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A DECISION SUPPORT SYSTEM FOR THE OPTIMIZATION OF CAR SHARING STATIONS

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Abstract

Approximately half of the world's population is living in cities and it continues to grow. Along with urbanization, scarce natural resources, rising energy costs, shortage of space, increasing traffic congestion, and environmental pollution require populations to rethink personal vehicle ownership. Car sharing is an alternative that allows individuals to satisfy their mobility needs and addresses modern transportation issues. The location and accessibility of car sharing stations are critical success factors. We provide decision support for planning car sharing stations, both existing and new ones. Therefore, we constructed and evaluated research artifacts according to the design science research principles. We suggest an optimization model to determine the prime location and size of car sharing stations. Based on this model, a decision support system (DSS) called OptCarShare 1.0 is used for exact optimization. This system integrates several applications to import, edit, and export data, solve the problem numerically and visualize optimization results. Using a major German city with 500,000 people to illustrate solutions, we evaluate and show the applicability of the DSS OptCarShare 1.0. According to Green IS, our DSS can provide a contribution to environmental sustainability.

Keywords: Car sharing, decision support system (DSS), optimization model, Green IS.

1 Introduction

Approximately half of the world's population is living in cities and it continues to grow (Shaheen and Cohen, 2013, p. 1). Along with urbanization, scarce natural resources, rising energy costs, shortage of space, increasing traffic congestion, and environmental pollution require populations to rethink personal vehicle ownership. Aside from public transportation, an alternative to address these issues is car sharing. This concept is becoming a mainstream transportation solution with more than a million users in over 26 countries (Shaheen and Cohen, 2013, p. 1-2). By sharing a vehicle sequentially, individuals, especially young adults and best agers, are able to satisfy their basic need for mobility without owning a car. The location and accessibility of car sharing stations is a critical success factor. However, positioning and sizing of stations in order to design an efficient transport network is challenging.

Green information systems (IS) and sustainability are becoming major topics within the IS research domain (Dedrick, 2010, p. 174). The increased demand for energy is a chronic problem that demands immediate action. Heavy use of information and communication technology is a factor of higher energy consumption and emission of greenhouse gases (Butler, 2011, p. 2). However, the use of IS does not necessarily imply high energy consumption. On the contrary, intelligent utilization of IS can contribute to higher sustainability. Through an interaction of IT and people, Green IS enables the optimization of processes and products to raise resource efficiency. Thus, direct and indirect conservation of resources and higher sustainability can be achieved.

Car sharing is a sustainable mobility concept (Duncan, 2011). Within existing literature, little methodological support for car sharing is available. The optimal location and size of stations lack thorough and quantitative investigation. In this void, we provide decision support for planning stations optimally. Based on existing research about car sharing and established Operations Research (OR) models, we have formulated an optimization model. This model minimizes the cost by calculating the optimal location and size of stations, while satisfying consumer demand. In order to enhance usability, a decision support system (DSS) helps the user import, edit, export, and visualize data. The system also triggers numerical solving of the underlying model within mathematical programming. The DSS allows parameter setting and visual optimization results that enable instant validation, comparison and assessment of results and scenarios. This paper addresses the following research question:

> *RQ: How can the optimal location and size of car sharing stations be determined and decision support be provided?*

The remainder of this paper is structured as follows: After this introduction, the research background is addressed, including foundations, related work and research design. In the third section, a quantitative approach to car sharing is provided. A formal and verbal description of the optimization model is given and explained. Then, the implemented DSS, which employs the underlying model, is presented. Within a representative application example in section four, the optimization results for a German major city are shown. Section five provides a discussion about results, theoretical and practical recommendations as well as limitations. The paper ends with a short conclusion and outlook.

2 Research background

2.1 Theoretical background and related work

When Watson et al. (2010) called for more attention to energy informatics, eco-friendliness and sustainability, many new topics have come into focus in the IS research domain, see e.g. Loos et al. (2011). Initially, resource-saving information technology was the main topic of research in Green IT (Dedrick, 2010, p 174). However, the actual use of IS is to broaden the scope and potential of environmental sustainability. By employing information and communication technology, Green IS enables direct and indirect resource conservation and thereby increases environmental sustainability. Car sharing optimization by using IT and IS is clearly an example of Green IS.

Car sharing emerged in Switzerland in 1948 (Shaheen et al., 1998, p. 37). A small private community had the basic idea to share cars and thus split ownership costs. In the late 1980's, the first successful car sharing organizations were founded in Germany and Switzerland (Katzev, 2003, p. 68; Shaheen et al., 2006, p. 116). Since then, car sharing has become more popular with a rising number of users. Today, almost all countries in Western Europe have car sharing organizations. In Switzerland, car sharing is very popular and is used more often per capita than anywhere else (Shaheen and Cohen, 2013). Car sharing has also been successfully implemented in North America. In Canada, the first enterprise was founded in 1994 and in the USA in 1998. Like in Germany and Switzerland, car sharing in North America has developed positively. This leads to the conclusion that a demand for alternative mobile services exists primarily in industrial countries (Shaheen and Cohen, 2007, p. 83). Nevertheless, these services will also be important for urban areas in developing countries and megacities with 5, 10, or even 20 million people in the near future.

Car sharing is defined as a mobility service which offers consumers the use of vehicles in an organized and collaborative manner. Before a car sharing vehicle can be used, the consumer has to register at a car sharing organization. A desired vehicle from the fleet is reserved for a specific period and retrieved at a specific location. After the use of the vehicle, it must be parked at the same location where it was obtained. This form of mobility service has special characteristics that differentiate from other similar concepts such as car rental or carpooling. A contract between the consumer and the car sharing organization will facilitate convenient use. The consumer can reserve and use a vehicle at any time of the day and pays for the rented time and driven distance. However, the organization is still the sole owner of the car. In most cases, the car is used for short trips within a city (e.g. to buy groceries). Further details about car sharing can be found in specialized literature, such as Barth and Shaheen (2002) and Stillwater et al. (2009).

The fact that car sharing is growing in popularity highlights utilization issues with private vehicles. Private parties drive to work in the morning and return in the evening. Within this timeframe, the car could be driven by someone else. By utilizing car sharing, fewer vehicles are needed to satisfy the same transport demand. However, car sharing can only be integrated in areas where people do not strongly depend on cars (Celsor and Millard-Ball, 2007). An infrastructure that includes bus and metro networks is needed because combined mobility enhances car sharing (Huwer, 2004). For example, a car sharing vehicle can be reached by bicycle and after the return of the car, the trip can be continued by bike, bus, metro or train. In this context, car sharing represents one option the traveler can choose from to satisfy mobility needs. Young people living in big cities are less car-oriented (Kuhnimhof et al., 2011). The focus should be to fulfill the actual need for mobility and not possess a car as a status symbol. Car sharing users are usually between 25 and 45 years old, highly educated, ecology-minded, and are employed. They often live in large cities alone or with one person and regularly use public transportation (Millard-Ball et al., 2005). A negative correlation exists between population density and kilometers driven by car (Holtzclaw et al., 2002). The higher the population density, the fewer kilometers are driven. Traffic congestion, public transportation, and parking issues are factors in explaining the use of cars in cities.

Car sharing is only one approach to address rising sustainability problems in large cities. Sustainability can be divided in three components: social equity, economic efficiency and ecologic awareness. Social equity can be achieved by anti-discriminatory registration of car sharing organizations. Low-income households have the opportunity to use cars. Economic efficiency is achieved by higher utilization of vehicles. Consumers are able to drive on demand and save money by sharing the ownership costs (Schuster et al., 2005, p. 176; Duncan, 2011). The ecologic component has the largest potential of car sharing. By using car sharing vehicles, the consumer is able to calculate the true costs and compare them with other transport modes. The consumer may realize that using the bus, railway or riding a bike can be cheaper and can use these alternatives more often. A 'learning effect' can result in lower car use. Consequently, emissions and traffic noise decreases and fewer parking spaces are needed

(Martin and Shaheen, 2011). Moreover, the number of people who own a car can also decrease (Martin et al., 2010). The positive ecological effect of car sharing can spur the use of small cars that decrease the use of fossil fuels or use alternative energy (Kriston et al., 2010). To operate car sharing successfully and increase sustainability, the location and accessibility of car sharing stations is a critical success factor.

2.2 Research design

To address relevance and enhance rigor of the research process and outcome, our research was conducted using the design science research (DSR) principles. According to the above-mentioned research question, the design and evaluation of artifacts that can promote ecological and sustainable action was our main objective. We used key recommendations provided by Hevner et al. (2004, 2007) and March and Smith (1995). The design-oriented research process was advised by Peffers et al. (2007) and Offermann et al. (2009).

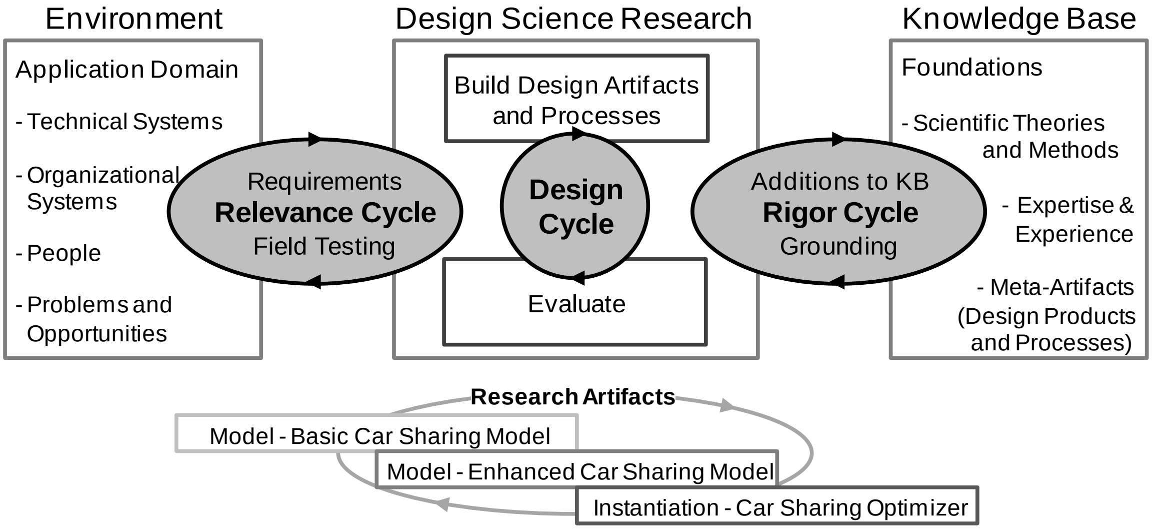


Figure 1. Research design according to design science research (Hevner, 2007, p. 88)

The actual research design is depicted by three DSR cycles according to Hevner (2007, p. 88) and Figure 1. The research process is initiated by the relevance cycle that provides requirements and acceptance criteria of the contextual environment (Hevner, 2007). Here, the growing interest of society and cooperation with a major German car sharing company gave rise to new research. To ensure methodological rigor, foundational information must be gathered from the academic body of literature (Hevner, 2004). We conducted a comprehensive literature review within the operations research (OR) and IS research domain. We also conducted a targeted review within the DSR domain. The practical and scientific input is used in the design cycle to generate and evaluate artifacts in a tight loop with rapid interactions (Hevner, 2007). After the problem domain had been refined and detailed requirements had been defined, we constructed the first research artifact: the basic car sharing model. Within this optimization model, we included only basic parameters, variables and constraints. According to guideline six, “design as a search process”, by Hevner (2004, p. 88ff.), we used an iterative approach to generate and refine artifacts cyclically (see Figure 1). Due to evaluation and additional requirements, the basic model was refined with extra parameters, variables and constraints resulting in the enhanced car sharing model. March and Smith (1995) name constructs, models, methods, and instantiations as the result of design-oriented research. In addition to the constructed formal models, we implemented a DSS as an instantiation. The DSR cycles are then completed by more extensive tests of the artifacts (preferably field tests) followed by a publication of the research results. Based on the DSS, we performed comprehensive tests of the system itself and the underlying model to enable the documentation of research results.

3 A quantitative approach to car sharing

3.1 Optimization model

The objective of the model is to find the best location and size of car sharing stations while satisfying consumer demand and preferences and minimizing total cost. The model is subject to the following assumptions: Consumers use car sharing vehicles to satisfy their mobility needs. Total demand is stochastic and modeled by a normal distribution. The demand is represented on a punctual basis and aggregated in specific demand locations within a city. Car sharing cars have to be parked at designated stations. Each car occupies one of the parking lots of a station. Further, the car sharing organization uses one type of vehicle. In addition to location, and the number and size of stations, the maximum distance to a station is an important determinant. It is calculated using geographic coordinates. Thus, the optimal balance between number and size of stations has to be determined. Population density of different areas represents a major factor due to its impact on the utilization of car sharing (Millard-Ball et al., 2005, p. 26). The resulting mathematical problem can be formulated as follows:

$$Min. \quad F(f,y) = \sum_{i=1}^{m} f_i(kf + ka) + y_i \cdot ks \tag{1}$$

$$d_{ij} \cdot z_{ij} \leq maxd \quad \forall \ i = 1, ..., m \ \text{ and } \ j = 1, ..., n \tag{2}$$

$$\sum_{i=1}^{m} z_{ij} = 1 \quad \forall \ j = 1, ..., n \tag{3}$$

$$y_i \geq z_{ij} \quad \forall \ i = 1, ..., m \ \text{ and } \ j = 1, ..., n \tag{4}$$

$$f_i \cdot kp = \sum_{j=1}^{n} n_j \cdot z_{ij} \quad \forall \ i = 1, ..., m \tag{5}$$

$$f_i \leq maxp_i \quad \forall \ i = 1, ..., m \tag{6}$$

$$v_i \leq a \quad \forall \ i = 1, ..., m \tag{7}$$

$$w_i \geq minb \quad \forall \ i = 1, ..., m \tag{8}$$

$$z_{ij}; \ y_i \in \{0,1\} \quad \forall \ i = 1, ..., m \ \text{ and } \ j = 1, ..., n \tag{9}$$

$$f_i \geq 0 \quad \forall \ i = 1, ..., m \tag{10}$$

Where:
i = potential station locations (i = 1,…, m);
j = demand location (j = 1,…, n);
ks = costs for a station;
ka = costs for a parking lot;
kf = costs for a vehicle;
n_j = normal distributed demand;
a = default shortage of parking;
v_i = actual shortage of parking;
minb = default population density;
w_i = actual population density;
maxd = max. distance btwn demand point and station;
d_{ij} = actual distance between i and j;
$maxp_i$ = maximum number of parking lots;
f_i = actual number of parking lots and cars;
z_{ij} = 1 if demand point j is served by station i, else 0;
y_i = 1 if station i is built, else 0;
kp = customer parameter: number of customers who can be served by one vehicle a day.

The objective function (1) is used to minimize the total cost of the car sharing organization. More precisely, the costs are the accumulated annual fees for renting vehicles and parking lots, plus annual costs to maintain stations. The distance between a demand point and a car sharing station should not exceed a maximum distance that is ensured by (2). Constraint (3) ensures that every demand point is served by one car sharing station to avoid redundancy. Due to constraint (4), a demand point can only be assigned to a car sharing station if a station is built. Satisfaction of the total demand is guaranteed by (5). There are four threshold values within the model (**a**, **minb**, **maxd**, **maxp$_i$**) plus four variables for the actual values of the items ($\mathbf{v_i}$, $\mathbf{w_i}$, $\mathbf{d_{ij}}$, $\mathbf{f_i}$). A station cannot provide space for more vehicles than there are allotted, as avoided by (6). Variable $\mathbf{v_i}$ is defined as follows:

$\mathbf{v_i}$ = free parking lots around station **i** / registered vehicles around station **i** * 100 [%]

The smaller variable $\mathbf{v_i}$, the higher is the shortage of parking. Due to (7), the actual shortage of parking cannot be bigger than the default shortage of parking. High population density has a positive effect on the utilization of car sharing vehicles. Variable $\mathbf{w_i}$ is defined as following:

$\mathbf{w_i}$ = population at station **i** / area at station **i**

Because of constraint (8), a minimum level of the population density within each area is reached. Equations (9) and (10) constitute the value range of the decision variables $\mathbf{f_i}$, $\mathbf{y_i}$, $\mathbf{z_{ij}}$.

3.2 Decision support system

The DSS integrates the optimization model and several applications within one system to enable decision support. The system architecture and data flow can be seen in Figure 2:

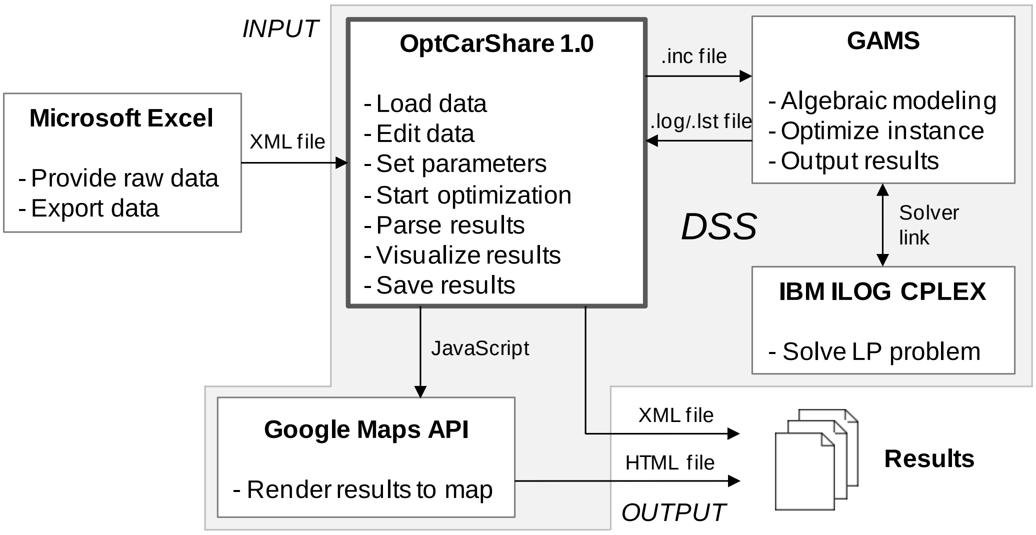
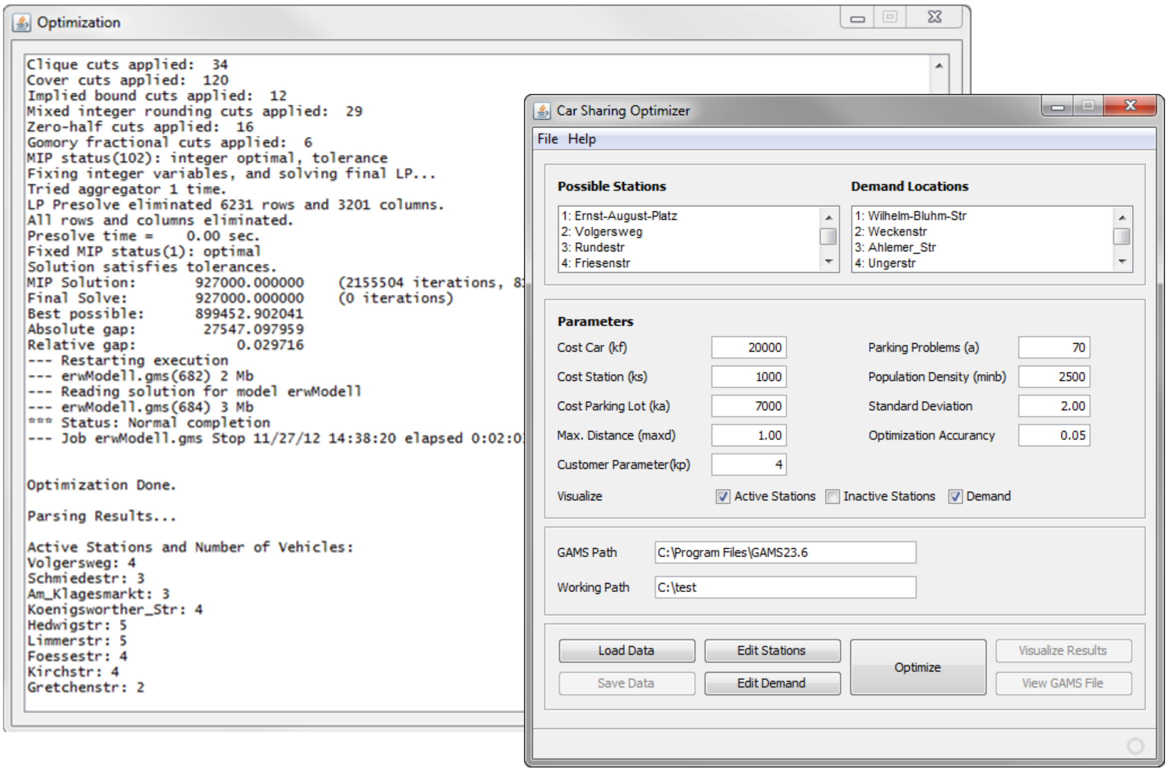


Figure 2. System architecture and data flow of the decision support system

Raw data about possible station locations and the demand locations can be kept in a spread sheet using application software such as Microsoft Excel. Stations and demand with their attributes are exported to a XML file according to a XML scheme. The implemented Java application which is called OptCarShare 1.0 gathers data from the XML file. The graphical user interface (GUI) shows and allows editing of imported data in addition to parameter configuration. The application triggers the actual optimization process by sending information to GAMS, which provides the mathematical modeling. A solver link is used to communicate with IBM ILOG CPLEX which solves the underlying mixed integer programming (MIP) model numerically. During the optimization, the progress is presented on screen as shown on the left-hand side of Figure 3. Once the optimal solution is found, the results are sent to GAMS and parsed by OptCarShare 1.0. Finally, results can be visualized and saved to a file. Mashup technologies (JavaScript, Google Maps API) are used for the visualization of optimization results to enable instant graphical validation.

The OptCarShare 1.0 web application, underlying model, and a sample data pool are available online:
http://www.iwi.uni-hannover.de/CarSharing (open access)

The progress of the optimization is displayed on the left-hand side of Figure 3, and the GUI with loaded data, parameters, and functions is shown on the right-hand side:



```
Clique cuts applied:  34
Cover cuts applied:  120
Implied bound cuts applied:  12
Mixed integer rounding cuts applied:  29
Zero-half cuts applied:  16
Gomory fractional cuts applied:  6
MIP status(102): integer optimal, tolerance
Fixing integer variables, and solving final LP...
Tried aggregator 1 time.
LP Presolve eliminated 6231 rows and 3201 columns.
All rows and columns eliminated.
Presolve time =    0.00 sec.
Fixed MIP status(1): optimal
Solution satisfies tolerances.
MIP Solution:        927000.000000    (2155504 iterations, 8
Final Solve:         927000.000000    (0 iterations)
Best possible:       899452.902041
Absolute gap:         27547.097959
Relative gap:             0.029716
--- Restarting execution
--- erwModell.gms(682) 2 Mb
--- Reading solution for model erwModell
--- erwModell.gms(684) 3 Mb
*** Status: Normal completion
--- Job erwModell.gms Stop 11/27/12 14:38:20 elapsed 0:02:0


Optimization Done.

Parsing Results...

Active Stations and Number of Vehicles:
Volgersweg: 4
Schmiedestr: 3
Am_Klagesmarkt: 3
Koenigsworther_Str: 4
Hedwigstr: 5
Limmerstr: 5
Foessestr: 4
Kirchstr: 4
Gretchenstr: 2
```

Possible Stations

1: Ernst-August-Platz
2: Volgersweg
3: Rundestr
4: Friesenstr

Demand Locations

1: Wilhelm-Bluhm-Str
2: Weckenstr
3: Ahlemer_Str
4: Ungerstr

Parameters

Cost Car (kf)	20000	Parking Problems (a)	70
Cost Station (ks)	1000	Population Density (minb)	2500
Cost Parking Lot (ka)	7000	Standard Deviation	2.00
Max. Distance (maxd)	1.00	Optimization Accurancy	0.05
Customer Parameter(kp)	4		

Visualize ☑ Active Stations ☐ Inactive Stations ☑ Demand

GAMS Path: C:\Program Files\GAMS23.6
Working Path: C:\test

Figure 3. Graphical user interface of the decision support system

Like other facility location problems, the optimization problem presented in section 3.1 belongs to the class of combinatorial optimization. According to the computational complexity theory, the problem is np-hard. That implies that it is difficult to solve and computationally expensive. Especially for large instances, the optimal solution is hard to determine. Because the DSS allows problem solving to the provable best solution, the optimization may take a while. The solver uses exact procedures like the cutting plane, branch and bound, and branch and cut algorithm. The actual time to solve the problem depends on the size of the instance and settings. Results of benchmarks are presented in section 4.

4 Application example: car sharing in Hanover

To show the applicability of our research artifacts, the DSS and the underlying model are validated in an example. For varying parameters, optimal locations and sizes for car sharing stations are exemplified by the German city of Hanover. The city has an appropriate size (about 500,000 people), population density and public transportation to allow efficient car sharing. The data set includes 100 potential car sharing stations and 30 demand locations with geographic information. For each potential station, the shortage of parking ($\mathbf{v_i}$) and population density around the station ($\mathbf{w_i}$), and the maximum number of parking lots ($\mathbf{maxp_i}$) are contained within the data set. Each demand location specifies the expected value of customer demand ($\mathbf{n_j}$) within the area. The setting of independent variables (**kf**, **ks**, **ka**, **maxd**, **kp**, **a**, **minb**) is depicted in Figure 3. The maximum distance between a station and a demand point is a critical determinant and is initially set to 1km. As stated by Katzev (2003), car sharing is mainly used by people living no more than 10.75 minutes by foot to a station. However, Stillwater et al. (2009) name 400 meters as an appropriate value. Due to heterogeneous statements in academic literature, the setting is varied between 0.3 and 2.0 [km] within this example. The customer parameter, which describes the number of customers that can be served by one vehicle a day, is varied between 1 and 8. Low values of this parameter imply that consumers use vehicles for a greater amount of time, while high values indicate that consumers use vehicles for shorter amounts of time. The parameters for shortage of parking and population density are set to realistic values for this inner city area. The benchmarks are carried out on a notebook (Intel i7 2.67 GHz CPU, 4 GByte RAM) using GAMS 23.6.5 and CPLEX 12.2.0.2. Due to high computation time for exact solutions, a maximum gap of 5% to the optimum is permitted. Based on these settings, the subsequent table shows the benchmark results:

	maxd=0.30				maxd=0.50				maxd=0.75				maxd=1.00			
	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]
kp=1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
kp=2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
kp=3	24	55	1509000	0.33	16	48	1312000	0.32	13	48	1309000	0.97	12	46	1254000	0.78
kp=4	21	44	1209000	0.34	13	36	985000	0.40	13	35	958000	0.99	12	34	930000	42.12
kp=5	25	40	1024000	0.31	13	31	850000	0.57	9	28	765000	1.78	8	27	737000	0.90
kp=6	25	36	916000	0.36	12	26	714000	2.82	10	24	658000	0.46	7	23	628000	1.89
kp=7	23	30	806000	0.41	12	23	633000	1.25	10	20	550000	0.48	6	20	546000	1000.00
kp=8	22	27	751000	0.33	12	21	579000	1.53	8	18	494000	0.92	6	17	465000	2.21

	maxd = 1.25				maxd = 1.50				maxd = 1.75				maxd = 2.00			
	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]	s	#	costs [€]	t [s]
kp=1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
kp=2	---	---	---	---	---	---	---	---	15	69	1878000	1.71	15	69	1878000	1.41
kp=3	11	45	1226000	1.29	11	45	1226000	16.47	10	45	1225000	4.11	10	45	1225000	2.86
kp=4	9	34	927000	1.50	8	34	926000	1.39	8	34	926000	2.43	7	34	925000	1.13
kp=5	8	27	737000	0.95	8	27	737000	2.26	6	27	735000	1.76	8	27	737000	2.37
kp=6	6	22	600000	980.29	6	23	627000	1000.00	5	22	599000	69.86	5	22	599000	71.29
kp=7	6	19	519000	22.25	5	19	518000	3.29	6	19	519000	1.36	4	19	517000	3.87
kp=8	7	17	466000	1.15	5	17	464000	1.3	5	17	464000	1.19	6	17	465000	0.69

Table 1. Benchmark results

Depending on the available capital and the main objectives of the car sharing company, one of the alternatives from above can be chosen. Within Table 1, column s represents the number of stations to be built and column # stands for the total amount of vehicles. Further, the costs and the computing time are indicated for each alternative. The optimal number of stations, vehicles and the resulting costs heavily depend on the set of parameters **maxd** and **kp**. For low values of **kp**, the total customer demand cannot be satisfied due to the limited number of parking lots; thus no feasible solution can be found. Concerning the maximum distance to a station (**maxd**), no feasible solution can be found for values lower than 0.3 because some demand points are not close enough to a station. Further conclusions about the correlation of the different variables can be drawn from the table. The lower the value of **kp**, the more cars are required. Fewer customers can satisfy their need for mobility with the same car sequentially, therefore more cars are required to satisfy total demand. Because each station has a maximum number of parking lots and cars, more stations are needed. As the value of **maxd** falls, the demand for stations rises. To guarantee a short distance between a demand location and a station, more stations must be built. Moreover, total cost falls with higher values of **maxd** and **kp** because less stations and cars are needed. Since the costs of a car are higher than a station, total cost rather depends on **kp** than on **maxd**. The computation time hardly depends on the settings of the parameters. However, for higher values of **maxd**, the computation time slightly increases. For some instances with **kp**=6 and **kp**=7, the optimization takes longer than for other values of **kp**.

Visual representation using Google Maps can be generated instantly by the DSS to validate the outcome of the optimization process. The optimal result for Hanover with **kp**=4 and **maxd**=0.3 is shown in Figure 4. In order to minimize total cost, the car sharing company should open 21 stations with a total of 44 vehicles. Future stations are indicated by red markers on the map, while demand locations are represented by blue markers.

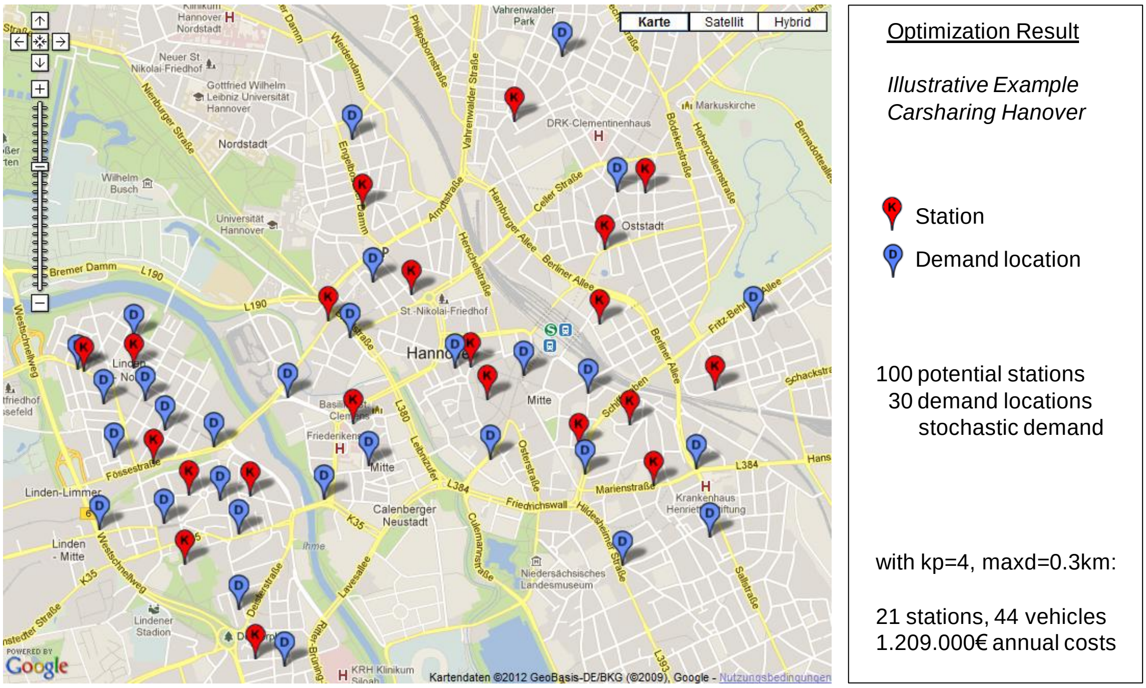


Figure 4. Visual representation of optimization results

The location, number and size of stations depend on the variables (characteristics of the city and used settings) and have an impact on the ecological and economic dimension of sustainability. Different alternatives can be created, evaluated, and visualized to allow decision support. The alternative a company actually chooses depends on the goals (such as customer satisfaction, keep costs as low as possible, enable sustainable mobility, etc.).

5 Discussion, limitations, and recommendations

We constructed and evaluated research artifacts that determine the optimal location and size of car sharing stations in order to provide decision support. An optimization model based on existing OR models (warehouse location problem and covering location problem) was formulated to fit this task. The model produces the optimal location and size of stations. To further provide decision support, we implemented an actual DSS which integrates the model and several systems in an intuitive IS. Due to the fact that car sharing and the system aim at ecological sustainability, we claim that the system is a Green IS and also a Green DSS.

Within the illustrative example we show that the DSS is able to help planners with the complex task of setting the location and size of car sharing stations. The DSS can be used easily for other cities and metropolitan areas. The characteristics of the city (structure, population density, etc.) influence the outcome of the optimization result significantly. Thus, input data need to be assessed thoroughly and parameters need to be adjusted to the specific city and context. Regarding computing time, a very good result (e.g. 3% gap) is found quickly, thus practical instances can be optimized within a few minutes on a standard PC or notebook. However, to improve a very good solution or to prove that it is the optimum, a lot of additional computing time is needed. Because this is a strategic planning problem, computing time is not a critical aspect.

The subsequent discussion follows recent remarks of Arnott and Pervan (2012) about design science in DSS research.

A key differentiator between design science and routine design practice is the amount of innovation or novelty of the artifacts (Arnott and Pervan, 2012). Arnott and Pervan (2012, p. 924) further state that "Design-science research should also address intellectually important topics […]" and "[…] produce important and interesting contributions to both IS theory and practice." Similar to a large part of design-oriented research, we move on a fine line between theory and practice. However, our artifacts address important, future-oriented topics: car sharing, sustainable mobility and Green IS. Due to these intellectually important topics and the rigorous research process, we argue that our artifacts and research contributions belong to design science.

Arnott and Pervan (2012) argue that the abstract artifacts (constructs, models, and methods) contribute to theory. We support this statement and argue that our optimization model is able to contribute to theory. The instantiation represented by our implemented DSS, however, has a strong practical focus. In terms of theory and academics, the DSS is used to "[…] demonstrate feasibility, enabling concrete assessment of an artifact's suitability to its intended purpose" (Hevner et al., 2004, p. 79). The DSS helps to show the feasibility and evaluation of the underlying optimization model.

We identified certain limitations with regard to our research artifacts. First, we evaluated the research artifacts within one business context for one major German city. However, our optimization model and DSS should be evaluated for other cities. A goal of DSR is that practitioners adopt the artifacts (Arnott and Pervan, 2012). Yet, only 13.5 percent of DSS design-science research artifacts are evaluated in the field (Arnott and Pervan, 2012, p. 940). Empirical evaluation in the field by car sharing experts will help to increase rigor and generalizability for our approach. Second, the optimization model does not allow free-floating or one way trips explicitly. For most car sharing organizations, free-floating or one way trips are not needed because a vehicle has to be returned at the same station where it was retrieved. A few car sharing organizations, however, allow one way trips. One challenge of returning vehicles to different stations is the relocation effort needed to fill demand in the car sharing network from where the vehicle originated. For example, commuters drive from the suburbs into the city in the morning and cease use. There are not enough cars in the suburbs and too many cars in the city. In the evening, commuters return to the suburbs that results in an opposite imbalance. In future developments of our optimization model, one way trips should be integrated more explicitly. Third, our model does not seek to maximize the profit but to minimize total cost while satisfying stochastic user demand. Usually, the main goal of companies is to maximize profit. In case of car sharing, however, organizations may have other goals. Due to the importance of alternative concepts of mobility and sustainability, some companies do not seek to maximize income from car sharing in the short run. Alternative goals can include a desire to penetrate the market, gain experience for future application, protect the environment, enable individual mobility, or simply for reputation. With this in mind, we formulated a model based on cost and not on profit. Fourth, we modeled a stochastic but discrete demand on a punctual basis. The total demand does not have a continuous character but is concentrated at certain points within a city. Within the application example, we were able to recognize that a discrete representation of the demand is adequate but that the number of demand locations needs to be higher. Demand locations can be positioned next to public transportation stations and according to population density and number of vehicles per person. An advantage of discrete modeling is that, next to demographic information, surveys can be used to determine customer demand at these spots.

In addition, the model could be refined in certain aspects by adding extra variables and constraints. In our existing model, the costs of each car and each parking spot are equal. Due to different price levels in city districts and different car sizes, differing costs would be more adequate. A discrete or continuous variable for the individual preference of potential stations would provide utility. Planners are then able to contribute their experience and individual impression to the planning process. By adding soft factors, a list of preferred stations can be implemented in the model, e.g. to prefer stations close to railway stations or next to landmarks. In future refinements of the model, we intend to implement these aspects and others such as: visibility of stations, prosperity in the various districts, time-variant demand, different types of parking lots (private vs. public), and cooperation with public transportation. However, these variables are not as important as the items that we already include.

Several theoretical as well as practical implications can be drawn from this paper. In regard to theoretical implications, the OR and IS research community now has an initial mathematical model to determine the optimal location and size of car sharing stations. The optimization model can be used as foundation for other research dealing with similar optimization problems. Researchers can use the model from the academic knowledge base, adopt, and apply it for a specific task. Further, the model can be refined by the OR and IS research community, e.g. by allowing one way trips. Electric mobility within big cities and, especially in combination with car sharing, is an important issue for the future. The optimization model represents a starting point to optimize electric car sharing stations; however, adjustments of the model will be required. With regard to economic and ecologic sustainability, theoretical and practical implications can be drawn. Researchers and car sharing experts can use our quantitative approach as a starting point to further evaluate and increase the sustainability of car sharing. From an academic point of view, we claim that Green DSS is an important subfield of Green IS and we provide an example of an actual Green DSS. Our model and DSS aims to increase the sustainability of individual mobility in cities. In practical terms, cities that experience ecological issues due to increased traffic can use our DSS to plan a car sharing network. Our DSS enables faster and better decision making. To address changing variability, managers and planners can use our system to run through different scenarios by setting parameters, e.g. cost structure or customer demand. The integrated DSS allows decision support by instant visual representation of optimization results.

6 Conclusion and outlook

Important issues concerning car sharing, sustainable mobility and Green IS are in need of further research. We provide decision support for the complex task of planning of existing and new car sharing stations. Within design-oriented research, we constructed and evaluated research artifacts. An optimization model was formulated to optimize the location and size of car sharing stations. This model is employed by an integrated DSS which allows data import and triggers the optimization and visualization of results. We evaluated and demonstrated the applicability of the DSS and the underlying optimization model in a representative example of a major German city. The DSS as a Green IS optimizes car sharing and thus contributes to environmental sustainability.

Following the identified limitations, further research steps are required in regard to our artifacts. The optimization model can be enriched by additional parameters and constraints, e.g. for explicit consideration of one way trips and public transportation or the integration of soft factors. A quantitative analysis of the benefits and deeper empirical validation of the artifacts that go beyond the application example are required. We will conduct a comprehensive case study with a car sharing organization.

Based on our Green DSS to enable sustainable car sharing, implications for further research are drawn. Our optimization model can be adopted and refined by other researchers. Electric mobility is an important issue that can be integrated in the model to further increase sustainability of car sharing. We conclude that Green DSS should be constructed and evaluated for domains other than car sharing.

References

Arnott, D. and Graham, P. (2012). Design Science in Decision Support Systems Research: An Assessment using the Hevner, March, Park, and Ram Guidelines. Journal of the AIS, 13 (11), 923-949.

Barth, M. and Shaheen, S. (2002). Shared-Use Vehicle Systems - Framework for Classifying Carsharing, Station Cars, and Combined Approaches. Transportation Research Record: Journal of the Transportation Research Board, 1791, 105-112.

Celsor, C. and Millard-Ball, A. (2007). Where Does Carsharing Work? - Using Geographic Information Systems to Assess Market Potential. Transportation Research Record: Journal of the Transportation Research Board, 1992, 61-69.

Dedrick, J. (2010). Green IS: Concepts and Issues for Information Systems Research. Communications of the AIS, 27, 173-184.

Duncan, M. (2011). The cost saving potential of carsharing in a US context. Transportation, 38 (2), 363-382.

Hevner, A.R. (2007). A Three Cycle View of Design Science Research. Scandinavian Journal of Information Systems, 19 (2).

Hevner, A.R., March, S.T., Park, J. and Ram, S. (2004). Design Science in Information Systems Research. Management Information Systems Quarterly, 28 (1), 75-105.

Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D. and Haas, P. (2002). Location Efficiency - Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use-Studies in Chicago, Los Angeles and San Francisco. Transportation Planning and Technology, 25 (1), 1-27.

Huwer, U. (2004). Public transport and car-sharing-benefits and effects of combined services. Transport Policy, 11 (1), 77-87.

Katzev, R. (2003). Car Sharing - A New Approach to Urban Transportation Problems. Analyses of Social Issues and Public Policy, 3 (1), 65-86.

Kriston, A., Szabó, T. and Inzelt, G. (2010). The marriage of car sharing and hydrogen economy - A possible solution to the main problems of urban living. International Journal of Hydrogen Energy, 35 (23), 12697-12708.

Kuhnimhof, T., Buehler, R. and Dargay, J. (2011). A New Generation - Travel Trends for Young Germans and Britons. Transportation Research Record: Journal of the Transportation Research Board, 2230, 58-67.

Loos, P., Nebel, W., Gómez, J., Hasan, H., Watson, R.T., vom Brocke, J., Seidel, S., and Recker, J. (2011). Green IT: A Matter of Business and Information Systems Engineering?. Business & Information Systems Engineering, 3 (4), 245-252.

March, S.T. and Smith, G.S. (1995). Design and Natural Science Research on Information Technology. Decision Support Systems, 15 (4), 251-266.

Martin, E. and Shaheen, S. (2011). Greenhouse Gas Emission Impacts of Carsharing in North America. IEEE Transactions on Intelligent Transportation Systems, 12 (4), 1074-1086.

Martin, E., Shaheen, S. and Lidicker, J. (2010). Impact of Carsharing on Household Vehicle Holdings, Results from North American Shared-Use Vehicle Survey. Transportation Research Record: Journal of the Transportation Research Board, 2143, 150-158.

Millard-Ball, A., Murray, G., Ter Schure, J., Fox, C. and Burkhardt, J. (2005). Car-Sharing - Where and How it Succeeds. Transit Cooperative Research Program, Working Paper.

Offermann, P., Levina, O., Schönherr, M. and Bub, U. (2009). Outline of a Design Science Research Process. In Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technologies, Philadelphia.

Peffers, K., Tuunanen, T., Rothenberger, M.A. and Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. Journal of Management IS, 24 (3), 45-77.

Schuster, T., Byrne, J., Corbett, J. and Schreuder, Y. (2005). Assessing the Potential Extent of Carsharing - A New Method and Its Implications. Transportation Research Record: Journal of the Transportation Research Board, 1927, 174-181.

Shaheen, S. and Cohen, A. (2007). Growth in Worldwide Carsharing - An International Comparison. Transportation Research Record: Journal of the Transportation Research Board, 1992, 81-89.

Shaheen, S. and Cohen, A. (2013). Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends. International Journal of Sustainable Transportation, 7 (1), 5-34.

Shaheen, S., Cohen, A. and Roberts, J. (2006). Carsharing in North America - Market Growth, Current Developments, and Future Potential. Journal of the Transportation Research Board, 1986, 116-124.

Shaheen, S., Sperling, D. and Wagner, C. (1998). Carsharing in Europe and North America - Past, Present, and Future. Transportation Quarterly, 52 (3), 35-52.

Stillwater, T., Mokhtarian, P. and Shaheen, S. (2009). Carsharing and the Built Environment - Geographic Information System-Based Study of One U.S. Operator. Transportation Research Record: Journal of the Transportation Research Board, 2110, 27-34.

Watson, R.T., Boudreau, M.C. and Chen, A.J. (2010). Information systems and environmentally sustainable development: energy informatics and new directions for the IS community. MIS Quarterly, 34 (1), 23-38.