests that several business and transport-sharing models may bridge the gap uncovered by LifeSC and other experimental projects. It proposes a use case combining project outcomes, authors' experiences, and available commercial solutions. It also simulates a real case scenario, based on Italian census data, of a feasible business model with a dedicated algorithm.

The Life for Silver Coast (LifeSC) project began its public mobility services on 22 May 2021, and focuses on developing and testing new electric vehicles and mobility services in the regions of Orbetello, Monte Argentario, and Isola del Giglio. It provides land and water electric transport services (like minibuses, e-boats, e-bicycles, e-scooters, and e-cars). All these services are integrated into a single mobility platform, allowing users to plan their travel, purchase tickets, and book and use the services through a "one-stop-shop" system. Professional drivers provided the minibus and e-boat services, which worked via fixed scheduling. So the literature review in this article focuses on commercial sharing services for urban mobility, especially e-cars.

As expected from the literature, the LifeSC ended with negative results for e-car sharing services, while e-scooter and e-bike sharing services were positive. These positive results do not properly take into account the winter period, and so the real results with a year of service average would be worse.

Our research efforts focus on increasing the efficiency of sharing systems, which are too underutilized today, but do not involve new business models. This article discusses possible features and technological solutions to make the business positive, even in small peripheral areas or towns. A new business model was therefore tested with dedicated simulations and real transportation data; the purpose of this simulation was to demonstrate its feasibility as a commercial solution for a sharing service.

Beyond this introduction, this paper is organized into four sections. Section 2 details the literature on sharing transport services, models, and their benefits. Section 3 describes the LifeSC project, its results and lessons learned, and identifies a few solutions to make electric vehicle sharing profitable. Section 4 is devoted to the algorithm description and simulations of the new ride-sharing business model. The Section 5 concerns conclusions and future development.

2. Literature Review

The concept of car-sharing, first defined by Susan Shaheen, explores the impacts of vehicle-sharing systems on society and mobility (one of the latest publications [6]). No single business model for sharing services dominates ([7]), suggesting that these services aim to reduce vehicle ownership by encouraging infrequent car users to opt for shared vehicles. These models can vary significantly in tourist areas due to seasonal demand fluctuations. Shaheen's research indicates that the initial motivation for sharing services was to provide the benefits of car mobility without the associated purchase and maintenance costs [8]. Advances in digital technologies have made car-sharing more attractive, enabling remote bookings, vehicle access, and real-time tracking. These developments have established car-sharing as a viable alternative transport mode in various urban areas [9].

Business car-sharing models are typically categorized into round-trip, point-to-point, non-profit/cooperative, and peer-to-peer (P2P) sharing. However, differences exist even within these categories. Remané proposed a detailed classification scheme in 2016 [6] to address this, as shown in Table 1.

It translates the aforementioned technological advances into creating value-added economic solutions; it can be used for more accurate analysis than existing operators and the systematic discovery of new business models. This taxonomy, later adopted by SAE International in 2018, aims to standardize terms and definitions [10].

The paper [11] describes the socio-demographic factors influencing the demand for different car-sharing services. A study titled "I like it, but I don't use it" suggests that free-floating electric vehicle services are generally preferred [12]. It also notes that the decision to use car-sharing services depends on service characteristics, trip type, and service quality. High-quality services with accessible vehicles are crucial for maintaining active users. Research [13] has shown that fare is critical in attracting users. As the references [14–16] suggest, the attractiveness decreases in sprawled cities with low inhabitants where transport lacks frequency and capillarity. Many studies have investigated the attractiveness of a sharing service in areas not covered. These studies are based on surveys and various demand transport models [17–19].

A simulation method was developed and tested in Turin to define optimal fares based on user profiles, considering mobility needs, usage hours, frequency, and urban congestion levels [20].

Low utilization rates are a common issue in car-sharing, often due to demand polarization. A proposed solution involves user-based vehicle relocation, where users are incentivized ([21]) to park in high-demand areas, increasing vehicle availability and operator profits.

Table 1. Taxonomy of the different car-sharing services and business models (Reprinted from Ref. [22]).

<table>
<tr><th colspan="2">Dimension</th><th colspan="12">Characteristics</th></tr>
<tr><td rowspan="4">Value proposition</td><td>Destination</td><td colspan="4">Roundtrip</td><td colspan="4">One-way</td><td colspan="4">Roundtrip with option for one-way</td></tr>
<tr><td>Minimum duration</td><td colspan="4">At least 1 day or longer</td><td colspan="4">Hourly</td><td colspan="4">By the minute</td></tr>
<tr><td>Vehicle types</td><td colspan="6">Identical or very similar vehicle available</td><td colspan="6">Very different vehicle available</td></tr>
<tr><td>Additional benefits</td><td colspan="4">Free/discounted parking</td><td colspan="4">Delivery by owner</td><td colspan="4">No additional benefits</td></tr>
<tr><td rowspan="2">Interface</td><td>Vehicle booking</td><td colspan="4">Reservation and fixed return time</td><td colspan="4">Instant access and fixed return time</td><td colspan="4">Instant access and open ended</td></tr>
<tr><td>Vehicle access</td><td colspan="4">Manual key handover</td><td colspan="4">Lock box for key</td><td colspan="4">Automatic</td></tr>
<tr><td rowspan="2">Service platform</td><td>Booking platform</td><td colspan="6">Proprietary</td><td colspan="6">Open for other providers</td></tr>
<tr><td>Parking infrastructure</td><td colspan="3">Dedicated carsharing station</td><td colspan="3">Only attached to other stations</td><td colspan="3">Street parking</td><td colspan="3">Private homes</td></tr>
<tr><td rowspan="3">Organizing model</td><td>Vehicle ownership</td><td colspan="6">Operator owned</td><td colspan="6">Private customers</td></tr>
<tr><td>Vehicle maintenance</td><td colspan="6">Maintained by operator</td><td colspan="6">Maintained by private customer</td></tr>
<tr><td>Vehicle refueling</td><td colspan="4">Refueled and paid by owner</td><td colspan="4">Refueled by driver and paid by owner</td><td colspan="4">Refueled and paid by driver</td></tr>
<tr><td rowspan="4">Revenue model</td><td>Price structure</td><td colspan="6">By duration only</td><td colspan="6">Combination of duration and distance</td></tr>
<tr><td>Transaction-based revenues</td><td colspan="6">Service fee (including insurance)</td><td colspan="6">Commission and/or insurance</td></tr>
<tr><td>Continuous revenues</td><td colspan="2">Membership fee from drivers</td><td colspan="2">Service fee from car owners</td><td colspan="2">Subsidies</td><td colspan="2">Advertising</td><td colspan="2">Combination of multiple sources</td><td colspan="2">No continuous revenues</td></tr>
<tr><td>Organizational ownership</td><td colspan="4">Private company</td><td colspan="4">Cooperative</td><td colspan="4">Government owned</td></tr>
</table>

Another strategy is to offer different services at different times, catering to commuters in the morning and central city activities during the day. The analysis of the (simulation) results shows that, with a user-based relocation strategy, the number of rejected bookings can be significantly reduced, even with a relatively small number of vehicles, and, at the same time, the operator's profit can be increased by satisfying more demand with the same vehicle fleet. Another way to improve the utilization rate of shared vehicles is to guarantee different services by the same fleet at different times. In the early morning, the service is oriented towards commuters and would be conceived to have them driving toward the attractive destinations of the city.

In contrast, in the middle of the day, the service remains concentrated in the center of the main centrality. The research [23] has studied an interurban car-sharing service by modelling the behavior of potential users through a stated preferences survey, demonstrating the considerable theoretical attractiveness of a service aimed at bringing commuters from other smaller municipalities of the same province to Salerno city.

P2P sharing services, where individuals share vehicles, have gained attention. In 2012, Shaheen [24] found 33 personal vehicle-sharing operators worldwide, indicating the potential of these services to enhance transport sector connectivity and reduce vehicle ownership.

Car-sharing services have demonstrated various positive impacts, including:

- Environmental benefits [25,26];
- Reduction of car-ownership rates [9,27];
- Reduction of vehicles-miles travelled [25,26];
- Efficient transportation alternative, particularly when it complements existing transportation modes or supplements off-peak public transit services [28,29];
- Decreasing the demand for cars, reducing traffic and parking congestion, and increasing social cohesion among sharers [9,26,30–32].

A recent evaluation [33] identified 245 car-sharing operators worldwide; 58% station-based, 30% free-floating, and 11% P2P. The I Share Life project [34] has at least three fundamental objectives in common with LifeSC. These are:

- Maximize vehicle utilization rate;
- Serve customers with different needs who would not guarantee intensive use of the vehicle but who, having complementary needs, can do it together;
- Identify a main customer (preferably a business) who acquires (buys or rents) electric vehicles and who, not using them entirely, makes them available to others on certain days and within certain time slots so that they contribute (even if minorly) to lowering the overall costs of vehicles.

Other considerations come from sharing the same space; sharing a vehicle reduces privacy as well as security [31] and personal safety. For example, sharing raises the risk of contagion, as demonstrated by the COVID-19 pandemic, which lowered people's sharing propensity in LifeSC (evaluated with surveys), which opened its service in the summer of 2021 with the first re-openings of public transportation.

This effect was partially mitigated in LifeSC thanks to explicit (and well-publicized) sanitization protocols, convincing people to re-commence sharing rides through information and education.

Two noteworthy papers have addressed the issue of education and the problem it poses for the use of shared services [35] and electric vehicles [36]; both will be needed with technological solutions to share rides without any contagion risks.

Lastly, several papers have investigated the role of the legal framework (see [15,37,38]), which sets up the basis for behavioral change in people. It could "help" with pushing measures (Limited Traffic Zone—LTZ, circulation taxes, parking lot absence, enforcement in traffic control, and no parking zones, etc.) These measures force people to find other solutions for transport that they had not yet considered, such as giving up their car and using public sharing systems. It is worth noting that a specific information and education campaign for people and stakeholders should accompany these solutions. It should aim at understanding people's needs, spread knowledge of the benefits of sharing, and avoid misunderstandings (see [39,40]).

In conclusion, effectively managing and integrating car-sharing services are essential to attracting and retaining users, ultimately contributing to more sustainable urban mobility solutions.

3. Life for Silver Coast Project: Outcomes, Lessons Learnt, and New Business Models

This section concerns the Life for Silver Coast project, the lessons learnt from this experience, technical parameters, performances, costs, revenues, and economic results. It also discusses possible solutions to achieve viable commercial models in real applications.

LifeSC introduced three vehicle-sharing services: e-bikes, e-cars, and e-scooters. Initially, all journeys were round-trips with pre-established parking areas, but the system transitioned to a free-floating model for flexibility. Initially, it was cluster 1 ([22]), where all journeys were round-trip.

The Life for Silver Coast (LifeSC) project began its public mobility services on 22 May 2021, and focused on developing and testing new electric vehicles and mobility services in the regions of Orbetello, Monte Argentario, and Isola del Giglio. The services provided included collective options, such as electric minibuses and boats in the Orbetello lagoons and at sea, and individual services, like sharing e-bicycles, e-scooters, and e-cars. All these services were integrated into a single mobility platform, allowing users to plan their travels, purchase tickets, and book and use the services through a "one-stop-shop" system. The vehicles were different and multipurpose, so the project switched to a service that covers two types: cluster 4 (free-floating services) and cluster 5 (one-way services), with stations to pick up and leave the vehicles (hubs for bicycles and charging stations for cars and scooters).

This section is divided into three parts: the economic results and outcomes from the LifeSC project, the lesson learnt from LifeSC, and new business models to bridge the gap.

3.1. The Economic Results and Outcomes from the LifeSC Project

The tariff structure used is challenging to classify compared to others in the past; those applied in LifeSC demos are indicated below (https://www.lifeforsilvercoast.eu/en/summer-2021/, accessed on 30 August 2024):

- E-bikes were rented for €0.21 per minute up to the first hour of use, for €19.90 from 1 to 3 h, for €26.90 from 3 to 6 h, and €34.90 after 6 h for the daily rate;
- E-scooters were rented for €0.25 per minute up to the first hour of use, €22.90 from 1 to 3 h, €29.90 from 3 to 6 h, and €39.90 after 6 h for the daily rate;
- E-cars were rented for €0.28 per minute up to the first hour of use, €26.90 from 1 to 3 h, €32.90 from 3 to 6 h, and €49.90 after 6 h for the daily rate.

The tariffs changed with the rental time, covering more business models with the same service. The pay-by-minute model typical of free-floating services and used for short trips to move quickly in a selected area was supplemented by the tourist-excursions model typical of the short-term rental for bicycles and (mostly) scooters in tourist areas to reach a faraway beach or another tourist attraction and by the daily-rental model typical of people needing to travel by car for one or a few days.

This last model was mostly used to drive to Florence or Rome because the car was rented in Orbetello with the battery fully charged and driven for almost its entire available range (from 200 to 300 km), where the electric car could access the central LTZs and be parked for free in a parking spot reserved for EV charging.

The person would then spend the entire day in the city center and retrieve the car fully charged to drive back to Orbetello. It is an unconventional use of electric vehicles but has significantly increased the rental hours (and therefore the utilization rate) and responded to a specific need. Naturally, from the point of view of sustainability, it might have been better to favor the use of the train to reach both Florence and Rome, but financially, it helped the service.

Table 2 shows the overall results of the LifeSC sharing service. The project usage rates were: e-bikes 22%, e-cars 16%, and e-scooters 7%.

Table 2. LifeSC main results.

Parameter	Unit	Car	Scooter	E-Bike
Number of rents	#	907	116	110
Average rents per vehicle	#	302.3	4.64	4.78
Total rental time	-	587 h 29′ 24″	586 h 41′ 31″	298 h 51′ 10″
Total distance travelled	Km	9394	5543	1300
Service period	Day*vehicle	156	349	57
Utilization rate	%	16	7	22

Overall, the three vehicle-sharing services collected €12,120 in revenues, divided as follows:

- €4986.49 was collected from the cars over 156 total days of availability for all vehicles, which, extended throughout the year, would make the estimated income of a car over the course of a year 11,650 €/year*vehicle;
- €5387.30 was collected from the scooters in 349 total days of availability for all the scooters, which extended over 365 days, would make the estimated income for a scooter 5635 €/year*vehicle;
- €1764.10 was collected from bikes, with bikes available for a total of 57 days, which extended over the 365 days of a year, brings the expected income for a bike to 11,500 €/year*vehicle.

The annual costs of sharing services were the following:

- Vehicle Depreciation Costs: These costs were determined by dividing the purchase cost of the vehicle by its years of use. Shared cars typically travel 10,000–12,000 km/year for a maximum of 5 years, after which they require replacement due to obsolescence and safety concerns. Scooters and bikes have even shorter lifespans. So the purchase cost was divided by five for cars and three for e-scooters and e-bikes.
- Fixed Ownership Costs: These encompass property taxes and insurance. Insurance expenses vary based on the number of vehicles insured, usage patterns, and the initial cost. A standard cost of €1000/year per vehicle has been applied here. Smaller, cheaper scooters and bikes, despite their lower value and speed, incur higher insurance costs due to unfavorable accident statistics.
- Maintenance: based on local market research, maintenance is typically calculated as a percentage of the vehicle's purchase price, about 5% for traditional vehicles and 2% for electric ones annually.
- Washing Costs: each car required a weekly wash at €6 per wash. Scooters and bikes can be cleaned every two weeks, with each wash costing €4.
- Personnel Costs: this covers vehicle repositioning, washing, recharging (where applicable), maintenance, and emergency interventions. The number of people required depends on the service offered. In the LifeSC, a person managed 3 cars, 25 scooters, and 23 bikes. the exact time allocation for each service is unknown, so it was assumed to be evenly distributed for calculation purposes.
- Energy Costs: actual energy consumption costs were not billed to the service manager during the project, as the energy provider was a project partner and specific energy consumption data for each vehicle was unavailable; these were therefore estimated based on average energy consumption.
- Infrastructure Investment Costs: These were evaluated by dividing the total infrastructure expenditure by the useful life of the infrastructures (including depots, workshops, and charging stations). In this project, only the e-bike sharing service required a dedicated infrastructure to be maintained and amortized; the others were demanded by third parties, which also managed other services.

Table 3 compares the vehicle and operation costs of the three services and shows the energy evaluation. For example, the energy costs were 0.45 €/kWh. This parameter is an average value based on billing data provided by EnelX, the partner of the project, across the whole experimentation period. Public data by the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) are available at: https://www.arera.it/dati-e-statistiche/dettaglio/andamento-del-prezzo-dellenergia-elettrica-per-il-consumatore-domestico-tipo-in-maggior-tutela, accessed on 20 August 2024), and the cars had an average consumption of 0.2 kWh/km; so a car costed 0.09 €/km. The car fleet travelled (overall) 9394 km in 156 days*vehicle of operation, expanding from 156 to 365 days; each vehicle was expected to travel 21,980 km/year, costing 1980 €/year of energy.

Table 3. Operation and energy cost comparison between the three services.

Cost Per Vehicle	Unit	Car	Scooter	E-Bike
Purchase (VAT included)	€	34,000	2460	1200
Number of vehicles	#	3	25	23
Years of depreciation	Year	5	3	3
Depreciation cost	€	6800	820	400
Insurance and circulation	€	1000	1000	1000
Maintenance	€	680	50	24
Washing (52 weeks/year)	€	312	104	104
Personnel	€	3333	400	440
Infrastructure	€	0	0	330
Sub-Total Operational Costs	**€**	**12,125**	**2374**	**2298**
Energy cost	€/kWh	0.45	0.45	0.45
Energy consumption	kWh/km	0.20	0.05	0.02
Distance travelled	km	9394	15,510	1330
Days of operation	days	156	349	57
Equivalent yearly distance	km	21,980	16,221	8516
Sub-total energy costs for a year of service	**€**	**1980**	**130**	**80**

In the LifeSC demonstrations, bikes were stored and recharged within technological hubs; each costed €20,000 and accommodated 6 bikes with 10-year life expectancies. Amortizing the cost of the infrastructure on the 6 bikes over 10 years added a further cost of 330 €/year*vehicle to the e-bike costs.

The annual cost of sharing one vehicle is the sum of operation and energy costs (sub-total from Table 3).

It equals 14,105 €/year*vehicle for cars; 2504 €/year*vehicle for scooters; and 2378 for e-bikes, €/year*vehicle. Though costs (and revenues) are commercially sensitive data not commonly publicly available, validating their share in the balance is possible.

Table 4 shows the share of the different costs, with data collected by the Rome mobility agency (Roma Servizi per la Mobilità) [41].

Table 4. Direct cost component shares, translated from the Rome Car-sharing Service (slide 25).

Direct Costs Component Share	Percentage
Fuel	14%
Car wash	2%
Vehicle rental (depreciation, maintenance, insurance, and taxes)	36%
Personnel	24%
Call center	12%
Technologies	10%
Administrative costs	2%

Table 5 compares results from the Rome service with the ones from LifeSC, where this latter used only the first four categories and accounted for the first.

Table 5. Results comparison between Rome and LifeSC use cases.

Direct Costs Component Share	Rome	Rome Re-Scaled Value	LifeSC
Fuel/energy	14%	18.4%	13.1%
Car wash	2%	2.6%	2.1%
Vehicle depreciation	36%	47.4%	60.1%
Personnel	24%	31.6%	22.0%
Total	76%	100%	100%

The difference in categorizations between the Rome and LifeSC use cases forced us to re-evaluate the Rome results to fit with LifeSC (see the relative column “Rome re-scaled value") by using a linear proportion. The Rome car-sharing service cost of technologies, administration and the call center are (overall) 24% of the total service costs (Table 4), but in LifeSC they were neglected. The linear proportion method neglects the same categories of LifeSC in the Rome case and re-scales their percentages to 76% (i.e., Rome personnel represent 31.6% of the 76%).

LifeSC car costs, including depreciation, taxes, insurance, and maintenance, equal 60% of the annual cost; in Rome, it was only 47%. On the contrary, fuel/energy accounts for 13% of LifeSC's costs, and 18% of Rome's. These differences align with expectations as the LifeSC vehicles were electric (more expensive than traditional ones), and they were not leased or rented but purchased, which had a higher overall cost, but electric energy is cheaper than fuel. Car wash costs were in line, and LifeSC's personnel costs were cheaper (22%) than Rome's (32%).

The personnel cost is a highly relevant factor; one person did manage the services in the demonstration, but the demonstration period was too short to consolidate the value. On the other hand, Rome had a much more dispersive environment, and even the easy task of reaching the carwash might have required much longer than in Orbetello. Overall, the magnitude of the calculated shares is in line with expectations and the Rome experience.

Financially, the services generated revenues of €12,120, divided among e-cars (€4986.49), e-scooters (€5387.30), and e-bikes (€1764.10). Costs included vehicle depreciation, insurance, maintenance, washing, personnel, and energy, totaling annual costs of €14,105 for e-cars, €2504 for e-scooters, and €2378 for e-bikes. The balance between costs and revenues per year is extraordinarily positive, so positive that it is unlikely. These are as follows:

- The cars have 11,560 €/year*vehicle of prospective revenues and 14,105 €/year*vehicle of prospective costs, losing 2455 €/year each; i.e., just over 17% of the annual cost is not covered by the revenues;
- The scooters have 5635 €/year*vehicle of prospective revenues and 2580 €/year*vehicle of prospective costs, earning 3131 €/year each or more than 125% of the expenses is profit;
- The bikes have 11,500 €/year*vehicle of prospective revenues and 2318 €/year*vehicles of prospective costs, earning 9122 €/year each, i.e., the net profit is almost four times the cost invested.

3.2. The Lesson Learnt from LifeSC

From LifeSC data, e-bikes were used 22% of the time they were available, cars 16% (also thanks to several multi-day rentals that extended the rental times encouraged by the maximum daily rate), and scooters 7%. The e-bike data is less robust than the others because not all bikes were available at the same time as there were not enough active stations, and the e-bike sharing model was station-to-station; their availability is therefore calculated as a sum of the times each e-bike was made available for rental. However, over nearly four months, from May the 22nd to 21st September (when data were collected), 23 e-bikes, instead of being available more than 2500 e-bike*days, were available for only 57.

These data are from the summer of 2021, in the thick of the COVID-19 pandemic. The tourist flow has been verified to check whether the summer of 2021 was less attractive for tourists than the preceding ones going back to 2019. According to the local Chamber of Commerce data for 2021, the tourist flow was slightly above the data for 2019.

The decrease in international tourist presence was more than compensated for by the increased presence of Italian tourists. There was marginally less presence in hotels and more in summer houses (whether rented or owned). Overall, the COVID-19 pandemic did not influence the tourist flow into the area for the summer of 2021.

The e-bike balance is biased by only 57 days of availability for 23 bikes (less than 3 days per bike on average), maybe due to the hub (the rental stations) being late and the 23 bikes not being available altogether, which had increased the utilization rate of the few bikes available. These rates were influenced by the limited availability of the e-bikes and the differing rental purposes for each vehicle type, such as daily rentals for long-distance trips to cities like Florence and Rome.

As reported in the Chinese study, a realistic service has an average utilization rate of 4% to 10%; it reaches 15% (only in peak hours with some other conditions). So the average of 20% measured in Orbetello seems overestimated. The e-scooter service had a very positive balance, with a utilization rate of only 7%. The bike service would have a positive balance with a similar utilization rate. Each bike would collect about 4200 €/year*vehicle, still nearly twice the costs.

The utilization rate is the cornerstone of the profitability of any sharing services.

The studies [42–44] suggest a few ways to raise the utilization rate by optimizing intermodal hub vehicle location with predictive analysis of traffic and transport demand and using an operator that can relocate the vehicles just in time for their utilization; indeed, such approach could solve the problem in short term, but it requires wide investigations of the territory and its peculiarity (it cannot be applied everywhere) with real data simulations on booked services, and it should be repeated with change of boundary conditions.

Another way to raise the utilization rate is reducing the number of vehicles, but this affects the quality of service with a twofold negative impact. Firstly, it reduces the transport demand, and even the remaining demand loses confidence in the system, which would negatively impact the possibility of users making radical choices like giving up private vehicle ownership, which is the main contribution to sustainability sharing services. This utilization rate, obtained for the summer months, was considered constant throughout the year. This assumption can be plausible for cars (a limited number of vehicles used mainly by permanent residents even in summer) but is much less so for scooters and bicycles, which will be affected by weather and environmental conditions.

If the utilization rate for bikes and scooters were 7% in summer (3 months of the year) and 1% in the other 9 months of the year, this means an average value of 2.5%, the equivalent revenues being 1800 €/year*vehicle for bikes and 1900 €/year*vehicle for scooters. These more realistic projections for using scooters and bicycles over the year would bring all three balances into negative territory.

It is worth noting that the budgets of the three shared services are neutral if the company costs, mobile APP and IT services costs, and remuneration of capital and personnel are not paid by the service revenues but “offered” by local (or not local) supporters and partners. Such a situation is typical of services organized by municipalities or municipal companies that use existing staff, structures, call centers, and public funds to purchase (or build in-house) IT services for mobility.

To make any of these services an appealing investment for private investors, who use their risk capital and expect remuneration, supplying these services is not convenient. The critical parameter remains the utilization rate, which should be enhanced. Separate studies are required to improve it due to significant differences in vehicle costs between cars, scooters, and bicycles. The utilization rate measured for cars (16%) is insufficient to even the balance. Increasing it above 16% for the whole year is extremely difficult; as a comparison, the car-sharing service managed by the mobility agency of Rome (a much more populous municipality), directly measured by CTL of La Sapienza University in 2012, has a utilization rate between 13% and 19%, and for a sharing business model with fixed stations this extends rental times. Those rates are also aligned with other services, such as free-floating car-sharing, which varies between 15% and 25% during peak hours [45].

Repositioning vehicles dynamically to follow demand can increase the rate. Still, enabling automatic cars requires either many human resources that worsen the balance or a technological revolution. The 7% utilization rate measured for scooters would be widely sufficient to ensure profitability if it could be maintained throughout the year. For example, this goal seems difficult to achieve in winter without a full (or partial) relocation. In any case, sharing bikes and scooters in winter is less doable due to climate conditions.

On-demand management and a personalization of the relationship between customer and carrier would allow for the development of several new connected business lines that would never be applicable otherwise.

3.3. New Business Models to Bridge the Gap

This section discusses how to deploy a potentially profitable sharing service based on background and LifeSC experience; thus, it outlines the key features a vehicle-sharing service must have to be profitable outside the central areas of large cities where the isotropic demand allows for a free-floating sharing model. Vehicle sharing is beneficial when it allows citizens to live without owning cars.

Any such service should not compete against conventional mass transit but be complementary, especially when and where transits are less effective. Generally speaking, transport demand is highly variable throughout the day, the week, and the year. Dimensioning the fleet based on maximum demand would have a negative financial impact; dimensioning it on its lower levels would mean not supplying a good enough service to build customer loyalty.

To deploy a profitable vehicle-sharing service outside central urban areas can be done using five key strategies, each described in the following paragraphs:

- Sharing rides at peak hours and in directions complementarily to public transport;
- Self-repositioning of empty vehicles;
- Shortening or eliminating charging times;
- Differentiating vehicles to lower costs and allowing different uses;
- One integrated service to cover all mobility needs.

3.3.1. Sharing Rides at Peak Hours and in Directions Complementarily to Public Transport

One solution would be to mix car-sharing and ride-sharing. At peak times (and for prevalent directions), the customer rents a seat instead of renting the vehicle. In contrast, the standard free-floating business model is adopted in off-peak times and directions.

The ride-sharing model can work even better if the service is integrated with other "scheduled" transport modes (such as trains or metros). This way, all people from one area travel together toward the transport hub (or vice versa, getting off the train to reach their home). One of the customers drives the car, and the others are passengers. Rental costs are shared (and therefore, services can be used daily), and fewer vehicles are needed because some of them are relocated and can be used again.

A second innovation is also needed to enable this business mode to work. It can be the "on-the-fly" driver exchange. When a pool of customers travels, their trip foresees at least one stop for each destination required by the person involved. The innovation could be adding one more stop (is necessary and if it does not match other scheduled stops) to pick up the driver of the next pool. So, this little detour allows the customers in the first pool to reach their destination, and the vehicle can continue its trip without parking and the customer is picked up before (they have to drive).

Vehicle parking includes the parking slot search, parking, and the closing of the rent (and other non-remunerative actions that require a small amount of time), which could lead to time wasted. If the next driver is not picked up during the trip, when the vehicle is available, it can be too far from the vehicle, while if the previous pool reaches him directly at his home, it can be more productive in terms of time and quality of service.

When looking for a vehicle to rent, each customer must state the origin, destination, desired travel time, and drive availability if required. This service can be implemented quickly thanks to recent improvements in ICT technologies. This new feature can solve the repositioning problem studied in Genova [21] without the inconvenience of parking the car far from the desired destination and could increase the perceived quality of service, which has been demonstrated [12] to be crucial to customer satisfaction.

3.3.2. Self-Repositioning of Empty Vehicles

Vehicles already need much less repositioning with the ride-sharing and the on-the-fly exchange, especially in small places like the LifeSC locations, where picking up the next customer at the "other end" of the municipality only increased the travel by no more than

5 min, while reaching the doorsteps of the destination without the need for parking saves much more than that.

However, having a customer wait for a car when the other one is arriving is still a matching problem with uncertain results and off-peaks; when the demand is deficient, empty-vehicle repositioning might still be needed.

As described in [46–48], technology exists for empty automated vehicles driving at low speeds along pre-certified infrastructures. For example, the patent [49] aims to convoy multiple vehicles (of various types together) with a safeguard mechanical connection to guarantee the same trajectory for all. It also uses a steering mechanism as a backup for automated vehicles (with a steer-by-wire system).

Though this is less certain, even the legal framework might allow it (up to a certain extent and in specific locations). The other technological option to reposition empty vehicles at low cost is to have one driver driving a convoy of up to 10 vehicles (depending on the country and its road regulations, the convoy can be up to 18.5, 32, or 60 m long).

There must be a large enough fleet and a big enough demand to justify repositioning that many vehicles simultaneously. It would be difficult to pay a driver for less than six vehicles at once to reposition. Besides, even to ride an automated vehicle (sharing or not) will cost more than a traditional one, but the people willingness to pay for such a service could be higher and this could justify the investment [50].

3.3.3. Shortening or Eliminating Charging Times

The utilization rate can rise by decreasing vehicle idleness, even for recharging. It is not just a matter of increasing a vehicle's mile range with one charge; the charging strategy must change. There are several technological options to do this, ordered from the easiest to the most complicated:

- Use hybrid vehicles instead of electric ones. Bringing back refueling (customers can do it in exchange for discounts) and extending the range when the vehicle is used for longer trips.
- Faster wireless automatic charging at high power would reduce charging times and the burden on the customer. However, this requires a feasibility investigation because such charging infrastructures are not easy to implement everywhere; e.g., one of LifeSC's issues came from the legal and formal authorization (on-the-road installations) of "static" charging stations and bicycle hubs.
- Online fast charging, analogous to the overhead electricity line used by trams, a few main corridors can be electrified (i.e., be "energy-active") and recharge the passing vehicles. Those technologies would eliminate any need for charging stops, especially in urban settings.

3.3.4. Differentiating Vehicles to Lower Costs and Allowing Different Uses

The vehicle purchase cost impacts the profitability of the models proposed. A mixed fleet composed of many lighter vehicles (slower and cheaper, such as mopeds or microcars); standard vehicles (cars); and a few larger vehicles (mini-vans of up to nine seats) can be a good trade-off. Urban service exploits small vehicles assisted by the larger ones to fulfil most peak-hour transport demand by using car-sharing mixed ride-sharing. Moreover, this second vehicle type expands the covered area by offering interurban trips, especially for off-peak rentals.

Such a mix allows for the selection of different power trains for the various vehicle types, and, as demonstrated in [51], allows for increased efficiency (reduced energy consumption and circulating vehicles for the same transport demand). Larger and standard vehicles can be hybrid, and lighter ones can be electric and have fast charging.

3.3.5. One Integrated Service to Cover All Mobility Needs

Overall, the new service will need to respond to all the customers' mobility needs wherever they need to go with whoever (e.g., pets or babies) at whatever time. This means that every trip needs a vehicle appropriate to its size.

A convenient mobility solution for a standard commuter journey may be a train trip with a shared car waiting for the last mile trip at the arrival station. A crucial requirement is that the customer can plan, book, manage, and have all the information through the same integrated tool.

This solution will increase customer confidence in the service and boost the probability of convincing them to give up vehicle ownership and completely embrace sharing, which will positively affect urban space consumption.

Even more important is that increasing customers' use of shared vehicles can make the balance of the services positive, thus relieving the need for cities to subsidize and sustain shared mobility services.

Many attempts to create a MAAS (Mobility As A Service) integrated platform to have a one-stop-shop platform to access all transport services are underway. However, the main problem has been to "force" every service to be reachable by the same platform. An interesting approach to open innovation and data sharing has been proposed by [52].

4. The New Business Model: Algorithm Description and Simulation of Transport Service in Monterotondo (Rome)

The Ride-Sharing Algorithm (RSA) aims to optimize vehicle use, reduce operational costs, and provide a reliable, integrated service, promoting sustainable urban mobility.

This model intends to offer alternative transport to those users who must reach the station daily (and must return from there in the afternoon or evening). At the same time, other people come to the station and need to reach other locations around the city.

This section consists of five steps: the algorithm description, data collection, Origin–Destination matrices generation, iterative simulations to size the fleet (depending on transport demand and using a random calls generator), and results evaluation for each step.

4.1. Algorithm Description

This RSA for local public transport combines car-sharing and ride-sharing for those areas where the demand does not justify a bus. Such a transport concept is feasible, assuming a demand for counter-flow. When the user calls for a ride, they can either be told to drive a shared car parked nearby or that somebody else driving it will pick her up. Up to nine people share the same ride to the station, with one driving the others (and having a free ride for doing this). The maximum number of people in the same vehicle is limited by street regulations, allowing up to nine people in the same car with the type B license (the most diffused required to drive a car).

After the first ride, the vehicle is left at the station or exchanged "on the fly" so it is picked up by a person driving counter-flow called "User1". They leave the train station, and while reaching their destination, they pick up the driver, "User 2", of the next ride (directed again to the station). Both users go to the destination of User 1, where they leave and give the driver seat to User 2 or another person picked up in the meantime and drive back to the station. The on-the-fly exchange allows a user to close their ride while another user opens theirs up, and such a feature eliminates the search for parking and time losses for people to reach their destination (from the parking slot to their house and vice versa).

Such a transport scheme complements a bus service because it is tailored to areas (or times of the day) where the demand would not justify a busload. To correctly size the vehicle fleet and fine-tune the RSA for planning each user's daily travel requests, simulations were carried out, starting with a zoning exercise of an actual city with distances and conditions of a real use case. The city of Monterotondo (30 km from Rome) was used as a test. The numbers mentioned concern the city of Monterotondo, which has a population of almost 40,000 inhabitants and sees 8222 of them travel to Rome daily. Of these users, about 40% use the train, so they reach the railway station daily using their own transport.

Table 6 identifies the reported categories of trips in the commuting matrix: incoming, outgoing, and internal.

Table 6. Trip categories.

Cat.	Name	Description
A	Internal	They reside in the municipality under consideration and move within it.
B1	Outgoing	They reside in the municipality and move towards an attractor pole (e.g., Rome is an attractor pole for municipalities bordering the ring road).
B2	Outgoing	They reside in the municipality and move to another municipality other than the pole of attraction.
C1	Ingoing	They reside in the attractor pole and move towards the municipality under consideration.
C2	Ingoing	They reside in another municipality other than the attracting pole and move to the municipality under consideration.

Table 7 shows those categories for Monterotondo, divided by mode of transport. The simulations (Section 3.3) were carried out using only outgoing and ingoing trips by train, with B1 plus B2 equal to 3364 and C1 plus C2 equal to 378 users. From now on, internal trips will be neglected. Each category of Table 3 must have an Origin–Destination Matrices (ODM) for each mode of transport.

Table 7. Matrix of trips divided by mode of transport and by reason (study or work).

Cat.	Train	Cars	Bus	Bikes	On foot	Tot	Workers	Students
A	0	6279	823	248	3504	10,854	47%	53%
B1	3199	4561	302	518	160	8740	87%	13%
B2	154	1965	202	34	9	2364	89%	11%
C1	184	910	84	24	0	1202	93%	7%
C2	164	3927	2122	120	67	6400	52%	48%

The following paragraphs describe the data collection, the ODM generation, methods of simulations, and results.

4.2. Data Collection, Assumption, and Simplification

This chapter explains the data collection and elaboration used to feed the algorithm. The primary data sources are the Italian national census entity (ISTAT) through the 2011 census and a local survey of urban travel carried out in cooperation with the Municipality of Monterotondo and the ENEA research department. The following paragraph describes these data sources, the files for graphical processing and the first processing of them, i.e., a simplification concerning the aggregation (graphical and numerical) of the census section data aimed at reducing the computational burden of the simulations.

The Italian census (ISTAT) provides these data, which help design transport services for the Italian territory:

- Commuting matrix (https://www.istat.it/it/archivio/139381, accessed on 15 December 2023), mainly includes the number of individuals who commute daily between one or two cities, their reason (e.g., study or work), and the mode of transport used (vehicle);
- Population data by census section (http://datiopen.istat.it/, accessed on 10 December 2023): This contains information on the number of residents for each section, age, gender, number of persons with income, number of students, buildings, etc. In addition, there is specific data on commercial activities by census section;
- Census of Industry and Services (https://www.istat.it/it/archivio/104317, accessed on 15 January 2024) provides the number of workers and activities available for

each "ATECO" code (Source Italian Chamber of Commerce: http://ateco.infocamere.it/ateq/home.action, accessed on 9 November 2023) for each section. The latter categorizes the type of each activity;
- Geo-fenced graphic files (shapefiles) for processing the census sections, allowing the census information to be analyzed geographically.

For example, Figure 1 shows the 65 sections of Monterotondo (identified by the smaller numbers on the map) that have been reduced into 20 more extensive sections to decrease the computational effort.

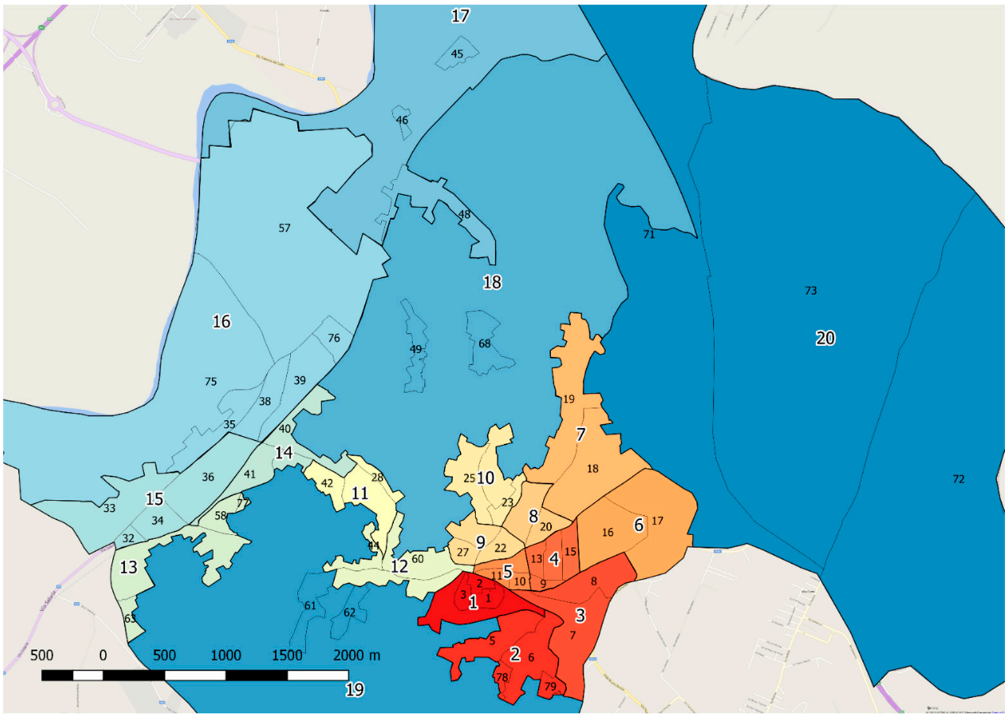

Figure 1. Graphical representation of census area shapefiles, with evidence of census sections. Numbers identify the section and colours have no meaning.

Monterotondo has a resident population of 39,502 (year of reference 2011), and the 65 sections have an average resident population of 607; by applying the abovementioned areas, the average number of residents per zone increased to 1974.

The construction of areas where there is a high residential density (greater than 500 inhabitants per square kilometre^2) has been done by trying to keep the maximum width of the area within 1 km so that it can be considered a single point of generation and attraction of movements to and from that area. While areas with low residential density (less than 500 inhabitants/km^2) were constructed by analyzing the road graph and the travel time by car, e.g., between the two furthest points of the area, the travel time by car should be lower than 5 min.

The survey processing results in:

- Table 8 regarding travel from Monterotondo to Rome by any mode plus train and by car (outgoing);
- Table 9 shows journeys from Rome to Monterotondo by train (incoming) and from Monterotondo to Monterotondo by any mode (internal).

For example, as shown Table 8 for those leaving by train (outgoing), of the 97 valid responses to the question concerning possible interest in the new transport service, 52% went to the station by car, 30% by bus, and 19% on foot, and, respectively, 80%, 86%, and 78%, would be interested in using the service. Those who might be willing to drive are 54%, 28% and 28%, respectively. This proportion applied to the ISTAT numbers (3353 commuters to Rome and other destinations by train from Monterotondo) yields a potential user pool of 1200 people (about 41%), while the incoming commuters by train are 126 (about 33% of the 378).

Table 8. Survey results in Monterotondo: Potential users of the service proposed by Medium (outgoing users).

	Mode of Transport	**Survey Answers**	**Interested in the Service**	**Willing to Drive**	**Total ISTAT**	**Inhabitants Potentially Interested in Driving**
52%	Car + train	50	80%	54%	1728	933
30%	Bus + train	29	86%	28%	1002	277
19%	Feet + train	18	78%	28%	622	173
	TOTAL outgoing by train	97	81%	41%	3353	1383
	Outgoing by Cars	38	80%	26%	4561	1200

Table 9. Survey results in Monterotondo: Potential users of the service proposed by Medium for users travelling to Monterotondo by train (incoming) and within Monterotondo (internal).

	Mode of Transport	**Survey Answers**	**Interested in the Service**	**Willing to Drive**	**Total ISTAT**	**Inhabitants Potentially Interested in Driving**
	Incoming by Train	11	50%	33%	378	126
62%	Internal by Cars	89	12%	8%	6279	494
14%	Internal by Bus	20	50%	10%	823	82
24%	Internal on foot	34	56%	18%	3504	618
	TOTAL internal users	143	28%	10%	10,606	1113

A few assumptions of RSA to reduce complexity:

- Each random generation of calls is repeated three times, so the result indicators represent the average values;
- The RSA based the vehicle availability for accepting new trips in the relocalization. Each vehicle is pre-located the night before near the location of the first passenger. Once they reach the station, the incoming user or the operator relocates the vehicle. The operator can also use the cited patent [49] to convoy up to 6 vehicles at a time, and it is estimated that in 1 h, an operator can relocate up to 12 vehicles;
- The fleet dimension (number of vehicles) should be the same all day; during the afternoon, the transport demand is spread out over a longer time: the same commuters departing from 6:00 a.m. to 9:00 a.m. arrive in the afternoon between 1:00 p.m. and 8:00 p.m.;
- Vehicle size is the same, with a maximum of 7 passengers simultaneously. Even if bigger vehicles exist (up to 9 passengers) those are too large and usually difficult for average drivers to drive, whereas the 7-passenger vehicle is more or less an ordinary SUV or of station wagon size;
- As a first approximation to give more flexibility to the RSA, the algorithm could ask the user if she can change her train after the call assigning is carried out. RSA assumes the user will accept the change indiscriminately, with the previous or right after her first train choice. In the real world, such possibilities can be implemented with commercial strategies that make the time shift advantageous for the user and gather enormous advantages for the business (otherwise, they could need more vehicles to satisfy the same calls);
- Travel time to reach the train station is equal to 300 s;
- Safety coefficient time: traffic time loss 1.3, detour time for passenger collecting 1.2;
- Passenger boarding time is equal to 30 s;
- The tolerance time between two consecutive trips of the same vehicle is equal to 180 s;

- The alert time for the operator (or a counter-flow user who relocates the vehicle) starting from the depot/station with a new vehicle is 600 s;
- The counter-flow demand is sometimes too small to satisfy an efficient relocation, so the RSA evaluates the operator's requirement. They also proceed to other duties such as vehicle services (bringing them to maintenance or washing in off-peak hours);

This new business model can have a tariff model with a user fare equal to 0.5 €/pax*km (minimum 1.2 €/trip and maximum fare of 2.5 €/trip), which is waived for the driving user.

The costs are:

- Operator 27,000 €/year, used to move vehicles to the depot for maintenance and wash and to relocate when necessary (average gross annual remuneration of a pro driver);
- Vehicle 6500 €/year, using a leasing formula, which includes maintenance, tax, and insurance costs (quotation of a 9 seat vehicle for a rental period of 4 years);
- Average vehicle consumption is 15 km/L of diesel, with an average value of 1.5 €/L.

4.3. Procedure for Generating Origin–Destination Matrices (ODM)

This chapter concerns the generation of a set of ODM representing the demand for mobility. The matrices were constructed using a bi-proportional method [53] and then simplified to reduce their size and constitute the database for the simulation.

The simulations are limited to analyzing only the trips needed for simulation, and they are outgoing and ingoing trips by train.

Attraction percentages were applied to each category to produce a travel demand for the simulations. The first hypothesis is for outward journeys by train (outside the municipality) and internal (within the municipality). The initial percentage of interest was set at 10%, and it increased by 5% in each iteration. The reasons for these attraction hypotheses are social and economic, and sometimes, they are due to the needs of individuals (e.g., the need to accompany a relative or child) and introduce a further degree of randomness to the survey. Therefore, partly as a matter of caution, because specific categories of travelers (mainly those who use cars) are challenging to attract, even if they have stated that they are interested in a new service, these values have been used. During the simulations, the attraction hypothesis varies to analyze the impacts on results (number of vehicles, takings, kilometers travelled, filling coefficients, etc.) when demand changes. A similar assumption was made for the return journey, so travel occurs between the railway station and the census area. ISTAT origin data are only available for the morning, but it is assumed that users who have left must return on the same day to the same origin from which they left.

Tables 8 and 9 report total potential trips by applying the attraction percentage to the ODM for each iteration step, making it possible to build and achieve the simulation of trips.

The number of workers and students that originate within the city and go to the train station can be estimated by multiplying:

- The total outgoing trips by train (shown in Table 8);
- The ISTAT value 'Resident population that commutes daily outside the municipality' (available for each section);
- The inverse of total "residents income earners" from ISTAT is available in the municipality.

The destination of these outgoing trips is the census section, including the train station.

The incoming trips are opposite to the previous ones. They begin in the train station and go to a section with commercial activities. Monterotondo has high schools and only a small university, attracting local students from neighboring cities (especially mid- and high-school students). Usually, they come together with a parent (same vehicle) or use an extra-urban bus, so these trips are neglected due to the difficulty of predicting them.

4.4. Simulation Methods of RSA

The simulation phases are as follows:

1. Assigning a random time to each trip, named call, up to reach the total trips expected, and assigning each call to a train;

2. Organize pools of users who are assigned to the same vehicle, even if they come from different areas;
3. Calculate the number of vehicles to meet the generated demand and plan the trips;
4. Generate calls for incoming commuters and assign them to the vehicles to be relocated;
5. Repeat all previous steps for the afternoon trips using the same morning numbers with inverted roles between outgoing and ingoing.

Step 1 generates the calls for each train. Starting from the users who make their first trip during morning rush hour, between 6:15 a.m. and 9:15 a.m., the percentage of interest in the service was applied, with an initial attraction percentage of 20%. Figure 2 shows the distribution measured at the train station during a working day, with the number of people departing and arriving by train; data are collected directly at the Monterotondo train station. The morning hours seem to have a Gaussian-similar distribution for departure trips, while the arrival people seem to have almost a steady value. Outgoing and ingoing trips in the afternoon therefore follow a similar distribution.

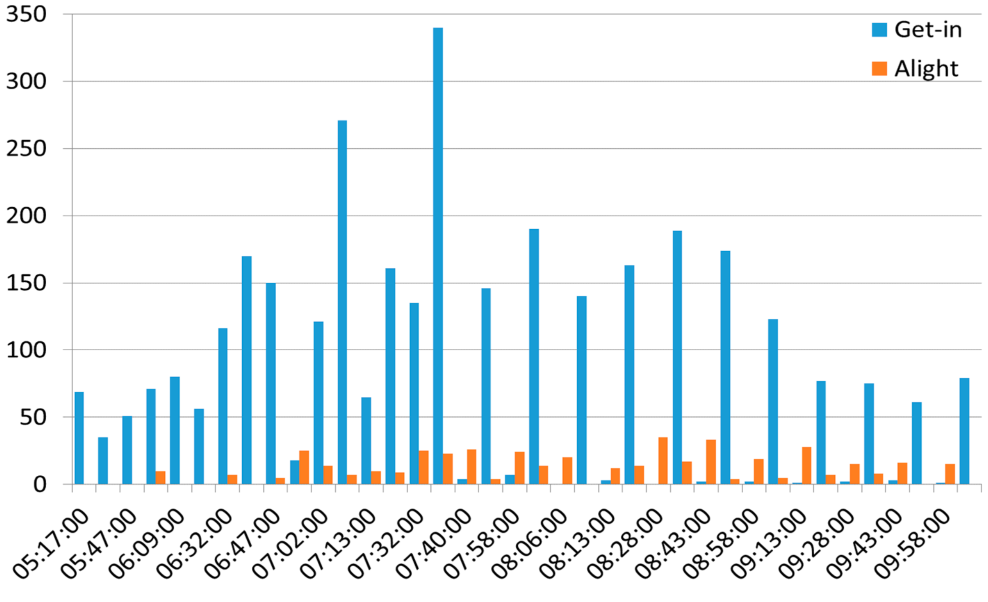

Figure 2. Distribution measured at the Monterotondo train station in the morning hours.

Table 10 shows the random calls generated with an attraction percentage of 28%, the commuter's willingness to drive a vehicle with this new service (399 of 1383). The rows represent the trips generated by the origin area and directed to the station (14), divided into the trains that pass between 6:00 a.m. and 9:00 a.m.

Step 2 concerns the pool scheduling. It is conducted iteratively by evaluating the following six possibilities, which identify the type of schedule:

TYPE 1: Minimum number of people. The first pools are those with trips generated by the same origin–destination pair (OD pair) filling the vehicle. It has assumed at least four people to constitute a new pool and a maximum of seven (as the maximum available seats);

TYPE 2. Change the train from the next to the previous. From the newly generated TYPE 1 pools, the algorithm searches for those that can accommodate other users by adding these users of the next train who want to anticipate their departure. These users are part of the same pool generated with TYPE 1.

TYPE 3. Change the train from the previous to the next. This step is similar to TYPE 2 and involves reassigning the randomly generated train with the previous one available in the station (instead of the next one as in TYPE 2).

TYPE 4. This step identifies the possible OD pairs that can be satisfied from the previously generated pools by collecting users along the route to the station without any significant detours (only with intermediate stops). This merging can only occur if the users in the already generated (but still incomplete) pool and those potentially included have been assigned to the same train.

TYPE 5. As in the previous case, but with a train change from the next to the previous.

TYPE 6. Once the previous steps have been completed, new pools must be generated to collect the remaining people unserved. This schedule contains users who might change trains and/or come from different zones.

Step 3 sizes the fleet and involves an iterative calculation to plan individual vehicle rides; each ride contains a pool. The following parameters are identified: travel time, waiting time, kilometers travelled, passengers per kilometer (pax*km), people not served, and ride revenue. At the end of each scheduling process, the algorithm checks the availability of vehicles, and if one is not available, it activates another one. Ride revenue is determined with a simplified model of a fixed cost per km travelled by each passenger and two saturation parameters: maximum and minimum trip costs, which limit the user's cost between two values. Revenue is determined by the sum of the cost incurred by each passenger on the ride.

Table 10. Trips matrix with hourly random generation from Monterondo by train.

			Train Timetable at Monterotondo Station											
Orig Area	**Dest Area**	**Total Trips**	**6:15**	**6:24**	**6:30**	**6:46**	**7:05**	**7:12**	**7:25**	**7:32**	**7:37**	**8:08**	**8:33**	**9:02**
1	14	22	1	1	2	3	4	3		4	1		2	1
2	14	28	4		1		1	5	1	6	4		3	3
3	14	16	1	1	1	2	4	3			1	1	2	
4	14	20	1	1	4	3		2	5	3				1
5	14	14	1	2		1	2	3		1	1	2	1	
6	14	24	2	2			4	5	2	4	1		1	3
7	14	25			1	2	4	2	4	3	2	1	2	4
8	14	9	1	1		1		2			2		2	
9	14	18	2			1	2	1	4		2	1	2	3
10	14	24	3	1		1	4	4	4	2	2	1	1	1
11	14	21	1	1		2	2		1	5	6	1		2
12	14	29	4		3	4	3	2	3	4	1	1	3	1
13	14	25	3	3	3	2	2	1		1	2	3	4	1
14	14	6	1		1			1	1		1		1	
15	14	57	6	3		4	7	3	6	8	3	12	3	2
16	14	38	5	4	2	4	3	3	6	3		3	3	2
17	14	12	1	2	1	2		1	2	1		1	1	
18	14	2				1				1				
19	14	8	1		1	1		1	1		2		1	
20	14	1					1							

The random generation of the previous steps provided a vehicle schedule such as the one summarized in Table 11.

The first vehicle (column "Id veh" and row value equal to 1) during the time slot 6:00–9:00 transports 50 users, covering 47 km with eight rides. The vehicle's occupation time is just under 2 h (taking into account all travel times and tolerance times to ensure a smooth operation of the service and to allow for any minor delays), just under 1 h is the time the vehicle is stationary, i.e., waiting to be picked up by users.

Step 4 simulates the incoming trips similarly to the outcoming ones. The algorithm is the same as seen for outward travel and uses the same vehicles arriving at the station. The types of planning are equal, but the purpose of this simulation is to relocate the vehicles that will be the origin of the movements leaving the municipality immediately afterward.

Firstly, random calls are generated and assigned to the train. The last step is checking the vehicles available that require relocation and matching between OD pairs of the incoming user with the vehicle pre-scheduled for the outgoing trips. The matching between the departure times from the station towards the Monterotondo areas (thus incoming transport demand) and the arrival times at the station of residents (outgoing) are inherently predetermined; in fact, trains arriving at Monterotondo then depart towards Rome, or if they terminate, there is bound to be at least one more train in the opposite direction (the railway line is double-tracked with an average frequency of one train every 15 min).

Table 11. Extract of simulation results and vehicle indicators.

Id Veh	Pax Tot Veh	Total km	Pax*km	N Rides	Vehicle Time (s)	Waiting Time (s)
1	50	47	132	8	7548	3302
2	37	33	76	7	5833	4881
3	40	23	86	6	4411	4699
4	19	21	52	4	3298	3932
5	26	28	71	4	4858	3830
6	25	28	67	4	4718	3987
7	25	25	71	4	4282	4568
8	19	27	48	4	3952	4718
9	16	13	39	3	2224	2983
10	9	31	30	3	3682	1739
11	16	15	41	3	2776	1874
12	21	13	40	3	2312	2537
13	5	16	22	2	2124	983
14	8	15	30	2	2226	1876
15	7	4	28	1	775	140

The simulation uses the incoming trips measured by train, using the numbers available from ISTAT on commercial activities divided by census section with the application of an attraction percentage and a measured interest through the public survey. Generally speaking, the proposed service could affect trips from other municipalities only via the railway station, probably also a small fraction are traveling from outside using their own vehicles. In the case of Monterotondo, about 63% of incoming trips are made by car. The value of potential interest in this new service of these users is difficult to quantify. This demand could only be generated after the creation of the offer; subsequently, other variables could affect this attractiveness, but at this preliminary stage, they have not been considered.

In the fifth and final step, the number of vehicles needed for afternoon service is less than that required for morning service (due to higher people concentration). Using the number of vehicles required for morning service implies that a few are not used in the morning; vice versa, a small part of morning people will not be served. The RSA accepts those people as unserved to reduce costs.

4.5. Results of the Simulations

The RSA has been reiterated by changing the potential market, which is calculated as the attraction percentage (or demand) that multiplies the potential users measured with the survey and the commuting matrix method. Figure 3 shows the results of simulations in terms of vehicles required and people not served by varying the attraction percentage. It shows the economic results (€/year) compared with the number of vehicles required and personnel costs per vehicle by changing the attraction percentage.

Instead, Figure 4 shows the passengers (served and not served) compared with the vehicle filling rate; this latter indicator measures the average value of passengers transported for the same distance travelled. The greater this indicator is, the greater the vehicle utilization and the lower the possibility of enhancing the results.

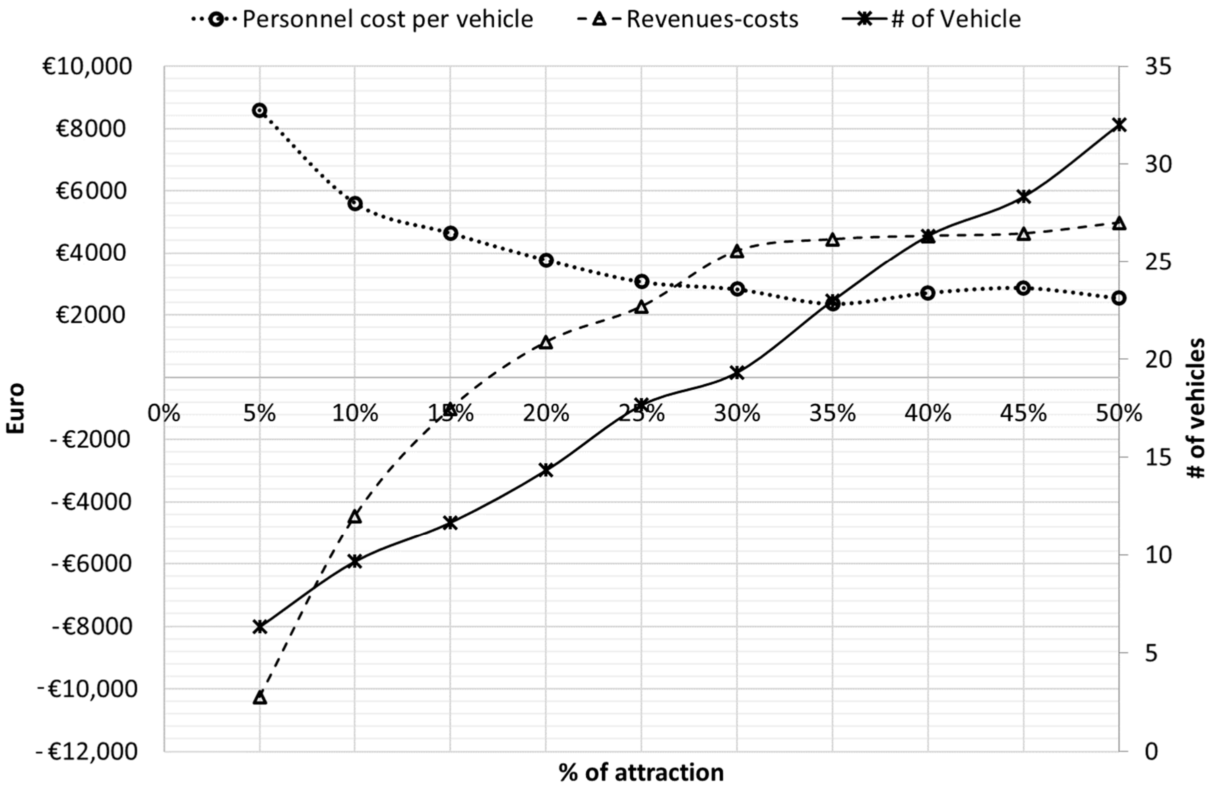

Figure 3. Results of simulation by varying the attraction percentage in terms of revenues and vehicles.

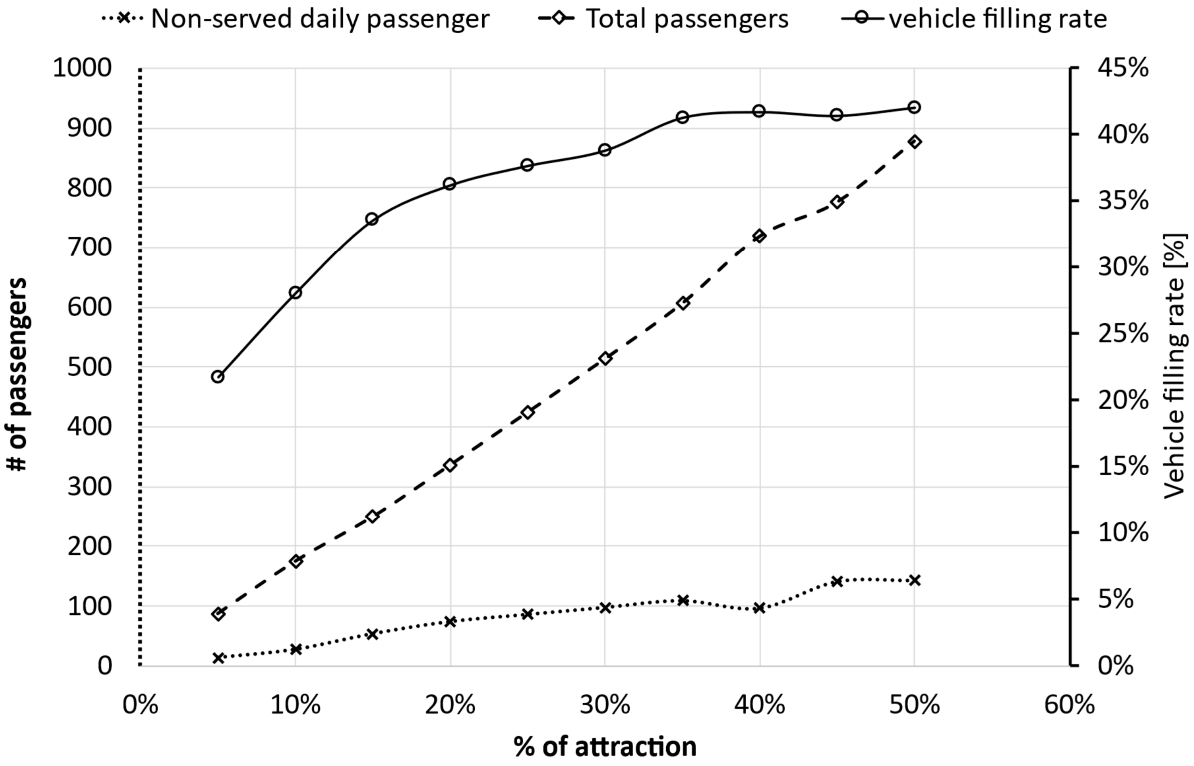

Figure 4. Simulation results by varying the attraction percentage in terms of vehicle filling rate and passengers.

For example, an attraction percentage of 10% means less than 200 people a day (20 not served); they travel from Monterotondo to Rome in the morning and return in the afternoon, requiring a fleet of 13 vehicles, filled at 55%. It has a negative economic result, with losses of 4500 €/vehicle per year.

If the attraction percentage increases to 20% (400 served passengers), 15 vehicles will be required, and the positive economic results will be about 1000 €/year. Greater attraction percentage increases positive results, but the difference between the revenues and costs trend seems to reach a plateau above 30%.

5. Conclusions and Future Developments

This paper has investigated the business models of vehicle-sharing services through a literature and project review and then presented the results of the financial analysis of the electric vehicles-sharing demonstration done by the LifeSC Project in the municipalities of Orbetello, Monte Argentario, and Isola del Giglio on the southern Tuscany Tyrrhenian coast of Italy. These financial analyses showed how the investigated sharing services can be profitable, but with difficulty and with the support of public subsidies. These findings hold for most sharing services outside the centers of large cities. However, the findings also highlight how lowering the purchase price of shared vehicles and increasing the service utilization rates could be profitable. A few features are suggested as the best chances to organize a vehicle-sharing service based on the latest developments in ICT technologies and strategic choices.

The new “Ride-Sharing Algorithm” has been tested through dedicated simulations. It combines ride-sharing and car-sharing into one service. It offers a sharing service for people moving from a city center to reach an attraction pole (typically an intermodal hub like a train station). From this pole, other people relocate vehicles parked here to the city center (this former demand is in counter-flow); when this demand is not enough, an operator relocates the vehicles using innovative solutions that enable a driver to relocate up to six vehicles simultaneously with vehicle automation.

Responding to a fluctuating demand without increasing the fleet can improve the utilization rate without lowering the quality of the service. Such a solution can be done by introducing ride-sharing at peak times, using an on-the-fly driver exchange, and relocating empty vehicles. Selecting the most appropriate vehicle type, powertrain, and charging method also influences the utilization rate. An integrated service would help build customer confidence, impacting urban mobility sustainability.

The economic result of simulations is positive when attraction demand reaches 20% of the potential transport demand, which means about 400 served passengers, less than 30 rejected passengers; the fleet size required is 15 vehicles, and revenues are 1000 €/year greater than costs. Higher costs for leasing the vehicle or increasing the number of operators could worsen the economic results to neutral or negative outcomes that could drive away investors and sharing companies. Still, they can enhance their incomes with ancillary services selling (on-board or at the collection point) or long rental vehicle services during off-peak hours or weekends, primarily because the ride-sharing daily service covers almost all its total cost (vehicles and operators).

To use such a service, people can book their travel through a one-stop-shop interface, for example, a smartphone app, allowing them to follow the vehicle in real-time, purchase an ancillary service, manage their booking and provide feedback. The cost factor of app development and maintenance has not been evaluated due to the high innovation associated and difficulty quantifying the required development time. Moreover, the transport company offering this service could have other sharing services and applications that can be modified to achieve this scope.

The new algorithm proposed here promises to achieve positive economic results and fill the gap of underused vehicles in classic or mixed car-sharing models.

Future work will include simulation with different and changed parameters, testing other relocation strategies and simulating the variation of counter-flow demand. Other simulations will do a sensitive analysis of the parameters adopted. ISTAT data for potential transport demand will be updated, and a further survey about personal preferences in sharing vehicles and/or ride availability will be conducted.

Moreover, the authors plan to deploy a transport service analog to the one proposed in an experimental project called TUSS (https://www.tuss.unifi.it/p1.html, accessed on 28 August 2024). This will help improve our understanding of the feasibility and tangible economic impact of such a model.

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