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Designing a Crowd-Based Relocation System—The Case of Car-Sharing

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Abstract: Car-sharing services promise environmentally sustainable and cost-efficient alternatives to private car ownership, contributing to more environmentally sustainable mobility. However, the challenge of balancing vehicle supply and demand needs to be addressed for further improvement of the service. Currently, employees must relocate vehicles from low-demand to high-demand areas, which generates extra personnel costs, driven kilometers, and emissions. This study takes a Design Science Research (DSR) approach to develop a new way of balancing the supply and demand of vehicles in car-sharing, namely crowd-based relocation. We base our approach on crowdsourcing, a concept by which customers are requested to perform vehicle relocations. This paper reports on our comprehensive DSR project on designing and instantiating a crowd-based relocation information system (CRIS). We assessed the resulting artifact in a car-sharing simulation and conducted a real-world car-sharing service system field test. The evaluation reveals that CRIS has the potential for improving vehicle availability, increasing environmental sustainability, and reducing operational costs. Further, the prescriptive knowledge derived in our DSR project can be used as a starting point to improve individual parts of the CRIS and to extend its application beyond car-sharing into other sharing services, such as power bank- or e-scooter-sharing.

Keywords: sharing economy; car-sharing; supply and demand management; vehicle relocation; crowdsourcing; green is/it; design science

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1. Introduction

A car-sharing service offers customers access to a fleet of shared vehicles, which are strategically distributed in a city area and can be rented for short-term use [1]. It is considered a cost-effective and convenient alternative to private car ownership by replacing multiple privately owned vehicles with a single shared one [2]. Thereby, car-sharing has become a prime example of the potential of the sharing economy [2,3]. Various studies have revealed a nearly 30 percent reduction in car-bound mobility for car-sharing customers because they tend to re-evaluate the need to use a car; instead, they prefer alternative and more sustainable means of transportation [4,5]. In this way, car-sharing customers can reduce annual emissions by up to 18 percent [6]. Further, car-sharing promotes inter- and multimodal mobility behavior because it can supplement classical public transportation means to form a comprehensive intermodal mobility chain. This increases public transportation's viability and accessibility and decreases the overall share of car-bound travel [7,8]. However, relative to other transportation modes, car-sharing is still struggling to reach mainstream acceptance [9], application, and use [10].

One aspect that needs improvement is the operational challenges associated with managing vehicle supply and demand [11,12]. With vehicles placed at constantly changing locations, their distribution can become imbalanced, resulting in some locations being undersupplied while others are oversupplied. For instance, many individuals drive from the train station to their workplaces in industrial areas in the morning. Hence, vehicles accumulate at these workplaces. During the day, the demand for vehicles at these workplaces is low (i.e., most individuals work about eight hours in their offices, not needing a vehicle to drive anywhere), while the constant demand for vehicles at the train station cannot be satisfied (Note that this is an example from one of the participating car-sharing providers. The literature gives examples of similar patterns (e.g., [1])). Consequently, in cases of inadequate vehicle supply and demand management, customers can perceive car-sharing as an unreliable and unsatisfactory substitute for private car ownership. This is one important obstacle to attracting and retaining customers for car-sharing, which reduces the car-sharing provider's revenue and profitability [13,14]. More importantly, insufficient vehicle supply and demand management counteract the environmental benefits of car-sharing [15,16] due to the high number of vehicles required to serve all customers [17,18]. Therefore, vehicle supply and demand management are central processes in car-sharing.

Currently, car-sharing providers address this problem by appointing employees to manually relocate vehicles (this approach is called "operator-based relocation"). High personnel costs make this an expensive endeavor, and the additional kilometers driven make it environmentally unsustainable [19,20]. An alternative is a so-called user-based relocation approach. For user-based relocation, the company requests customers currently renting and using a vehicle (therefore called users) to return rented vehicles to under-supplied stations [11,21]. Further, pricing approaches in which the business offers a fee or discount structure to influence customers' behavior can contribute to keeping the system balanced [22,23]. These approaches reduce the kilometers driven in car relocation and thus are more cost-efficient and environmentally sustainable than operator-based relocations [19,24].

However, user-based relocation is still difficult to implement in practice because of the challenge of communicating and negotiating an incentive during an ongoing rental while customers are driving [25]. Further, pricing and user-based relocation approaches are not suitable for relocating vehicles in low-demand locations. Nonetheless, at times relocating a vehicle from a low demand location to a high demand location is necessary. To the best of our knowledge, operator-based relocation is still the prevailing approach for such relocations. This significantly diminishes profits and car-sharing's contribution to environmental sustainability. Therefore, car-sharing providers need a new approach that will enable relocation from low-demand to high-demand locations, which is more cost-efficient and environmentally sustainable than existing approaches.

Extending beyond the scope of car-sharing, managing supply to meet demand is a challenge multiple sharing economy business models face [3,26]. However, not all types of supplies can be relocated (such as apartments in apartment-sharing), some do not need physical relocation (such as knowledge in knowledge-sharing), and some are entirely consumed by using them (such as food in food-sharing). We would like to call this subgroup of sharing systems physical, movable, and reusable (PMR) sharing, which includes services such as bike-, power bank-, tool-, or umbrella-sharing. These services face the challenge of being environmentally sustainable and profitable to fully leverage the promises of the sharing economy to enable a sustainable society [27]. Hence, exploring how new IS can increase both aspects is a pressing issue of our time. Against this background, our study leverages the increasing digital infrastructure of car-sharing systems to answer the following research question:

RQ. *How should a vehicle supply and demand management system that increases car-sharing systems' cost-efficiency and environmental sustainability be designed?*

To address this research question, we developed and instantiated a crowd-based relocation information system (CRIS) for a German car-sharing provider. We leveraged the benefits of the design science research (DSR) paradigm to rigorously develop a relevant and practical solution [28–30]. The CRIS is based on the idea of sourcing relocations from the customers of a car-sharing system. This idea, accompanied by the design knowledge regarding the design of a CRIS, has the potential to be transferred to other PMR sharing services.

2. Research Background

Recently, several new mobility-sharing services have been developed, which are designated by terms that include "car" (e.g., car-sharing, car-pooling, car-rental) or "sharing" (e.g., ride-sharing, car-sharing). Many terms are ambiguous; for instance, the service Uber provides is variously called car-pooling [31], car-sharing [32], ride-sharing [33], and, recently, ride-hailing [34]. Against this background, this study defines the term car-sharing as a service that offers customers individual access to a fleet of vehicles, which is strategically distributed within a confined operation area, for short-term use. Further, we focus on business-to-consumer car-sharing, which is also the most common form of car-sharing [35]. Unlike business-to-business car-sharing systems, private individuals are car-sharing customers [36,37]. Moreover, compared to peer-to-peer car-sharing (sometimes called customer-to-customer sharing) [26], in business-to-consumer car-sharing, an organization, mostly a private company, owns the vehicle fleet and provides the sharing service.

2.1. Forms of Car-Sharing and Vehicle Supply and Demand Management

A car-sharing fleet can be comprised of vehicles with petrol, electric, or other types of engines [38]. Furthermore, the literature distinguishes three major operating formats in business-to-consumer car-sharing systems [39,40]:

1. Station-based two-way car-sharing: Vehicles are positioned at stations where customers can rent a vehicle. After use, customers must return the rented vehicle to the same station from which it was rented [41,42].
2. Station-based one-way car-sharing: Similar to station-based two-way car-sharing, except that customers can return the rented vehicle to any available station [41].
3. Free-floating car-sharing: Vehicles are not at fixed stations. Vehicles can be rented from and returned to any location within the operation area of the car-sharing provider [11,41].

Station-based one-way and free-floating car-sharing formats give customers greater flexibility than the station-based two-way format. However, for the provider, a significant challenge is the constantly changing vehicle distribution, which can lead to vehicle supply shortages in some locations, so customers might not find a vehicle available to rent in their vicinity. Hence, car-sharing providers have to balance vehicle supply and demand to provide sufficient vehicle availability [12,43].

Station-based one-way and free-floating car-sharing have similar relocation problems because, in both systems, vehicles can accumulate in low-demand locations. Free-floating car-sharing can be seen as a station-based one-way car-sharing system with an infinite number of stations [11]. Thus, their procedures are comparable but not interchangeable [11]. Against this background, we can distinguish three main approaches to balancing vehicle supply and demand (see Table 1 for a summary):

1. Operator-based relocation: Providers balance vehicle supply and demand by using operators (i.e., the car-sharing provider's employees) to drive, tow, or ride-share surplus vehicles from low demand to high demand locations [44]. This approach remains reactive in directly relocating vehicles parked in a low or relatively low demand location. Further, it is considered an expensive approach because it involves high personnel costs [19,20], comes with operational challenges such as staff rebalancing [45], and is environmentally unsustainable due to the extra kilometers driven in relocating vehicles [19,23,44].
2. User-based relocation: Providers motivate users (i.e., customers currently renting and using a vehicle (Note that all users are customers, but not all customers are users. Any individual with a valid car-sharing membership is a customer; a user, however, is a customer who rents a vehicle and actually uses it. Thus, our study refers to users as

currently renting and driving customers, while the term customer refers to all individuals with a valid car-sharing membership)) to change their destination and return the vehicle to an under-supplied location instead of an over-supplied one [11,42]. Thus, user-based relocation depends on an ongoing rental and tries proactively to get vehicles relocated to low-demand areas before they are parked. Research confirms this approach to be less expensive than operator-based relocation [21,42]. However, implementing such an approach is currently impractical due to the challenges of communicating with users while they are driving. Therefore, informing customers of the new destination and negotiating an incentive becomes virtually impossible [25]. Further, car-sharing customers are commonly not required to designate their destination and time of arrival [26]. This makes it nearly impossible to identify users who intend to return a vehicle to an oversupplied location.

3. Pricing schemes: Besides actively relocating the vehicles, service providers can balance vehicle supply and demand by developing more cost-efficient ways of manipulating vehicle distribution. Using innovative pricing schemas is one emerging approach by which companies apply fees and discounts for renting and returning vehicles in certain areas [22,23]. These price-based vehicle supply and demand management approaches try to keep the vehicle distribution balanced by preventing undesired rentals from high-demand start locations to low-demand end locations.

Table 1. Overview of Vehicle Supply and Demand Management Approaches.

No.	Approach	Modus	Rental	Relocator	Expenses	Examples
1	Operator-based	Reactive	Independently arranged	Operator	High	[43,45,46]
2	User-based	Proactive	Arranged during rental	User	Low	[11,19]
3	Pricing	Preventive	Arranged before rental	-	Low	[22,47,48]

Against this background, this study investigates another possible and promising solution to the relocation problem. Specifically, we see potential in relocating vehicles in a way similar to operator-based relocation (i.e., reacting to imbalances and relocating vehicles independently of a rental) by requesting all customers to perform relocation tasks. This approach is based on crowdsourcing, which (as explained below) engages a large number of individuals (called a crowd) to source labor [46].

2.2. Crowdsourcing

There are various definitions of crowdsourcing, of which some have the same and others have different foci. This study follows Howe's [47] widely accepted definition [48] of crowdsourcing as a new way of outsourcing labor. Howe [47] coined "crowdsourcing" as a term that merges the words "crowd" (i.e., an undefined body of individuals, teams, or companies) and "outsourcing" to create an umbrella term for a wide range of ways to recruit a large, open group of people via the internet to source labor or knowledge. In general, a company, institution, or individual (often called a crowdsourcer) publishes an open call via an online platform for volunteers to perform a task. Individuals in the crowd who receive the call can respond, and if their offer is accepted, they can complete the assignment [49,50]. Figure 1 schematically illustrates this interaction.

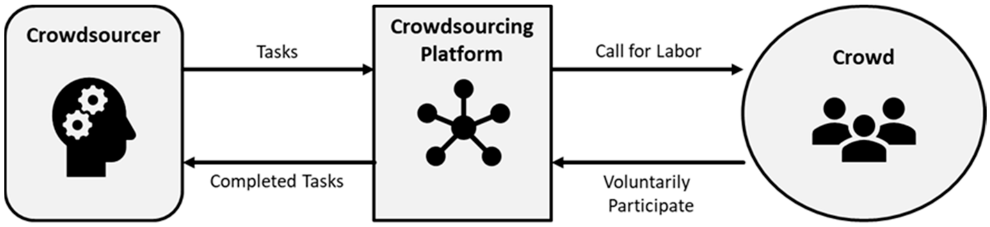

Figure 1. Crowdsourcing Framework.

Typically, tasks that cannot be carried out by the organization due to the sheer size and/or complexity of the tasks themselves are outsourced using crowdsourcing [46], e.g., labeling or tagging documents and photos, processing vast amounts of data, or translating descriptions [51]. Utilizing the crowd allows the organization to perform these usually digital tasks more quickly and efficiently [46]. The underlying concept of crowdsourcing is that "many hands make light work" ([46], p. 78), leading to better results [52] by capitalizing on the workforce, knowledge, and/or experience of the crowd [53]. This concept is not new, and companies strive to bundle the dispersed wisdom of many by identifying and accessing the distinctive knowledge of many [46]. Modern IT and especially the internet facilitate the concept of crowdsourcing. They make it possible to engage a large group of people, e.g., through social media or open platforms [46].

Crowdsourcing in transportation and mobility is often used for purposes like social navigation or mapmaking; users are engaged as "walking and live sensors" [54] (p. 1596). Thus, crowdsourcing is used to gather information for better mobility solutions. Furthermore, parts of crowdsourcing are also included in other new mobility services. For example, Uber implemented a real-time bidding mechanism to match mobility supply and demand [55].

In crowdsourcing, financial incentives are often used to motivate workers and therefore stand as a crucial part of the concept [56]. Different methods were developed to compute incentives. They can be based on various factors such as necessary knowledge, quality of solution, grade of participation, and difficulty of task [46,57]. For task-independent incentives, there are other methods, for example, rank-order tournaments, bidding, or one incentive fits all [55,56]. Nonetheless, incentives are mainly task-dependent [46].

Specifically, in the context of vehicle relocation in car-sharing, we focus on microtask crowdsourcing, which is a crowdsourcing sub-type [48,54]. Based on Deng et al. [48], microtask crowdsourcing is the activity of sending an open call to an undefined group of individuals (i.e., a crowd) via a web-based platform, inviting them to complete tasks in exchange for compensation (e.g., payment).

3. The Design Science Research Project

DSR is a research paradigm aiming to develop novel and innovative solutions for prevailing practical problems [28–30]. Hence, it fits our research goal of developing a CRIS. Furthermore, it has already been shown to lead to great system development in the context of car-sharing [23,58]. We conducted the DSR project following Kuechler and Vaishnavi's [59] guidelines, working through four consecutive design cycles (see Figure 2). To identify a solution for the problem of relocating vehicles in a car-sharing context, we developed our artifacts in close cooperation with two German car-sharing providers: a provider (SB) of station-based one-way car-sharing and a provider (FF) of free-floating car-sharing. We developed the design principles (DP) for a CRIS inductively during the research process [28,60] and codified them in the conclusion step [59]. Below, we outline the four design cycles and the research activities conducted in each cycle.

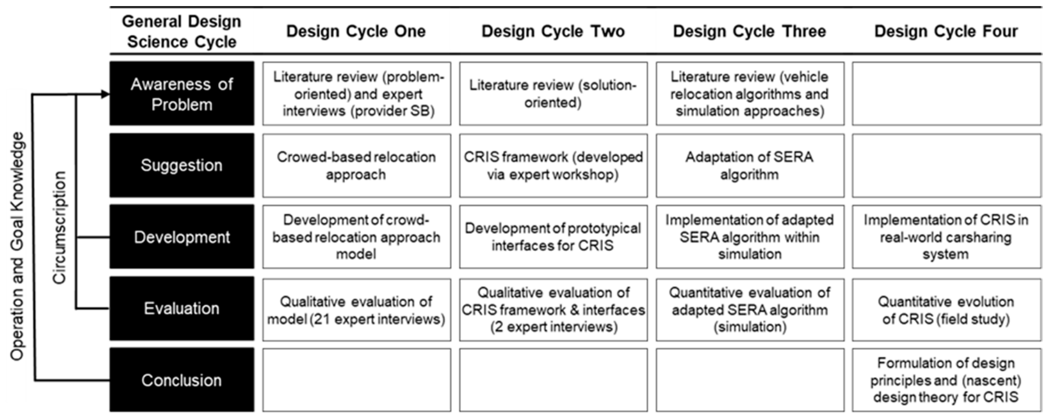

Figure 2. DSR Approach.

We started our DSR project in design cycle one by reviewing current vehicle relocation research, as well as associated IS research fields, such as crowdsourcing and Green IS, to understand the identified problem better. Subsequently, we discussed our findings with two managing directors of car-sharing provider SB in expert interviews. Our literature review and the two expert interviews revealed difficulties with practical relocation approaches regarding the capability to relocate vehicles left in low-demand areas without relying on operators to complete the task. Recognizing this problem, we identified four initial requirements for a new vehicle relocation approach. Subsequently, we derived the crowd-based relocation approach, which entails the car-sharing provider and car-sharing customers (the crowd) interacting via a crowd relocation platform regarding vehicles' (re-)location. We evaluated the crowd-based relocation approach by interviewing 21 car-sharing providers in their role as domain experts. The expert-based evaluation revealed three additional requirements, leading to the second design cycle.

We started design cycle two by extending the literature review on car-sharing vehicle relocation. In this solution-oriented review, we identified Wagner et al.'s [11] framework for a user-based relocation IS as input in designing a CRIS. Subsequently, we conducted a workshop with car-sharing provider FF to develop the CRIS framework, following the general brainstorming method [61]. Overall, we identified 13 components that we divided into four modules, which formed the CRIS framework—an architectural blueprint of the structure and components of a CRIS. In addition, we created prototypical interfaces to illustrate the interaction between customers and a CRIS. We discussed the CRIS framework and the prototypical interfaces with two experts from provider SB. Provider SB's managers agreed with the CRIS architecture but requested simulation results as evidence before the system could be implemented. Hence, we followed the "technical risk and efficacy" evaluation strategy [62] and simulated crowd-based relocation in the next design cycle.

We started the third design cycle with a review of relocation algorithms and related simulation approaches. The review revealed that most existing vehicle relocation algorithms are highly specialized for certain application scenarios (e.g., e-car-sharing relocation under parking space restrictions) with insufficient room for adaptation. Hence, we developed an adaptable relocation algorithm [58], the Algorithm (SERA), to be applicable in user-based, operator-based, and crowd-based relocation approaches, in addition to being applicable in station-based and free-floating car-sharing systems. We implemented SERA in a discrete-event simulation for all three approaches. Overall, the simulation revealed that crowd-based relocation performed similarly to user-based relocation and slightly worse than operator-based relocation regarding the ratio of the number of relocations to the number of additional rentals. This indicates that crowd-based relocation can be valuable for optimizing vehicle distribution. We, therefore, decided to evaluate our approach in a real-world environment in the next design cycle.

We started design cycle four by instantiating CRIS in a car-sharing system. The successful simulation demonstrated that we could expect limited risk for the provider.

Consequently, we applied the "human risk and effectiveness" evaluation strategy [62] and tested our approach with real customers in a field test. For the field test, provider FF's own IT department implemented a CRIS as part of their online renting system. Our field test revealed that customers accepted crowd-based relocation and that it provided a valuable tool for balancing vehicle supply and demand. In the fourth design cycle, we concluded by reflecting on the DSR project and writing up our findings in the form of DPs [63].

4. Designing Crowd-Based Supply and Demand Management Information Systems for Car-Sharing

In the following section, we present the key findings of our DSR project, including the set of requirements we identified, the architectural framework, and the final evaluation results.

4.1. Design Derivation

4.1.1. Requirements

In design cycle one, we identified a set of seven requirements, as summarized below in Table 2. The overall goal of crowd-based relocation is to reduce costly operator-based relocations (R1) and replace them with ones more cost-efficient for the provider (R2) while avoiding problems such as staff rebalancing [45]. The potential areas of cost reduction include wages for extra personnel, wear and tear on vehicles, and fuel costs. In this context, a relocation has to increase vehicle availability (i.e., leading to more vehicle rentals) (R3). Moreover, operator-based relocation replaced with a less efficient type of relocation would not be viable [11]. Car-sharing providers have, to date, not implemented user-based relocation due to the complex communication process implied by trying to interact with customers while they are driving, negotiating an incentive, requiring information on the duration and destination of rentals, etc. [25]. Thus, an alternative must be easy to implement (R4) while overcoming the issues that complicate user-based relocations. Additionally, car-sharing providers need relocations to be requested, performed, and monitored automatically (R5), in that computing relocations should not need the provider to give manual input. Crowd-based relocation should replace contracting operators; therefore, requiring operator input would render it pointless.

For crowd-based relocation to be a valid alternative, it has to be an inexpensive option for the provider (R6) because user-based relocations are expected to be cheaper than operator-based ones [19]. Hence, incentives for crowdsourcing relocations should be below the costs of an operator-based relocation. Finally, crowd-based relocation must be easy for customers to understand (R7). Complex pricing schemes [26] or various vehicle types [26], for example, can lead to customers experiencing information and choice overload [64]. In summary, crowd-based relocation can only be effective if customers find the procedure easy to understand and then actually perform the relocations, while at the same time, the complexity of the car-sharing system and the user interface do not significantly increase (R7). In the end, a categorization of the requirements emerged on the levels of performance, implementation, and application.

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Table 2. Revised Requirements for Crowd-based Relocation.

No	Requirement	Description	References
		Performance	
R1	Reduction	The approach should reduce the number of operator-based relocations.	[39]
R2	Efficiency	The approach should reduce the costs and emissions of vehicle relocations.	[39,45]
R3	Availability	The approach should increase the car-sharing provider's vehicle availability.	[39]
		Implementation	
R4	Implementable	The approach should be easier to implement than user-based relocation.	Provider SB
R5	Automation	The decision process regarding the relocation of vehicles should be completely automatic.	Provider FF & SB
R6	Inexpensive	The approach should be inexpensive for the car-sharing provider to implement (e.g., no expensive hardware).	[11]
		Application	
R7	Understandable	The approach's relocation procedure should be easy for customers to understand.	Provider FF & SB

Note that we link the requirements to testable propositions (TP) in Section 4.2. Note, also, that we gathered the requirements in design cycle one by two different means, but for a coherent presentation, we presented them as one set here.

4.1.2. Framework

Drawing the customer into the relocation activity seemed similar to crowdsourcing for task completion. Thus, we consulted the crowdsourcing literature (see Section 2.2) to develop crowd-based vehicle relocation by combining crowdsourcing concepts with existing vehicle relocation approaches in car-sharing. Figure 3 illustrates our crowd-based relocation approach.

In crowd-based relocation, the car-sharing provider requests relocations via a crowd relocation platform (1). The request is similar to the task description given to operators in operator-based relocation, which includes all information regarding the to-be-relocated vehicle, its current location (the relocation origin), the relocation destination, and information on the time when the relocation is to take place. The provider forwards all this information to the car-sharing crowd in the form of a "call for labor" (2). The crowd consists of all the car-sharing provider's customers. Subsequently, the incentive for the relocation task is negotiated (3). When a car-sharing customer accepts and performs the relocation (4), the platform monitors the vehicle relocation (5) and rewards the customer after the successful completion of the assignment (6). The car-sharing provider pays for the incentive as agreed in advance (7). Against this background, we define crowd-based relocation as follows:

> *Crowd-based relocation is the approach by which a provider outsources vehicle relocations to its customer base (i.e., the crowd) via an open call for participation.*

We evaluated the approach in interviews with 21 car-sharing providers. Overall, we contacted 59 German car-sharing companies, of which 21 agreed to be interviewed. The interview partners were either managing directors or employees entrusted with the task of vehicle relocation. Eighteen of them provided information on station-based car-sharing, and three provided free-floating car-sharing. We conducted all interviews by telephone in a semi-structured way between August and October of 2016. The interviews lasted up to a maximum of 55 min. Every interview was recorded and transcribed, with the records running up to 7100 words per interview. The interview guideline's open questions referred to (1) the importance of vehicle relocation, (2) the company's currently implemented vehicle relocation approaches and policies, (3) the concept of user-based relocation, (4) their opinion on crowd-based relocation, (5) how crowd-based relocation could be applied in their own or other car-sharing systems, and (6) what the requirements would be for implementing crowd-based relocation. All interviewed partners confirmed our view of the problem of vehicle relocation and agreed that the crowd-based relocation approach could be used to improve vehicle availability.

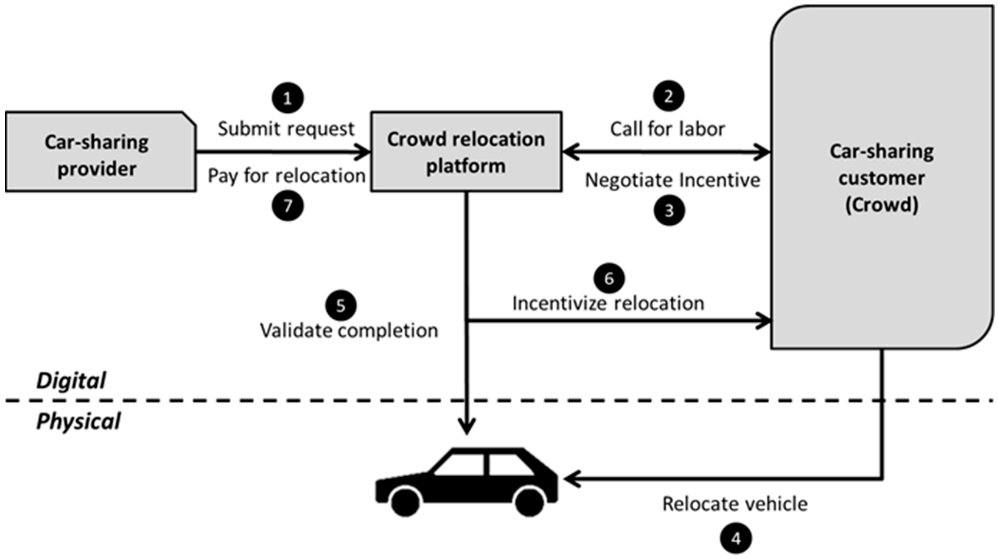

Figure 3. Crowd-based Relocation Approach. Note that the crowd relocation platform can be an independent system or part of the car-sharing renting system.

Subsequently, based on the crowd-based relocation approach (see Figure 3), the derived set of requirements (see Table 2), and Wagner et al.'s [11] framework, we developed a guiding architectural framework for a CRIS. Figure 4 visually represents our CRIS framework with its three main modules. We conducted a workshop with car-sharing provider FF to build on the identified frameworks and performed two expert interviews with provider SB to evaluate the resulting CRIS framework. Based on the workshop, we identified three CRIS modules, namely data analysis, relocation, and a crowd platform. The gray components in Figure 4 are also present in other vehicle relocation decision support systems [11] and therefore are not specific to the crowd-based relocation context.

The data analysis module produces the necessary predictions to guide the relocation computation. Similar to other relocation approaches [11,42,65], it is important to analyze historic vehicle rental data to predict future spatial vehicle demand. Different approaches to prediction range from kernel density estimators [11] to neural networks [66]. The resulting predictions are forwarded to the demand component of the relocation module.

In the relocation module vehicle, relocations are computed based on demand predictions and current vehicle supply. The system has to calculate an incentive that should reflect the urgency of the vehicle relocation and how it will improve vehicle availability.

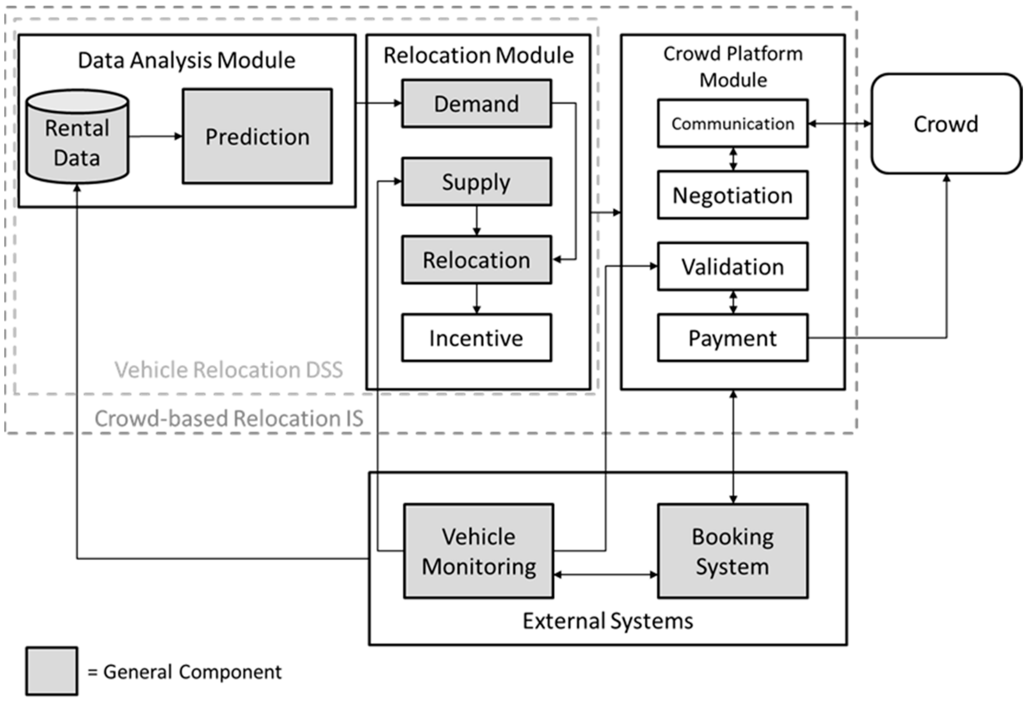

Figure 4. Crowd-based Relocation Information System (CRIS) Framework.

The crowd platform module is specific to our crowd-based relocation approach. This module communicates with the crowd to find a customer willing to perform the relocation. The incentive is negotiated until either a customer agrees or the relocation is no longer necessary. If a customer agrees to relocate a vehicle, it is booked for them. Next, the module checks for the relocation's completion (validation; crowd platform module), and as soon as the vehicle monitoring component registers the arrival of the relocated vehicle, it rewards the customer. We developed prototypical interfaces similar to those we later implemented in the field test to visualize this module.

Further, we identified external systems as an essential part of a vehicle relocation system, such as modules providing information on vehicle positions and bookings, which were only implicitly included in other frameworks. Digital technologies play a key role in modern car-sharing, utilizing IT and IS for automated vehicle rental, instant vehicle access, vehicle monitoring, and electronic billing [26,67]. Building on the existing digital infrastructure, a CRIS has the ability to access available information on previous and ongoing vehicle rentals (collected in a rental database; data analysis module), as well as on the current positions of vehicles, showing the current supply at various locations (supply; relocation module).

Provider SB approved the presented CIRS framework and agreed to participate in a field test. However, they insisted on testing the used SERA in a simulation beforehand to ensure no serious damage to the provider, which was also an issue raised by provider FF.

4.2. Design Evaluation

In line with the technical risk and efficacy strategy [62], we ran a simulation before testing the CRIS framework and SERA in a field test setting [68]. Based on gathered real-world rental data, we simulated crowd-based, operator-based, and user-based relocation based on SERA.

We wrote the simulation in Python, with the process illustrated in Figure 5. First, to set up the simulation, we loaded a historical car-sharing rental data set from provider FF, which they used to generate the heat map for SERA. This also determined the vehicles' starting position. This dataset included over 43,000 rentals, all collected between 1 January 2016 and 12 December 2017 (Note that we presented the simulation run on a larger dataset (including all data up until one day before the field test), which was applied during the field test to provide further evidence for the applied algorithm. Preliminary results on a smaller dataset (1 January 2016 to 31 December 2016—a total of 17,814 rentals) led to similar results). The dataset represents a free-floating car-sharing system with predominantly short rentals regarding distance and duration, which mainly take place during the daytime. Second, we set the simulation to randomly draw rentals from the rental data set (i.e., bootstrapping the data set). Third, we set the simulation to iterate, with each iteration (covering 15 min) being checked for whether a rental is due and whether a vehicle is available. If no vehicle is available for a due rental, the request is rejected. Additionally, for each iteration showing a need for relocation, potential relocations are computed, and any corresponding relocations are attempted accordingly.

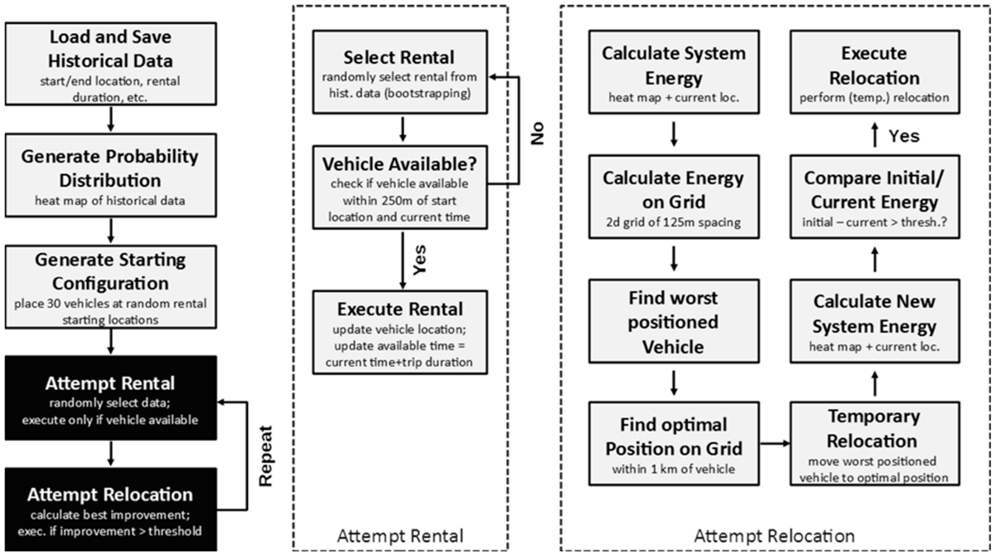

Figure 5. Discrete Event Simulation (based on Brendel et al. [58]).

To put the performance of crowd-based relocation into context, SERA was also applied for user-based and operator-based relocation (see Figure 6). Operator-based relocation outperforms both user-based and crowd-based relocation for an overall lower number of relocations (fewer than 60% of relocations) (Note that we evaluated the efficiency of relocation approaches based on the ratio of accepted rentals (accepted rental attempts in %) and performed relocations (relocation in % of accepted rentals). In order to be efficient, the number of accepted rentals should be high, while the number of performed relocations remains low). However, operator-based relocation remains the most efficient at around 35% of relocations. A potential explanation for this result is that operator-based relocation can successfully relocate every vehicle (not just currently rented ones) in any way or mode (not just in a preset radius of the vehicle). Thus, more relocations do not always give a better result, while the limitations of user-based and crowd-based relocations seem to reduce the number of ineffective relocations. Nonetheless, the result indicates that crowd-based relocation can provide a valuable measure to relocate vehicles.

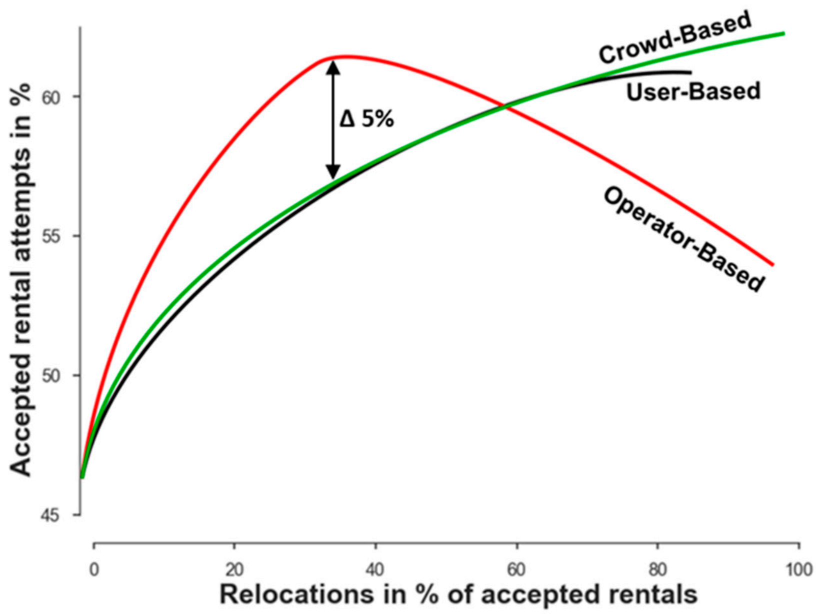

Figure 6. Comparison of Relocation Approaches. Note that the curve chart displays connected markers, where the markers are the best combination of parameters for a given accepted rental attempt in % and relocation in % of accepted rentals. See [60] for more details on this way of displaying and comparing relocation algorithm parameter combinations.

The subsequent field study evaluated how implementing a crowd-based relocation approach based on the proposed CRIS framework would meet the set of requirements (see Table 2) in real-world conditions. Thereby, we proposed the following set of TPs to test the fulfillment of all requirements:

- TP1: Implementing a CRIS reduces the number of operator-based relocations required (R1 Reduction);
- TP2: Implementing a CRIS leads to lower costs and emissions than operator-based relocation (R2 Efficiency);
- TP3: Implementing a CRIS leads to more vehicle relocations than the "no relocation" approach (R3 Availability);
- TP4: Implementing a CRIS leads to a similar number of vehicle relocations compared to user-based and operator-based approaches (R3 Availability);
- TP5: Implementing a CRIS can be done successfully (R4 Implementable);
- TP6: Implementing a CRIS does not require the car-sharing provider to intervene in the relocation procedure (R5 Automation);
- TP7: Implementing a CRIS does not entail high implementation or maintenance costs (e.g., hardware or personnel) (R6 Inexpensive);
- TP8: Implementing a CRIS leads to an easy system for customers to use (R7 Understandable);
- TP9: Implementing a CRIS allows multiple users to accept and complete a relocation task (R7 Understandable).

To test these propositions, we implemented a CRIS to enable crowd-based relocation in provider FF's car-sharing system.

4.2.1. The CRIS Framework Implementation

FF's IT department supported and partly carried out the implementation of our crowd-based relocation approach in their car-sharing system. Following the developed CRIS framework, the components for rental and vehicle monitoring (also validation) already existed in the system. We implemented the data analysis and relocation functionalities covered by SERA in provider FF's existing car-sharing system. In more detail, we now describe the three implementation components.

The incentive model computes an incentive for the task of vehicle relocation. Determining an effective incentive is still a matter of open debate in the literature, which focuses largely on the user-based relocation setting (e.g., [25]). Against this background, we decided to apply an easily understandable approach (according to R7) in the form of a linear time-dependent function. The incentive directly depends on how much time passes after publishing the request until take-up. To formulate the function, we conducted an online survey in which 258 of car-sharing provider FF's customers participated (see Table 3).

Table 3. Results of Survey (258 participating customers of carsharing provider FF).

No	Responses					
How satisfied are you with the availability of the vehicles?	1	2	3		4	5
	9.7%	38.8%	37.2%		11.2%	3.1%
Would you re-park a vehicle for a credit or discount, even if your actual destination was a different one?	32.2% No I 67.8% Yes					
How high would the credit or discount have to be to get you to re-park a vehicle?	€1	€2	€3	€4	€5	€6
	1.2%	4.2%	15.5%	10.9%	42.2%	26%
Would you use a vehicle that is further away than the nearest one if you get a discount or credit for it?	24.8% No I 75.3% Yes					
How far would you be willing to walk to a vehicle which needs to be re-parked?	0 m	100 m	200 m	300 m	400 m	500 m
	10.9%	2.7%	5.0%	9.7%	6.2%	39.5%
	600 m	700 m	800 m	900 m	1000 m	-
	7.0%	4.7%	3.5%	0.8%	10.9%	
How far would you be willing to walk to your actual destination, after re-parking a vehicle?	0 m	100 m	200 m	300 m	400 m	500 m
	5.3%	10.5%	12.7%	10.5%	41.2%	9.2%
	600 m	700 m	800 m	900 m	1000 m	-
	3.9%	2.2%	0.4%	0.0%	3.9%	
Would you re-park a vehicle, even if you did not actually want to use car-sharing?	51.6% No I 48.4% Yes					

Based on the survey, we implemented the following function to compute incentives:

$$Incentive = (time \cdot 0.042) + 1$$

$$Incentive \leq 6$$

time = time in minutes after publishing the relocation request.

Building on this linear function, the negotiation model offers an initial incentive of €1 and increases the incentive every minute by about €0.04, up to a maximum of €6 per relocation. After 120 min, the relocation request is withdrawn.

For the communication component, we adapted car-sharing provider FF's existing car-sharing renting mobile application and website. It communicates a relocation request to customers with a red vehicle marker instead of the regular black one (see Figure 7A). A click on the red marker activates customer information on the relocation task, which includes the time limit (in our case, 30 min as car-sharing provider FF requested) and the currently offered relocation incentive, as well as an option to accept the relocation request (see Figure 7B).

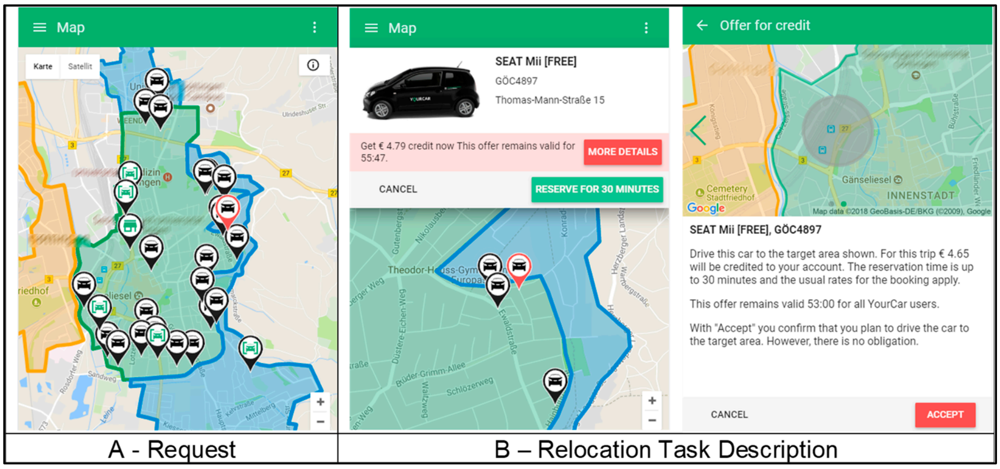

Figure 7. Implemented User Interfaces.

4.2.2. Field Test Evaluation of the Crowd-Based Relocation Approach

The field test to assess crowd-based vehicle relocation was divided into two phases. Table 4 shows the results. The data covering the same period in the previous year is displayed for each phase to place the results in context.

Table 4. Results of Field Test.

	Phase 1		**Phase 2**	
Case	Base-Case	Crowd-Based	Base-Case	Crowd-Based
Time frame	12 December 2016–9 April 2017	12 December 2017–9 April 2018	10 April 2017–28 May 2017	10 April 2018–28 May 2018
Number of Rentals	8250	7600	3442	2984
Active Customers	724	799	545	593
Number of ob Relocations	165	0	83	0
Number of cb Requests	-	1591	-	1184
Number of cb Expired	-	1169	-	1047
Number of cb Relocations	-	50	-	12
Emissions for Relocation (CO_2)	89,100 g	10,800 g	44,820 g	2592 g
Costs of Relocation	€990	€192	€498	€42.36
Average Incentive	-	€3.88	-	€3.54
Distance driven	67,137 km	78,319 km	31,499 km	31,792 km
Duration of Rentals	605,988 min	780,551 min	230,768 min	290,820 min
Revenue of provider FF	€32,897	€38,376	€15,435	€15,578
Number of Rentals	8250	7600	3442	2984
Number of Workdays	101	97	38	39
Number of Holidays	18	22	11	10
Test Workdays/Holidays	0.600		1.000	
Average Rentals per Workday	7275	6689	7439	6313
Average Rentals per Holiday	5011	5055	5591	5220
Hours with Rainfall	689	556	128	94
Hours without Rainfall	2166	2299	1048	1082

Table 4. *Cont.*

	Phase 1		Phase 2	
Test Hours with/without Rainfall	<0.001 ***		0.020 **	
Average Temperature	3.14 °C	2.49 °C	10.38 °C	14.55 °C
Test Hourly Temperature	<0.001 ***		<0.001 ***	

- Number of Rentals: Total number of rentals in time period
- Active Customers: Number of customers who rented a vehicle in the given periods
- Number of ob Relocations: Number of performed operator-based relocations
- Number of cb Requests: Number of requests for crowd-based relocations
- Number of cb Expired: Number of requests for crowd-based relocations that expired
- Number of cb Relocations: Number of performed crowd-based relocations
- Emissions for Relocation: Estimate of emissions based on km driven (on average 5 km per operator-based relocation and 2 km per crowd-based relocation) multiplied by 108 g CO_2 per km (based on SEAT Mii—2012—efficiency class "C")
- Costs of Relocation: Number of operator-based relocations multiplied by €6 (BLINDED); paid out incentives for crowd-based relocations.
- Average Incentive: Average of incentives paid in Euro.
- Distance driven: The distance in kilometers driven by all customers within active rentals.
- Duration of Rentals: The duration in minutes of active rentals by all customers, which includes parking and driving time.
- Revenue of provider FF: The kilometers driven by all customers multiplied by a kilometer price of 0.49 €. (Note that the prices were slightly altered and simplified to disguise provider FF's actual revenue)
- Number of Workdays: Number of workdays in the state of the field test including Saturdays
- Number of Holidays: Number of holidays in the state of the field test including Sundays
- Test Workdays/Holidays: Chi-squared-test (p-value)
- Average Rentals per Workday: Average of the total number of rentals for each workday
- Average Rentals per Holiday: Average of the total number of rentals for each holiday
- Hours with Rainfall: Sum of hours where weather conditions were classified as rain, fog, snow, drizzle or thunderstorm
- Hours without Rainfall: Sum of hours where weather conditions were classified as clear or cloudy
- Test Hours with/without Rainfall: Chi-squared-test (p-value)
- Average Temperature: Average of hourly measured temperature in degrees Celsius
- Test Hourly Temperature: t-test (p-value)

ob = operator-based; cb = crowd-based; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Note: we acknowledge that comparing time windows one year apart has a set of limitations. Foremost, the expected increase of the customer base, difference in the number of workdays and holidays, and varying weather conditions weaken the validity of any comparison. However, in our study design we trade controllability for realism. Any observed customer behavior is genuine and not caused by external factors (such as socially desired behavior). Hence, all assertions and assumptions based on this data should be considered with caution.

The first phase was a pretest (especially for the incentive function) that tested the initially designed system from 12 December 2017 to 9 April 2018. Phase 1 follows the previously described process in which a relocation request is offered every two hours for two hours, and the incentive increases over time from €1 to €6. This configuration enabled us to gather a large dataset of accepted and declined requests for later analysis. However, unlike the simulation, we did not limit the relocation distance because we wanted to collect data that would provide implications regarding the distance customers were willing to relocate.

In the second phase, the initial parameters were adapted and tested from 10 April 2018 to 30 May 2018 (A necessary change to the car-sharing rental software ended the field test. The participating car-sharing provider FF intends to implement crowd-based relocation in the near future once the new software is fully set up and established). Contrary to phase 1, we requested relocation every hour for one hour, and the incentive decreased from €5 to €2 within that time frame. We made this change because of the phase 1 results, which indicated that the initial incentive function was ineffective. Relocations are most valuable to the system directly after their computation. Therefore, performing them later can be less effective and even counterproductive because of changes in vehicle distribution. Hence, the incentive has to be high initially to motivate early relocations; the phase 1 results indicated €5 to be an effective incentive.

Overall, respondents accepted and completed 62 of 2256 relocation requests. However, the system was set up to test various incentives and other parameters, such as time of request/acceptance and pick-up/drop-off locations. We give the analysis of accepted and expired relocation requests in the following paragraphs to disclose patterns for successful requests that will provide input for optimization. Based on our statistical analysis, the hour of day and closeness to points of interest of a request significantly determine whether the crowd will accept it or not. Other factors, such as temperature, weather category, working day/holiday, and trip distance, showed no significant influence on request acceptance in our sample (see Table 5).

Table 5. Adjusted Relocation Acceptance Ratio.

ID	Adjustment	∑ Total	∑ Completed	∑ Expired	Acceptance Ratio
1	No adjustment	2278	62	2216	2.72%
	Adjusted by request time				
2	Requests only during main service-hours (10 h–19 h)	778	44	734	5.66%
	Adjusted by pickup locations:				
3	Vehicle pickup in a radius of 200 m around points-of-interest (train station and university)	234	20	214	8.55%
	Adjusted by request time and pickup locations:				
4	2 and 3 combined	141	17	124	12.06%

Regarding the request/acceptance time, relocation requests were primarily accepted between 10 a.m. and 6 p.m., which fit the time window in which customers primarily rented vehicles (see Figure 8). Thus, providers should not expect relocation requests to be accepted outside of the main service hours, and therefore, they should not request relocation at such times.

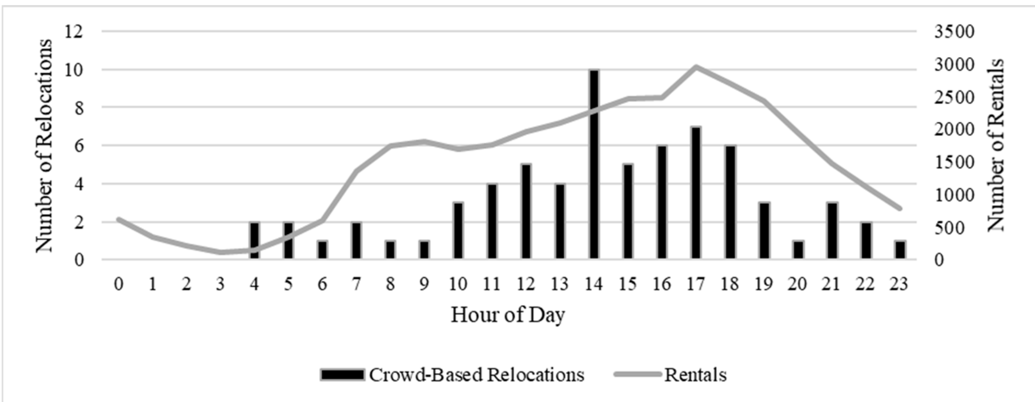

Figure 8. Distribution of customer activities and pick-up times of accepted relocations.

A clear pattern emerged in analyzing the locations for vehicle relocation pick-up and drop-off (see Figure 9). Similar to the vehicle rental locations (see Figure 9A,B), the pick-up locations for vehicle relocation are near points of interest (such as the train station, university, or town hall) and residential areas (see Figure 9C,D, the top area of the map). Therefore, relocation requests from points of interest and residential areas, where a large portion of the customer base lives, are more likely to be accepted and executed.

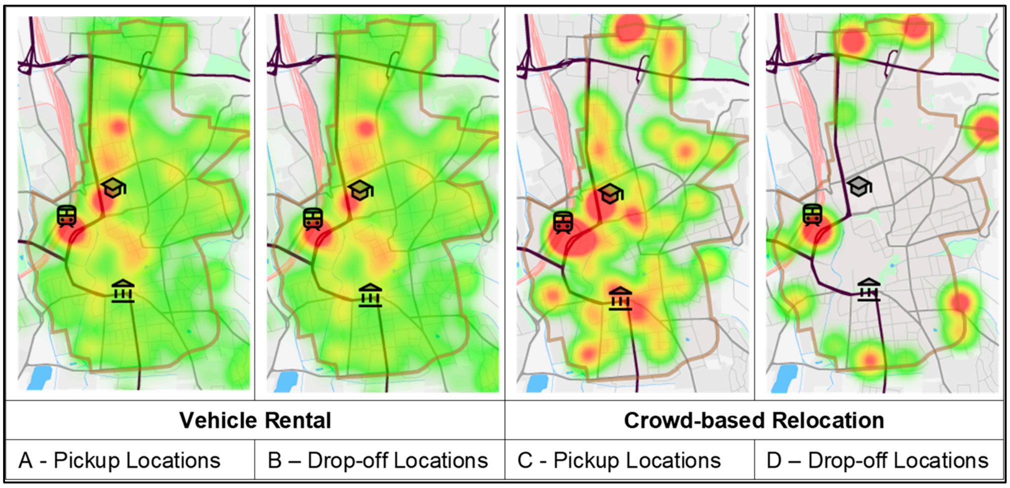

Figure 9. Locations of Relocation and Rental Pickups and Drop-offs.

Further, considering customers who performed more than one relocation (14 of the 45 participating customers), it became apparent that they performed relocations that fit their normal travel behavior (see two examples in Figure 10). Thus, based on our data, relocation requests that fit the travel pattern of customers are more likely to generate a response.

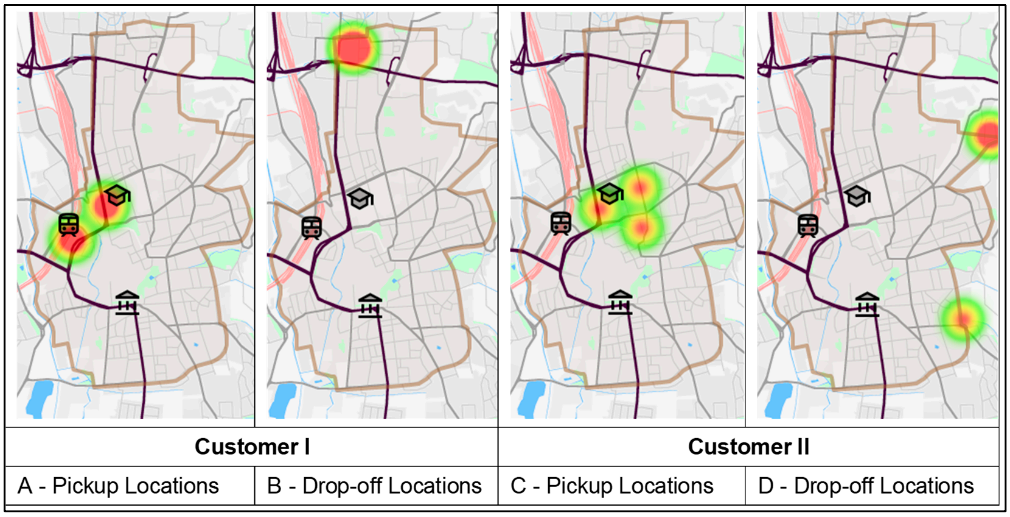

Figure 10. Examples of Customer Pickup and Drop-off Locations.

Overall, considering the time and location of relocation requests (see Table 5), the first impression is that crowd-based relocation requests are rarely accepted and executed (2.72%). However, when adjusting for main service hours (5.66%) and pick-up locations (8.55%), 12.06% of the relocation requests are accepted. We could observe no clear preference for drop-off locations. Nonetheless, we would argue that this is context-specific and that other systems might have different patterns. Thus, optimizing for these patterns would lead to more relocation request acceptance than the unoptimized field test implementation because we refrained from making any a priori assumptions in this regard.

4.2.3. Assessing Requirements

Table 6 summarizes our field test results in the context of the formulated requirements and proposed TPs.

Table 6. Results of Field Test.

No	Requirement	Description	Testable Propositions	Evaluation Result
		Performance		
R1	Reduction	The approach reduces the number of operator-based relocations.	TP1—When implementing R1, the resulting CRIS reduces the number of operator-based relocations required.	No operator-based relocation is required, while a similar level of revenue (e.g., €32,897 in phase 1 base case vs. €38,376 in the crowd-based system) is maintained.
R2	Efficiency	The approach reduces costs and emissions of vehicle relocation.	TP2—When implementing R2, the resulting CRIS leads to lower costs and emissions than operator-based relocation does.	The cost of relocations reduced significantly (80.6% and 91.5%) as did the emission rates (94.2% and 91.5%).
R3	Availability	The approach increases vehicle availability.	TP3—When implementing R3, the resulting CRIS leads to a higher number of vehicle relocations compared to the "no relocation" approach. TP4—When implementing R4, the resulting CRIS leads to a similar number of vehicle relocations compared to user-based and operator-based approaches.	The vehicles remained as available as in operator-based relocation.
		Implementation		
R4	Implementable	The approach is easier to implement than user-based relocation.	TP5—When implementing R4, the resulting CRIS can be successfully implemented.	Provider FF's IT department attested to CRIS being easy to implement and integrate into the existing system.
R5	Automation	The decision process is completely automatic.	TP6—When implementing R5, the resulting CRIS does not require the car-sharing provider to intervene in the relocation procedure.	Provider FF had no need to intervene during the field-study because all crowd-based relocations were requested and completed automatically.
R6	Inexpensive	The approach does not lead to extra costs for the car-sharing provider.	TP7—When implementing R6, the resulting CRIS does not lead to high implementation or maintenance costs (e.g., for hardware or personnel).	Besides the implementation costs, applying crowd-based relocation did not lead to any additional costs.
		Application		
R7	Understandable	Customers can easily understand the approach.	TP8—When implementing R7, customers find the resulting CRIS easy to use. TP9—When implementing R7, the resulting CRIS allows multiple users to accept and complete a relocation task.	Provider FF did not report any notice of customers confused by crowd-based relocation. Relocation requests were accepted and completed by different customers.

In summary, implementing the CRIS framework and using SERA to enable crowd-based relocation met all seven requirements and the related nine TPs. Next, we explicate the prescriptive knowledge gained from all our DSR project findings.

4.3. Design Theorizing

Consistent with Kuechler and Vaishnavi's [59] framework, we followed an inductive theorizing approach. Based on the heuristic theorizing approach [60], we iteratively developed and refined our prescriptive knowledge in the form of DPs, changing them according to the insights gained after each research step throughout our project. Following the anatomy of a DP [63], we inductively derived two DPs based on our findings.

The first design principle (see Table 7) summarizes the collected prescriptive knowledge regarding the process of outsourcing relocation tasks to customers, which provides a more efficient, cost-effective, and environmentally sustainable vehicle relocation process (see Table 7).

Following DP1, a crowd-based relocation IS allows car-sharing providers to substitute operator-based relocations with relocations performed by customers. This is more cost-effective and environmentally sustainable (see Table 4). The IS requests customers to relocate vehicles, i.e., uses customers as a crowd for sourcing relocations (M1). This way, operator-based relocation can be replaced by crowd-based relocation, fulfilling R1. Further, the requests for relocations are communicated openly, potentially to be seen by all customers (M2), which increases the likelihood of finding a customer willing to perform the relocation. This would decrease the potential number of operator-based relocations required (R1). The relocation request is integrated into the car-sharing provider's rental system instead of having a separate system to which customers have to log in (M3). Overall, this approach of integrating crowd-based functionality into the existing rental system is easier to implement than user-based relocation (fulfilling R4) and does not require any additional hardware, such as in-car IS (fulfilling R6). Additionally, it meets customers' expectations of a quick and easy car-sharing rental process [9] and does not require additional skills or knowledge (fulfilling R7).

The crowd-based relocation IS offers them an incentive (e.g., credit or discount) (M4), which is a typical crowd-working procedure [46,49,56]. The monetary value of the incentive is below the cost of operator-based relocations, which creates a cost reduction (fulfilling R2). In this context, our study provides support that customers are willing to perform relocations for comparatively small incentives because, in contrast to workers in the gig economy, they are not trying to accumulate a living wage via relocation incentives [69,70]. In the context of environmental sustainability, operators are driving to and from the origin and destination of a relocation, adding extra kilometers and emissions to the relocation process [23] (fulfilling R2). Lastly, the value of a relocation (i.e., the increased probability of a rental brought on by the relocation) is the highest right when the need for a relocation is identified. Consequently, the incentive for a customer to relocate a vehicle should be the highest when the relocation is first issued (M5). Based on this approach, crowd-based relocation is more likely to improve vehicle availability (fulfilling R3).

The second design principle (see Table 8) summarizes the prescriptive knowledge we collected to address the vehicle relocation computation and, overall, CRIS architecture, which enables car-sharing providers to identify the necessary crowd-based vehicle relocations.

Flanking the DP1 perspective on the process of crowd-based relocation, DP2 summarizes the design knowledge regarding the underlying backend architecture. Besides interacting with customers (see DP1), the crowd-based IS must identify necessary relocations. Accordingly, the IS should be able to analyze rental data based on current and historical data from the car-sharing rental system. The IS can identify necessary relocations (M5) based on such analysis. This architecture and task bundling has proven to be effective in various car-sharing vehicle relocation studies (e.g., [11,71]) and has also proven to be a robust framework for our study. A relocation algorithm should be implemented to identify the need for relocations (M6) effectively. We see SERA as a good starting point with good improvement potential. Our data suggest that relocation should originate or end at a point of interest because customers perform relocations that fit their transportation needs, effectively leading to this pattern. Further, a relocation algorithm for crowd-based relocation should account for the relation between time and rental behavior (e.g., customers typically rent vehicles at the train station in the morning). Following this design increases the probability of a customer accepting and performing a relocation. Eventually, implementing a crowd-based relocation system in this way ensures that the car-sharing provider does not have to train specialist personnel and spend manual time and labor in executing the relocations (fulfilling R5).

Table 7. First Design Principle.

<table>
<tr><th colspan="2">Design Principle 1</th></tr>
<tr><td>Summary</td><td>Give the car-sharing provider the capability to outsource relocation tasks to its customers, to increase the car-sharing system's overall efficiency, cost effectiveness, and environmental sustainability.</td></tr>
<tr><td>Aim, Implementer, and Users</td><td>Enable car-sharing providers to increase the efficiency, cost effectiveness, and environmental sustainability of their vehicle relocation operations.</td></tr>
<tr><td>Context</td><td>Car-sharing providers have the digital infrastructure to monitor vehicle rentals in real-time and to bill customers.
Car-sharing providers do not have the capabilities to implement complex and intricate relocation systems.
• R4—Implementable—The approach should be easier to implement than user-based relocation.
• R6—Inexpensive—The approach should be inexpensive for the car-sharing provider to implement (e.g., no expensive hardware).
Car-sharing providers' vehicle distribution is consistently changing, thus it can become unbalanced (R3).
• R3—Availability—The approach should increase the carsharing provider's vehicle availability.
• R2—Efficiency—The approach should reduce costs and emissions of vehicle relocations.
Car-sharing providers are looking for ways to reduce the costs arising from vehicle relocation (i.e., to replace operator-based relocations) (R1, R2).
• R1—Reduction—The approach should reduce the number of operator-based relocations.
Car-sharing customers expect a fast and easy rental process.
• R7—Understandable—The relocation procedure of the approach should be easy for customers to understand.</td></tr>
<tr><td>Mechanism</td><td>M1—Request customers to relocate vehicles.
M2—Request all customers to relocate via an open relocation request.
M3—Incentivize customers with credit or discounts that are below the cost of operator-based relocations.
M4—Integrate the request communication functionalities into the car-sharing renting system.
M5—Offer the highest incentive directly after issuing the relocation request.</td></tr>
<tr><td>Rationale</td><td>M1—Customers cost less than employees [11,24].
M2—All customers could perform a relocation, and requesting all customers ensures a bigger crowd than sending selective requests; widely sent calls increase the possibility of a customer answering to a relocation request [49].
M3—A single point of access reduces the risk of customers not noticing the requests. Further, it automatically restricts access to the system to customers, who are known to and validated by the provider, thus this is an effective crowd building process [49].
M4—Incentivizing customers with credit and discounts does not require participating customers to have permits and to be self-employed [68,69]. Also, customers expect a quick and easy rental process [9].
M5—The impact of a relocation on the overall vehicle availability decreases over time, as a result of the frequently changing vehicle distribution [71].</td></tr>
</table>

Table 8. Second Design Principle.

Design Principle 2	
Summary	Equip the car-sharing provider with the capability to automatically analyze current vehicle distribution and forecast future demand in order to determine required crowd-based relocations that increase vehicle availability.
Aim, Implementer, and Users	Allow car-sharing providers to identify necessary vehicle relocations, i.e., relocations that lead to an improved vehicle distribution, which will result in a higher number of vehicle rentals.
Context	Car-sharing providers have the digital infrastructure to monitor vehicle rentals in real-time and to bill customers. Car-sharing providers have to perform multiple relocations during a single day (R5). • R5—Automation—The decision process regarding the relocation of vehicles should be completely automatic.
Mechanisms	M5—Include components for data analysis, relocation computation, and connections to the car-sharing provider's rental system. M6—Apply a vehicle relocation algorithm (e.g., ALGO) to compute the necessary crowd-based relocations. In this process, the algorithm selects and requests relocations that originate and/or end at points-of-interest (e.g., train station, hospital, city center) and take place during main service hours (e.g., when customers regularly use the service).
Rationale	M5—The three identified components are required to compute a vehicle relocation. This design extends Wagner et al.'s [11] framework for user-based relocation. M6—Relocation has to be necessary; performing no relocations or unnecessary relocations are ineffective in attracting more vehicle rentals. Customers are less willing to perform relocations that do not fit their regular rental behavior regarding destination, origin, and rental time.

5. Discussion

This study has addressed the challenge of balancing vehicle supply and demand in a car-sharing system. The current modus-operandi is to relocate vehicles via employees, which leads to extra costs, more driven kilometers, wear-and-tear on vehicles, and high emissions. In this context, our study has developed the approach of crowd-based relocation and a CRIS. Via the CRIS, customers are requested and incentivized to relocate vehicles, shifting the task from company employees to their customers. Overall, our DSR project with multiple evaluation steps provides support for crowd-based relocation as a cost-effective and environmentally sustainable alternative to current relocation approaches. The following sections will present the study's theoretical and practical implications and give its limitations and potential avenues for future research.

5.1. Theoretical Implications

Current (vehicle) supply and demand are managed by following operator-based relocation approaches, causing alternative approaches to be less researched. Thus, the crowd-based relocation approach, framework, relocation algorithm, and instantiation within a free-floating car-sharing system, as we have developed them, count as improvements in the field since this work enhances the sharing industry by adding a new approach to their toolbox. Prominently, our results provide fertile ground for research regarding developing new algorithms for parts of a CRIS and benchmarking them against the presented instantiations [72]. For instance, developing alternatives to SERA or designing a more sophisticated approach to compute incentives are valuable research areas.

Additionally, our research contributes to the research domain of Green IS [73]. Specifically, we respond to the need for more Green IS research on design [74,75] and research with real-world impact [76]. By outsourcing relocation tasks to the customers, our solution reduces unnecessarily driving longer distances and the associated carbon emissions for relocation. Previously, operators had to get to the distantly located vehicles, drive them to the new location, and move to another vehicle or back to the office [45]. This process was inefficient precisely because it led to unnecessary carbon emissions due to many kilometers being driven purely for relocation. As an alternative, crowd-based relocation offers customers the possibility of relocating vehicles for an incentive such as credit or a discount. Our data indicate that customers relocate vehicles when the task is along a route they typically use (i.e., from points of interest). This approach could be used in car-sharing and other sharing services, thus increasing the sustainability of sharing services in various industries. In summary, our research provides insight into how IS can support sharing service operations and increase their environmental sustainability.

Finally, we theorize about the potential to extend the derived prescriptive knowledge of our project beyond our class of problems (i.e., car-sharing). At its core, crowd-based relocation addresses the problem of redistributing goods so that supply and demand remain balanced. Customers are invited to perform the required relocation tasks themselves, motivated by some incentive (e.g., credit or discount). This approach fits a greater context than car-sharing or even mobility-sharing (e.g., bike- or e-scooter-sharing). Managing supply to meet demand is a challenge multiple sharing economy business models face [3,26]. Against this background, crowd-based relocation has the potential to be applied to other PMR sharing services. In PMR sharing, the value of goods depends on their position. In the case of car-sharing, the "nicest" vehicle with the lowest rental price has little to no value for customers if it is positioned out of their reach. The same is true for other goods, such as bikes, power banks, umbrellas, tools, or clothing. As long as the goods being shared are PMR, approaching customers as a crowd to source relocation tasks is likely to be effective. In such circumstances, our design provides prescriptive knowledge on implementing such a system. Against this background, we identify a valuable area of future research in investigating the contextual differences of these systems and how they influence the design of a CRIS. For instance, the relations between relocation incentive, the value of relocation, the effort of relocation, and service price will most likely highly influence the success of crowd-based relocation. For instance, the service cost of renting a power bank is relatively low compared to car-sharing. Hence, a power bank-sharing provider would only be willing to offer a small incentive for a relocation. However, relocating a power bank is a relatively easy task compared to driving a car-sharing vehicle to a new location. Nonetheless, it might be necessary to implement additional features such as gamification [77], persuasive messages [78], or digital nudges [79] to motivate customers to participate. In the end, efficient crowd-based relocation solutions for PMR sharing could lead to an improved profit structure for providers, facilitating widespread use of the shared goods and increasing environmental sustainability because sharing is more sustainable than individual ownership and use [27].

5.2. Practical Implications

Primarily, our study contributes to practice by offering a new approach and tool car-sharing providers can use to manage vehicle supply and demand. Currently, operator-based relocation is the only viable option car-sharing providers have for redistributing vehicles in accordance with demand. Crowd-based relocation offers providers the ability to outsource parts of the overall redistribution task by letting customers perform individual relocations in exchange for a discount or credit on their next rentals. As the field test showed, this approach reduces costs by diminishing providers' need to appoint employees for manually relocating vehicles.

Further, practically, this approach not only reduces costs it also reduces carbon emissions in comparison to operator-based relocation. The results of the field test enabled us to estimate emissions reduction. Unfortunately, we have no specific data available on the vehicle relocation practices of car-sharing companies, such as the number of relocations per day, average distance driven for relocation, etc. The available data on the car-sharing industry in Germany [80] indicates that 13,400 vehicles are currently part of a free-floating car-sharing system that has 1,580,000 active customers. According to our field test, one vehicle is relocated in a fleet of around 30 vehicles per day. Extrapolating this data to Germany's entire car-sharing market, around 450 relocations are performed daily (not accounting for different levels of activity in systems). This would amount to

164,250 relocations annually, resulting in an estimated 886,950 kg of CO_2 emissions. If the entire free-floating car-sharing industry in Germany were to adopt crowd-based relocation (applying the reduction of crowd-based relocation by 85%), relocation would produce only 133,042 kg of CO_2 emissions annually. Compared to the German transportation sector's total emissions [81], this would amount to a rather small reduction in emissions (less than 1%). Nonetheless, car-sharing is an expanding industry [80] that can replace up to 20 vehicles with a single shared one [82]. In such circumstances, crowd-based relocation would make two practical contributions by (1) increasing vehicle relocation efficiency and (2) improving vehicle availability, thereby attracting more customers and replacing many private vehicles.

The results of this study contribute to the sharing economy industry [2,3]. The concept of value co-creation that jointly engages sharing service providers and customers has recently captured researchers' (e.g., [83]) as well as practitioners' interest. For instance, the e-scooter sharing company, Lime, incentivizes freelancers to recharge scooters at home for a monetary reward, thereby making it a prime example in the gig economy. However, the crowd-based relocation approach we present differs from the gig economy in not requiring professional and self-employed individuals for the gig (i.e., the task). Any customer can participate in crowd-based relocation because no monetary payment is offered; participating customers earn a discount or credit for their next rental. This adds a new facet to the idea of inviting individuals to perform micro-tasks that support and enable sharing services.

Overall, we would recommend that practitioners (i.e., car-sharing providers) adopt a system similar to the presented one to harness the described benefits. For instance, piloting a crowd-based relocation system as part of an event could provide a valuable indication of whether crowd-based relocation works for the individual car-sharing system.

5.3. Limitations and Future Research

We still recognize some limitations despite rigorously conducting the DSR project and its various evaluations. Moreover, our results have implications for future research. We outline these limitations and avenues for future research in the following paragraphs.

First, the evaluations we applied were primed by the two main evaluation partners, car-sharing providers SB and FF. The field test was limited because we conducted it in a single free-floating car-sharing system. The organizational and infrastructural limitations of the evaluation partners could have affected the results and the eventual CRIS design. Therefore, future research should engage other sharing systems to confirm the CRIS application's reported effectiveness. For instance, our approach to allocating the relocation task to customers rather than freelancers (as is common practice in other sharing business models, such as e-scooter sharing) is based on the size of the car-sharing system. In a relatively small car-sharing system, we anticipate a small number of necessary relocations, which would make it unattractive to freelancers because they cannot count on achieving an adequate hourly income.

Second, the field test evaluation results have to be interpreted with caution. Relocation requests were issued at all times of the day, with various origins and destinations. We did not optimize to match the time of the day, origins, and/or destinations. This resulted in a high number of relocation requests and a relatively low number of performed relocations. Thus, future research should implement optimization to evaluate the full potential an optimized CRIS has for improving vehicle distribution. For instance, understanding the interrelation of various factors, such as weather, time, location, vehicle type, and relocation distance, is important to predict when a customer will accept a relocation task and at which price. For instance, the challenge of managing electric vehicles [84,85] should be addressed in future algorithmic solutions because electric vehicles are regarded as an important part of the future of transportation [86,87]. Therefore, looking more closely at the feasibility and efficiency of different pricing strategies and negotiation mechanisms would be an important area of research. Moreover, the developed CRIS is based on an adaption of the SERA, which does not account for the potential of other algorithms.

Third, unlike the predominant DSR research strategy that derives DPs from explanatory kernel theory, this study follows the less often applied strategy of developing artifact instantiations in practice and inductively deriving DPs [28,60,88]. The design is mostly based on prescriptive knowledge and references from real-world instantiations and practices. Thus, the design's connection to the foundational descriptive knowledge and explanatory theory can be considered limited. Future research should identify connections to theory, explain how and why specific DPs work, and potentially develop new ones.

Against this background, designing artifacts to solve problems is an iterative research process that aims to develop an improvement of the status quo [28,29]. The solution design presented in this study is a first step toward understanding the complex design of a CRIS. It offers a first architectural framework, a set of DPs, an algorithmic solution, and an exemplary implementation. Future research can engage in optimization [72], for example, benchmarking new algorithms or further investigating the design of individual modules. For instance, the applied function of computing incentives could be improved by including other parameters (such as the weather) and utilizing machine learning. Moreover, some relocation requests are unattractive to customers (e.g., after dark or far from points of interest) and should, therefore, still be performed by operators. Hence, designing an IS to orchestrate crowd- and operator-based relocations is a worthwhile future research focus.

Last, we want to turn researchers' attention to a pressing paradox contained in improving vehicle supply and demand in car-sharing. Various studies have shown that car-sharing decreases car use and increases the use of other transportation modes, such as biking, walking, or using public transportation (e.g., [4,89]). However, increased vehicle availability leads to car-sharing being almost as highly convenient as a privately-owned car. Hence, customers could be enticed to use car-sharing more frequently rather than biking and walking. A similar effect has been reported in the context of ride-hailing services (e.g., Uber or Lyft). These services' increased availability has led to more cars on the street [90]. Thus, we have to find approaches that will protect car-sharing from losing various advantages, such as environmental sustainability [35]. Other sharing services face similar challenges because improving their value proposition and availability has led to unwanted side effects. This is illustrated in accommodation-sharing (e.g., Airbnb), where the option to share one's apartment can become more profitable than renting it, which effectively destroys much-needed parts of the housing market [91]; another example is dockless bike-sharing, which can flood cities with cheap and disposable bikes and could call environmental benefits into question [92]. Therefore, we support the direction the Green IS research community takes, engaging the "dark side of the sharing economy" [93].

6. Conclusions

The problem of balancing vehicle supply and demand in a car-sharing system and the associated lack of environmentally friendly and cost-efficient relocation approaches motivated our research. In this context, we developed an IS to support a crowd-based relocation approach called CRIS. We derived several DPs based on an application and evaluation in a real-world free-floating car-sharing system to design a CRIS. Overall, we were successful in piloting a new vehicle relocation approach, which displayed great potential. However, further research is needed.

Regarding a theoretical perspective, we address a relevant real-world problem and have developed a nascent design theory. This theory addresses the effective design of a CRIS for the entire class of car-sharing systems. We demonstrated how the DSR paradigm and methodology can be applied to address relevant problems and how to derive design knowledge in close conjunction with practitioners. Further, our results are accompanied by the proposition of several future research opportunities. For instance, we suggest extending the design theory to the problem class of PMR goods' supply and demand management. In this regard, the design principles we presented can serve as a point of reference for future research on a CRIS design.

From a practical perspective, our research contributes by proposing a CRIS design to support car-sharing providers by supplementing and improving their vehicle supply and demand management. The results of our evaluation, specifically of our field test, confirm that a CRIS can improve the availability of vehicles in a car-sharing system. By consolidating the design knowledge, we collected it into generalized DPs for designing a CRIS, and the proposed design can serve as an adaptable "blueprint" to fit multiple contexts and organizations. We enable practitioners to implement their own CRIS that could balance supply and demand via engaging customers as a crowd inviting them to take on relocation tasks, complying with the individual, organizational, and infrastructural specifications.

With a view to the future, we would like to encourage researchers and practitioners alike to apply, implement, evaluate, and refine the proposed design theory for a CRIS to advance the nascent design theory toward a fully developed design theory.

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