CONTRIBUTIONS TO SUSTAINABLE INVOICING PROCESSES AND TRANSPORTATION

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Abstract

Irrespective of potential benefits of sustainability, both individuals and organizations, are faced with current challenges. This thesis is organized in two parts consisting of two research articles in Part A (Electronic Invoices) and three research articles in Part B (Transportation). In both parts, the three types of sustainability - social equity, economic efficiency, and ecological awareness - are addressed in detail.

Given that XML-based invoice standards are designed for an invoice exchange, Part A of this thesis proposes that adoption of these standards depends on a range of adoption determinants and furthermore not only on the organizations focal perspective but rather on synergies between business partners (dyadic perspective). XML-based invoices have the high potential of being quickly transmitted and offer major cost reductions in times of digitization and globalization. Therefore, we have conducted two studies. The first study contains twelve expert interviews to identify and organize adoption determinants using a structured content analysis with respect to an XML-based invoice standard. Building on these results, the second study includes an empirical qualitative online inquiry to study the influence of technological, organizational, as well as external adoption determinants on XML-based invoice standard adoption. Results from partial least squares analyses show that all three aspects impact the adoption, but the strongest influence derives from technological aspects, like XML-specific characteristics (e.g., integration into software and hardware).

One approach to making transportation more sustainable is to transition away from a car-oriented society and either voluntarily forgo private vehicles or use new transportation alternatives like carsharing. Part B of this thesis considers first carless households and characterizes and clusters them with regards to build-environment and socio-economic characteristics. We then conducted our generalized structural equation modeling analysis in two environmental leader areas (Germany & California) using national travel surveys. Transportation alternatives (e.g., carsharing) are needed to fulfill mobility needs of individuals but at the same time organizations require profits to successfully implement carsharing services. Thus, we have developed two mathematical models on a strategical and tactical level to maximize organizations' profit but restricted with diverse parameters and limits (e.g., CO_2 emission limit, or maximum distance of potential carsharing station to demand points). Our distinguishing feature is the heterogeneity of the carsharing fleet (petrol, hybrid, and electric vehicles). Both models are extensively tested and benchmarks are conducted for a case example (San Francisco, U.S.). The results of both optimization models demonstrate the influence of slight parameter modifications and indicate how a profitable operation of heterogeneous fleets can be established and optimized.

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1. Introduction

1.1. Motivation, Research Topic and corresponding Research Questions

A greater environmental awareness and an increased competitive pressure cause organizations to rethink internal processes and also open up new fields of business (see e.g., European Expert Group on e-Invoicing 2009; Shaheen and Cohen 2013). Decision-making is closely linked to the advancement of businesses. There are often several aspects influencing the decision either to adopt a new technology or to start and optimize businesses (Rogers 1983; Tornatzky and Fleischer 1990; Kreuzer et al. 2013). However, not only organizations are encouraged by internal or external factors to reduce costs and protect the environment but individuals are also faced with ecologic and economic aspects (see e.g., Buehler 2010; Dedrick 2010). Thus, individuals also have to make decisions, e.g., to own a private vehicle or not, and therefore gain advantages of reduced air pollution and greenhouse gas emissions. In addition, individuals are able to save running costs of owning a vehicle (Shaheen et al. 2005). The present thesis discusses three important and growing research areas with regards to sustainability: e(lectronic) invoice processes, carlessness and carsharing.

The reasons for the growing popularity of these fields are manifold. However, they can be predominantly summarized using three types of sustainability: social equity, economic efficiency, and ecological awareness (Boudreau et al. 2009).

Social equity can be achieved when organizations provide a greener environment for every individual by reducing their paper for business documents (less paper and no physical transportation) (Sandberg et al. 2009; Koch 2017). Similar reasons hold for a reduction of private vehicles (Kuehne et al. 2018a). In addition, parking lots can be replaced by parks and green spaces and thus carlessness contributes even more to a high-quality environment (Mitra & Saphores 2016). Carlessness is accompanied by transportation alternatives, e.g., carsharing. Individuals can use shared vehicles regardless of social background or income and therefore meet the sustainability aspect of social equity (Shaheen & Cohen 2013).

Economic sustainability often represents the most important aspects since organizations as well as individuals strive to reduce expenses. Electronically exchanged invoices save costs due to a diminution of manual work, input errors, printing expenses, postage charges, and physical transportation (Expert Group on e-Invoicing 2009; Sandberg et al. 2009). Living without a privately-owned vehicle also aids economic sustainability due to the obvious cost reduction when individuals (voluntarily as well as involuntarily) forgo a vehicle (Mitra & Saphores 2016). Joining a carsharing organization instead of owning a vehicle also contributes to economic sustainability since carsharing members can achieve tremendous savings with very calculable costs per ride when compared to a private vehicle (Duncan 2011).

Nevertheless, the electronic exchange of invoices, the renunciation of a private vehicle as well as the usage of electric vehicles within a carsharing fleet lead further to the third type of sustainability: ecological awareness (Duncan 2011). A reduction of paper and also of traffic and transportation contributes to a greener environment, e.g., by reducing greenhouse gas emissions and noise caused by traffic (Sandberg et al. 2009; Alfian et al. 2014).

Part A: Electronic Invoices

The invoice is one business document in the business-to-business (B2B) sector that is exchanged in almost every business transaction and could be the first business document to be digitalized along the entire value chain (Expert Group on e-Invoicing 2009; Koch 2017). Automatically processed invoices can lead to cost savings of 60-80%, amounting to huge sums for the more than 200 billion invoices that are exchanged in the business and government sector worldwide (Koch 2017).

Maximum advantages can be gained when the e-invoice is not only processed as a PDF-file but is also accompanied by structured data, such as EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) or XML (Extensible Markup Language). In this thesis, the focus is set to XML-based invoices since many existing standards (e.g., ZUGFeRD as a national standard in Germany, UBL/XML as a cross industry and business standard, or Rosetta Net PIPs as electronic and IT industry business standard) are already based on this comparably simple technical language. Although the adoption rate of XML-based invoice standards has risen, the actual share is still low (Koch 2017). In fact, only 26% of German organizations report that they are currently exchanging electronic invoices with structured data sets (Seidenschwarz et al. 2017). Hence, it is important to identify adoption factors in order to support and accelerate a successful implementation and consider different aspects with regards to process integration and standardization. Consequently, the research article #1 (Kuehne et al. 2015) addressed the following research question:

> **RQ1: How can XML-based standards succeed in electronic invoice transmission and processing?**

Using the "ZUGFeRD" standard as a case example, the research article #1 starts with twelve expert interviews and thereby identifies relevant adoption factors. The majority of the participants of the study assume a high future potential of the "ZUGFeRD" standard since it combines both, a simple PDF-file and an XML-file. Therefore, it can fill the gap between paper invoices and fully integrated and automated processed invoices like EDIFACT. The market share of XML-based invoice standards will increase in the coming years and thus open up new potentials. However, most organizations are waiting for a critical quantity of participating business partners and need pressure from third parties before even thinking about an implementation.

However, a quantitative verification and a more global view is necessary to measure the influence of relevant adoption determinants of an XML-based invoice standard applying the previous results to other XML-based standards. Research on adoption of closely-related areas identifies different adoption factors for a standard, e.g., a positive cost-benefit relation regarding the implementation of e-invoice exchange or technology readiness (Zhu et al. 2006b; Venkatesh & Bala 2012). The current market position of an organization and e-invoice exchange and acceptance certainty trends help to motivate organizations to either implement a standard or follow the practice of business partners (Chau & Tam 1997; Melville & Ramirez 2008; Krathu et al. 2015). Existing research mostly concentrates on the adoption of e-invoices of the perspective of focal organizations with a special focus, e.g., for business-to-government transactions, small and medium-sized organizations, or a national context (Edelmann & Sintonen, 2006; Penttinen & Tuunainen, 2009; Hernandez-Ortega, 2012). XML-based invoice adoption with respect to technology, organization and environment from a dyadic perspective have so far neither been investigated nor discussed in research. Thus, research article #2 (Kuehne et al. 2018b) aims to fill this research gap and considers the following second research question in this thesis:

> **RQ2: How do technological, organizational and environmental factors influence the adoption of an XML-based invoice standard?**

Research article #2 builds on the previous article and tests a nomological model with partial least squares path modeling of the relationships among technology, organization, external task environment and the adoption of XML-based invoices from a dyadic perspective based on a conducted online inquiry. We used the results of 93 returned questionnaires. The strongest impact comes from organizational factors (including innovativeness and readiness), followed by technological (including characteristics of the XML-based standard and standardization possibilities) and external task environment (network effects and competitive pressure).

Part B: Transportation

One approach to making transportation more sustainable is to move away from a car-oriented society and shift to greener alternatives (Buehler 2010; Mitra & Saphores 2016). In particular, households may voluntarily (or not) forgo their vehicles and reduce thereby greenhouse gas and CO_2 emissions and air pollution. A number of policies have been introduced in order to counteract the environmental pollution. Two car-loving societies but with different rates of carless households are Germany (~12%) and California (~6%) (Romero 2014; Flanagan 2017). So far, research on carlessness is very rare and has been only investigated within one society (see e.g., Mitra & Saphores 2016). Research article #3, however, compares two leader areas in terms of environmental awareness (Germany in the European Union and California in the United States ((Dallinger et al. 2013)), and identifies socio-economic and built-environment factors that can entice households to become voluntarily carless. Understanding these factors could help policymakers formulate policies to reduce our dependency on motor vehicles. As the share of carless household is much higher in Germany than in California, Californian politicians above all may be able to learn from these findings. This leads to the third research question in this thesis:

> **RQ3: What are the differences of carless households in Germany and California in terms of socio-economic and built-environment factors to become voluntarily carless?**

Using the 2008 Mobility in Germany (MiD) survey and the 2012 California Household Travel Survey (CHTS), research article #3 (Kuehne et al. 2018a) tests two generalized structural equation models. Model I compares voluntarily carless households with motorized households and Model II with involuntarily carless households. Model I shows that, in both Germany and California, the probability that a household is voluntarily carless decreases when any of the following variables increases: income, number of children aged 6 to 17, older members, or employed members. In contrast, Model II shows differences between Germany and California. In Germany, households with a higher income and a better education are more likely to be voluntarily carless whereas in California, only income and the number of female adults in the household seem to matter. An increase in income raises the probability that a household is voluntarily carless whereas an increase of female adults reduces the probability.

Having no private vehicle available is described by literature as one characteristic of a typical carsharing user (e.g., Burkhardt & Millard-Ball 2006; Firnkorn & Müller 2012). Carsharing services offer a sustainable, environmentally friendly alternative to vehicle ownership (Millard-Ball et al. 2005). As carsharing services profitability depends on the demand, it is typically offered in urban areas where it is easier to live without a car. You can distinguish between free-floating (carsharing service without any station but rather a designated operation area where vehicles can be picked up and returned) and station-based carsharing (carsharing service where vehicles are assigned to stations).

In the latter case, carsharing organizations must make decisions in terms of location of carsharing stations and size of fleet in order to be successful (Rickenberg et al. 2012). Optimization models and IT-supported systems assist carsharing organizations to choose an optimal carsharing network (see e.g., Boyaci et al. 2015). Heterogeneous carsharing fleets (including electric and petrol vehicles) address environmental as well as economic aspects (Shaheen & Cohen 2013). While a pure electric fleet contributes to a green environment, it also leads to long service times during charging operations and also creates high infrastructure costs. Whereas a petrol vehicle comes with lower cost and does not require charging but has the disadvantage of fuel consumption and high emissions. Existing carsharing services support the approach of a heterogeneous carsharing fleet, for instance Zipcar and Car2go in the United States, who have already included electric vehicles in their fleets (GreenCarReports 2016; Zipcar Inc. 2012). As station-based carsharing can be further distinguished between one-way (vehicles are allowed to be returned to a different station to where they were picked up) and two-way services (vehicles must be returned to the same station where they were picked up; also called round-trip), two-way concepts are suitable for fleets with electric vehicles since each vehicle has a particular parking lot and charging infrastructure, if necessary.

In order to maximize the profit of carsharing organizations, to meet customer requirements and at the same time to reduce overall CO_2 emissions of a carsharing fleet, research article #4 (Sonneberg et al. 2018) develops an optimization model to meet the objectives. This research article is an enhancement based on feedback received of our already published work at the International Conference on Information Systems 2015 (Sonneberg et al. 2015). Consequently, the fourths research question of this thesis is:

> **RQ4: How can carsharing organizations provide a profitable and sustainable carsharing service?**

The research article #4 introduces a Mixed-Integer-Problem (MIP) and considers a maximum CO_2 threshold that enables a carsharing organization to set, review, or reduce the maximum average emissions of a carsharing fleet. The optimization model is applied to the city of San Francisco in the United States and extensive sensitivity analyses for different input parameters are conducted. Results show, that with cost increase of parking lots, stations, and vehicles the strategic network structure does not change but obviously the expected profit of a carsharing organization will decrease. With a low set CO_2 emission limit, the fleet size remains the same, but electric vehicles (which are more expensive) replace hybrid and petrol-driven ones and thus also reduces profit. This demonstrates how sensitive the model reacts and how important it is, to find a good balance between sustainability in cities and successful businesses for carsharing organizations.

For a station-based carsharing organization, the distribution and availability of vehicles over times play a crucial role to satisfy the customers' mobility needs as well as to obtain profits (El Fassi et al. 2012; Rhee et al. 2014). As fluctuations in demand impact the profit, a tactical optimization model can help to meet customer demands and at the same time realize maximum profits for the carsharing organization. Different to the previous optimization model, a second model was developed, which considers three types of vehicles (petrol, hybrid, electric) as well as two car classes (small, medium) to meet customers' demands. The model is developed in accordance to a design science research approach (Hevner et al. 2004). It optimizes the fleet composition for every month based on an existing carsharing network with fixed carsharing stations. By considering an even more heterogeneous fleet and providing a decision support system it is possible to contribute to sustainable transportation alternatives with regards to Green IS (Gregor & Hevner 2013).

In order to maximize monthly profit of carsharing organizations, to meet customer requirements in terms of vehicle size and propulsion method and at the same time to reduce overall CO_2 emissions of a carsharing fleet, research article #5 (Kuehne et al. 2017) develops a tactical optimization model to meet the objectives. Thus, the fifth research question of this thesis is:

> **RQ5: How can a heterogeneous carsharing fleet be optimized while considering emission limits and demand variations?**

Again using the case example of the city of San Francisco in the United States, research article #5 tests the tactical optimization model, and different calculation results are discussed and analyzed. The calculations for two different demand scenarios support city planners and carsharing organizations to provide a sustainable and profitable mobility concept in cities. Results show, that especially the demand of medium sized vehicles is not completely fulfilled (between 73% and 89% in the second demand scenario) due to higher costs of the vehicles compared to small ones. Like already seen in the previous model in research article #4, the CO_2 emission limit has a strong impact on the fleet composition (more electric vehicles and thus less profit).

1.2. Academic Classification and Task Sharing of Publication

Part A: Electronic Invoices

The research article #1 “Will XML-based Electronic Invoice Standards Succeed? – An Explorative Study” was developed together in equal parts with Lubov Kosch and Angelica Cuylen (see Kuehne et al. 2015 and Appendix A2). It was accepted in a double-blind review process for publication and presentation at the 23rd European Conference on Information Systems (ECIS) in the track “Adoption and Diffusion”. After minor revisions as requested by the associate editor and two reviewers, our submission has gone through the final review process and was ultimately accepted for presentation at ECIS, and for its publication in the ECIS 2015 proceedings. We presented our research article at the ECIS in May 2015 in Münster, Germany.

The annually held ECIS (since 1993) is a meeting place for European as well as non-European IS researchers from divers disciplines. It is the largest and most prestigious conference on IS in Association for Information Systems (AIS) region 2. The ECIS has generally acceptance rates in the low 30% range. The conference proceedings are assigned to the ranking “A” of the WKWI and GI-FB WI (Wissenschaftliche Kommission Wirtschaftsinformatik im Verband der Hochschullehrer für Betriebswirtschaftslehre e.V., 2008). The rating in VHB JOURQUAL 3 by Henning-Thurau & Sattler (VHB-JOURQUAL3, 2015) is “B”.

The research article #2 “Standard adoption of XML-based invoices: An empirical study using a technology-organization-environment framework” (see Kuehne et al. 2018b and Appendix A3) was mainly developed by the author of this thesis. The model calculations were conducted by Dr. Nadine Guhr. The discussion of the results are a joint work. We submitted the research article in February 2018 to the international journal “Information Systems and e-Business Managements”. The renowned journal has an impact factor of 1.723 and is published quarterly (Information Systems and e-Business Management, 2018). The published research articles have a strong focus on information systems management, conceptual analysis, design and development of information systems and further e-business related topics (Information Systems and e-Business Management, 2018). The scope of the journal is appropriate for our research article. The rating of the journal in the VHB JOURQUAL 3 by Henning-Thurau & Sattler (VHB-JOURQUAL3, 2015) is “C”.

Part B: Transportation

The research paper #3 "Without a Ride in Car Country: A Comparison of Carless Households in Germany and California" (see Kuehne et al. 2018a and Appendix A4) was developed in an international collaboration together with Dr. Suman M. Mitra and Professor Jean-Daniel Saphores at the Institute of Transportation Studies (ITS) at the University of California, Irvine (UCI). The research project entailed a six months stay abroad as visiting scholar at the ITS.

Our paper is partly based on previous research on carlessness in California of Mitra and Saphores (2016). The new emerged research article has the special feature of a comparison of two demographic regions. Comparative studies are rarely available within the scientific community due to language barriers, problems of data availability, and explicit background knowledge of the considered regions. We submitted our unique joint work to the international journal "Transportation Research Part A: Policy and Practice". It was accepted in January 2018 after a double-blind peer review and three revisions demanded by three capable reviewers. The Transportation Research Part A: Policy and Practice is an international transportation premium journal and "*contains papers of general interest in all passenger and freight transportation modes: policy analysis, formulation and evaluation; planning; interaction with the political, socioeconomic and physical environment; design, management and evaluation of transportation systems*" (TR-Part: A, 2017). It is part of the set of Transportation Research Part A to F journal, which "forms the most cohesive and comprehensive reference of current research in transportation science" (TR-Part: A, 2017). The impact factor of Part A in the year 2016 was 2.609 and the 5-Years Impact factor was 3.489. Furthermore, the rating of the journal in the VHB JOURQUAL 3 by Henning-Thurau & Sattler (VHB-JOURQUAL3, 2015) is "B".

The research article #4 "Optimization of carsharing networks: Increasing sustainability through heterogeneous fleets and emission control" was developed together in equal parts with Marc-Oliver Sonneberg (see Sonneberg et al., 2018 and Appendix A5). We are still in discussions where to publish and we are going to submit this paper soon to an international journal in the transportation area with a focus on operations research.

The last included research paper in this thesis #5 "Ecological & Profitable Carsharing Business: Emission Limits & Heterogeneous Fleets" was developed together with Marc-Oliver Sonneberg (see Kuehne et al. 2017 and Appendix A6). It was accepted in a double-blind review process for publication and presentation at the 25th European Conference on Information Systems (ECIS) in the track "IS for a smart, sustainable and inclusive world". After minor revisions as requested by the associate editor and two reviewers, our submission has gone through the final review process and was ultimately accepted for presentation at ECIS, and for its publication in the ECIS 2017 proceedings. Marc-Oliver Sonneberg presented our research article at the ECIS in June 2017 in Guimarães, Portugal. For detailed information about the quality of the conference proceeding please see the description of research paper #1.

2. Critical Appraisal and Outlook

2.1. Contributions to Research and Practice

All five presented research articles outline decision-making processes either of the perspective of an individual or of an organization. With regards to three types of sustainability (social equity, economic efficiency, and ecological awareness) this cumulative doctoral thesis contributes to a more sustainable environment. The three already published research articles were accepted after a peer-review process with constructive comments. The comments helped to improve the articles and enhanced thereby the quality.

Part A of this thesis deals with electronic invoice processes which is currently a very important topic in times of the digitization and the aim of paper reduction and automatization enhancement. The research articles considering the adoption of XML-based invoice standards provide essential knowledge of adoption determinants for a successful implementation. A qualitative and a subsequent quantitative study outline the most important determinants and serve as a basis for further, detailed research in this field. The tested TOE-model is a valuable tool to organize adoption determinants and measure their influence. Previous research has identified different adoption determinants of electronic invoices in general. However, Part A of this thesis contributes to the identification of very specific adoption determinants and provides thereby a foundation for further research in the field of XML-based invoice standards.

Due to the great potentials and the simplicity of XML files and the lack of e-invoice standard adoption from a dyadic perspective, our studies focused on XML-based invoice standard adoption in order to combine adoption determinants of business partners for the invoice dispatch as well as for the invoice receipt. We have empirically validated the influence of several determinants on XML-based invoice standard adoption. In accordance to Vankatesh and Bala (2012) business standard adoption is a consensual operation and knowledge in this research field is important for theory and practice. We found in the research article #2 support for our identified constructs (from the expert interviews; research article #1 and from literature) and showed their significant influence on XML-based standard adoption.

Our research article contributes to the understanding of adoption determinants by providing a theoretical foundation and empirical support for the influence of XML-based invoice standard adoption. We contribute to a very specific research area which is rarely investigated and discussed from a science perspective. The overall XML-based invoice standard adoption rate can be increased by theoretical models and frameworks.

Our findings from the tested TOE-model of the research articles #1 and #2 also contribute to business practices and have important practical implications since they support organizations with their decision to adopt XML-based invoice standards. The XML-specific adaption determinants support organizations when it comes to an automatic invoice exchange. The identified and validated determinants must be considered from a dyadic perspective and are valid for the invoice dispatcher as well as for the recipient. An understanding of these determinants from both perspectives will help to increase and accelerate the overall adoption rate of XML-based invoice standards and to develop appropriate implementation strategies for a successful implementation.

Decision makers, management in organizations, and standard developers (like public institutions or authorities) can use these determinants and the measured impact to realize the mentioned potentials of an automated XML-based invoice exchange (e.g., increased efficiency, or improved transparency). The adoption determinants are relevant for both trading partners and are especially relevant within the organization itself (organizational innovativeness and readiness).

However, also public authorities and politics might be able to use our findings to enforce policies and directives on national or even international level. Knowing the crucial determinants will help to develop strategies and corresponding directives and laws. For instance, the German public authorities have provided a semantic data model for an XML-based invoice standard (called X-Rechnung; *engl. X-invoice*) which is in conform to the European Standard EN13739 (European Standard for distribution measurements of fertiliser spreaders) and can be sent to public administrations in Germany beginning in 2017. It will become mandatory in November 2018 for the Federal constitutional organs and in November 2019 for the entire federal authorities and is in accordance to the European Directive 2014/55/EU (European Union 2014). However, our findings can help politics and organizations (from both perspectives) to overcome challenges and thus gain advantage of an automated XML-based invoice exchange.

Attention should not merely be given to the business sector but also to private consumers and household regarding sustainability. One aspect, which contributes to sustainable lifestyle is the waiving of private vehicle ownership. Thus, Part B of this thesis deals with transportation issues. The carless study in research article #3 concentrates on household level and contributes to a more sustainable environment by identifying the characteristics which impact carlessness most. The tested theoretical model contrasts Germany and California and shows the differences for the both regions. Carlessness is very rarely researched, and thus our study contributes to a very specific research area with the focus of two environmental leader regions. We identified several socio-economic and built environment factors which motivate households to voluntarily forgo their motor vehicles using two large national mobility surveys. Our findings indicate a high impact of several characteristics, e.g., the availability of public transportation or population density on carlessness. Our results can be used in the practice by policy makers and politics to plan and optimize cities to reduce private vehicle ownership and thus develop strategies for a sustainable and livable city.

As research articles #4 and #5 discuss carsharing network optimization they provide several theoretical contributions in this regard. The developed strategical and tactical optimization model represents a Green IS approach and thereby supports a society's path towards a sustainable environment within cities. Our mathematical models (partly based on Sonneberg et al. 2015) are developed in accordance to nascent design theory in the field of Green IS (Gregor & Hevner 2013) and are based on design science research (DSR) principles as proposed by Hevner et al. (2004). We created new and innovative artifacts and presented optimization models to reduce pollution and increase quality in terms of noise and place of cities. The applicability checks demonstrated the functionality of our artifacts. Many research articles have been published in closely related fields and demonstrate thereby the high relevance of the sustainable transportation research area. However, none of the identified optimization models dealt with CO_2 emission limits and included several vehicles classes and propulsions. Thus, our models are validated using a case example and provide decision support to enable a sustainable and at the same time profitable transportation alternative.

The mathematical models, however, provide strong contributions to practical implementations. Carsharing organizations can use the models for their strategical planning as well as tactical planning on a monthly basis to satisfy customer needs but also to gain profits and achieve economic efficiency. Therefore, the carsharing fleet can be composed of electric, hybrid and conventionally-powered vehicles while considering necessary charging cycles and expenses for charging infrastructure. When providing a heterogeneous fleet, advantages of different propulsion methods can be combined. In particular, electric vehicles have no emission and reduce noise in cities but are still expensive, need charging, and have limited range. In general, lower CO_2 limits lead to higher costs and consequently to a decrease of the carsharing organization profit caused by higher number of electric and hybrid vehicles.

However, a successive implementation of electric vehicles might be affordable in coming years when their ranges are higher and then they might replace conventionally powered vehicles. Carsharing organizations are able to use the optimization models to provide sustainable transportation alternatives without compromising profitability. Our models and the conducted benchmarks can also be used in the practice by policy makers and politicians to plan and optimize cities by refining the CO_2 emission threshold. Thus, our models support decision-makers in their efforts to solve the multi-dimensional challenge of fulfilling demands and maximizing profit while satisfying customer expectations and governmental requirements regarding sustainability. Special attention should be paid to input values such as the demand forecast and the maximum allowed distance between a demand point and station location since they have a strong impact on profit generation and can influence to decision to start a carsharing business.

2.2. Overall Limitations and Further Research

As in the case of any research, this thesis is also bound by some limitations. Part A (XML-based invoice adoption) as well as Part B (transportation) face diverse limitations regarding data availability, quantity and quality of data or assumptions and simplifications.

Data availability is the greatest challenge and thus a major limitation for all five presented research articles since it was not possible to collaborate with businesses or data from national survey were restricted. Nevertheless, the co-authors and I have tried to minimize these data availability problem by taking extra efforts when it came to the acquisition of participants for expert interviews and online surveys in the XML-based invoice adoption studies in Part A. Part B of this thesis dealt with transportation. Studying carlessness in article #3, we used existing national travel survey data, but were restricted to the questions asked and variables considered in these surveys. However, we used the best available data for our comparison study. Also in Part B, but dealing with optimization models for carsharing organizations, we faced the problem of non-availability of data on demand due to the lack of collaboration. We have tried to find an approach to depict the demand by using census data and variables identified by academic literature.

All articles still have room for enhancements for further research. Case studies and a broader range of online surveys may open up new insights for generalization and transferability for the results of the five presented research articles. In particular, case studies in the field of implementing an XML-based invoice standard in collaboration with organizations can provide detailed description of crucial adoption factors and develop and test theories and procedure models. A larger online study could further provide the possibility to differentiate between small and medium and large organizations as they presumable face different adoption determinants. Regarding organization size, adoption determinants of the three factors (technological, organizational, and external task environment) may also have different impacts. Nevertheless, the TOE-model for XML-based invoices of the first two research articles could be adopted to other business documents (e.g., order, order confirmation, and delivery note) along the entire supply chain to increase digitization within organizations and hence reach a higher degree in the three types of sustainability: social equity, economic efficiency, and ecological awareness.

A subsequent research task after implementing an XML-based invoice standard could be the success measurement with the help of KPIs (Key Performance Indicator) in order to evaluate the usage. Thereby, it is possible to create reports, support controlling tasks within organizations, and thus identify crucial flaws in the workflow. Then, adjustments and enhancements can be integrated into running systems and improve the usage of XML-based invoice standards. Results from introduced KPIs could convince skeptical other organizations to implement XML-based invoice standards.

The same enhancement possibilities for further research hold for Part B, when e.g., studying also vehicle usage and not only vehicle ownership, or calculating the demand for carsharing more precisely (e.g., with historical data of existing carsharing organizations). Studying car usage or travel behavior in general (e.g., research on multi-modal travelling or biking) in other areas as in Germany and California (e.g., in Scandinavian countries or Canada) can support city planners and politicians to introduce appropriate policies or directives to further improve air quality and livability in cities. Thus, carsharing (in particular, with heterogeneous fleets or pure electric fleets) represents one sustainable transportation mode within multi-modal travelling. To be successfully adopted and implemented, carsharing has primary requirements: profit generation for carsharing organizations and at the same time carsharing user satisfaction. In order to address these two crucial aspects, important real-life data is necessary to further improve our developed optimization models. More specific data about demand and travel behavior of carsharing users could be addressed within the models and hence improve model results.

Furthermore, the optimization models (in research article #4 and #5) only consider the strategic (location, number, and size of stations) and tactical level (fleet size and composition) but so far they have not integrated operational businesses (vehicle relocation, or pricing). Including all three levels in one model or in two separate models but running the second model with results of the first one, could depict the reality even better and achieve high level of satisfaction of carsharing organizations, their customers and city planners and decision makers.

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A Appendix

A.1 Overview of all Publications

Year	Title	Authors	Outlet	Ranking
2018	Standard adoption of XML-based invoiced: An empirical study using a technology-organization-environment framework	Kuehne, K., Guhr, N., & Breitner M.H.	Information Systems and e-Business Management (submitted)	VHB-JOURQUAL3 (2015) “C”
2018	Optimization of carsharing networks: Increasing sustainability through heterogeneous fleets and emission control	Sonneberg, M.-O., Kuehne, K. & Breitner M.H.	To be submitted (not defined yet)	n/a
2018	Without a ride in car country – A comparison of carless households in Germany and California	Kuehne, K., Mitra, S., & Saphores, J.-D.	Transportation Research Part A: Policy and Practice	VHB-JOURQUAL3 (2015) “B”
2017	Adoption Determinants of XML-Based Invoices: an Exploratory Investigation	Kuehne, K., Guhr, N. & Breitner, M.H.	International Journal of Business, Humanities and Technology	n/a
2017	Ecological & Profitable Carsharing Business: Emission Limits & Heterogeneous fleet	Kuehne, K., Sonneberg, M.-O., & Breitner, M.H.	Proceedings of European Conference on Information Systems	VHB-JOURQUAL3 (2015) “B”
2016	Revenue Management meets Carsharing: Optimizing the Daily Business	Broihan, J., Moeller, M., Kuehne, K., Sonneberg, M.-O., & Breitner, M.H.	Proceedings of Operations Research 2016	VHB-JOURQUAL3 (2015) “D”
2016	Comparison of Standard and Electric Carsharing Processes and IT Infrastructures	Isermann, J., Kuehne, K., & Breitner, M.H.	IWI Discussion Paper	n/a
2015	Ein Smartphone-Bonussystem zum energieeffizienten Fahren von Carsharing–Elektrofahrzeugen	Kreutz, M., Luepke, Kuehne, K., Degirmenci, K., & Breitner, M.H.	IWI Discussion Paper	n/a
2015	A Decision Support System for the Optimization of Electric Car Sharing Stations	Sonneberg, M.-O., Kuehne, K. & Breitner M.H.	Proceedings of International Conference on Information Systems	VHB-JOURQUAL3 (2015) “A”
2015	Will XML-based electronic invoice standards succeed? – An explorative study	Kuehne, K., Kosch, L., & Cuylen, A.	Proceedings of European Conference on Information Systems	VHB-JOURQUAL3 (2015) “B”
2014	An Optimization Model and a Decision Support System to Optimize Car Sharing Stations with Electric Vehicles	Kuehne, K., Rickenberg, T., & Breitner, M.H.	Proceedings of Operations Research 2016	VHB-JOURQUAL3 (2015) “D”

A.2 Research article #1: Will XML-based electronic invoice standards succeed? – An explorative study

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Published in:

Proceedings of the twenty-third European conference on information systems (ECIS 2015), Münster, Germany

WILL XML-BASED ELECTRONIC INVOICE STANDARDS SUCCEED? – AN EXPLORATIVE STUDY

Complete Research

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Abstract

The digitalization of business processes is a crucial method for cutting down administrative costs, improve productivity in business processes, and achieving process transparency. Since invoices are some of the most important documents exchanged between business partners, it makes sense that invoices be sent and received electronically. There are no formal rules that determine the format of electronic invoices. However, companies benefit most when invoices contain structured data that can be processed automatically. The acceptance and adoption of structured electronic invoicing is generally rather low in the European Union, but it differs significantly among European countries. The electronic data interchange with the invoice standard EDIFACT is most favored by larger companies. An XML-based invoice could fill the gap between EDIFACT invoices and unstructured invoices like PDF and paper invoices. Some European countries have already established a national XML-based invoice standard. This paper addresses critical success factors to the adoption of XML-based standards. In an explorative study with experts, various aspects of acceptance were derived, and the results adapted to the Technology-Organization-Environment framework.

Keywords: electronic invoicing, XML-based standard, adoption, technology-organization-environment model.

1 Introduction

Invoices are usually one of the most important documents that are exchanged between business partners, including public authorities. They are an integral part of the order, delivery, payment, and accounting business processes. Further, invoices, including self-bills issued by the receiving party, are the core element of the European system of value added tax. According to Council Directive 2010/45/EU, companies are only entitled to pre-tax deductions based on an invoice. As in the case with paper invoices, the integrity of the content, the authenticity of the origin (assurance of identity of the invoice issuer), and the legibility have to be ensured by the taxable companies until the end of the storage period (European Union, 2010). The electronic exchange and processing of invoices promise savings of both cost and time, because they reduce manual work, input errors, printing, and transport costs (European Commission, 2010; Expert Group on e-Invoicing, 2009; Sandberg et al., 2009). Workflows, process transparency and traceability are improved by e-invoice processes (Haag et al., 2013). Despite the obvious benefits, the market penetration of electronic invoices (e-invoices) in the European Union (EU) is still low for business-to-business (B2B) transactions (European Commission, 2010). Some critical success factors to participation in electronic processes are a lack of awareness, unclear business strategy, and missing adequate information systems (IS) for process optimization.

High investment costs, legal uncertainty, lack of standard e-invoice processes, heterogeneous demands of the business partners, and change management efforts are also among the reasons that companies avoid process automation (Haag et al., 2013; Legner and Wende, 2006; Sandberg et al., 2009; Tanner et al., 2008). Since the late 1960s companies have recognized that fast, economic and precise exchange of business data is a strategic factor in opening up potential savings (Kabak and Dogac, 2010; Westarp et al., 1999). As a consequence, orders, delivery notes, and payments and invoicing data have been transmitted via electronic data interchange (EDI). This technology requires both an application-to-application connection between business partners and a standardized IS-processable format (Penttinen et al., 2009; Westarp et al., 1999). EDIFACT was developed as the EDI-standard for administration, commerce and transport (Kreuzer et al., 2013; Westarp et al., 1999). Despite the process-orientated reasons there are some public sector initiatives for supporting e-invoices "with the aim to reduce fraud and increase tax income" (Koch, 2014).

The European Commission (EC) "wants to see e-invoicing become the predominant method of invoicing by 2020 in Europe" (European Commission, 2010). No formal rules determine the format of e-invoices. The invoice can be an unstructured format like PDF or a structured format like EDIFACT or XML. Companies benefit most from e-invoice processes when the invoice contains structured data that can be processed automatically (Expert Group on e-Invoicing, 2009). As a consequence one task for the EC is to support "the development of open and interoperable e-invoicing solutions based on a common standard, paying particular attention to the needs of [small and medium-size companies] SMEs" (European Commission, 2010). EDI with EDIFACT is not profitable for any company due to its high level of complexity, uncertainty about the appropriate standard, high implementation and operating costs, lack of know-how, and too few business transactions. It is more suitable for companies that exchange business documents along the entire supply chain and less for SMEs with only a few documents to exchange (Beck et al., 2002; European Commission, 2010; Westarp et al., 1999; Zhu et al., 2006). Companies take part in e-invoicing in order to retain important business partners and not only for the benefits of it (Lumiaho and Rämänen, 2011). To involve any company, an easier standard with fewer contractual agreements and lower investment is necessary. Therefore, an XML-based invoice may fill the gap between the EDIFACT invoices and the unstructured invoices like PDF or paper invoices. There will be no migration from EDIFACT to XML-based invoices, but it is expected, that the overall adoption rate for e-invoices will increase. Prior research on the adoption of electronic invoicing does not focus specifically on the critical success factors of an XML-based invoice standard. Research mostly concentrates on the adoption of e-invoicing with a special focus on, e.g., business-to-government (B2G), SMEs, or a national context (e.g. Arendsen and Wijngaert, 2011; Hernandez-Ortega, 2012; Kreuzer et al., 2013; Penttinen and Hyytiänen, 2008). But e-invoicing has many different aspects with regard to process integration with business partners based on standardized structured invoice data. Consequently, the following research question is addressed:

How can XML-based standards succeed in electronic invoice transmission and processing?

Due to a lack of homogeneity of standards within Europe, Germany is used as the case example. Germany also recently published an XML-based invoice standard ZUGFeRD (Zentraler User Guide des Forums elektronische Rechnung Deutschland: "central user guide of the German electronic invoicing forum") in 2014. This standard was developed by the German forum on e-invoicing (FeRD) to support the acceptance and adoption of e-invoices.

First, the theoretical background of e-invoice standards in the EU and the adoption of e-invoicing are introduced. Then, the research design and data collection are explained. Subsequently, the empirical results are discussed and recommendations are derived. Limitations, conclusions and an outlook on future research complete this paper.

2 E-Invoicing Standards in the EU: Status Quo and Research Gap

2.1 Standards in Europe

The digitalization of business processes is essential to cut administrative costs, to improve productivity in business processes, and to achieve process transparency (EU Expert Group on e-Invoicing, 2009). Especially a fully integrated procure-to-pay process chain provides essential cost savings (EU Expert Group on e-Invoicing, 2009). An important factor is a well-justified and comprehensively designed implementation of e-invoice processes, combined with an awareness of the benefits (Sandberg et al., 2009). Since at least 2004 invoices are allowed to be exchanged electronically in all EU member states. Despite the obvious benefits of e-invoicing, the market penetration of e-invoices in the EU is still low: 29% of EU-based companies with at least 10 employees are sending or receiving at least one structured e-invoice (Eurostat, 2014). Finland and Denmark are leaders in sending and receiving structured e-invoices in the EU (cp. Figure 1). Some EU member states have already established mandatory e-invoicing to public authorities (cp. Figure 1): Austria, Denmark, Finland, Greece, Italy, Norway, Portugal, and Sweden (Koch, 2014; Pihamaa, 2014). France, Spain, and Slovenia have planned it (Koch, 2014; Pihamaa, 2014).

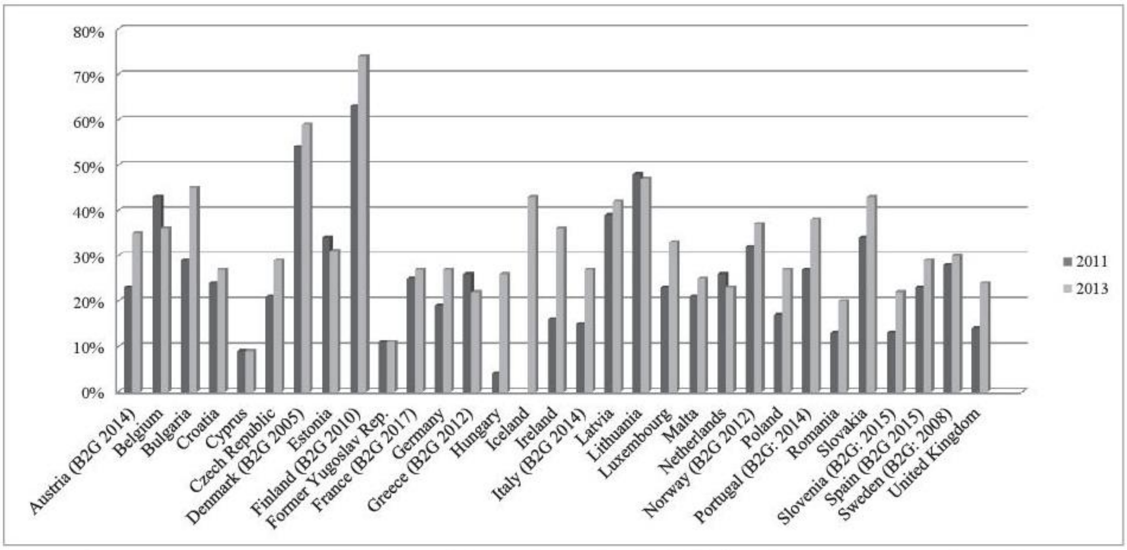

Figure 1. Companies (with at least 10 employees) of the EU sending/receiving at least one structured e-invoice (Eurostat, 2014)

In order to tap the full potential of e-invoicing, all business partners involved in B2B and B2G transactions have to accept e-invoices (Haag et al., 2013), even better are structured e-invoices for automatic processing. But there are many different standards for structured e-invoice formats, including industry-specific, national, or company-specific standards (cp. Table 1). Therefore, business partners have to agree on both a common standard for data syntax and on semantics to structure the content of the documents. The implementation costs are high, and not only do they cover software and hardware costs, but also redesigning the company's processes. This is not profitable for all companies due to the high level of complexity, uncertainty about the appropriate standard, lack of know-how, and too few business transactions. Therefore, some EU member states already established structured e-invoice standards for B2G transactions (cp. e.g. Table 1). Mainly, they chose XML-based invoice standards instead of the internationally accepted EDIFACT invoice standard. XML-invoices are human-readable and IS-processable because the data is presented with a clear syntax and semantic information (Huemer, 2000). But there is also the requirement to define the semantic information clearly, so that it is objectively understandable to all users. In contrast, EDIFACT invoices are only understood by IS and by some experts. They contain data without any meta-information and the meaning of the data is determined by its position in the message (Huemer, 2000). This order is defined by the standardization committee. Advantages of XML include its flexibility and the fact that programming is easy due to the combination of syntax and semantics (Bernius, 2013). Humans feel more comfortable with XML than they do with EDIFACT (Huemer, 2000).

	Standard	Type	Organization	Advantage	Disadvantage
Neutral standards	EDIFACT	EDIFACT	UN/CEFACT	global used standard, existing market adoption, stable, not industry or country specific; compact data format	complex structure, not easy to read and understand for non-experts, not flexible
	CII (Cross Industry Invoice)	XML	UN/CEFACT	global used standard including a general description of invoice processes and data, existing market adoption, stable, not industry or country specific, also for SME	huge structure that will in most cases have to be further restricted
	ebXML	XML	UN/CEFACT, OASIS	global used standard collection for data and transmission to conduct e-business processes, existing market adoption, stable, not industry or country specific, also for SME	huge standard family
	UBL	XML	OASIS	global used standard, esp. in Europe, existing market adoption, stable, not industry or country specific, also for SME	no standard format or syntax for European invoices, only the semantics of the required information
Industry specific standards	EANCOM	EDIFACT	GS1	used standard for the retail industry	low global dispersion
	VDA 4938	EDIFACT	ODETTE	used standard for the automotive industry	industry specific
	ISO 20022	XML/ CII	ISO	used standard for the financial industry that based on the semantic modell form CII	industry specific
Producer spezific standard	IDoc	IDoc	SAP AG	global disperion because of broad user group	proprietary standard
National standard	ZUGFeRD	PDFA/3 and XML/CII	Germany	combination PDF and XML; also for SME; developed by representatives for business, government, and relevant committees	new standard but emerging adoption
	UBLNES	XML/UBL	UBL Northern European Subset	definition and documentation of business processes and scenarios, of the usage of the specifiction including the validation tools to support e-invocing in the member states	only used in the member states
	OIOUBL (formerly: OIOXML)	XML / UBL	Denmark	national adoption in conformity with law, obligatory for B2G in Denmark	no global adoption possible because of customizing to Danish law
	Svefaktura	XML / UBL	Sweden	national adoption in conformity with law, obligatory for B2G in Sweden	no global adoption; national standard
	Finvoic	XML	Finland	used in a four-party model by local banks; B2B, B2C, B2G; national adoption and conformity with law	no global adoption; national standard
	ebInterface	XML	Austria	national adoption in conformity with law, obligatory for B2G in Austria	no global adoption; national standard
	facturae	XML	Spain	national adoption in conformity with law, obligatory for B2G in Spain (start 2015)	no global adoption; national standard

Table 1. Selected standards in Europe (extension of Cuylen et al., 2013)

But, none of those standards have become fully accepted in the EU and "most of them are not interoperable with one another" (European Union, 2014). The EU wants to establish a single European standard for the semantic data model on e-invoicing in public procurement that describes the obligatory core elements of an e-invoice reduce the "obstacles to cross-border trade deriving from the co-existence of several legal requirements and technical standards on electronic invoicing and from the lack of interoperability" (European Union, 2014). This standard will also be suitable for B2B transactions, easy to use for SMEs (Bernius, 2013), and will be based on existing technical specifications such as UN/CEFACT Cross-Industry Invoice (CII) v.2. Further, a list of supported syntaxes will be determined. By the end of 2020 companies and public authorities in the EU have to accept e-invoices in this European standard (European Union, 2014). Every member state is encouraged to start with e-invoicing based on structured invoice data before an uniform standard is developed. Therefore, ZUGFeRD was developed by FeRD in Germany, which promotes e-invoicing in B2B and B2G (cp. http://www.ferd-net.de). An invoice in the ZUGFeRD format is a combination of PDF and integrated

XML data that is based on UN/CEFACT CII. It is interesting to analyze the critical success factors for a migration from EDIFACT invoices to XML-based invoices.

2.2 Adoption of an XML-based invoice standard

The majority of the research streams on e-invoicing already address the identification of drivers and critical success factors that affect the diffusion of the e-invoice exchange. According to the technology acceptance model (TAM) by Davis (1989) the acceptance of information technology is identified as the subjective perception of a user that the new technology will improve the efficiency of the business process (perceived usefulness) and that it can be used in a company without much efforts (perceived ease of use). Adoption in the context of the diffusion of innovations (DOI) theory by Rogers (1983) is a decision that makes "full use of an innovation at the best course of action available", and that is based on „the perceived attributes of the innovation, the type of decision making, communications channels used, change agent's efforts and the nature of the social system" (Arendsen and Wijngaert, 2011). Tornatzky and Fleischer (1990) developed another acceptance model containing three dimensions: technology, organization, and environment (TOE). The focus of TOE is the companies and their decision making with regard to technology innovations. Technology includes infrastructure and processes. The structure and resources of companies such as company size, degree of centralization, and hierarchical structure are consolidated in the "organization" dimension. The "environment" dimension describes, for example, competitive, legal, and political environment of the company. IS adoption has been analyzed by a number of empirical studies in various domains. Table 2 demonstrates selected studies on e-invoicing and EDI as well as the closely related areas of electronic business and open standard adoption. Currently, there is no research on the requirements and challenges for the adoption of XML-based invoice standards. Kreuzer et al. (2014) examine in a broader sense XML-based e-invoicing. They analyze the adoption of open-standard IS by SMEs. Cuylen et al. (2013) analyzed the requirements and challenges for the dispersion of e-invoice processes. In this context some general aspects of standardization were identified. In this paper, the research focus is on the adoption of XML-based invoice standards. ZUGFeRD was chosen as a specific example as it is newly developed and introduced to the German market, where no national e-invoice standard existed up to now.

	Year	Outlet	Focus			Theoretical basis				Topic
			EDI	E-invoicing	Open standards	TOE	TAM	DOI	Other	
Delhaye and Lobet-Maris	1995	ECIS	x		x				x	factors of EDI adoption and standard message choice
Iacovou et al.	1995	MISQ	x						x	EDI adoption and technology impact by SMEs
Kuan and Chau	2001	Information & Management	x		x	x				EDI adoption by SMEs in Hong Kong
Zhu et al.	2003	EJIS			x	x				electronic business adoption by European firms
Edelmann and Sintonen	2006	International Journal of Enterprise Network Management		x				x		slow adoption rate of e-invoing by Finnish SMEs
Zhu et al.	2006	MISQ			x				x	open standard diffusion
Penttinen and Hyytiänen	2008	ECIS		x				x		e-invoicing adoption in Finnish companies
Arendsen and Wijngaert	2011	Electronic Government		x					x	impact of the government as a launching customer on e-invoicing adoption in Netherlands
Juntumaa and Öörni	2011	HICSS		x					x	partial adoption of e-invoicing
Hernandez-Ortega	2012	Academia Revista Latinoamericana de Administración		x			x	x		adoption and subsequent use of e-invoicing in Spanish companies
Hernandez-Ortega and Jimenez-Martinez	2013	Information Systems and E-Business Management		x			(x)			performance of companies that use e-invoicing regularly in Spain
Kreuzer et al.	2013	Information & Management		x					x	factors of e-invoicing adoption at public administrations
Kreuzer et al.	2014	AMCIS		x	x	x				adoption of interorganizational IS for e-invoicing among German SMEs

Table 2. Selected studies on adoption of e-invoicing and related topics

A few years ago, major topics being discussed were the electronic signature and legal requirements, like the equal treatment of paper and electronic invoices (Legner and Wende, 2006). These factors were removed by the EU in the directive 2010/45/EU. Hence, the legal circumstances are no longer a challenge to inhibiting the acceptance and adoption of e-invoices. According to the current legal situation, ensuring the authenticity and the integrity of paper-based invoices and e-invoices alike is required. A company can draw on existing internal control procedures, which are already being used for business reasons to secure and assess the payment process (Cuylen and Breitner, 2012). In the literature, the acceptance and integration of business partners is pointed out (Penttinen et. al., 2009). High effort is required to agree on a single common standard and to find a solution that business partners can both deal with and benefit from it in an automated business process. ZUGFeRD invoices provide a standardized XML-file that allows automatic validation and processing of invoice data. Companies profit mostly from e-invoice standardization when they have a sufficient number of business partners who use or at least accept the same standard. This positive network effects conduct to benefits, which can be even higher the larger the number of participating business partners is (Zhu et al., 2006). Thus the investment can be better justified within the company (Penttinen et al., 2009; Schizas, 2012).

Not only must the effort to convince the business partner be considered, but also the effort to implement the e-invoice standard into existing business processes and IS (Haag et. al., 2013, Sandberg et al., 2009). Integration into company workflows results in cost savings, fewer errors, and more efficient processes because the processing of invoices is accomplished without media disruption (Hernandes-Ortega, 2012). The companies do not see a positive cost-benefit-analysis. This is aggravated by a rejection of employees, executives, and stakeholders of the companies, who argue that there is no need to change the business process (Haag et al. 2013). Organizational readiness is a key factor for implementing or enhancing e-invoicing (Iacovou et al., 1995). The ZUGFeRD standard poses a new possibility. Companies can decide whether to use the PDF file to process the invoice (semi)-manually or the XML-file to process the invoice automatically. Only one format is necessary for all business partners and no adaptations are required. Furthermore, software is needed to create and read the XML-files. The company can develop one or can order one from the software provider, which of course means additional cost. Many potential adopters just see the cost savings for the print and the dispatch and not the time and costs they can save on the entire invoice process (Haag et al., 2013; Penttinen and Hyytiäinen, 2008). Some SMEs do not have the resources to implement automated business processes, for instance the small ones, like butchers, craftpeople or hairdressers. Partly, they do not use any IS and are not prepared for an electronic exchange (Legner and Wende, 2006; Penttinen and Tuunainen, 2011). A further reason for the non-acceptance of e-invoicing and an XML-based standard is the lack of international standards and legislation (Agostini and Naggi, 2009; Penttinen and Hyytiäinen, 2008). ZUGFeRD is based on UN/CEFACT CII (basis for the European standard for B2G transactions), and it can be already used to gain competitive advantages.

In the literature, a lack of knowledge about the necessary IS, the potential of e-invoicing, and the implementation of electronic business processes are often mentioned as critical success factors for the dispersion of e-invoicing (Legner and Wende, 2006; Haag et al., 2013). More information and awareness is needed. FeRD addresses the objective of communicating e-invoices as well as their developed standard (FeRD, 2014). Especially SMEs need information about selection criteria for technology and service providers (Ballantine et. al., 1998; Haag et. al., 2013). As mentioned, harmonization is an important factor. EDI procedures with EDIFACT messages are often used by large companies to exchange electronic business data, not only invoices. This is only viable at a sufficiently high volume of transactions (Balsmeier and Borne, 1995). Many EDIFACT standards are already established. The effort for the transfer from one standard to the ZUGFeRD standard has to be evaluated. Further, the effort for the integration of e-invoices into IS such as accounting and payment systems must be considered. This is important because these factors are responsible for the denial of e-invoicing (Iacovou et al., 1995).

3 Research Design and Data Collection

The overall research design is presented in Figure 2. The research process began with a structured literature review to identify all relevant aspects of e-invoice acceptance and standardization. The focus was on XML-based standards with regard to the case example ZUGFeRD. In information system research qualitative methods are applied to analyze in particular the use of IS and technology acceptance. The qualitative approach supports the analysis of cohesion between critical success factors (Martin and McKneally, 1998) and offers deep insights into organizational contexts (Palvia et al., 2003). A qualitative study with semi-structured expert interviews was considered the best method of discussing the critical success factors for adoption and acceptance of a new XML-based invoice standard. The experts were supposed to represent their company's perspective and opinion on e-invoice processes. The first question was formulated as a "warm-up" question so that the expert would start talking and feel comfortable. The following questions were about the status quo, the current invoice formats and processes, the reasons for their decision and factors of awareness as well as questions about the potential of XML-based invoices. All questions were orientated around the literature review. The last question is about the future vision of the expert and his or her opinion of the establishment of XML-based invoices.

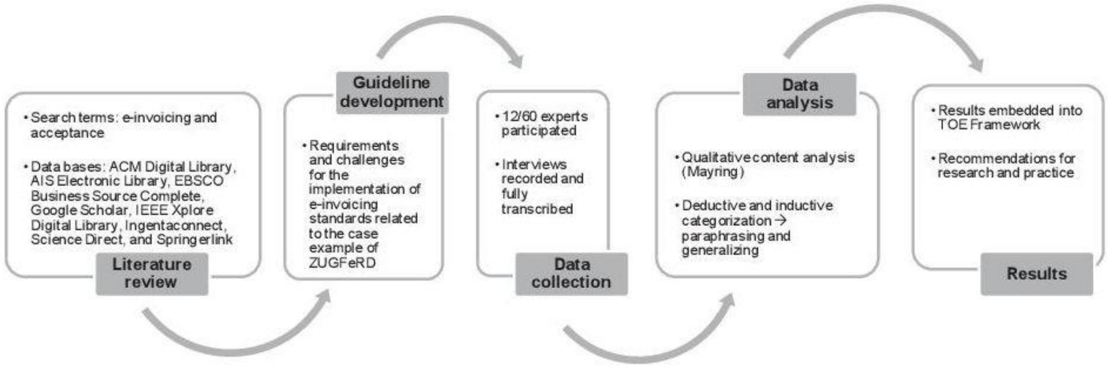

Figure 2. Research design

The explorative study with the guideline-based expert interviews was conducted between July and August 2014. All experts (cp. Table 3) were from German companies due to a lack of homogeneity of standards in Europe and the ZUGFeRD case example. They had comprehensive knowledge of e-invoice processes. In order to identify requirements and challenges for adoption of XML-based invoices, we explicitly chose experts from large companies and SMEs which already use e-invoice standards.

Expert	Company size	ZUGFeRD	EDIFACT	Position	Industry	E-invoice experience	# of codes
1	SME			Head of finance	Retail	1.5 years	16
2	SME			CEO	Management consulting	5 years	21
3	SME		✔	Head of finance	Retail cooperative	11 years	15
4	SME	✔	✔	Department manager of EDI invoice	Invoice service provider	22 years	21
5	SME	✔	✔	Senior manager eBusiness	Service provider	13 years	21
6	SME			Head of finance	Logistics	1-2 years	11
7	SME			CEO	Gastronomy	5 years	8
8	SME	✔		Authorized officer & software engineer	Management consulting	3 months	14
9	SME		✔	Senior application manager	Logistics	10 years	11
10	Large			Coordinator of special projects	Telecommunication	8 years	15
11	Large	✔		Head of invoice dispatch	Software/Service provider	5 years	14
12	Large	✔	✔	Head of accounting	Groceries	20 years	22

Table 3. Interviewed experts and relevant data

Twelve interviews were conducted, some by phone and some in person. Every interview was recorded with the permission of the expert and transcribed afterwards. It was essential to determine the participants' assessment and experience with both established and new standards of e-invoices. With this information, critical success factors of acceptance and adoption for the implementation of XML-based e-invoice standards were investigated. Furthermore the interviews considered the "status quo" and organizational readiness.

Initially, theoretical main categories were derived from the literature review. Thus, the deductive categories are the followings (in some cases, subcategories can be applied):

- Formats (outgoing and incoming)
- Process
- Standardization and requirements
  - Internationalization
  - Software modification
  - Sufficient number
  - Agreements for XML

For the tool-based content analysis, the MAXQDA software was applied. The uploaded text material provided an opportunity to define the deductive categories accurately and add a category description. The coding agenda determined a basis for the collected categories. Mayring (2014) recommends establishing a definition, an example, and coding rules for each deductive category. In this case, the definition and coding rule were consolidated since the clear categories already delimited the coding. All text passages were assigned to the categories, which are in a coherence with the deductive categories. The inductive category application (open coding procedure) applied new categories. The entire text material was reviewed and new categories were found continuously. Some old categories were replaced, more subcategories were created and later some of them consolidated. In this way we were able to determine the critical success factors of the ZUGFeRD invoices implementation. Mayring (2014) calls this step the summary. Figure 3 shows the final coding system in the MAXQDA software. The larger a point the more codes could be found. Through the appropriated coding of both the deductive and the inductive categories, a paraphrase and a generalization for every code were formulated. The paraphrases structured the code by shortening and reforming the quotations of the experts. The generalization formulated a general statement for every paraphrase. In some cases it was possible to summarize two or more paraphrases to one generalization. Table 4 provides an extract of the definition and coding.

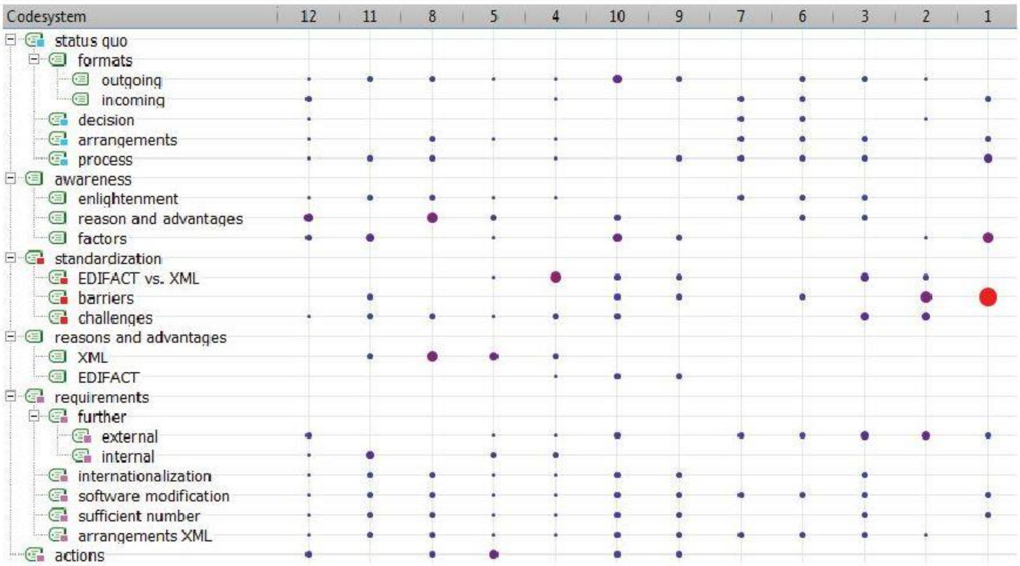

Figure 3. Excerpt of coding in MAXDA

The acceptance of e-invoice standards and their adoption can be illustrated in an adjusted and enhanced technology acceptance model, since it can be seen as an advanced and actually not widely used technology in the accounting and payment business processes. The TOE was chosen due to its applicability for EDI adoption in the past (Kreuzer et al., 2014; Ordanini, 2006). The results were integrated into this model in section 4.

Category	Definition	Code	Paraphrase	Generalization
status quo/ decision	The reasons and factors why the enterprises have decided to send the current formats.	There was no other solution in the market rather than EDIFACT or paper. All the other possibilities were legally not permitted.	There was no alternative to EDIFACT and paper. All the others were legally not permitted.	The decision for the formats EDIFACT and paper is influenced by the market situation since other alternatives were legally not
awareness/ enlightenment	Statements about the influence of enlightenment.	Yes probably information and enlightenment would support the decision, but I never got it. But I am not the CEO of the company, so maybe he gets it.	Probably steady information could help to think on e-invoices earlier but I never got information or enlightenment.	Enlightenment could affect the acceptance of e-invoices.
reason and advantages/ XML	Reasons and advantages of the invoice format XML.	But that is certainly not replacing EDIFACT ... As I said, I do think that it can be adopted in these areas where still paper oder PDF is used, and there it will be definitely an advantage.	I think that there is an adoption for ZUGFeRD and it has an advantage everywhere where only paper or PDF invoices are used.	ZUGFeRD fills the GAP between EDI (EDIFACT invoices) and paper based invoices.
...	...	...	...	...

Table 4. Code, paraphrase, and generalization

4 Discussion of the Results

We analyzed the text material to identify critical success factors for the integration in the TOE model.

External Task Environment. To use a further standard such as ZUGFeRD business partners must also accept this standard. Most of the experts illustrate that a sufficient number of business partners is required to implement a standard efficiently. A minimum quantity of users should always exist to implement a new standard or to replace an existing standard. This is also mentioned in further studies e.g. about migration to open-standards or e-invoicing and e-business in general which deal with network effects. The participants only want to use an e-invoice standard when more business partners take part, which confirms previous research (Zhu et al., 2003; Zhu et al., 2006; Haag et al., 2013). Thus, the critical quantity poses a critical success factor. Therefore companies are needed that are pioneers. In matters of ZUGFeRD the developer companies act mostly as pioneers or as advocates of this standard. The FeRD promotes ZUGFeRD on national and European level. The structure of the business partners and the IS they use were frequently mentioned during the interviews. Companies that have many small business partners who rarely use IS have no inducement to implement structured e-invoice standards, which is also a factor on standard choice within EDI (Delhaye and Lobet-Maris, 1995). Hence this is a further critical success factor. An additional critical success factor is pressure from external business partners or from the market. Due to pressure from business partners and changed market situations companies have to decide whether to maintain or modify their processes and invoicing standards as to not lose any market power or market share. These findings are consistent with quantitative studies of Zhu et al. (2003), Zhu et al. (2006) and Iacovou et al. (1995), where the competitive pressure have a significant positive influence of the adoption of standards. The ZUGFeRD standard is promoted with the advantage that, compared to EDIFACT, no additional agreements are necessary and therefore an interchange with almost any business partner would be possible. Eight experts support this statement and explain that some minor agreements are necessary. Especially no additional agreements are required for the mapping or the structure of the XML-file, since a strict guideline is already in place for the standard. The omission of agreements represents one critical success factor. In addition to this some experts mention that XML-based invoices require more data volume than EDIFACT invoices and therefore more processing time. Therefore some of them reject XML-based invoices generally. Although modern IS can process and transfer high data volumes quickly the transmission and processing time presents a critical success factor. On the one hand as there exist this attitude to XML-based invoices and on the other hand as performance of processing data is an important issue in general. Producers of software and solutions have to consider this. Many companies have not been informed about new technologies and standardizations in e-invoicing and about the legal situation. This could be confirmed by the expert interviews, since many smaller companies (who do not use any structured data) have never heard of EDIFACT, XML-based invoices, and automated processing. External support in the realm of IT systems and the handling with structured e-invoices might help for the adoption and is also validated in paper about EDI adoption in general (Kuan and Chau, 2011). Many experts pointed out that they do not need any information or awareness. But when assessing their background and their circumstances we come to the conclusion that information and effort from institutes and government could influence their thinking. In any case, what can be also found in articles about EDI adoption (Iacovou et al., 1995; Kuan and Chau, 2001), efforts and the resulting awareness of external organizations or institutions, as well as the legal compliance could affect acceptance and successful implementation which is mentioned in further paper about adoption.

Organization. The EDIFACT messages can already be processed automatically and therefore it would be useful to have a process that is close to the existing one. But certain circumstances, such as IS of business partners, the internal need to modify processes and managerial capability must be taken into account (Haag et al., 2013; Zhu et al., 2006). The ZUGFeRD standard provides a simple solution for invoice exchange, but cannot convince companies that demonstrate organizational readiness or are not able to process structured data. Companies consider alternatives when they have many business partners who are not using established standards like EDIFACT. Furthermore, not many companies are asking for the new standard and this is the reason the widespread implementation has not occurred yet. Critical success factors are the expected effort for the modification and organizational readiness in order to have at least an incentive to rethink established invoice processes. These factors are already figured out of Arendsen and Wijngaert (2011) and Iacovou et al. (1995) in studies about e-invoicing to have an influence on adoption and are therefore not specific ones. One internal critical success factor for adoption is internal company communication and thus the acceptance of an XML-based standard. The critical arrays within the standard are important to communicate, leaving little room for other interpretations by providing detailed information for legal and accounting departments. Starting with the decision of a company to start with a standard, business partners need to be convinced. The advantages and benefits for both sides must be presented, not just the request itself, as some participants of the explorative study explained. ZUGFeRD is a common and cross-industry standard and not a specific solution for only one business relationship. The interview partners expected different efforts for it. The conviction of the business partners and thus the mentioned benefits present a strong critical success factor, which is associated with network effects. The larger the network, which uses e.g. ZUGFeRD or open-standard in interorganizational systems, the more business partners will join the network and use the standard (Zhu et al., 2006).

Technology. Critical success factors for technology are the market situation of e-invoices and the possibility to use one common, uniform standard for any business relationship. Most of the experts explain that they would adopt the standard if these basic factors are present. The experts often mentioned the current invoice and the mapping compatibility. Not all invoices are suitable for every standard, because not all of the mandatory data in the standard is actually used. The process readiness is already mentioned in studies about e-invoicing and EDI (Haag et al., 2013; Delhaye and Lobet-Maris, 1995). Additionally, the possibility to purchase standardized billing/accounting software and components to create and select the XML-file influences the decision toward one e-invoice standard. The EDIFACT format includes a comprehensive portfolio and the entire supply chain is involved. This does not yet exist for ZUGFeRD. Many participants explain that they would require a larger portfolio of messages as well as a strict guideline to adopt the standard. Hence, the quantity of business documents in an XML-based standard and their detailed specifications influence successful adoption. With larger invoices, a reduction for the structured data set is necessary to keep the file as small as possible state some experts. They compare it to the EDIFACT messages, which are compressed for a low transmission rate. They fear that XML-files have a larger transmission rate due to the internet speed and the size of the files and that therefore errors can occur and the transmission can fail. Not all companies have a modern infrastructure. XML-based invoices are not only exchanged between IS but also via e-mail. Some e-mail post boxes have limited the maximum size of an e-mail message. A further critical success factor is therefore the compatibility with large amounts of invoice data. On the European level ZUGFeRD has not been adopted yet, since EDIFACT messages and national standards in XML like ebInterface in Austria or FINVOICE in Finland already exist (cp. Table 1). However, the

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ZUGFeRD standard is based on international specifications for the European market (e.g. UN/CEFACT CII) and has the potential to be adopted by European countries. The participants of the underlying study have no unified opinion about this topic, since some are convinced that the standard can be used and some do not see a market for it. In opinion of the experts the standard is not more accepted compared to previous ones and therefore currently has no competitive advantage, which is e.g. not consistent with a study about e-business, where the competitive pressure is the only significant environmental factor for the adoption (Zhu et al., 2003). However, in this study the internationality of a standard is not a dominant critical success factor. From the interview material it can be inferred that a modifying existing software is possible. However, a new development or a purchase of a software component for XML-based invoices is more efficient since a new or additional processes will occur. The existing software for EDIFACT messages has no affect on the adoption of XML-based invoices. E-invoicing has not only advantages, the risk to hide an invoice exist. However, some companies of the interviews use OCR scanner and automatic provision for paper invoices, therefore they see no additional risk or manipulation possibility for e-invoicing. The software or tool has to prove anyway the correct amount and compare it e. g. to the order. The acceptance and adoption of the ZUGFeRD standard is highly influenced by the business partner demand (external), as well as by the effort required for the implementation (internal). As from the expert interviews, critical success factors do not differ much from general ones for implementing e-invoices and standards. This can be explained by the lack of knowledge that the companies have and the novelty of the ZUGFeRD standard. Many companies have not heard about it and do not know how to handle structured data sets. Hence this research can confirm the already known critical success factors, expand them with specific ones and organize them in the TOE model (cp. Figure 4).

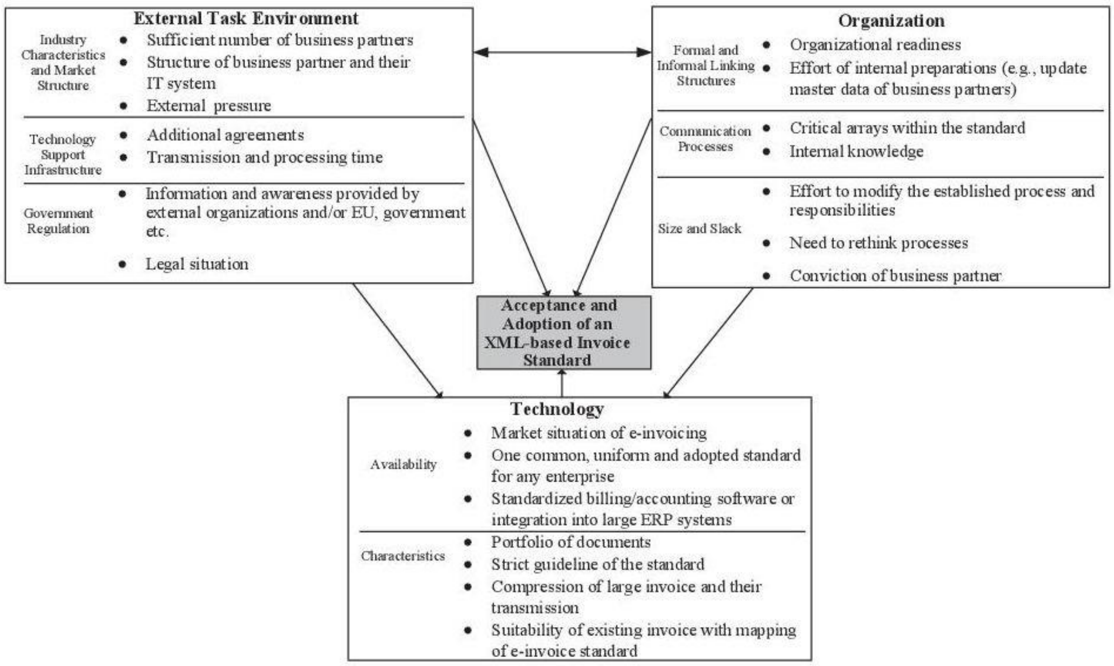

Figure 4. TOE for the acceptance and adoption of an XML-based invoice standard

It will be always difficult to change running systems and motivate companies to modify their processes if they feel no necessity or pressure to make changes. A solution with less effort but much potential of savings is needed to convince companies. The key factors are here: requests and information. When they receive many requests from business partners, companies will rethink their processes to satisfy customer and supplier demand. As soon as many of their business partners are using a uniform standard, the EDI users will be ready for another option for document exchange, the XML-based invoices. Adoption will occur in new business relationships, with SMEs, and with large companies. The migration can only proceed by a first implementation and adoption by non-users of EDI by replacing PDF and paper invoices.

5 Recommendations

Based on the results, recommendations for research and practice can be given to achieve successful adoption and implementation of XML-based standards in companies. The TOE model represents a first approach illustrating the critical success factors and the relationship among them. It supports companies by implementing an e-invoice process. For example, the master data of the business partner will need to be updated since the e-mail address for the invoice dispatch is required. To implement an e-invoice receipt, an e-mail address must be created and communicated to business partners. The creation of the e-mail post box is associated with the software development or extension. The software for the existing invoice processes could be modified, but the results show that an additional solution for the new implemented process is useful. The entire process must be examined and has to be integrated. The testing and validation of IS infrastructure is important. It is recommended that a pilot phase is set up with selected business partners to figure out the weak spots before modifying the entire business relationships. To keep the relationship perpetuate and also for the company's own requirements, a service package and a support hotline would be helpful to support business partners when questions or errors occur.

The main objective is to increase the acceptance of a new e-invoice standard to achieve a critical quantity. The more users a standard has, the more companies will adopt it. This is the biggest challenge at the same time. A standard always needs innovators who start to dispatch or even send requests for the invoice receipt. This can not only occur through company use; the public authorities should also be involved and should implement processes for e-invoices. An example for this is Directive 2014/55/EU to introduce an European standard for e-invoices with public procurement in the whole EU. When a company decides to use a new standard, business partners need to be convinced. The company can send a request via e-mail either for receipt or dispatch. With important and close business relationships, a personal appointment with the responsible employee should be arranged. The advantages and benefits for both sides must be presented, not just the request itself. For an XML-based standard, the standard has the potential to be a dominant standard for both e-invoices and other business documents in the coming years. It is a common and cross-industry standard and not a specific solution for only a single business relationship. It is also a standard for B2G transactions. In order to come up with a full cost-benefit analysis, a sufficient number of participating business partners is required. Hence, the request can already be used to find a decision by estimating how many invoices could be exchanged in this format. Companies could set up a portal solution as a possibility for those business partners who are not able to create data in XML. A further option is to provide software licenses for affordable software products to motivate the business partners to create their own e-invoices. Since ZUGFeRD has the advantage of a digital image, there is no need for a portal to provide the structured data. However, this critical success factor may also be supported by public authorities and the government by setting up a major information and awareness-raising campaign. When using a standard such as ZUGFeRD and its specifications, additional adjustments are not necessary. This may support the adoption of this standard. Some points need to be discussed and communicated, but they are not associated with much effort or cost. If companies would like to exchange their own XML-based standard, additional adjustments and testing are necessary and cannot be eliminated.

The critical success factors of an implementation that were identified within this qualitative study support the adoption and provide an overview for further research. When XML-based standards are established and a high adoption rate is achieved, the error-proneness will decrease. The same development took place for EDIFACT invoices due to testing and continuous developments. The internationalization is possible and the applicability throughout Europe is feasible. The largest disadvantage of EDIFACT messages is that agreements are required and that the implementation is associated with higher effort and investments. The ZUGFeRD standard has less room for interpretation and is developed for the implementation without any additional adjustments. Hence, these disadvantages will not arise. The invoice standard can be used as a basis for other electronic business documents and represents a chance for a higher standardization than EDIFACT has reached up to now. Due to all these factors, XML-based standards have much potential to achieve a large market share and, in the foreseeable future, may completely replace established standards, as well as paper and PDF invoices. The migration will start with an increasing market share of XML-based invoices.

6 Limitations

The research was limited to German experts as this study focused on the exemplary case of ZUGFeRD, since it is the first XML-standard in Germany that has the potential of adoption. XML-based standards from other countries were not considered. But the research results can be applied to another national standard with a similar structure. However, in further research, other countries and standards must also be considered and the internationalization of the standards must be analyzed due to the advanced globalization. The adoption of these standards could be examined and compared to these research results. Then conclusions could be drawn and the TOE model expanded. The different legal situations and the lack of homogeneity are challenges for comparing e-invoice standards from other countries. Hence, the transferability of the results has not been analyzed. The enhanced TOE model contains the identified critical success factors. Further validation applying a quantitative-explorative study is advisable. Currently, only twelve expert interviews were held and interpreted. A sufficiently large sample should be examined. Further research can further deepen the results of this study. The TOE and the results can be used as a basis of other related topics of a successful adoption of e-invoicing standards.

7 Conclusions and Outlook

The aim of this study was to identify the critical success factors for the implementation of XML-based invoices. The case of the German ZUGFeRD standard was applied as no predominant other standard or governmental regulation of the market exist. Twelve qualitative expert interviews were conducted with the purpose to discuss the experts' experiences and opinion of the XML-based standard ZUGFeRD and the possible migration from EDIFACT where applicable. As is known from the results, the XML-based invoices have the potential to initially fill the gap between the invoices of a fully automated process within the EDI procedure and the remaining paper or PDF invoices. A greater competition, increasing digitalization of business processes, and environmental awareness may cause companies to rethink electronic invoicing and are therefore drivers for implementation. The expanded TOE model provides an overview of factors to be considered and brings them in relation. It supports practice as well as research within the implementation of an XML-based standard. In the coming years, a large market share of an XML-based standard must be achieved to install automated invoice processes. The potential of an adoption is seen and a successful implementation can proceed, but many companies are still waiting for the critical quantity and need pressure by the market or business partners. Future research must evaluate the qualitative results from this study with a quantitative survey in order to be able to generalize, reject, and extend them. Case study research can provide description, test or develop theories (Eisenhardt, 1989). Thus, case studies with companies' transition from EDIFACT to XML-based standards will be valuable to uncover further critical success factors and differentiate circumstances of small and large companies. The process of agreements, process and IS infrastructure change can be seen through by research in cases with SMEs first implementing e-invoices. This can provide more in depth recommendations for companies, interest groups, and governments in Europe. This theoretical research can support the practice and give recommendations for a successful implementation of an XML-based standard in companies. Considering that, networks between companies and researchers can help to promote the adoption of e-invoicing standards. For more detailed critical success factors special cases and specific industries have to be analyzed in further studies. However, the TOE model with the critical success factors gives a solid overview and advice for implementation of XML-based invoices successfully.

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A.3 Research article #2: Standard adoption of XML-based invoiced: An empirical study using a technology-organization-environment framework

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Submitted to:

Information Systems and e-Business Management

STANDARD ADOPTION OF XML-BASED INVOICES: AN EMPIRICAL STUDY USING A TECHNOLOGY-ORGANIZATION-ENVIRONMENT FRAMEWORK

Abstract

Irrespective of potential benefits of XML-based invoices, its adoption is still limited. Given that XML-based invoice standards are designed for an invoice exchange, we propose that adoption of these standards depends not only on the focal organization perspective but rather on synergies between business partners (dyadic perspective). While the adoption of information systems innovations and business process standards is well known in many areas, there is limited understanding of the adoption of XML-based invoices and the determinants which influence the adoption from a dyadic perspective. We conducted a study based on a quantitative survey to proof specific adoption determinants. Based on the technological, organizational, and environmental (TOE) framework, we propose a research model that postulates a set of TOE determinants which influence the adoption of XML-based invoice standards. The research model is empirically tested by means of partial least squares path modeling (PLS-SEM) with data collected from employees across different industries. Our results indicate that the three factors jointly: technological, organizational, and external positively impact the adoption of XML-based invoice standards. Our study permit a technological and practical understanding of the determinants that influence the organizational adoption of XML-based invoice standards.

Keywords:

Electronic invoice, XML-based standard adoption, TOE framework, Empirical survey, Partial least squares

1 INTRODUCTION

The digitalization of business documents has increased in recent years. In order to remain successful and competitive, organizations tend to have less paper documents and automatize their business processes. The electronic invoice (e-invoice) is one business document in the business-to-business (B2B) sector that is exchanged in almost every business transaction and hence represents one business activity which can be digitalized. An e-invoice can be digitally created and processed without any media discontinuity and creates the potential for cost savings and higher efficiency (European Expert Group on e-Invoicing 2009; Sandberg et al. 2009; Cuylen et al. 2016). Automated processed invoices can lead to cost savings of 60-80% for the more than 200 billion invoices that are exchanged in the business and government sector worldwide (Koch 2017). Workflows as well as process transparency and traceability can be improved by processing e-invoices (Haag et al. 2013).

Major advantages occur when the e-invoice is not only received as a PDF-file but is also accompanied by structured data, such as EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) or XML (Extensible Markup Language). EDIFACT is part of the well-established EDI (Electronic Data Interchange), which includes not only invoices but also orders and other business documents along the entire supply chain. EDI is especially prevalent within value added networks because the data is only machine-readable and can therefore be processed at high speed. However, EDI is not affordable for every organization and not worthwhile for every business relationship due to high implementation and transmission costs (Balsmeier and Borne 1995; Kabak and Dogac 2010). Organizations must invest e.g., in in-house developments and maintenance for e-invoice processes but organizations often eschew these investments or are not able to generate saving potentials from an e-invoice exchange (Koch 2017).

By contrast, XML does not need special technologies for its transmission since it can be sent and received via an e-mail. The generation as well as the processing of an XML file are basic functions of current software and do not usually present great challenges for IT departments (Kabak and Dogac 2010; Bernius et al. 2013). It is also possible to combine an XML file with a simple PDF file, which became popular as hybrid e-invoice in recent years (Koch 2017). The fact that the market penetration of e-invoices in general has increased in the last few years signifies that many organizations have recognized the advantages of a digital invoice exchange (Koch 2016). In June 2017 a European norm was published which was developed in accordance to the EU directive 2014/55/EU (which introduces a European standard for e-invoices with public procurement in the whole EU) to define a semantic data model for e-invoices in Europe. The norm EN 16931-1:2017 is depicted through XML-based standards, e.g., Factur-X which was developed together from Germany and France.

However, adoption of a uniform invoice standard is still limited. Research identifies different adoption determinants, e.g., a positive cost-benefit relation regarding the implementation of e-invoice exchange or technology readiness but concentrating at focal organizations and always with a special focus, e.g., on business-to-government transactions, small and medium-sized organizations, or national context (Edelmann and Sintonen 2006; Zhu et al. 2006b; Penttinen and Tuunainen 2009; Hernandez-Ortega 2012). Like Venkatesh and Bala (2012) and Kreuzer et al. (2014) mention, also the respective business partner and the environment have an influence on business standard adoption. Yet, this has been scarcely researched in the past. More precisely, focal organizations were under the scope of the investigation within the e-invoice adoption research field. For instance, the study of Penttinen and Hyytiänen (2008) who use Rogers Diffusion theory (Rogers 1983) to identify adoption determinants or the recent study of Lagzian and Naderie (2015) who focus on the affecting factors of e-invoices. Venkatesh and Bala (2012) have investigated adoption determinants using the example of interorganizational business process standards and provide thereby insights of the influence of synergistic factors.

Due to the great potentials and the simplicity of XML files, the need to implement XML-based invoices and the lack of e-invoice standard adoption from a dyadic perspective, our study focuses on XML-based invoice standard adoption. Our paper aims to fill this research gap. We combine and explain adoption determinants for business partners for the invoice dispatch as well as for the invoice receipt and support thereby organizations with the indispensable implementation of XML-based invoices. This study investigates the following research question:

How do technological, organizational and environmental factors influence the adoption of an XML-based invoice standard?

This paper is structured as follows: Firstly, we provide the theoretical basis and identify the targeted research gap (e-invoices and related work). Secondly, we demonstrate our research design and the applied methodology including hypothesis generation, empirical setting as well as the measurement instrument of our quantitative study. After presenting the data analysis procedure, we report the results. Following the discussion of our findings and the implications for research and practice, we conclude by pointing out limitations followed by a short conclusion and outlook.

2 THEORETICAL FOUNDATION

2.1 E-Invoices and Adoption

The advancing digitalization of economic processes has created the need to decrease administrative cost, improve productivity and efficiency of business processes and to achieve process transparency (European Expert Group on e-Invoicing 2009). Thus, the digitalization of invoices and related business processes seems obvious given the predominance of internet and global e-business. Larger organizations are more likely to adopt e-invoices and play a pioneering role in initially persuading their large business partners and thereafter also their smaller business partners to follow suit (Koch 2016). Nevertheless, the expected market penetration for 2017 in the B2B sector differs from country to country with the highest rates of more than 40% in Denmark, Finland, Norway, Sweden, Estonia, Brazil, Chile and Mexico (Koch 2017).

E-invoices that include structured data such as XML or EDIFACT offer significant potentials for time and cost saving. These savings comprise printing and dispatch savings as well as savings resulting from process automatization. The invoice data can be automatically created, sent and processed using master data and process-related data from organizational software (European Expert Group on e-Invoicing 2009). This means that manual interaction is unnecessary and input errors can be avoided. For the recipient of an e-invoice the advantages are even greater due to the minimization of human interactions when checking and paying the invoice (Penttinen and Tuunainen 2009; Lagzian and Naderi 2015). For example, European law allows electronic exchange for all EU members and even supports the adoption of e-invoices in their directive 2014/55/EU which specifies e-invoices in public procurement with effect from 2016. To benefit the most from an e-invoice exchange, both business partners must agree to one standard. It is even more worthwhile if all business partners of an organization adopt the same standard so that only one technology and its corresponding invoice format can be used for the whole invoice exchange business process (Haag et al. 2013; Chen et al. 2015). Many different standards for e-invoices exist, including industry-specific and country-specific norms. A summary of all the standards that we have identified is given in Table A1 in the appendix. One dominant standard is EDIFACT, which was developed and published in the 1980s. As EDIFACT messages are well established, transactions can be processed instantly and automatically and the error-proneness is almost 0% (Georg 1993). However, specific knowledge and special technology to process the data are preconditions for its successful implementation and application (Balsmeier and Borne 1995; Kabak and Dogac 2010).

XML-based standards (also as hybrid format) offer an alternative to the latter. Many countries already offer invoice standards which are open-source, XML-based and partly also hybrid compatible and the majority of available XML-based standards are based on existing and public technical specifications such as UN/CEFACT, IAO/ UDE or GS1 (see Table A1 in the appendix). While the market volume of pure images such as PDF files is shrinking, especially the hybrid format gains most in importance (Koch 2017), which is illustrated in Figure 1.

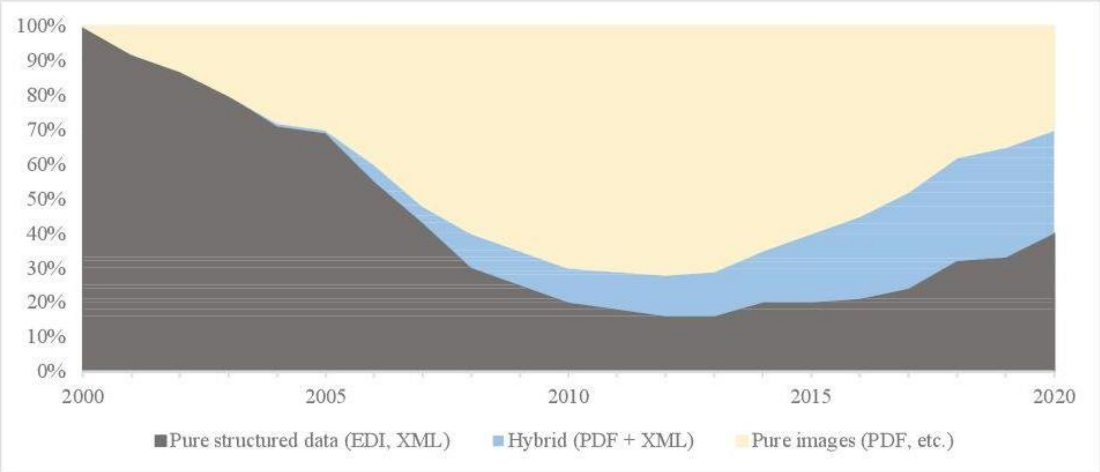


Figure 1: Shares of different invoice formats over the years (based on (Koch 2017))

2.2 Related Work

Research in the field of e-invoices or EDI from a focal organizations point of view in general has been carried out for several decades. Most studies address e-invoice performance and national diffusion (e.g., Edelmann and Sintonen 2006), influence factors (e.g., Haag et al. 2013), or EDI standard adoption (e.g., Iacovou et al. 1995). We have carefully reviewed the existing literature on standard adoption in the field of e-invoices and EDI as well as other closely related topics such as e-business and open-standard adoption. Our review indicates that especially XML-based standard adoption research from a dyadic perspective is very limited.

Nevertheless, one exploratory study is presented by Penttinen and Hyytiänen (2008), who examined the adoption of general e-invoices in Finish companies. They conducted six qualitative interviews which they analyzed to identify influence factors for the adoption of e-invoices using Rogers' diffusion theory. The most cited influence factors were communication factors, technology readiness and management support. They also demonstrate factors that inhibit the adoption, whereby the internationalization of business is identified as one major problem owing to the existence of local regulations for e-invoicing (Penttinen and Hyytiänen 2008). These authors do not provide an adoption model, however. In contrast, Kreuzer et al. (2013) developed a meta-model of the e-invoicing adoption, but restricted to the governmental level. After conducting a literature review, they used semi-structured expert interviews to create their extensive model, which sorts all relevant factors for e-invoicing adoption (Kreuzer et al. 2013). A smaller model for EDI adoption by smaller organizations is the framework model presented by Iacovou et al. (1995). They used seven case examples to investigate the effects of organizational readiness, external pressure, and perceived benefits. These three factors had a strong influence on EDI adoption and integration and hence had an effect on the EDI impact for organizations (Iacovou et al. 1995). A large quantitative study involving 1,394 participants which examines the migration to open-standard systems is provided by Zhu et al. (2006a). Network effects, switching costs and path dependency were identified to be the three most significant determinants of technology adoption (Zhu et al. 2006). Hong and Zhu (2006) conducted a further large study limited to e-commerce adoption. From this investigation it was concluded that technology integration, web functionalities and expected expenditures are the major driving forces for the adoption, whereas the size of the company is not positively related to the adoption due to more complex business processes and structures within larger organizations (Hong and Zhu 2006). Jeyarai et al. (2006) analyzed IT innovation adoption for individuals as well as for organizations. They discussed the independent variables and compared these for organizations and individuals. Two major independent variables for organizations were identified to have a significant influence on IT adoption, namely, innovation characteristics and organizational characteristics (Jeyarai et al. 2006). Another paper published by Kreuzer et al. (2014), who focuses on open standard adoption for inter-organizational information systems and takes account of XML-based standards. The authors conducted an extensive literature review and subsequently applied the TOE model to illustrate their findings on organizational standard adoption (Kreuzer et al. 2014). Venkatesh and Bala (2012) concentrate on the business process standard "RosettaNet PIPs" and conducted a quantitative survey to confirm previous hypothesized statements, e.g., that process compatibility has a significant influence on business process standard adoption. The TOE model is applied to organize the hypothesis and discuss the results of the study (Venkatesh and Bala 2012). Two explorative studies based on expert interviews and concentrating on XML-based e-invoice standard succeed are published by Kuehne et al. (2015) and Kuehne et al (2017). They identified but not quantified internal as well as external adoption determinants like for instance the available portfolio of documents in the format or the current market situation.

In our quantitative study, we focus on XML-based invoices since they provide significant potentials and are relatively easy to integrate into current IS. We identified many related studies which we make use of in our research model to generate hypotheses for the adoption determinants of an XML-based invoice standard. As the presented related work section provides insights into closely-related adoption determinants, we are able to partly apply them in our specific research model.

3 RESEARCH DESIGN AND METHODOLOGY

3.1 Hypothesis Generation and Research Model

In accordance with the diffusion theory of Rogers (1983), the acceptance of an innovation is not a simple decision but rather a diffusion process. Regarding the innovativeness of organizations, Rogers (1983) identified three independent elements (innovation, individual, and organization) while repeatedly noting the impact of technological aspects but lacking the environmental context. The TOE model developed by Tornatzky and Fleischer (1990), consisting of the three elements technology, organization and external task environment, is in complete harmony with Rogers diffusion theory but considers a broader range of influence elements. This model focuses on the choice of a technological innovation by organizations (Tornatzky and Fleischer 1990). A frequent application of the model is demonstrated by empirical research regarding business process standard adoption (Kreuzer et al. 2014), EDI standard adoption (Premkumar et al. 1997; Kuan and Chau 2001), and e-business adoption (Hong and Zhu 2006; Oliveira and Martins 2010). As there is much evidence of the applicability of related topics, we apply this innovation adoption model in our research study on the adoption of XML-based invoice standards. The Technology element of the model describes the technologies which are relevant for organizations and is distinguished from the environmental aspect to demonstrate its strong influence. The Organization element expresses the structure and resources of organizations such as organization size, degree of centralization, and hierarchical structure. All aspects which are beyond the control of an organization and thus exogenous, are comprised in the External Task Environment element, e.g., government regulation or competition (Tornatzky and Fleischer 1990). Since we decided to use the TOE model for our empirical study, the literature content is organized according to the same pattern.

Technology

The technology element of the model describes the characteristics of an innovation, which in our case represents the characteristics of an XML-based invoice standard. As XML-files are structured text files, they can be transferred via the Internet and stored on a computer or server without additional effort (Bohannon et al. 2002; Chen et al. 2003). The secure procedure and the related error-proneness of the transmitted files as well as the subsequent digital archiving are critical factors regarding the perceived security of important business documents such as e-invoices (Penttinen and

Hyytiäinen 2008; Haag et al. 2013; Hernandez-Ortega and Jimenez-Martinez 2013). Furthermore, the performance expectations of an electronically-transferred document can influence its acceptance (Lagzian and Naderi 2015; Lian 2015). Since only an internet connection is required for the transferal of XML-based invoices, the transmission and processing times are not crucial factors in this specific case. However, the mentioned simple technology behind XML-based invoices allows to integrate XML-files into PDF enabling a unified business process even though respective business partners have heterogeneous IS. This approach not only unifies the process but also increases productivity as well as raises the rate of adoption by business partners as a whole (Kuehne et al. 2017). The XML code is machine-readable and is also easily comprehensible for humans due to the text format, even though this is not necessary when it comes to an automated process. The creation as well as the interpretation of XML files are basic functions of current software and are very common among employees in IT departments (Bohannon et al. 2002; Kuehne et al. 2017). Since the complexity of an e-invoice standard is a determinant for its adoption (e.g., Chen et al. 2003; Penttinen and Hyytiäinen 2008), the simplicity of an XML-based standard permits an easy integration into current systems, increases productivity and hence may encourage organizations to use it. The XML-specific characteristics thus play a critical role regarding the adoption of an XML-based invoice standard.

The technology element further covers the standardization of an XML-based invoice, which points to a high level of diffusion. The standardization of an electronic document and hence its diffusion encourages organizations to adopt the same standard (Zhu et al. 2006a). Standardized Enterprise-Resource-Planning (ERP)-systems or billing software equipped with an option to automatically create and also read a certain standard are very advantageous and permit easy use of the standard. These functions are demanded by many organizations as a prerequisite for adoption (Kuehne et al. 2015). Sub-standards for different industries or countries using one uniform standard as a foundation can increase the overall adoption rate (Penttinen et al. 2009). Having business partners who have already adopted a standard also increases the rate, as organizations are hesitant to lose market power and want to remain successful in their business (Chen et al. 2015). Essentially, if environments and the market situation change and trends are set, organizations are more motivated to change their invoice exchange as well to run an innovative and modern business (Melville and Ramirez 2008; Kuehne et al. 2015). Furthermore, organizations not merely require a different market situation for implementing XML-based invoices, but rather a larger portfolio of documents of the standard, e.g., including order or dispatch advise to cover and unify the entire value chain (Kuehne et al. 2015; Kuehne et al. 2017). If organizations feel uncertain about future use, they are hesitant to invest any resources in the migration (Edelmann and Sintonen 2006; Venkatesh and Bala 2012; Krathu et al. 2015).

Hence, the current standardization of an XML-based invoice combined with XML-specific characteristics is crucial for further adoption and leads us to our first hypothesis.

H1: XML-specific technologies have a significant positive influence on the adoption of XML-based invoice standards.

Organization

The innovativeness of an organization is the openness of an organization to adopt a new technology and thus we measure it by availability of sufficient resources, quantity of exchanged invoices and size of the organization since these are pre-conditions to innovativeness (Venkatesh and Bala 2012). Implementing a new XML-based standard requires financial, human or time resources, depending on the current status of the organization (Hernandez-Ortega 2012; Kreuzer 2017). Thus, an organization must have the capability and appropriate resources to implement a new XML-based invoice standard (Edelmann and Sintonen 2006; Zhu et al. 2006a; Zhu et al. 2006b). The innovativeness of an organizations is also related to the size of the organization. Larger organizations usually exchange a higher volume and amount of invoices (Zhu et al. 2006a; Hong and Zhu 2006; Penttinen et al. 2009) which permits consequently higher investment possibilities for innovations. In addition, smaller organizations concentrate more on the operative business period and are often not familiar with XML data. This means that they are unable to evaluate the long-term perspectives and the long-term benefits they could achieve from an adoption (Chau and Hui 2001; Kuan and Chau 2001). The innovativeness of an organizations hence plays a crucial role in the decision to adopt an XML-based invoice standard.

Furthermore, the organization should demonstrate a technology readiness to be able to process the invoices and to initiate the new business process within the organization (Zhu et al. 2006b; Venkatesh and Bala 2012). A lot of non-adopter organizations expect a negative cost-benefit relation due to the amount of effort required and the high financial investments necessary to set up a new or adjusted system (Kuehne et al. 2017). The benefits are not rated high enough to cover the expected efforts and costs (Hong and Zhu 2006; Haag et al. 2013). Many organizations are investing considerable efforts to modify their established business processes and revise human responsibilities to adopt new technologies (Kuan and Chau 2001; Zhu et al. 2006a; Haag et al. 2013). Some other organizations think differently. These are willing to invest effort and financial resources to satisfy customer needs, to be innovative and competitive and to take advantage of the benefits of an automated invoice exchange (Hong and Zhu 2006; Penttinen et al. 2009).

In addition, the selected invoice standard should fit well with existing work processes and the conversion of currently-used invoices (a different electronic standard or even paper invoices) to an XML-based invoice standard should be possible (Venkatesh and Bala 2012; Kuehne et al. 2015; Kuehne et al. 2017). A significant driver for an adoption is the need to rethink existing internal processes. If organizations have no internal reasons to modify processes because their invoice processes run well and their evaluation of the perceived benefits are too low, they show no readiness to adopt a new XML-based standard (Zhu et al. 2006b; Penttinen and Tuunainen 2011; Haag et al. 2013). Organizations wishing to strengthen their competitiveness or improve their relationships to business partners in order to achieve the status of a modern digital business or organizations that are pressurized by management on the grounds of inefficient business processes are more likely to adopt XML-based invoice standards (Cragg and King 1993; Hernandez-Ortega and Jimenez-Martinez 2013). An adoption depends on the available internal technical expertise of an organization, e.g., competence in IT and relevant accounting systems or prior experience with related XML-based business processes (Chau and Tam 1997; Zhu et al. 2003; Kim and Lee 2008). In particular, organizations which deploy a host of IT systems and engage in e-business are in command of the technical competence necessary to process XML-based invoice standards. Such organizations will be more likely to adopt a new standard than organizations which do not work with IT at all (Kuan and Chau 2001; Haag et al. 2013).

All the necessary technical requirements and circumstances are covered by the term organizational readiness. In combination with organizational innovativeness, organizational readiness represents a strong adoption determinants of an XML-based invoice standard. This leads us to our second hypothesis, namely,

H2: High organizational readiness and innovativeness have a significant positive influence on the adoption of XML-based invoice standards.

External Task Environment

The external task environment of an organization plays a major role regarding the adoption of innovative technologies such as XML-based invoice standards (Tornatzky and Fleischer 1990). Thus it is essential when measuring the adoption determinants from a dyadic perspective (Venkatesh and Bala 2012; Kreuzer et al. 2014). Hence, our last suggestion describes the entire external situation, as influenced by the business partners. One effect that has often been discussed in the literature is the network effect. With a sufficiently high number of business partners already using an XML-based invoice standard, other organizations are subject to coercive pressure to also adopt this standard (Zhu et al. 2003; Kim and Lee 2008; Haag et al. 2013; Kreuzer 2017). As long as organizations do not receive enough requests from business partners for an adoption, they will not consider an implementation (Edelmann and Sintonen 2006; Kuehne et al. 2015; Kuehne et al. 2017). Not every organization if following when several business partners implement an XML-based invoice standard but competitive pressure can significant influence the adoption decision. Pressure from suppliers and as well customers is found to be a significant driver of organizational adoption (Vankatesh and Bala 2012; Kreuzer 2017). Furthermore, not every organization that has already adopted or is willing to adopt an XML-based invoice standard limits its action to merely sending polite requests to their business partners. In some cases, organizations use their market power to force their business partners to use the same standard. If no agreement is reached on this issue, they may well threaten to terminate the business relationship (Premkumar et al. 1997; Venkatesh and Bala 2012; Kuehne et al. 2015; Kreuzer 2017).

Thus, the external factors such as business partners and their pressure is crucial for further adoption and leads us to our third hypothesis.

H3: The external task environment, as represented by network effects and competitive pressure, has a significant positive influence on the decision to adopt XML-based invoice standards.

Figure 2 illustrates our derived research model based on the TOE model. The arrows of each element indicate the influence of every hypothesis.

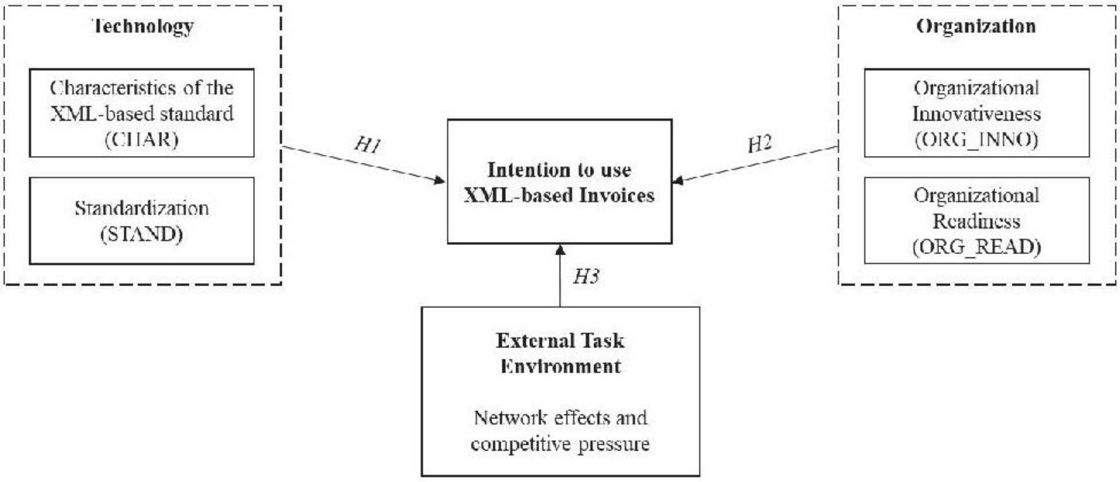


Figure 2: TOE - Research Model

3.2 Empirical Setting and Subjects

Our data was collected by means of an online survey. In order to assess the validity of our proposed research model, we surveyed employees in accounting and related departments in different countries who deal with the subject of e-invoices in their daily work or those who deal intensively with the subject in another context, e.g., in research. This set of users was therefore ideally suited for studying the adoption of XML-based invoice standards. Before deploying a main survey instrument, we initially conducted a prior qualitative study to collect qualitative feedback on our research model and on our measurement items. In order to assess the clarity and conciseness of the survey questions and establish content validity of the self-developed and adapted items, we consulted seven individuals to identify and rectify potential problems in the framing and phrasing of the survey questions. We collected their comments and opinions on the survey questions and used them to further improve the questionnaire regarding the phrasing and framing of the questions (Johnston and Warkentin 2010). Based on this procedure, we found preliminary evidence that the scales were reliable and valid.

As the final online survey was administered in German and English, we used a back-translation technique to check for translation bias. The original German instrument was translated into English for the international data collection and then back into German by another translator to ensure linguistic equivalence (Brislin 1970). We discussed wording differences, which were subsequently resolved by the translator. In this context, we reexamined the identified items and modified them to improve understandability and readability. The fact that the back-translated items corresponded to a high degree with the original English items, confirmed the relative lack of translation bias.

For the final study we used a simple random sample in order to obtain an unbiased random selection of employees. For this purpose, e-mail addresses and contact data were collected from international organization websites and social media profiles (e.g., Xing, LinkedIn) over a period of three months. Potential participants were contacted and the online survey was distributed. We included a broad range of industries and firms in different countries to maximize the generalizability of the findings. Our survey package consisted of a cover letter explaining the nature and purpose of this study and the importance of their participation. The cover letter also included an explanation of the data handling procedure. We then sent invitations to potential respondents who had not participated in the pilot study to make use of the main survey instrument. Of the distributed questionnaires to the participants in two waves (the survey was kept open for 90 days with a reminder sent to non-respondents after 14 days), 113 matched questionnaires were returned. We subsequently removed 20 replies from individuals who either did not complete the full survey or who stated that they were not at all familiar with the subject e-invoice. The participants came predominantly from Germany (69.9%) but also from the USA, Switzerland, Spain, Slovenia, the Netherlands, Luxembourg, Lithuania, Italy, France, Finland, Estonia, Canada, Belgium and Austria. The exact further sample demographic data are shown in Figure 3-5.

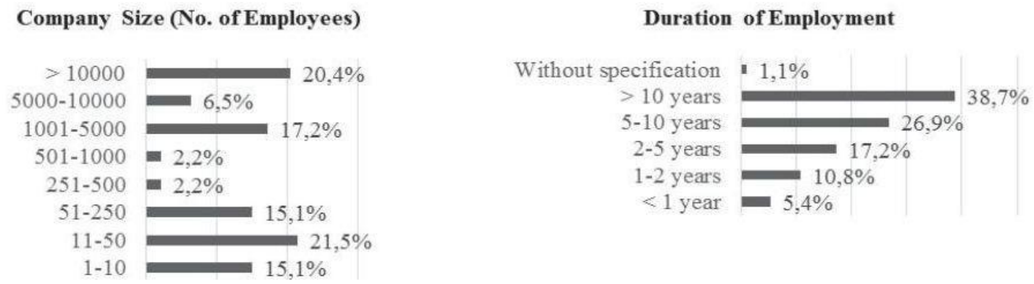


Figure 3: Company size and duration of employment

Figure 4: Participants position in the company

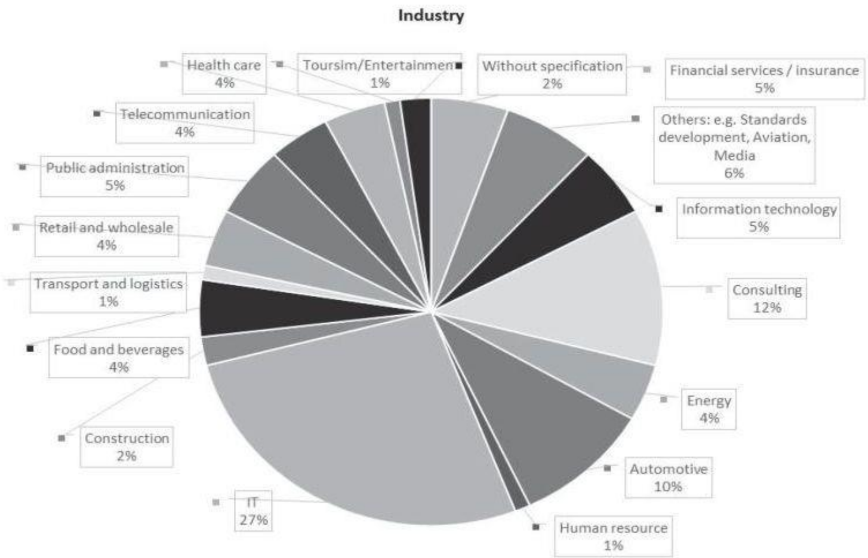


Figure 5: Industry of company

3.3 Measurement Instrument

We measured all constructs by scales drawn and used whenever possible from previously proven constructs relating to IT usage and adoption in order to modify them for our specific context with a special focus on e-invoices and the TOE framework. The measurement items for the constructs are listed in Appendix A2. The adoption of XML-based invoices was measured using a two-item scale that has been extensively validated in literature (Venkatesh and Davis 2000). The measurement instrument was adapted and adjusted to the specific context of XML-based invoices. The two items measured the intention and prediction to use XML-based invoices by the subjects in question, provided these can be processed in their organizations. Given the use of the hierarchical components model technology of type reflective-formative, the measurement instruments for the first-order constructs are described separately. The technology aspect covers standardization and XML-specific characteristics. The items we used for standardization are very specific to XML-based invoice adoption and describe the relatively easy standardization possibilities (integration into or supplementation of ERP-system/accounting software) and the possibility to create further business documents with the same standard foundation. These items, were hence measured on the basis of a previous qualitative study by Kuehne et al. (2015) and Kuehne et al. (2017). The XML-specific characteristics can be summarized by measuring the easy implementation of the XML-based invoice standard and by the higher productivity and efficiency resulting from its simplicity. Therefore, we adopt and adjust the items given by (Lian 2015) in his investigation of e-invoices.

The items for organizational innovativeness were developed based on studies on e-invoices and EDI as well as on a qualitative study (Kuehne et al. 2017). We adopted two items regarding monetary and technical resources based on the work of (Penttinen and Tuunainen 2011). The innovativeness of top management is covered by an item dealt with by Kim and Lee (2008). The size of the organization was considered by Zhu et al. (2006a) and is related to a sufficiently large number of invoices. As organizational readiness has already been considered and explained in many related studies, we were able to adopt and modify several items for our specific research model (Chen and Paulraj 2004; Grandon and Pearson 2004; Li and Lin 2006; Kim and Lee 2008; Penttinen and Tuunainen 2011).

The final aspect we deal with is the external task environment, which describes network effects and requests to adopt an XML-based invoice standard. We developed the related two items in accordance with various studies on e-invoices, EDI, and similarities (Chen and Paulraj 2004; Li and Lin 2006; Kim and Lee 2008; Penttinen and Tuunainen 2011). All of the above items were measured using a five-point Likert scale anchored between 'strongly agree' to 'strongly disagree'.

4 DATA ANALYSIS AND ASSESSMENT OF MEASUREMENT

We applied PLS-SEM to test our research model. Depending on the aim of the researcher in question, PLS path modeling can either be used for prediction or explanation purposes (Henseler et al. 2016). Our unit of analysis focuses on confirmatory/explanatory modeling. We hence used the proposed PLS approach, which provides a broad scope and flexibility for practice and theory (Richter et al. 2016). We carried out measurement validation and model testing be means of a two-step approach with the software SmartPLS/-Version 3.2.7 (Ringle et al. 2015). The two-step approach involves the structural model and a separate assessment of the measurement models (Hair et al. 2016). In order to analyze the two latent constructs technology and organization which are modeled as hierarchical component models of reflective-formative type we applied the repeated indicator approach (Cadogan and Lee 2013; Becker et al. 2012). The advantage of this approach is that it considers both the higher-order and lower-order components as well as the entire nomological network. Instead of estimating all dimensions separately, this approach permits the estimation of all constructs simultaneously (Lowry and Gaskin 2014; Becker et al. 2012). Before testing the hypotheses we evaluated the validity and reliability of the construct measures. Because reliability represents a necessary condition for validity, this aspect was checked first. In order to ensure indicator reliability we examined the loadings of each indicator relative to their respective underlying construct (compare Table 1).

Table 1: Factor Loadings and Cross Loadings

	CHAR	STAND	ETE	INT_USE	ORG_INNO	ORG_READ
CHAR_6	**0.945*** **	0.528	0.290	0.469	0.387	0.237
CHAR_7	**0.950*** **	0.592	0.380	0.574	0.448	0.339
STAND_1	0.567	**0.903*** **	0.299	0.477	0.326	0.243
STAND_6	0.490	**0.887*** **	0.396	0.436	0.342	0.200
ETE_1	0.049	0.180	**0.673*** **	0.360	0.413	0.371
ETE_2	0.189	0.224	**0.826*** **	0.503	0.664	0.692
ETE_4	0.311	0.136	**0.756*** **	0.387	0.563	0.481
ETE_7	0.434	0.509	**0.754*** **	0.627	0.522	0.426
INT_USE_1	0.531	0.500	0.628	**0.967*** **	0.648	0.556
INT_USE_2	0.538	0.488	0.631	**0.968*** **	0.676	0.560
ORG_INNO_1	0.435	0.384	0.596	0.648	**0.882*** **	0.741
ORG_INNO_2	0.286	0.210	0.561	0.487	**0.812*** **	0.790
ORG_INNO_3	0.491	0.382	0.640	0.697	**0.790*** **	0.591
ORG_INNO_4	0.286	0.247	0.604	0.430	**0.818*** **	0.548
ORG_INNO_5	0.342	0.328	0.615	0.583	**0.859*** **	0.634
ORG_READ_1	0.151	0.154	0.521	0.393	0.605	**0.897*** **
ORG_READ_2	0.217	0.169	0.538	0.464	0.710	**0.933*** **
ORG_READ_4	0.433	0.348	0.636	0.671	0.665	**0.730*** **

ORG_READ_8	0.242	0.176	0.530	0.431	0.715	**0.810*** **

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Notes: CHAR = Characteristics; STAND = Standardization; ETE = External Task Environment; INT_USE = Intention to Use; ORG_INNO = Organizational Innovativeness; ORG_READ = Organizational Readiness

Before testing the hypotheses we evaluated the validity and reliability of the construct measures. Because reliability represents a necessary condition for validity, this aspect was checked first. We assessed the reflective measurement models regarding their validity and internal consistency reliability. Firstly, we considered the composite reliability as a means of assessing the internal consistency reliability (ICR). Fornell and Larcker (1981) argue that the use of the composite reliability as an assessment measure is superior to Cronbach's alpha because it uses the actual item loadings obtained within the nomological network to calculate the ICR. The traditional criterion for internal consistency (Cronbach's Alpha) may be considered as lower reliability boundary (Sijtsma 2009). According to Henseler et al. (2016), the reliability of each construct should be sufficiently high with values of 0.70 or more (Diamantopolous et al. 2008). In our case, the values of all reflective constructs are above the threshold value (Table 2). In accordance with Fornell and Larcker (1981), we assessed convergent validity using the following three criteria: (1) significant factor loadings at $p < 0.01$ (see Table 2); (2) Cronbach's Alpha values of each construct above 0.70, assuring construct validity – Cronbach`s Alpha values are well above the threshold value mentioned previously. Standardization has the smallest Cronbach`s Alpha value of 0.752, while the construct intention to use has the highest value of 0.932; (3) the average variance extracted (AVE). The AVE values for all reflective constructs are well above the required minimum level of 0.50. Thus, the measures of the reflective constructs have high levels of convergent validity (Table 2).

In the research literature, many different approaches and criteria may be found which have been shown to be informative regarding discriminant validity, e.g. the Fornell-Larcker criterion, the examination of cross-loadings, and the HTMT (heterotrait-monotrait ratio of correlations) (Henseler et al. 2015b; Henseler et al. 2016; Ahrholdt et al. 2016; Voorhees et al. 2016). In our study, discriminant validity is determined on the basis of the HTMT ratio of correlations (Henseler et al. 2015b), because traditional criteria are insufficiently sensitive to detect problems with discriminant validity and the HTMT provides the best assessment of discriminant validity (Shafaei and Razak 2015; Voorhees et al. 2016). This approach, which is based on the multitrait-multimethod matrix, is referred to as the heterotrait-monotrait ratio of correlations. The HTMT is the average of the heterotrait-heteromethod correlations relative to the average of the monotrait-heteromethod correlations and represents an upper boundary for the factor correlation (Henseler et al. 2015b; Henseler et al. 2015a). The HTMT should be less than unity in order to clearly discriminate between two or more factors (Henseler et al. 2016). In our model the values for all constructs except the second-order constructs range from 0.37 to 0.87. Both the HTMT and the Fornell-Larcker criterion show evidence of discriminant validity (Henseler et al. 2015b). We thus conclude that discriminant validity has been established. Regarding second-order constructs, discriminant validity is not necessarily a requirement, because all the lower constructs are assumed to belong to one overarching concept.

Table 2: Validity and reliability of the reflective constructs

Construct	**Construct indicator**	**Convergent Validity**			**Internal Consistency Reliability**		**Discriminant Validity**
		Loadings	**t-statistics**	**AVE** (> 0.50)	**Composite Reliability** (> 0.70)	**Cronbach`s Alpha** (> 0.60)	**HTMT (confidence interval does not include 1)**
ETE	ETE_1	0.673	5.983	0.569	0.840	0.754	Yes
	ETE_2	0.826	19.374				
	ETE_4	0.756	11.828				
	ETE_7	0.754	12.658				
INT_USE	INT_USE_1	0.967	77.330	0.937	0.967	0.932	Yes
	INT_USE_2	0.968	91.648				
ORG_READ	ORG_READ_1	0.897	29.033	0.715	0.909	0.863	Yes
	ORG_READ_2	0.933	55.964				
	ORG_READ_4	0.730	9.293				
	ORG_READ_8	0.810	15.236				
ORG_INNO	ORG_INNO_1	0.882	28.331	0.694	0.919	0.889	Yes
	ORG_INNO_2	0.812	16.030				
	ORG_INNO_3	0.790	12.473				
	ORG_INNO_4	0.818	17.234				
	ORG_INNO_5	0.859	20.851				
CHAR	CHAR_6	0.945	31.147	0.897	0.946	0.886	Yes
	CHAR_7	0.950	44.594				
STAND	STAND_1	0.903	31.195	0.801	0.890	0.752	
	STAND_6	0.887	20.052				

When using formative constructs, multicollinearity can prove problematic from an interpretational and methodological standpoint (Hair et al. 2016). For this reason, it is obligatory to test for multicollinearity at the indicator level. We therefore examined the multicollinearity between CHAR and STAND (the two dimensions of technology) as well as between ORG_INNO and ORG_READ (the two dimensions of organization). A related measure of collinearity is the variance inflation factor (VIF) (Hair et al. 2016). The VIF value, which is defined as the reciprocal of the tolerance, should not exceed a value of 5. A value of 5 or above indicates a potential collinearity problem (Hair et al. 2011; Hair et al. 2016). The fact that all VIF values are below this threshold in our study (1.254 to 2.764) indicates sufficient construct validity for our formative constructs. Figure 6 shows the PLS-SEM path coefficient estimates from the two-stage approach and their significance (Henseler et al. 2015a). Following this procedure, the analysis produced estimates of both the explained variance and path coefficients. As shown by the PLS results all of the three hypotheses (H1 – H3) were found to be significant (compare Table 3 and Figure 6). The path coefficients, *t*-statistics, and *p*-values are summarized in Table 3.

Table 3: Results of the tested hypotheses

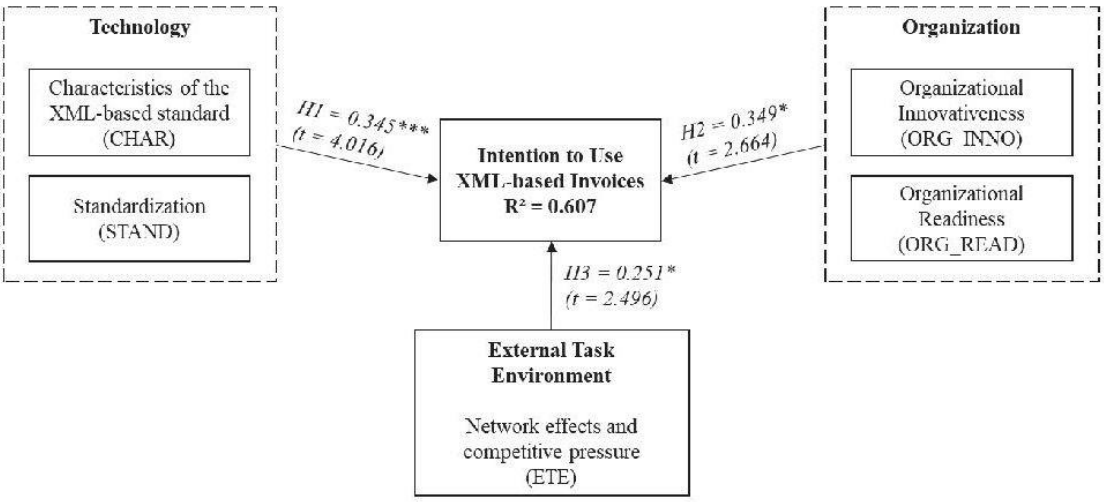
Tested hypothesis/path	ß	t-statistic	Support
H1. Technology → Intention to Use XML-based Invoices	0.345	4.016***	Yes
H2. Organization → Intention to Use XML-based Invoices	0.349	2.664*	Yes
H3. External Task Environment → Intention to Use XML-based Invoices	0.251	2.496*	Yes

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

5 RESULTS AND DISCUSSION

5.1 Testing the Structural Model

Figure 6 shows the model test results. Based on these results, preliminary clues regarding the tenability of our research hypotheses can be derived by inspecting the bivariate associations between the three independent variables and the intention to use XML-based invoice standards, which is a necessary prerequisite for a successful standard adoption. The analysis supported all three hypotheses. About 60% of the variance in the intention to use XML-based invoices is explained by our model.



* = $p < 0.5$, ** = $p < 0.01$, *** = $p < 0.001$

Note: Solid lines represent significant paths and dashed lines represent insignificant paths.

Figure 6: Results of Operational Model Testing

The final assessments address the effect size f^2. To evaluate whether the omitted constructs in our model are meaningful and have a substantive impact on the endogenous construct intention to use XML-based invoices as well as to check for practical significance we used f^2 as a measure of the effect size according to Cohen (1988). f^2 is an alternative measure for the substantial effect of exogenous latent variables on the latent endogenous variable. This measure provides information regarding the size of the effects, although it should be noted that a low f^2 does not necessarily imply an insignificant or unimportant effect (Chin et al. 2003). According to Cohen (1988), guidelines for assessing f^2 are the values of 0.02-0.14, 0.15-0.34 and above 0.35, representing small, medium, and large effects of the exogenous latent variable, respectively (Hair et al. 2016). The effect size of the construct 'technology' on the variable intention to use XML-based invoice standards should be evaluated as being prominent (see Table 4). The effects of the constructs 'organization' and 'external task environment' should be evaluated as being small. Effect sizes have the advantage that their evaluation permits a direct comparison between different measured quantities and that they are independent of the sample size (Selya et al. 2012).

Table 4: Effect Size

Latent variable being explained (endogenous)	Explanatory latent variable (exogenous)	f^2
INT_USE	ETE	0.07
	ORG	0.14
	TECH	0.24

Note: Cohen's f^2-statistics = [R^2incl. - R^2 excl.] / [1-R^2incl.] (1988); $f^2 \geq$ 0.02, 0.15 and 0.35 correspond to small, medium, and large effect, respectively; ETE = External Task Environment; ORG = Organization; TECH = Technology; INT_USE = Intention to Use

5.2 Implications for Research and Practice

We strongly encourage research which investigates the influence of technological, organizational and external adoption determinants on XML-based invoice standards from a dyadic perspective. In the context of digitalization and globalization, conditions and circumstances are constantly changing and therefore the adoption of an XML-based invoice standard will be contingent upon a variety of factors. Our study has shown that technological and organizational aspects highly influence the success of adopting XML-based invoices. Organizational innovativeness and readiness, including sufficient monetary and technical resources as well as the conviction of top management that an XML-based invoice exchange makes sense, are thereby of particular relevance. As already verified in related studies, network effects and competitive pressure play a crucial role (Zhu et al. 2003; Haag et al. 2013; Kreuzer 2017). One current aspect which impacts the network effects and competitive pressure even more is the obligation in Europe to only accept XML-based invoices for public procurement by 2020 at the latest (directive 2014/55/EU and norm EN 16931-1:2017).

Our model was found to be a valuable tool, the results of which indicate that, similar to other IT adoptions, decisions to adopt XML-based invoice standards are not primarily based on the characteristics of the technology itself but are also dependent on other determinants such as internal knowledge and expertise or a sufficiently large number of exchanged invoices. It might be helpful to test our theoretical research model in different contexts and consider a case example to further validate the model and gain more detailed insights and knowledge regarding this specific research area.

By way of our TOE research model, we contribute to IS research by identifying the most important determinants for the adoption of XML-based invoices and their respective impacts from a dyadic perspective. The TOE model is of great benefit for organizing research findings and serves as a basis for developing further and larger studies on the adoption of XML-based invoice standards. We contribute to a very specific research area which is rarely investigated and discussed in current research but very import in practice due to law restrictions and growing digitalization of business documents. The overall XML-based invoice standard adoption rate can be increased and the implementation can be supported by theoretical models and frameworks.

The confirmed influences of technological and organizational aspects also contribute to business practice because they support the self-assessment of organizations. Our findings assist organizations during the introduction phase of their XML-based invoice exchange. XML-specific characteristics combined with the ability to standardize the format also help to set up a new e-invoicing standard. Employees must be prepared and trained, and legal compliance must be secured before implementing an XML-based invoice standard. Organizations that wish to implement e-invoice exchange should first observe the market situation and current trends before making a decision. It is also important to evaluate the internal situation of an organization because organizations that already use digital business documents and appropriate software can expect less effort and lower costs for a modification and are therefore more likely to adopt an XML-based invoice standard. Prior experiences from related IT projects and further e-invoice formats complement the internal organizational aspects and are significant factors for a successful adoption. However, the greatest advantage of the adoption of an XML-based invoice standard is not only a reduction in costs but also an enhancement of transparency and traceability. Organizations must consider and quantify these advantages precisely in order to calculate a cost-benefit relation, which should be positive for a successful implementation. Organizations that have well-established invoice processes (either electronic or paper-based) are unlikely to adopt an XML-based invoice standard, regardless of its potential. Such organizations do not usually have to rethink and modify existing processes and are thus hesitant to consider additional options for their invoice exchange. As also confirmed by related studies (Hong and Zhu 2006; Penttinen and Tuunainen 2011; Venkatesh and Bala 2012; Haag et al. 2013; Chen et al. 2015), these organizations perceive low benefits and hence do not demonstrate an overall willingness and readiness to adopt XML-based invoice standards. However, external factors are might encourage those organizations since we found a significant influence of business partners pressure. The more business partners use XML-based invoices and request for an exchange, the more organizations will follow (network effect). Support for the implementation of an XML-based invoice standard from business partners and third parties might be helpful as well.

In addition, our research model can be used by policy-makers, public authorities and standard developers to support XML-based invoice standard adoption through the knowledge of adoption determinants for both business parties (sender and receiver). This can help to overcome critical factors, e.g., by developing and providing software which may be integrated into or added to current accounting software and ERP-systems.

6 LIMITATIONS AND FURTHER RESEARCH

As in the case of most empirical research studies, our study is not free of limitations. We are of the opinion that these limitations will open up new possibilities for fruitful further research. Firstly, additional research is desirable which examines the relations between additional potential determinants and XML-based invoice standard adoption criteria. We have tried to minimize this aspect by not only including selected factors of the TOE model but also the results of other related studies. The second limitation is related to the size of our survey population. Although we made efforts to recruit participants who are familiar with the topic of XML-based invoices at all levels of experience and expertise, the respondents who took part in the survey may not be representative. Additionally, while we primarily recruited respondents from Germany organizations, we had no way of ensuring that survey respondents were not based in countries with different work and organizational cultures. In view of the latter, scholars should be cautious when generalizing the results of the study.

7 CONCLUSIONS AND OUTLOOK

Although recent studies focus on the adoption of e-invoices in general, the role of a uniform XML-based invoice standard, a dyadic perspective and the factors which influence its adoption have received little attention in academic research. Our original premise was to answer the research question: How do technological, organizational and environmental factors influence the adoption of an XML-based invoice standard? We developed and tested a nomological model of the relationships among technology, organization, external task environment, and the intention to use XML-based invoices. We found that the technological context of an organization, as described by XML-specific characteristics and the standardization potential, has the strongest influence on the adoption of an XML-based invoice standard. The simplicity of XML means that the overall adoption rate can be increased. The second significant aspect is the organizational context, which covers organizational readiness and innovativeness. The greater these aspects, the more the adoption rate for XML-based invoice standards increases. The third significant aspect is the external task environment, which is especially important from a dyadic perspective since business partners using the same XML-based invoice standard are needed to successfully exchange them.

By identifying the underlying mechanisms and boundary conditions of XML-based invoice standards in a global international context and by investigating the factors which influence the adoption of an XML-based invoice standard, our study serves as a basis for future investigations in this important and growing research field. By empirically validating the relationship between the three aspects technology, organization, and external task environment, our study demonstrates the importance of organizational, technological, and external factors for improving and increasing the adoption of XML-based invoice standards. The results provide decision-makers and standard developers with valuable insights into the determinants for an XML-based invoice standard adoption.

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A1. APPENDIX

Table A1. E-invoice standards

Flow sheet	Standard	Subset/ Type	Characteristics	Advantages and Disadvantages
		EDIFACT	supposed for use in both national and international applications	+ globally-used standard + not dependent on the type of business or industry - complex structure - not easy to read and understand for non-experts
		EANCOM	Leading standard for EDI worldwide; used in retail industry	+ widespread - mainly designed for implementation within supply chains, not very flexible
		EDITRANS	Designed for transport and logistics industry	- industry-specific
		VDA (4938) (ODETTE)	Designed for automotive industry	- industry-specific
	EDIFACT	EDIBOB	Designed for construction industry	- industry-specific
		EDIFICE	Designed for electronic, software and telecommunications industry; subset of EDIFACT	+ widespread + international focus - industry-specific
		EDIWHEEL	Designed for tire industry	+ supports different type of standards, can be formatted for use with XML / HTTP - mainly used in European countries
UN/ CEFACT		RINET	Designed for reinsurance industry	- industry-specific
		ETIS	Designed for telecommunications industry	- industry-specific
		LITIG LEDES	Designed for legal industry	- industry-specific
	UBL	UBL/ XML	Universal Business Language (UBL) developed with the participation of various types of industries and businesses	+ free of charge + suitable for a variety of industries + focuses on purchase orders and invoices + OCR functionality - XML is not self-describing - Modelers might choose different names for the same component in XML
		NESUBL/ XML	Subset of UBL, developed by representatives of Northern European countries; focuses on the definition of business processes	+ avoids conflicting interpretation + can be modified for country-specific needs - only used in member states
	CII	XML	Globally-used, general standard for invoicing processes and document exchange	+ market adoption + stable + independent of industry and business processes + suitable for SMEs - general approach, needs to be further specified in most cases
ANSI	ANSI X12	XML	Predominant in North America	+ suitable for many businesses such as health care, insurance, government and transportation - mainly used in North America only
OASIS	ebXML	XML	Globally-used standard collection for invoicing processes and document exchange	+ market adoption + stable + independent of industry and business processes + suitable for SMEs - no syntax for European invoices
ISO	ISO	XML/ISO	Common standard for the financial industry (e-finance)	+ well-established - industry-specific
		Rosetta Net PIPs /XML	Aims to improve supply-chain transactions by establishing a standard between business partners; focus on electronic and IT industry	+ freely available + enables users to exchange documents between disparate systems - high implementation and adoption costs
GS1 US	Rosetta Net PIPs	PIDX/XML	Based upon RosenettaNet PIP standard; designed for use in the oil and gas industry	+ supported by a global organization + longtime experience by hundreds of companies - high implementation and adoption costs
		CIDX/ XML	Based upon RosenettaNet PIP standard; designed for use in the chemical industry	+ platform-independent + free of charge - only for very specific industries - high implementation and adoption costs
IAO/ UDE	BMEcat	XML	Published by more than 30 international companies; complementary to openTRANS	+ most common exchange standard for electronic product catalogues in German-speaking areas - focus on product catalogues and not really on invoices

	openTRANS	XML	Published by more than 30 international companies; complementary to BMEcat; similarities to EDIFACT standard	+ compatible with BMEcat + focus on exchange of electronic documents and invoices - market adoption is unknown, also only very little use outside Germany
SAP	IDoc	SAP	SAP standard document type to enable communication between different SAP applications and/or systems; can be read by all SAP applications	+ fast and easy use within SAP - limited, very technical monitoring within SAP, only IT experts can actually interpret potential errors
Country specific	EDI@Energy	EDIFACT	Initiative in Germany, designed for electricity and gas industry in Germany; subset of EDIFACT	- country-specific
	ZUGFeRD	XML	Initiative in Germany, designed for all types of business and industry with a focus on SMEs	+ platform-independent and industry-independent + easy to use - low level of dispersion so far
	Svefaktura	XML	Designed for the exchange of electronic documents with the Swedish government; mandatory for B2G	- country-specific
	Finvoic	XML	Used in a four-party model by local banks; B2B, B2C, B2G; national adoption and conformity with law	- country-specific
	ebInterface	XML	Austrian standard for electronic invoices; mandatory for B2G	- country-specific
	e-factura	XML	Spain's approach to establish e-invoices; mandatory for B2G	- country-specific
	Standaard Digitale Nota	XML		- country-specific
	EHF (Elektronisk handelsformat)	XML	Electronic invoicing mandatory in Norway for B2G	- country-specific
	SAF-T	XML	International standard for the exchange of electronic documents; managed by OECD; adopted by Portugal in 2008	+ international standard + can be personalized in some respects, e.g. legal tax components - market adoption so far only in Europe
	Tradacoms	EDIFACT	Originally developed as an EDIFACT subset; adopted by UK retail industry	+ Based upon international standard - Technical development was terminated in 1995, yet support can be bought from individual service companies
	eFactura	XML	Electronic invoicing in Argentina, was already mandatory for few types of industries; nowadays mandatory for companies that deal with VAT related invoices	- country-specific
	Nota Fiscal Electronic (NF-e)	XML	Process in Brazil to electronically validate invoices by the Brazilian tax authority	- country-specific
	Electronic Tax Document (DTE)	XML	Chile's process for electronic invoicing based upon XML document type	- country-specific
	Comprobante Fiscal Digital por Internet (CFDI)	XML	Mexico's standard for electronic invoicing which is mandatory for companies above a certain revenue level	- country-specific
	Dirección General Impositiva (DGI)	XML	Uruguay's process for creating and electronically signing invoices in XML format; mandatory for businesses above a certain revenue level	- country-specific
	OIOUBL (OIOXML)	XML	Mandatory for B2G in Denmark	- country-specific

A2. APPENDIX

Table A2. Survey Instrument – Measurement Items

Construct		Measurement Items
Technology	Standardization	Standardized billing software or integration possibilities of ERP-systems for XML-based invoice standards are beneficial for its utilization.
		The adoption of the XML-based invoice standard to additional business documents (e.g. order confirmation) is beneficial.
	Characteristics	XML-based invoice standards make transactions more productive.
		XML-based invoice standards make transactions more efficient.
Organization	Organizational Innovativeness	We have the necessary monetary resources to implement XML-based invoice standards.
		We have the necessary technical resources to implement XML-based invoice standards.
		Our top management is ready to invest in the implementation of XML-based invoices.
		We process a sufficiently large number of invoices to justify the implementation of XML-based invoice standards.
		Our firm size is large enough for an adoption of XML-based invoice standards.
	Organizational Readiness	We have internal expertise to implement XML-based invoice standards.
		We have the skills and knowledge for the utilization of XML-based invoice standards.
		XML-based invoice standards will fit well into our existing work processes.
		We have the technological resources to adopt XML-based invoice standards.
External Task Environment		A sufficient large number of our business partner using XML-based invoice standards is beneficial for its adoption.
		We have received requests to adopt XML-based invoice standards.
Intention to Use		Assuming that XML-based invoices can be processed in my company, I intend to use the invoice standard.
		Given that XML-based invoices can be processed in my company, I predict that I would use the invoice standard.

A.4 Research article #3: Without a ride in car country – A comparison of carless households in Germany and California

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WITHOUT A RIDE IN CAR COUNTRY

A COMPARISON OF CARLESS HOUSEHOLDS IN GERMANY AND CALIFORNIA

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ABSTRACT

One approach to making transportation more sustainable is to transition away from a car-oriented society. Unfortunately, our understanding of the factors that prompt households to voluntarily forgo their motor vehicles is limited. The 2008 Mobility in Germany (MiD) and the 2012 California Household Travel Survey (CHTS) provide an opportunity to start filling this gap by teasing out what built environment and socio-economic variables impact the likelihood that a household is carless (voluntarily or not) in Germany and in California, two car-dependent societies with different carless rates. Results from our generalized structural equation models show that in both Germany and California, households who reside in denser neighborhoods, closer to transit stations, and who have a lower income or fewer children, are more likely to be voluntarily carless. However, households with more education are more likely to be voluntarily carless in Germany, whereas the reverse is true in California. Moreover, employment density and public transit have a higher impact on voluntary carlessness in Germany than in California. Our results also show that different socio-economic groups have substantially different residential location preferences in Germany and in California. These differences may be explained by cultural preferences, historical differences in land use and transportation policies, and by the higher cost of owning a motor vehicle in Germany.

Keywords: voluntarily carless household; built environment; generalized structural equation modeling; Germany; California.

HIGHLIGHTS

- We compare carless households in Germany & California, two car-dependent societies
- We estimate generalized structural equations models on the 2012 CHTS and 2008 MiD
- Educated households are more likely to be voluntarily carless in Germany, not in CA
- Employment density has a higher impact in Germany than in CA
- To decrease car dependency, CA also needs to adjust the cost of driving

1 INTRODUCTION

A number of policies have been enacted to reduce greenhouse gas (GHG) emissions and air pollution from transportation such as particulate matter, ozone, and smog-forming pollutants, which cause premature deaths, trigger or worsen respiratory ailments like asthma, and increase the risk of cancer (UCS, n.d.). These policies include mandating fuel efficiency improvements, requiring cleaner fuels, promoting alternative fuel vehicles (e.g., electric or fuel cell vehicles), incentivizing higher vehicle occupancy, or encouraging people to forgo motor vehicles in favor of transit, biking, and walking. France and Great Britain recently pledged to ban the sale of new diesel and gasoline cars by 2040 (Castle, 2017). However, relatively little progress has been made to-date to transition away from a car-oriented society. In this context, the purpose of this paper is to conduct a comparative analysis of carless households in Germany and California, two car-dependent societies with different urban forms and transport policies, to elicit what socio-economic and built-environment factors can entice households to become voluntarily carless. Understanding these factors could help policymakers formulate policies to reduce our dependency on motor vehicles.

Germany and California have much in common when it comes to motor vehicles. Indeed, they both have vast road networks (Statistisches Landesamt Baden-Württemberg, 2016; Caltrans, 2014), with a high motor vehicle ownership rate, and a similar percentage of licensed drivers (BMVI, 2017; FHWA, 2017). Overall, both Germany (Flanagan, 2017) and California (Romero, 2014) had love affairs with cars, which have now soured.

Another similarity is that both Germany and California are environmental leaders, respectively in the European Union and in the United States, and their populations have similar attitudes toward the environment (Dallinger *et al.*, 2013). For example, Germany has committed to cutting its emissions of GHG by 55% by 2030, compared to 1990 levels, which exceeds the 40% target cut by 2030 for the European Union as a whole (Appunn, 2017).

California's GHG targets are not quite as ambitious - Executive order B-30-15 from April 29, 2015, requires a 40% cut in greenhouse gas emissions below 1990 levels by 2030 (Office of Governor E. G. Brown, 2015) –, but they compare favorably with U.S. targets of cutting GHG emissions by 6% to 12% below 1990 levels excluding land use, land use change, and forestry (Climate Action Tracker, 2017).

In spite of all these similarities, the percentage of carless households is substantially higher in Germany, where they represented 13.4% of all German households in 2016 (Statista, 2017), versus only approximately 9% of California households (2012 CHTS). One of our goals here is to understand this difference.

Our comparison of German and Californian carless households is possible thanks to the availability of the 2008 Mobility in Germany (MiD) survey and the 2012 California Household Travel Survey (CHTS). These two surveys asked a number of similar questions, and collected a wide range of socio-economic and built environment variables. Most importantly, both asked carless households why they do not own a motor vehicle, which enables us to distinguish between voluntarily and involuntarily carless households.

In Section 2, we review selected papers to inform our selection of explanatory variables and our methodology. In Section 3, we document our data sources and our variables, and justify our classification of carless households. Our generalized structural equations models are described in Section 4. In Section 5, we contrast our results for Germany and California. Finally, in Section 6 we discuss some implications of our findings, outline some limitations, and propose some avenues for future research.

2 LITERATURE REVIEW

2.1 Studies of Carless Households in Europe and in North America

Although a number of scholarly papers analyze car ownership, few have investigated carlessness. We found only three published studies that focus on Europe: one in Great Britain (Bromley and Thomas, 1992) and two in Austria (Ornetzeder *et al.*, 2008; Sattlegger and Rau, 2016). Bromley and Thomas (1992) point out that carless households have to rely on local stores, which are more expensive, as they are unable to visit newer, larger shops that offer cheaper and more diverse goods. Ornetzeder *et al.* (2008) find that residents of car-free communities may have only slightly lower emissions than comparable motorized households partly because of CO_2 emissions due to air transport. Sattlegger and Rau (2016) conclude that in order for a household to successfully make the transition away from cars, alternative transportation modes should be available to all family members and carless mobility should be socially acceptable.

Carless households in the United States have not attracted much more attention from academics. In two early studies, Paaswell and Recker (1976) and Marquez (1980), set out to characterize carless individuals, the former in Buffalo, New York, and the latter in Los Angeles County, California. More recently, Klein and Smart (2015) analyze the dynamics of carlessness in the U.S. using the Panel Study of Income Dynamics. While ~13% of U.S. families are carless in any given year, only 5% are carless over the longer term. As expected, poor families, immigrants, and people of color are much more likely to frequently transition in and out of car ownership than non-poor families, the US-born, and Whites.

Life stages and life cycle events have been shown to be important determinants of why households transition between one car and no car and vice versa. For example, after analyzing data from the UK Household Longitudinal Survey, Clark *et al.* (2016) report that changes in household composition, moving out of employment, a decrease in household income and residential relocation are strongly associated with losing ownership of a motor vehicle. In Halifax, Canada, after analyzing retrospective survey data, Khan and Habib (2016) conclude that a birth, member move-in, and the addition of a job in the household foster the acquisition of a motor vehicle, while the death of a household member, residential relocation, and the loss of a job prolong the duration of carlessness.

To our knowledge, Mitra and Saphores (2017) is the first U.S. study to contrast voluntarily and involuntarily carless households. Their analysis of the 2012 California Household Travel Survey shows that voluntarily carless households are more affluent and live in more walkable, more diverse areas, with better transit coverage than their involuntarily carless counterparts. Their results highlight the importance of land use diversity to help households voluntarily forgo their vehicles.

2.2 Car Ownership Studies in Europe and in North America

The car ownership literature is much richer than the literature on carless households so we focus on recent studies to identify suitable explanatory variables for our models.

2.2.1 Socio-economic/demographic characteristics

Both European and U.S. studies agree that car ownership increases with income (e.g., see Van Acker and Witlox, 2010; or Cao and Cao, 2014). Employment status (Dargay *et al.*, 2008; Prillwitz *et al.*, 2006) and the number of employed household members (Bhat and Guo, 2007) also help explain the number of household vehicles. More employed household members entails more non-discretionary trips and therefore more vehicles (Goetzke and Weinberger, 2012; Matas and Raymond, 2008; Maltha *et al.*, 2017).

In contrast, findings about age and generation effects are heterogeneous. In Europe, Dargay *et al.* (2008) conclude that age has a negative impact on car ownership based on an analysis of several European countries and Van Acker and Witlox (2010) confirm this result for Belgium. Matas and Raymond (2008) report that Spanish households whose head is over 65 (or under 25) tend to have fewer cars. However, Bhat and Guo (2007) conclude that the presence of seniors tends to increase household car ownership in the U.S. The presence of children is also related to more household cars likely because of the travel needs of children (Delbosc and Currie, 2012; Goetzke and Weinberger, 2012; Prillwitz *et al.*, 2006).

Gender differences are also of interest. According to Kuhnimhof *et al.* (2011), men have recently reduced their car ownership more than women among young adults, reducing the gender gap. However, both American and European studies agree that households headed by women tend to have fewer cars (Dargay and Hanly 2007; Cao and Cao, 2014).

Published studies also report that more education tends to trigger greater environmental awareness and a reduction in car ownership (Maltha *et al.*, 2017; Prillwitz *et al.*, 2006) as people shift to "greener" alternatives like carsharing and active modes like walking and biking (Sonneberg *et al.*, 2015).

2.2.2 Built environment characteristics

Built environment variables have been found useful to explain household car ownership in both Europe and North America (Table 1). Population density has frequently been used to explain car ownership levels, with similar findings in Europe and in the U.S. (Bhat and Guo, 2007; Dargay *et al.* 2008; Giuliano and Dargay, 2006). Other built environment variables matter as well. For example, in their study of car ownership in San Francisco, Bhat and Guo (2007) report that car ownership decreases with employment density. Likewise, Goetzke and Weinberger (2012), Maltas and Raymond (2008) and Woldeamanuel *et al.* (2009) find that car ownership is lower in high density and mixed-use areas.

Dwelling type has also received some attention. In their study of Great Britain and the U.S., Giuliano and Dargay (2006) report that households located in town/row houses or apartments are more likely to have fewer passenger vehicles. Conversely, Maltha *et al.* (2017) find that suburbanization increases the number of cars per household, and more generally households who live in single-family homes tend to own more passenger vehicles (Bhat and Guo, 2007; Goetzke and Weinberger, 2012).

Public transportation quality and accessibility have also been found to impact household car ownership (Delbosc and Currie, 2012; Lee and Senior, 2013) as households with few or no motor vehicles depend heavily on public transport to fulfill their mobility needs. In that context, a decrease in the distance to the closest station (Van Acker and Witlox, 2010; Woldeamanuel *et al.*, 2009) and improvements in the quality of public transportation (Matas and Raymond, 2008) significantly decrease the number of cars per household.

2.3 Comparative Studies on Car Ownership

The four cross national studies on car ownership we found helped us select variables that may influence households to be carless. These papers (lower part of Table 1) suggest that different factors matter in different countries.

In their comparison between the U.S. and Great Britain, Giuliano and Dargay (2006) find that income and density variables matter for explaining travel behavior and household car ownership. However, car ownership increases with the number of children in the U.S. but not in Great Britain. Likewise, Dargay *et al.* (2008) conclude that car ownership changes differently with age in different European countries: for elderly individuals, car ownership increases with age in the U.K., but decreases in Greece, France, and Portugal. According to Kuhnimhof *et al.* (2011), travel trends among young adults in Germany and Great Britain exhibit some similarities. However, whereas car ownership of the whole population keeps on increasing in France, Germany and Great Britain, it has been relatively constant and high in the U.S. (Kuhnimhof *et al.*, 2013).

In summary, carlessness has received little attention from transportation scholars. We therefore extended our review to the rich car ownership literature to identify potential explanatory variables. The four cross national studies discussed above were particularly helpful in that regard. However, our review did not turn up any cross-national investigation on what motivates people to voluntarily forgo their motor vehicles, which is our focus here.

3 DATA

Our German data are from the 2008 Mobility in Germany (MiD) survey and our California data come from the 2012 California Household Travel Survey (CHTS). Both surveys relied on stratified samples and weights to control for non-response bias and map respondents to their target populations. In addition, they asked a number of similar questions.

However, these two surveys also differ in important ways, which partly reflect different cultural and institutional realities. First, the processes used to draw the samples for these two surveys were different. The MiD relied on the German citizen registry (a government database with information about the dwellings of German residents) to draw a representative sample of the German population. In contrast, for the CHTS a stratified random sample was drawn from the list of all California residential addresses served by the U.S. postal service. To better target difficult-to-reach groups, it was supplemented with draws from listed working telephone numbers associated with a name and address.

Second, the MiD did not collect ethnicity information, even though Germany has a foreign population of more than 10 million (Statistisches Bundesamt, 2017). Unlike the CHTS, the 2008 MiD also does not give information about a "head of household".

Third, information about the location of MiD respondents is unavailable due to privacy concerns. This made it impossible to combine MiD data with external land use data for example but fortunately the MiD dataset came with some built environment variables that characterize the residential location of MiD respondents and their access to transit. For the 2012 CHTS, location information is available after signing a non-disclosure agreement, which allowed us to add to our dataset built environment variables from the U.S. census and from the Smart Location Database of the U.S. EPA.

Other notable differences are the ways information was collected and the size of the final datasets. After two pretests in December 2007 and in January 2008, the MiD study was commissioned by the Federal Ministry of Transport, Building and Urban Development and then conducted by the Institute for Applied Social Science and the Federal Ministry of Transport and Digital Infrastructure throughout 2008. The MiD consisted of a household interview followed by an interview of each household member (children under 10 years old were represented by another household member) to capture their travel behavior on a pre-selected day. Interviews were conducted by phone or in writing. The response rate was 20.9% and the final dataset contains data from 25,922 households. In addition, a regional spatial dataset was generated to measure land use around the residential location of respondents. Since the basic unit of our analyses is a household, we relied on data from the household interview combined with the regional dataset enabled by unique household IDs.

After a pretest in late fall 2011, the 2012 CHTS was administered in all 58 California counties between February 2012 and January 2013. Based on the methodology recommended by the Council of American Survey Research Organizations (CASRO), the CHTS main survey had a recruit response rate of 4.9%, which is in line with other household surveys that report CASRO rates. The final dataset includes data from 42,431 households. Participants were asked to provide personal and household information and to record their travel in a diary for a pre-assigned 24-hour period. Data were retrieved by phone, online, or by mail. In addition, 5,099 households had their travel information recorded by GPS.

As for all surveys with a substantial non-response rate, it is not possible to rule out that non-response bias may have affected our results, although extensive non-response tests were satisfactorily conducted for both the 2008 MiD (Clearing House Transport, 2012) and the 2012

CHTS (Caltrans, 2013).

3.1 Classification of Carless Households

Since our main goal in this paper is to elicit the determinants of carlessness in Germany and draw a comparison with California, we classified carless households into three groups: 1) voluntarily carless households, who freely choose to live without a car; 2) involuntarily carless households, who are forced to live without a car for economic or medical reasons; and 3) households who could not unambiguously be assigned to one of the other two groups. To classify households, we relied on answers to the survey questions that ask why a carless household does not have a motor vehicle (see notes below Table 2). We note that these questions were asked slightly differently in the CHTS and MiD surveys, which might affect the prevalence of voluntarily carless households and therefore our results.

We deemed that a carless household was voluntarily carless if the reasons for not having a motor vehicle were "no car necessary," and/or "voluntary choice" in the MiD, and "want to be without a car" and/or "concerned about impact on environment" in the CHTS, with no other reasons that could also imply that this choice was forced. Households who answered "too expensive," "health reason," or "age reasons" were deemed to the involuntarily carless provided they did not also select any of the reasons that define voluntarily carless households. All other carless households were deemed "unclassifiable". Table 2 summarizes the questions and the possible answers to the inquiry about why a household does not have a motor vehicle.

After excluding observations with missing data, our German sample has data from 21,302 households: 18,747 with at least one car and 2,555 without any (393 voluntarily, 1,731 involuntarily, 267 "unclassifiable" and 164 with motorbikes). After a similar clean-up process, our California sample includes 32,780 households: 30,811 with at least one car and 1,969 without any (302 voluntarily, 830 involuntarily, and 837 "unclassifiable"). For our analysis, we excluded carless households with motorbikes.

3.2 Explanatory Variables

Although both surveys had overlapping objectives, variables differ partly because of cultural, political, and built-environment differences. We therefore selected variables based on our literature review and on data availability in order to estimate similar models for Germany and California. We organized our explanatory variables into two sets: 1) built environment variables; and 2) socio-economic and demographic variables.

3.2.1 Built environment variables

As mentioned above, the only built environment variables available for Germany are the ones included in the MiD's additional regional dataset since residential location information is confidential. Unfortunately, these variables are available only at the municipality level, which may be problematic in large and heterogeneous cities. Moreover they come as intervals so for conciseness we created semi-continuous variables valued at their mid-point. Since we had location information for the CHTS dataset, we collected block group-level built environment data from the 2010 U.S. Census and from the EPA's Smart Location Database.

We included three density variables in our Germany and California models: population density, employment density, and car density. For our California model, density information comes from the 2010 U.S. Census. Car density is the number of cars per ten people. At the outset, we expected households who reside in areas with higher car densities to be less likely to be voluntarily carless and more likely to have cars. Please note that population density is measured at different scales in Germany (municipality level, with no possibility to use a different scale) and in California (block group where a respondent resides), so our data may appear to be biased (it is not) because our summary statistics show that the mean density for CHTS respondents is higher than for MiD respondents in our samples. Since Californians are concentrated along the coast and in a few inland areas, the mean block group density associated with CHTS respondents is higher than the California average (denser block groups are more likely to be in our sample because they contain more people) whereas the mean density of MiD respondents, which it is measured at the municipality level, is not similarly inflated. This effect is further amplified by the removal of observations with missing data as respondents with item non-responses seem more likely to live in lower density areas in California and in higher density municipalities in Germany.

To proxy transit service availability, we included the distances to the nearest bus and local transit (e.g., tram or train) stops for the MiD as carless households tend to rely on transit for their mobility needs. For California, we used the percentage of the regional population that could be accessed within 45 minutes by transit and/or walking. These data were extracted from the Smart Location Database of the U.S. EPA. We therefore expected a negative coefficient for our transit coefficient in the Germany model (as distance to the nearest bus and local transit stop increases we expect fewer voluntarily carless households) and a positive coefficient for the California model (transit becomes more attractive if it allows reaching a larger percentage of people within 45 minutes).

Previous studies (e.g., Van Acker and Witlox, 2010) indicate that dwelling type may be linked to vehicle ownership so we included in our models a variable that describes the percentage of 1 and 2 family houses around the dwelling of each respondent. We hypothesized that households who reside in an area with a higher percentage of 1 and 2 family houses are less likely to be voluntarily carless.

3.2.2 Socio-economic and demographic variables

One consistently important determinant of car ownership both in European and U.S. studies is household income (e.g., see Van Acker and Witlox, 2010; or Bhat and Guo, 2007). Household income is given as an interval in euros per month in the Germany dataset and in dollars per year in the California dataset. For simplicity, we created for each survey a continuous variable based on the midpoint of each income interval. Our datasets do not include any voluntarily carless household in the highest income category of either survey, which is open-ended.

A number of recent studies report generational effects, especially for Millennials (Kuhnimhof *et al.*, 2012; Buehler *et al.*, 2017), i.e., the first generation to come of age in the new millennium (Pew Research Center, 2017). To capture these effects, we created variables that reflect the number of household members in each generation. Following Klaffke (2014) and Fry (2015), we created the following groups, taking into account that the MiD was conducted in 2008 and that we only analyze adults: Millennials (or Y Generation), who were born between 1981 and 1995; Generation X, for people born between 1966 and 1980; Baby-Boomers, born between 1956 and 1965; Post-War generation, for people born between 1946 and 1955; and the Senior generation (born before 1946). This classification differs slightly for the U.S. where the Baby Boomers generation includes people born between 1946 and 1964, and older people are lumped into the Silent generation.

Our explanatory variables also include the number of children in a household with two count variables: 1) children up to five years old and, 2) children aged 6 to 17. Our initial hypothesis is that households with children are less likely to be voluntarily carless.

To capture possible gender effects, we created a variable that counts the number of adult females in a household for both datasets.

Since households with more workers need to undertake more non-discretionary trips, we hypothesized that they would be more likely to own a motor vehicle. We thus added to our models a count of the number of employed household members.

Another common variable in vehicle ownership studies is educational achievement. At the start of this study, we expected that more education would increase environmental awareness and motivate households to voluntarily forgo motor vehicles. We therefore created categorical variables for the different levels of education in each survey to reflect the education of the most highly educated adult in each household.

Supplementary Tables 1 and 2 display descriptive statistics for our model variables and provide the German translation of the education variables used in our Germany models.

4. METHODOLOGY

4.1 Conceptual Model

Figure 1 shows our conceptual framework. An arrow indicates a causal relationship. A variable is exogenous if it is determined outside of the model (arrows only depart from it) and it is endogenous otherwise (at least one arrow is directed toward it).

To establish causal relationships between built environment variables and car ownership status, and to properly quantify the magnitude of these relationships, it is important to account for residential self-selection (i.e., people choose where to live based on their travel needs and preferences (Mokhtarian and Cao, 2008; Schreiner, 2014). We therefore assumed that built environment variables around a dwelling are influenced by the socio-economic and demographic characteristics of its residents. In turn, household car ownership decisions are influenced by their socio-economic characteristics and by the surrounding built-environment. The error terms of our built environment variables are assumed to be correlated (as shown by double arrows on Figure 1) since they may share common unobserved variables.

To estimate our models, we relied on generalized structural equation modeling (GSEM) because it allows to easily represent endogenous relationships and it can handle non-continuous dependent variables (here, we have a binary dependent variable; see below), which structural equations modeling (SEM) cannot do (Rabe-Hesketh *et al.*, 2004).

4.2 Model Estimation

We estimated two GSEM models, where the dependent variable Y_i is defined by:

- Model I: Y_i =1 if a household is voluntarily carless and 0 if it owns at least one motor vehicle. The sample size is 19,140 households for Germany and 31,113 for California. Involuntarily and unclassified carless households were excluded; and
- Model II: Y_i =1 if a household is voluntarily carless and 0 if it is involuntarily carless. The sample size for the Germany and California models are 2,124 and 1,132 respectively. Unclassified carless households were excluded.

Our goal in the first model is to understand how voluntarily carless households differ from motorized households. The goal of the second model is to contrast voluntarily and involuntarily carless households. We estimated separate models for two reasons. First, tests of the independence of irrelevant alternatives (IIA) (Hausman-McFadden, 1984; Small-Hsiao, 1985) in a multinomial logit model with a structure similar to Equations 1 and (2a) below with voluntarily carless, involuntarily carless, and motorized households (but not unclassifiable households) showed that the IIA does not hold here. The second reason is simplicity because other common multinomial models are more difficult to interpret.

Our final model structure - a system of simultaneous equations - can be written:

$$\Pr(Y_i = 1 \mid \hat{\mathrm{V}}) = \frac{\exp(\hat{\mathrm{V}})}{1 + \exp(\hat{\mathrm{V}})}, \qquad (1)$$

where the following equations represent the causal paths shown on Figure 1:

$$\begin{cases} \mathbf{V} = \beta_{11}\mathbf{P} + \beta_{12}\mathbf{E} + \beta_{13}\mathbf{C} + \beta_{14}\mathbf{T} + \beta_{15}\mathbf{D} + \mathbf{X}_1\mathbf{\Gamma}_1 + \boldsymbol{\varepsilon}_1, & (2a) \\ \mathbf{P} = \mathbf{X}_2\mathbf{\Gamma}_2 + \boldsymbol{\varepsilon}_2, & (2b) \\ \mathbf{E} = \mathbf{X}_3\mathbf{\Gamma}_3 + \boldsymbol{\varepsilon}_3, & (2c) \\ \mathbf{C} = \mathbf{X}_4\mathbf{\Gamma}_4 + \boldsymbol{\varepsilon}_4, & (2d) \\ \mathbf{T} = \mathbf{X}_5\mathbf{\Gamma}_5 + \boldsymbol{\varepsilon}_5, & (2e) \\ \mathbf{H} = \mathbf{X}_6\mathbf{\Gamma}_6 + \boldsymbol{\varepsilon}_6. & (2f) \end{cases}$$

In the above:

- Y_i is a binary variable (see above for its definition for each model);
- **V** is an n×1 vector of latent variables that represents the potential that Y_i=1 for each household *i*, and $\hat{\mathbf{V}}$ is its estimated value from Equation (2a);
- **P**, **E**, **C**, **T**, and **H** are n×1 vectors. **P**, **E** and **C** are respectively population, employment, and car densities (**C** is not included in Model II because it does not help distinguish between voluntarily and involuntarily carless households). **T** represents transit availability. In the Germany model, it is captured by two variables: distances to the nearest bus stop and distance to the nearest local transit stop. In the California model it is the percentage of population accessible within 45 minutes by transit or walking. Finally, **H** is the percentage of 1 and 2 family houses in a neighborhood;
- $\mathbf{X}_k$, $k \in \{1,..,6\}$, is an $n \times p_k$ matrix of household variables;
- $\beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}$, and β_{15} are unknown model parameters that need to be estimated jointly with the $p_k \times 1$ vectors $\mathbf{\Gamma}_1$ to $\mathbf{\Gamma}_6$; and
- $\boldsymbol{\varepsilon}_1$ to $\boldsymbol{\varepsilon}_6$ are n×1 error vectors; $\boldsymbol{\varepsilon}_2$ - $\boldsymbol{\varepsilon}_6$ are assumed to be correlated with each other to reflect unobserved variables that may jointly impact built environment variables.

V, **P**, **E, C, T,** and **H** are endogenous variables, and the $\mathbf{X}_i$ matrices contain exogenous socio-economic and demographic variables. Equations (1) and (2a)-(2f) describe a recursive model with causality paths directed at car ownership, which guarantees that our model is well-identified (Kline, 2015).

To estimate model parameters, GSEM minimizes the difference between the sample covariance and the predicted model covariance (Bollen, 1989). To obtain our results, we used quasi-maximum likelihood with Stata's implementation of the Huber-White sandwich estimator (Greene, 2011). This approach relaxes the assumption that errors are identically and normally distributed, requiring only independence. It is a special case of the Generalized Method of Moments estimator, which is consistent and asymptotically normal (Greene, 2011). Assuming that our Germany and California samples are independent (which is not unreasonable since they were collected in two different countries), the asymptotic normality of model parameters enables us to test for the equality of model parameters β_{DE} and β_{CA} for similarly defined variables for Germany and California respectively, using the test statistic:

$$Z = \frac{\hat{\beta}_{DE} - \hat{\beta}_{CA}}{\sqrt{SE^2(\hat{\beta}_{DE}) + SE^2(\hat{\beta}_{CA})}}. \quad (3)$$

Under the null hypothesis H_0: $\beta_{DE} = \beta_{CA}$, (or $\leq$ or $\geq$), Z has (approximately) a standard normal distribution as the difference of two (asymptotically) normally distributed random variables.

An alternative would have been to pool the Germany and California datasets (as in Buehler, 2011) , but doing so would have required creating many interaction terms leading to a more complex model where multicollinearity may be present.

5. RESULTS AND DISCUSSION

We used Stata 14 to perform our statistical work. The variance inflation factors (VIF) for our explanatory variables are all under 10 so multicollinearity is not an issue. Common fit statistics developed for SEM are not available for GSEM, because they require that observed endogenous, observed exogenous, and latent endogenous variables be jointly normally distributed, which does not hold here since our dependent variable Y_i is binary (Rabe-Hesketh *et al.*, 2004).

GSEM decomposes the impacts of explanatory variables on dependent variable into direct, indirect and total effects. Direct effects quantify the impact of one variable on another without mediation. Here, direct effects refer to how socio-economic/demographic variables and built environment variables directly influence the probability that a household voluntarily does not own a motor vehicle. Indirect effects are mediated by at least one other variable; in our models, socio-economic variables impact the probability that a household is voluntarily carless via the built environment variables. Finally, total effects are the sum of direct and indirect effects (Bollen, 1989).

Tables 3 and 4 display direct, indirect, and total effects for the car ownership equation (Equation (1)) for Models I and II respectively. Since Equation (1) is a logit model, we report odds ratio with a superscript to refer to Model I or II and a subscript to distinguish between Germany (GER) and California (CA). Tables 5 and 6 display estimated model parameters for Equations (2a)-(2f) for Models I and II respectively.

5.1 Built Environment Variables

5.1.1 Model I: voluntarily carless vs. motorized households

Let us first examine the impact of the built-environment variables in Model I (Table 3). In line with previous studies (e.g., see Bhat and Guo, 2007; Dargay and Hanly, 2007), a higher population density leads to a higher likelihood of being voluntarily carless. We note that the odds ratio for Germany is higher (OR^{I}_{GER}=1.119*** and OR^{I}_{CA}=1.044***), and the difference between the two underlying coefficients is statistically significant. Employment density is associated with a higher likelihood to be voluntarily carless in Germany (OR^{I}_{GER}=1.221***), but it is not significant for California. Moreover, car density is important in both Germany and California as households who reside in neighborhoods with a higher car density are less likely to be voluntarily carless, especially in California (OR^{I}_{GER}=0.889*** vs. OR^{I}_{CA}=0.741***); the difference between the two underlying coefficients is again significant. Although housing type is significant, it has little practical importance because the corresponding odd ratios (OR^{I}_{GER}=0.992** and OR^{I}_{CA}=0.988***) are close to 1. In this case, the difference between the two coefficients is not statistically significant.

As expected, public transit matters: as the distance to the nearest local bus stop (OR^{I}_{GER}=0.852*) or to the nearest train/tram stop (OR^{I}_{GER}=0.898***) increases, the probability of being voluntarily carless drops in Germany. The transit variable in the California model is also significant (OR^{I}_{CA}=1.062***): as the percentage of population accessible by transit/walking within 45 minutes increases, so does the probability of being voluntarily carless. The impact of the California transit variable is relatively small given the scale we chose since the value of its odds ratio is close to 1. However, it cannot be compared with results from the Germany model because the transit variables in both models are completely different.

5.1.2 Model II: voluntarily carless vs. involuntarily carless households

Let us now contrast voluntarily and involuntarily carless households (Table 4). First, population density is significant neither for Germany nor for California. Employment density does not matter for California but it does for Germany, where higher employment density is associated with a higher likelihood of being voluntarily carless (OR^{II}_{GER}=1.240***). Housing type does not help explain whether households are carless voluntarily or not.

In the Germany model, the distance to the nearest bus stop is not significant but households who live farther away from the nearest train/tram stop are slightly less likely to be voluntarily carless (OR^{II}_{GER} =0.952**). In California, transit accessibility barely makes a dent in explaining why some carless households are so voluntarily (OR^{II}_{CA} =1.020**).

5.2 Socio-Economic and Demographic Variables

5.2.1 Model I: voluntarily carless vs. motorized households

Starting with direct effects (Columns 1 and 2 of Table 3), we see that the direct effect of household income is important in both Germany and California: higher income households are less likely to be voluntarily carless. This effect is larger in Germany (OR^{I}_{GER} =0.788***) than in California (OR^{I}_{CA} =0.986***).

Variables related to the presence of children in the household show mixed results. The number of children 5 and younger is not significant, but households with more children aged 6 to 17 are less likely to be voluntarily carless (OR^{I}_{GER} =0.654** and OR^{I}_{CA} =0.568***) possibly because of the trips these children need to attend various activities.

Generational effects are significant in the Germany model. German households with more Millennials are less likely to be voluntarily carless (OR^{I}_{GER}=0.313***). This result seems to contradict Kuhnimhof *et al.* (2012), who found a decreasing trend in car ownership among Millennials in Germany, but Model II (see below) shows that many Millennials are involuntarily carless. Other generation variables are also important: German households with more adults from any generation are less likely to be voluntarily carless. In California, only households with more Silent generation members are less likely to be voluntarily carless (OR^{I}_{CA}=0.723*) as variables for other generation are not significant.

In Germany, households with more female adults are more likely to be voluntarily carless (OR^{I}_{GER} =1.617***) but not in California. As expected, households with more employed members are less likely to be voluntarily carless in both Germany (OR^{I}_{GER} =0.595***) and California (OR^{I}_{CA} =0.572***).

Education has a different impact in Germany compared to California. In Germany, households with a secondary school degree are less likely to be voluntarily carless (OR^{I}_{GER} =0.769*) compared to the least educated households; otherwise education does not have direct effects. In California, however, an increase in educational achievement decreases the likelihood that a household is voluntarily carless.

Let us now consider indirect and total effects (Columns 3 to 6 of Table 3). In Germany, except for income and for the lowest level of education, indirect effects (Column 3) reinforce direct effects (column 1), i.e., odds ratios for direct and indirect effects for a variable are both smaller or both larger than 1. Hence, German households are significantly less likely to be voluntarily carless (and more likely to own a motor vehicle) if they have more children, more adults from any generation, and more employed members. Conversely, German households are more likely to be voluntarily carless if they are more highly educated.

Overall, total effects (Column 5) show that an increase in income, household size (children or adults from any generation), or in the number of people employed decreases the likelihood that a German household is voluntarily carless. Conversely, a higher number of adult females or a higher educational achievement has the opposite effect.

In California, indirect effects (Column 4) reinforce direct effects (Column 2) for income, the number of children between 6 and 17, the number of adult members except for Millennials, the number of females in the household, and all levels of education. Indirect effects mitigate direct effects only for the number of children 5 and younger, the number of Millennials and the number of employed household members, but not enough to flip odds ratio across unity or to change statistical significance.

As a result, total effects for California (Column 6) indicate that a higher income, more children between 6 and 17, more Silent generation members, more adult females, more employed members and especially more education decrease the likelihood that a household is voluntarily carless. The total effects of the other socio-economic variables are not significant.

5.2.2 Model II: voluntarily vs. involuntarily carless households

Starting with direct effects (Columns 1 and 2 of Table 4), we see as expected that households with a higher income are more likely to be voluntarily carless. This effect is strong in Germany (OR^{II}_{GER} =2.127***) but weak in California (OR^{II}_{CA} =1.019***). The numbers of children 5 and younger (OR^{II}_{GER} =0.477***) and between 6 and 17 (OR^{II}_{GER} =0.746*) are only significant for Germany, as households with more children are less likely to be voluntarily carless. Moreover, there are generational effects in the Germany model (but not in the California model): households with more Millennials, Generation X, or Senior members are less likely to be voluntarily carless.

Two more differences between Germany and California are noteworthy. First, gender is not statistically significant in the Germany model, but Californian households with more female adults are less likely to be voluntarily carless (OR^{II}_{CA}=0.765*). Second, education does not come into play in California, but German households with advanced technical college degrees (OR^{II}_{GER}=1.766*) or with college/university degrees (OR^{II}_{GER}=1.460**) are more likely to be voluntarily carless compared to households with only a secondary modern school education.

Let us now go over indirect and total effects (Columns 3 to 6 of Table 4). In the Germany model, except for the number of adult females in the household and the number of employed household members (for which both direct and indirect effects are not significant), indirect effects (Column 3) reinforce direct effects (Column 1). This causes two total effects (Column 5) to become significant: the number of Baby Boomers in the household (OR^{II}_{GER}=0.708*; when this number increases, the likelihood of being voluntarily carless decreases), and having a higher education entrance degree (OR^{II}_{GER}=1.525*; it increases the likelihood of being voluntarily carless compared to the lowest level of education). Otherwise, direct effects are close to total effects in the Germany model. In the California model, there is no substantial difference between direct and total effects for Model II.

5.3 Residential Self-selection

Estimated coefficients for Equations (2b)-(2f) (Tables 5 and 6) for both models confirm the presence of residential self-selection since built environment variables can be partly explained by socio-economic and demographic variables. They show substantial differences between Germany and California that likely reflect historical and cultural differences.

5.3.1 Model I: voluntarily carless vs. motorized households (Table 5)

First, as their income increases, German households are more likely to live in areas with higher population and job densities, and closer to train/tram stations. Likewise, households with more education are more likely to live in areas with higher population and job densities and lower car densities, closer to transit stops (bus, trains, or trams), and in areas with a lower proportion of 1 and 2 family houses. Adding children, adults from any generation, or employed members to a household has the opposite effect, although households with more adult females are slightly more likely to live in denser (population and job) areas.

By contrast, as their income increases Californians are more likely to live in areas with a lower population density and a higher car density, where transit accessibility is not as good, and with a higher proportion of 1 and 2 family housing units. These trends are amplified with educational achievement and with the addition of children between 6 and 17 (except for car density), and of older family members (Baby Boomers and members from the Silent generation). Conversely, households with more Y and X Generation members are more likely to live in denser areas (as do households with more workers), with a lower car density, better transit access and a lower percentage of 1 and 2 family houses.

5.3.2 Model II: voluntarily vs. involuntarily carless households (Table 6)

Model II results also show some noticeable differences between carless Germans and carless Californians. First, as their income increases or they are better educated, carless Germans are much more likely to reside in areas with denser populations and job densities than carless Californians. Second, family structure affects the likelihood that carless Germans live in areas with a denser population or with more jobs: households with more children are less likely to reside in denser areas, and so do households with more older members (from the Post-war and Senior generations) whereas these characteristics barely matter in California, with the exception of highly educated carless households who are more likely to reside closer to high job densities areas. One possible explanation is that many downtown neighborhoods with good transit access and high population density in California are occupied by poorer people after more affluent households fled to the suburbs to live the American dream (a single family detached house with a backyard); although gentrification is at work in some cities, downtown is still not a desirable place for families. In contrast, downtown areas in Germany tend to be highly valued as they offer good housing, as well as various recreational and employment opportunities (BBSR, n.d.).

5.4 Robustness Checks

To assess the robustness of our results, we explored a number of functional forms and specifications, including taking the logarithm of some explanatory variables. For Germany, we estimated models with distance to the nearest city center. We expected that this variable would matter for voluntarily carless households but it was not significant in any of our models. For California, we also estimated models with a land use entropy index to capture land use diversity and with pedestrian-oriented links per square mile to capture walkability. Although these two variables were significant, the values of other variables were very similar to those of our best

California model, which is presented here. Unfortunately, neither land use diversity nor walkability data are available in the 2008 MiD dataset. We also considered models with various correlation structures between error terms, although allowing errors to be correlated does not affect estimated model coefficients. Overall, our final models outperform all others based on values of the information criteria (AIC and BIC).

6. CONCLUSIONS

The purpose of our study was to examine what socio-economic and built environment factors motivate households to voluntarily forgo their motor vehicles in Germany and California, two societies that have been revisiting their dependence on motor vehicles. We estimated generalized structural equation models that account for residential self-selection to analyze data from the 2008 Mobility in Germany (MiD) Survey and from the 2012 California Household Travel Survey (CHTS).

Total effects for Model I (which contrasts voluntarily carless and motorized households) show that, in both Germany and California, the probability that a household is voluntarily carless decreases when any of the following variables increases: income, number of children aged 6 to 17, older members, or employed members. In Germany, the probability of being voluntarily carless decreases with household size but it increases with the number of adult females and with more education. In California, however, these last two variables have the opposite effect on the likelihood of being voluntarily carless.

Total effects for Model II (voluntarily vs. involuntarily carless households) draw an even starker contrast. In Germany, households with a higher income and a better education are more likely to be voluntarily carless. In California, only income and the number of female adults in the household seem to matter; an increase in income raises the probability that a household is voluntarily carless whereas an increase in the latter has the opposite effect.

Most of our built environment variables have similar effects on voluntary carlessness in Germany and California but the magnitude of their impacts differs. A higher population density and better access to public transit both increase the probability that a household is voluntarily carless, but the impact of these variables is larger in Germany. Conversely, as car density increases that probability decreases more in California than in Germany.

The determinants of residential self-selection are especially revealing. German households with higher incomes and a better education are more likely to live in higher density (population and employment) areas and closer to transit service, which evokes an urban environment. In contrast, Californian households with higher incomes and more education flock to areas with a lower population density, a higher car density, weaker transit service, and a higher proportion of 1 and 2 single family units, which evokes suburbs.

These dissimilarities likely reflect cultural preferences, differences in the built environment, as well as differences in land use, housing, and transport policies (Buehler, 2010). In the U.S., a number of policies have contributed to suburbanization over the years. It started after the Second World War when the federal government offered very affordable loan programs for millions of new single family homes in suburbs. This discouraged the renovation of existing homes, in particular mixed-use buildings, and enticed many middle-class families to move to the suburbs (Duany *et al*., 2000), weakening city centers. Urban stores that relocated to the suburbs had to adopt a new business model that led to the creation of strip shopping centers and road networks designed to serve segregated land uses. The planning profession, which was still concerned about the squalor of nineteen century European cities, helped enshrine segregated land uses into law (Duany *et al*., 2000).

In Germany, the suburbanization that started in the 1960s (BBSR, n.d.) was partly counterbalanced by the urban renewal movement that started after Earth Day 1970 in West Germany. This movement called for carefully restoring older buildings and for preserving the layout of older urban areas (Hofmeister, 2004). Although a number of heavily damaged German cities were radically transformed after the Second World War to accommodate modern cars, in many other cities old buildings were reconstructed, the existing road network was preserved, and pedestrian zones were later created in city centers (BBSR, n.d.). Since the 1980s, many German cities have pursued a dual strategy of urban renewal and new home construction to try to keep higher income groups in their midst (BBSR, n.d.). While it has been investing substantially in public transit (BBSR, n.d.), Germany's transport policies have also tried to internalize some of the external costs of motor vehicles with high taxes that make gasoline there more than twice as expensive as in California. Overall, the average monthly maintenance and operation costs for the smallest car category in Germany is ~335€ ($366) (Handelsblatt, 2012), which compares with ~170€ ($186) per month including repairs, insurance, and gasoline for an average car in California (Bankrate, 2017).

While it is tempting for California policymakers to invest in transit and favor compact development in the hope of decreasing car dependence by curbing car ownership and vehicle miles travelled, results are likely to be disappointing (e.g., see Los Angeles Times, 2016) if the cost of driving (and parking) remains so much lower in California than in Germany. Convincing more Californians to forgo their beloved cars will take time. It will require building more attractive compact developments with mixed land uses, and making public places more attractive to pedestrians while increasing the cost of driving and parking.

Our study is not without limitations. First, as may be expected from analyzing data collected by separate agencies in two different countries, many similar socio-economic and built environment variables in our German and Californian datasets were measured differently. In particular, population density associated with MiD respondents was measured at the municipality level with no way to better locate German respondents, whereas we associated to California respondents the density of the block group of their residence. As a result of this scale mismatch (for more details, see 3.2.1 or the note below Supplementary Table 2), density variables cannot be compared between the Germany and California models (we checked that our results are robust to using census tract instead of block group density for California). Similar studies (e.g., see Giuliano and Dargay, 2006; Buehler, 2010, 2011) experienced similar problems. Second, since the number of voluntarily carless households is relatively small in our samples - 302 for California and 393 for Germany -, the impacts of some of socio-economic variables may not have been estimated very precisely. Third, to distinguish between voluntarily and involuntarily carless households for our dependent variables, we had to rely on indirect questions, which might have affected the number of voluntarily carless households (267 MiD households and 837 CHTS households could not be classified as either "voluntarily" or "involuntarily" carless). It would have been preferable to directly ask carless households whether their state is voluntary or not, and what the underlying reasons are. Finally, data restriction in the MiD survey did not allow us to model land use diversity or walkability.

A promising avenue for future work would be to analyze life stage data and data on beliefs, interests, and attitudes needed to elicit lifestyles (Van Acker *et al.*, 2016) in order to better understand the choices of voluntarily carless households, preferably in a dynamic framework. It would also be useful to investigate the determinants of carlessness in other areas that exhibit a broad range of socio-economic and built-environment variables, lifestyles, and vehicle ownership costs. Finally, the expansion of transportation network companies (e.g., Uber or Lyft), and the emergence of shared automated vehicles, may drastically reduce the need to own a motor vehicle in a few year. These transformative changes may increase voluntary carlessness and provide mobility services to hitherto severely limited households.

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Table 1 Summary of Selected Car Ownership Studies

Author	Data	Model(s)	Socio-demographic, built-environment, and other variables	Key results
Single Country Studies				
Maltha *et al.*, (2017)	National Traffic Survey of the Netherlands for 1987, 1991, 1995, 1999, 2003, 2010, and 2014.	Logistic regression analysis	• HH income, size, composition; gender; age; educational level; working status. • Suburbanization level. • N/A	• HH that have no car have decreases between 1987 and 2014 by 68%. • HH composition, education and suburbanization have increased the average number of HH cars over the years.
Klein and Smart (2017)	Panel Study of Income Dynamics from 1999 through 2013 in the U.S.	Poisson regression models	• Age; race/ethnicity of family head; wealth quintiles. • Family lives in a rural area; population density; mean transit accessibility. • N/A	• Millennials have lower car ownerships as previous generations when they were young. • Economically independent Millennials own slightly more cars than initially expected.
Cao and Cao (2014)	Self-administered survey in April 2011 (1,303 respondents) in the Minneapolis-St. Paul metropolitan area, U.S.	Ordered logit	• Number of drivers; HH income; having a driver's license • Perception of "large back yards"; number of businesses within ¼ mile • N/A	• Residential self-selection influences car ownership. • Backyard size, off-street parking and business density marginally impact car ownership, but light rail transit does not affect it directly.
Van Acker and Witlox (2010)	Ghent travel behavior survey (Belgium) 2000-2001	Structural equation model	• Driving license; marital status; HH income; full-time employed; car use • Built up index (density); land use diversity; distance to nearest railway station, to CBD; accessibility by car. • N/A	• Car ownership is positively related to HH income and negatively to age, not owning a driving license and being single. • People living in a built-up and mixed use neighborhood are less likely to use a car. • Car use is lower among people living close to railway stations

Woldeamanuel *et al*. (2009)	German Mobility Panel Survey from 1996-2006	Random effect model	• HH cars, type, size, income. • Availability of public transportation; Availability of shopping/leisure facilities; Satisfaction with accessibility of public transportation. • Parking difficulties.	• Residential location is the main determinant of HHs car ownership. • Availability of bus/train/underground station influences the number of cars negatively. • Availability of shops and cinema/theatre decreases the number of owning a car, whereas the availability of bars/cafes and sport activities has no influence.
Bhat and Guo (2007)	San Francisco Bay Area Travel Survey from 2000	Ordered response car ownership model	• HH income; Ethnicity; Ownership of dwelling; HH structure. • HH and employment density; Drive commute time and cost; Street block density; Transit availability and access time; Multifamily housing unit. • N/A	• Marginally significant to insignificant negative impacts of HH and employment density on car ownership. • Low income HHs in high employment density areas are less likely to own cars.
Prillwitz *et al*. (2006)	German Socioeconomic Panel for the period 1998 to 2003	Bivariate analyses and probit model	• Relocation number of adults in HH; first child in HH; HH income; HH head: Employment status, Educational level. • N/A • N/A	• Number of cars per HH rises till the age category 35-55 and decreases afterwards • Car ownership increases with more adults and with born children as well as with higher income. • Life-course events have a significant influence on car ownership and ultimately travel behavior.
Comparative Studies				
Kuhnimhof *et al*. (2013)	Four national travel surveys over three periods (80s, 90s, and 00) in France, Germany, the UK, and the U.S.	Descriptive analysis	• Age; car accessibility. • N/A • Years	• Increase in car availability in European countries from the 1st to the 2nd study period for all age groups, but not in the U.S. (mainly caused by the earlier mass motorization and an already high car

				ownership rate in the first studied time period)
Kuhnimhof *et al.* (2011)	Mobility in Germany (2002 & 2008) and British National Travel Survey (1996, 2002, and 2005)	Descriptive analysis	• Age and age groups; access to cars; gender. • N/A • Traveled kilometers; car density.	• Both Germans and Britons young adults decrease their car ownership and use more alternative modes (slightly higher effect in Germany). • Men reduce their car ownership more compared to women.
Dargay *et al.* (2008)	European Community Household Panel (ECHP); 14 European countries	Dynamic probit	• Net and permanent income; 3 or more adults in the HH; Single; Children under 16; Adults above 65; female HH head, HH head unemployed. • N/A • N/A	• The number of motorized households increased in most countries over the study period. • The % of households becoming carless is highest in Greece and Spain and lowest in Luxembourg, Germany, France and Belgium. • With a female head, households have fewer cars.
Giuliano and Dargan (2006)	1995 US Nationwide Personal Transportation Survey (NPTS) and 1995/97 British National Travel Survey (NTS)	Ordered probit	• Number adults per HH; Children in HH; Pensioner HH; Different income groups; Town/row house; Apartment. • Different population density groups. • N/A	• The number of cars increases with income and the number of household adults in the UK and the U.S. but poorer people in the UK have fewer cars. • Household size has a smaller effect in Britain, (fewer households with two or more cars). • Having children increases car ownership in the US; being retired lowers it both countries.

Table 2 Classification of Carless Households

Voluntarily carless households	
MiD	• No car necessary; and/or • Voluntary abstention from car ownership.
CHTS	• Do not need a car – "Can do what I need and want without a motor vehicle"; and/or • Concerned about impact on environment.
Involuntarily carless households	
MID	• Too expensive and/or • Health reasons and/or • Age reasons
CHTS	• Too expensive to buy and/or • Too expensive to maintain and/or • Health/Age related reasons and/or • Cannot get insurance.
Unclassified carless households	
MiD	• Answers that span reasons to be voluntarily and involuntarily carless; • No answer; • Do not know.
CHTS	• Answers that span reasons to be voluntarily and involuntarily carless; • No driver's license without explanation; • No answer; • Do not know.

Notes:

1. MiD refers to the 2008 Mobility in Germany survey; CHTS refers to the 2012 California Household Travel Survey.
2. The CHTS question inquiring about the reasons for not having a motor vehicle reads: "Please let us know the reasons why you/your household does not own a motor vehicle."
3. The corresponding MiD question is: "For what reasons does your household not have a car?

Column number and area	Direct Effects 1: Germany	Direct Effects 2: California	Indirect Effects 3: Germany	Indirect Effects 4: California	Total Effects 5: Germany	Total Effects 6: California
Built Environment Variables						
Population density	1.119***	1.044***	--	--	1.119***	1.044***
Employment density	1.221***	1.010	--	--	1.221***	1.010
Car density	0.889***	0.741***	--	--	0.889***	0.741***
Percentage of 1 and 2 housing units	0.992**	0.988***	--	--	0.992**	0.988***
Distance to nearest bus stop[a]	0.852*	--	--	--	0.852*	--
Distance to nearest train/tram stop[a]	0.898***	--	--	--	0.898***	--
Percentage of population accessible by transit/walking in 45 minutes[b]	--	1.062***	--	--	--	1.062***
Household Characteristics						
Monthly (1,000€)[a] /Annual ($1,000)[b] income	0.788***	0.986***	1.042***	0.997***	0.820***	0.984***
Number of children 5 and younger	0.648	0.997	0.878***	1.027**	0.568*	1.024
Number of children 6 to 17 years old	0.654**	0.568***	0.864***	0.941***	0.565***	0.534***
Number of Millennials (Y Gen) in the household	0.313***	0.891	0.907***	1.144***	0.284***	1.019
Number of household members from the X generation	0.275***	1.229	0.829***	1.135***	0.228***	1.394
Number of Baby Boomers	0.291***	0.799	0.802***	0.958***	0.233***	0.765
Number of Post-War[a] generation members	0.226***	--	0.791***	--	0.179***	--
Number of Senior[a]/Silent[b] generation members	0.210***	0.723*	0.858***	0.898***	0.180***	0.649**
Number of female adults in the household	1.617***	0.810	1.016	0.963***	1.642***	0.780*
Number of employed household members	0.595***	0.572***	0.924***	1.010	0.550***	0.578***
Highest household educational attainment (Baseline: up to secondary modern school[a] / No high school[b])						
Binary: 1 = Secondary school[a] /High school[b]	0.769*	0.730	1.140***	0.755***	0.876	0.550**
Binary: 1 = Adv. technical college[a] /Some college[b]	1.179	0.418***	1.191***	0.688***	1.403	0.288***
Binary: 1 = Higher ed. entrance[a] / Associate degree[b]	1.049	0.408***	1.474***	0.640***	1.546**	0.261***
Binary: 1 = College or university degree	1.025	0.338***	1.546***	0.644***	1.558***	0.218***

Notes: a: For Germany model only; b: For California model only. Direct effects show the odds ratio corresponding to Equation (1). *, **, and *** indicate significance at 10%, 5%, and 1% respectively. The sample size is 19,140 households for Germany and 31,113 for California. Involuntarily and unclassified carless households were excluded.

Column number and area	Direct Effects		Indirect Effects		Total Effects	
	1: Germany	2: California	3: Germany	4: California	5: Germany	6: California
Built Environment Variables						
Population density	1.008	1.002	--	--	1.008	1.002
Employment density	1.240***	1.010	--	--	1.240***	1.010
% of 1 and 2 housing units	1.001	1.000	--	--	1.001	1.000
Distance to nearest bus stop[a]	0.899		--	--	0.899	
Distance to nearest train/tram stop[a]	0.952**		--	--	0.952**	
Percentage of population accessible by transit/walking in 45 min[b]	--	1.020**	--	--	--	1.020**
Household Characteristics						
Monthly (1,000€)[a] /Annual ($1,000)[b] income	2.127***	1.019***	1.067***	1.001*	2.270***	1.019***
Number of children 5 and younger	0.477***	0.923	0.950	1.028	0.453***	0.949
Number of children 6 to 17 years old	0.746*	0.916	0.965**	0.988	0.720**	0.905
Number of Millennials (Y Gen) in the household	0.495***	0.754	0.977	1.012	0.483***	0.763
Number of household members from the X generation	0.683*	1.203	0.999	1.009	0.682*	1.214
Number of Baby Boomers	0.763	1.122	0.928***	1.007	0.708*	1.131
Number of Post-War[a] generation members	0.876	--	0.928***	--	0.812	--
Number of Senior[a]/Silent[b] generation members	0.743*	1.388	0.907***	0.967	0.674***	1.341
Number of female adults in the household	0.876	0.765*	1.006	0.995	0.881	0.761*
Number of employed household members	1.078	1.230	0.990	1.013	1.068	1.246
Highest household educational attainment (Baseline: up to secondary modern school[a] / No high school[b])						
Binary: 1 = Secondary school[a] /High school[b]	1.131	1.171	1.074***	0.979	1.215	1.146
Binary: 1 = Adv. technical college[a] /Some college[b]	1.766*	1.306	1.107**	1.012	1.955**	1.322
Binary: 1 = Higher ed. entrance[a] / Associate degree[b]	1.317	1.438	1.157***	0.986	1.525*	1.418
Binary: 1 = College or university degree	1.460**	1.114	1.525***	1.029	1.625***	1.146

Notes: a: For Germany model only; b: For California model only. Direct effects show the odds ratio corresponding to Equation (1). *, **, and *** indicate significance at 10%, 5%, and 1% respectively. The sample size for the Germany and California models are 2,124 and 1,132 respectively. Unclassified households were excluded.

Germany	*Population density*	*Job density*	*Car density*	*Distance to nearest bus stop*	*Dist. to nearest train/tram station*	*% 1 or 2 family houses*
Monthly household (HH) income (1,000€)	0.107***	0.059***	-4.8E-3	-2.8E-3	-0.131***	-0.254
Number of children 5 and younger	-0.334***	-0.100***	0.093***	0.039**	0.296***	3.158***
Number of children 6 to 17	-0.350***	-0.107***	0.134***	8.1E-3	0.400***	3.354***
Number of Millennials (Y Gen) in the HH	-0.269***	-0.072***	0.072***	-1.7E-3	0.285***	1.849***
Number of X Generation HH members	-0.498***	-0.182***	0.105***	0.036	0.509***	2.863***
Number of Baby Boomers in the HH	-0.625***	-0.229***	0.109***	0.067***	0.554***	2.870***
Number of Post-War Gen. HH members	-0.696***	-0.215***	0.127***	0.079***	0.579***	3.082***
Number of Senior generation HH members	-0.537***	-0.145***	2.3E-3	0.077***	0.426***	0.712
Number of female adults in the HH	0.101*	0.050*	0.059**	0.027	-0.035	-0.219
Number of employed HH members	-0.131***	-0.071***	0.037**	0.039***	0.260***	1.501***
Binary: 1 = Secondary school	0.156***	0.088***	-0.146***	-0.041*	-0.285***	-5.439***
Binary: 1 = Adv. Tech. College	0.245***	0.134**	-0.196***	-0.064*	-0.385**	-6.005***
Binary: 1 = Higher ed. entrance	0.729***	0.318***	-0.402***	-0.061**	-0.965***	-10.708***
Binary: 1 = College or university	0.787***	0.336***	-0.473***	-0.043*	-0.949***	-13.030***
California	***Population density***	***Job density***	***Car density***	***% of population accessible in 45 minutes by transit and/or walking***		***% 1 or 2 family houses***
Annual household (HH) income ($1,000)	-5.2E-3***	1.5E-4	4.7E-3***	-8.4E-3***		0.040***
Number of children 5 and younger	0.030	-0.026	-0.042**	0.140		-0.403
Number of children 6 to 17 years old	-0.218***	-0.207***	-0.021**	-0.404***		2.834***
Number of Millennials (Y Gen) in the HH	0.383***	0.162***	-0.209***	0.375***		-2.781***
Number of X Generation HH members	0.416***	0.154***	-0.211***	0.447***		-1.464***
Number of Baby Boomers in the HH	-0.102***	-0.150***	-3.4E-3	-0.137**		2.657***
Number of Silent generation HH members	-0.299***	-0.131***	0.122***	-0.381***		2.965***
Number of female adults in the HH	-0.145***	-0.099	3.7E-3	-0.190**		1.579***
Number of employed HH members	0.090***	0.048**	-1.3E-3	0.054		-0.217
Binary: 1 = High school	-1.043***	-0.218***	0.509***	-0.816***		2.980***
Binary: 1 = Some college	-1.220***	-0.118	0.760***	-0.747***		4.059***
Binary: 1 = Associate degree	-1.390***	-0.271***	0.873***	-1.132***		4.795***
Binary: 1 = College or university	-1.112***	-0.027	1.091***	-0.439**		3.328***

Germany	*Population density*	*Job density*	*Distance to nearest bus stop*	*Dist. to nearest train/tram station*	*% 1 or 2 family houses*
Monthly household (HH) income (1,000€)	0.651***	0.199***	-9.1E-3	-0.448***	-3.028***
Number of children 5 and younger	-0.662**	-0.148	0.053	0.398	2.305
Number of children 6 to 17	-0.372*	-0.145**	0.051	0.086	2.274**
Number of Millennials (Y Gen) in the HH	0.073	-0.086	-0.018	0.101	-0.643
Number of X Generation HH members	0.582**	-0.030	-0.032	-0.118	-2.478*
Number of Baby Boomers in the HH	-0.243	-0.222***	-0.012	0.541**	1.830
Number of Post-War Gen. HH members	-0.568**	-0.224***	0.028	0.547**	0.866
Number of Senior generation HH members	-0.539***	-0.324***	0.092**	0.559***	1.790
Number of female adults in the HH	-0.182	0.088	0.018	0.266	-1.045
Number of employed HH members	0.180	-0.053	0.053*	-0.028	1.010
Binary: 1 = Secondary school	0.474**	0.217***	-9.8E-3	-0.505**	-6.951***
Binary: 1 = Advanced technical college	0.669	0.261**	-0.079	-0.920***	-8.898***
Binary: 1 = Higher education entrance	1.623***	0.422***	-0.105**	-1.127***	-12.682***
Binary: 1 = College or university degree	1.540***	0.289***	-0.024	-0.903***	-10.534***
California	***Population density***	***Job density***	***% of population accessible in 45 minutes by transit and/or walking***		***% 1 or 2 family houses***
Annual household (HH) income ($1,000)	0.026**	0.017	0.034***		-0.046
Number of children 5 and younger	-0.121	9.5E-3	1.450*		-4.534
Number of children 6 to 17 years old	-0.338	-0.102	-0.642		2.843**
Number of Millennials (Y Gen) in the HH	-0.248	0.310	0.629		-1.618
Number of X Generation HH members	0.389	0.30	0.477		-3.782
Number of Baby Boomers in the HH	0.464	0.015	0.377		-1.794
Number of Silent generation HH members	-1.027*	-0.436	-1.747**		0.156
Number of female adults in the HH	-0.658	-1.141**	-0.254		5.577***
Number of employed HH members	1.722***	0.095	0.669		-4.678***
Binary: 1 = High school	-1.320**	-0.032	-1.108		1.519
Binary: 1 = Some college	-0.680	1.195	0.606		-0.709
Binary: 1 = Associate degree	-1.389*	-0.575	-0.719		-0.345
Binary: 1 = College or university degree	-0.823	2.006**	1.456		-8.203***

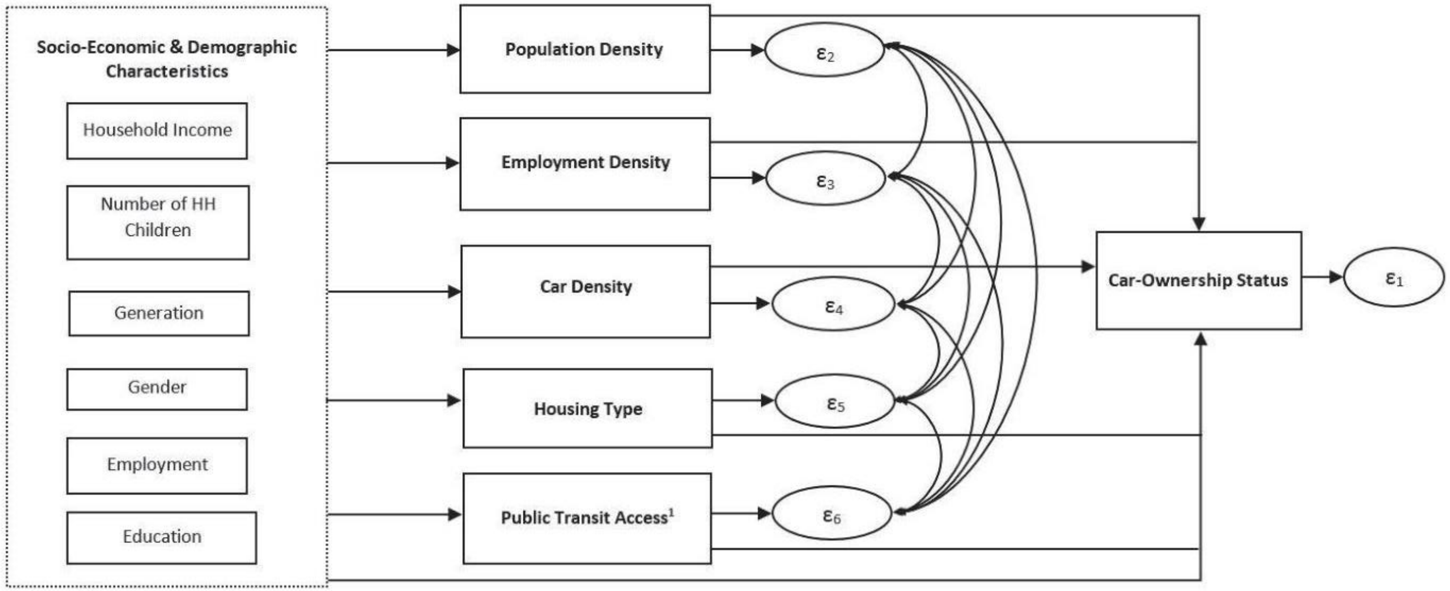

Figure 1: Conceptual Model Structure

Notes:

1. To capture public transit access in the German model we used distance to the nearest bus stop and distance to the nearest local transit stop (e.g. tram or train). For the California model, we used the percentage of population accessible by transit/walking within 45 min.

2. ε_1, ε_2, ε_3, ε_4, ε_5, and ε_6 denote error terms of car-ownership status, population density, employment density, car density, neighborhood housing type, and public transit equations respectively. ε_2, ε_3, ε_4, ε_5, and ε_6 are assumed to be correlated as shown by the double arrows linking them.

	(N=19,140)					(N=2,124)				
	Mean	Std. Dev.	Min	Median	Max	Mean	Std. Dev.	Min	Median	Max
Built Environment Variables[♣]										
Population density (1000 /km^2)	2.64	2.74	0.05	1.5	12.5	4.80	3.79	0.05	3.5	12.50
Employment density (jobs/10 people)	3.12	1.44	0.75	3	6	3.61	1.23	0.75	4	6.00
Car density (cars/10 people)	5.18	1.36	2.45	5.65	6.25	--	--	--	--	--
% of 1-2 family housing	47.75	26.38	12.5	62.5	87.5	31.63	23.36	12.50	12.5	87.50
Distance to nearest bus stop (km)	0.69	1.01	0.05	0.7	12.5	0.50	0.74	0.05	0.3	12.50
Distance to nearest train/tram station (km)	4.41	4.17	0.05	3.5	12.5	2.58	3.44	0.05	0.7	12.50
Household (HH) Characteristics										
Monthly HH income (1,000€)	2.78	1.37	0.25	2.3	7	1.43	0.85	0.25	1.2	5.8
Number of children 5 and younger	0.11	0.38	0	2	3	0.04	0.25	0	1	3
Number of children 6 to 17 years old	0.38	0.76	0	0	6	0.12	0.47	0	0	5
Number of Millennial (Y Gen) in HH	0.27	0.58	0	0	5	0.19	0.50	0	0	6
Number of HH members from the X generation	0.38	0.69	0	0	3	0.20	0.47	0	0	3
Number of Baby Boomers in HH	0.50	0.74	0	0	3	0.20	0.45	0	0	2
Number of Post-War Gen in HH	0.40	0.68	0	0	3	0.18	0.44	0	0	2
Number of Senior generation HH members	0.56	0.81	0	0	3	0.67	0.73	0	0	3
Number of female adults in the HH	1.05	0.49	0	0	5	0.86	0.48	0	1	3
Number of employed HH members	1.20	0.99	0	1	7	0.42	0.66	0	1	4
Binary: 1= Up to secondary modern school (Hauptschulabschluss) [baseline]	0.23	0.42	0	1	1	0.37	0.48	0	1	1
Binary: 1 = Secondary school (Realschulabschluss)	0.30	0.46	0	1	1	0.25	0.43	0	0	1
Binary: 1 = Advanced technical college (Fachabitur)	0.05	0.21	0	0	1	0.04	0.19	0	0	1
Binary: 1 = Higher education entrance qualification (Abitur)	0.09	0.28	0	0	1	0.12	0.32	0	0	1
Binary: 1 = College or University degree (Fachhochschul- oder Universitätsabschluss)	0.33	0.47	0	0	1	0.22	0.41	0	0	1

	(N=31,113)					(N=1,132)				
	Mean	**Std. Dev.**	**Min**	**Median**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Median**	**Max**
Built Environment Variables♠										
Population density (1,000/km^2)	2.82	3.22	5.8E-06	2.12	78.79	6.95	7.96	6.2E-04	4.61	78.79
Employment density (1,000 /km^2)	0.79	3.28	1.2E-06	0.2	222.48	2.83	8.14	5.2E-05	0.71	121.66
Car density (cars/10 people)	6.67	1.37	0	6.83	11.01	--	--	--	--	--
% of 1-2 family housing	72.81	23.51	0	78.68	100	50.13	28.88	0	52.2	100
% of population accessible by transit/walking in 45 min	3.03	5.90	0	0	48.56	9.22	9.14	0	7.59	42.27
Household (HH) Characteristics										
Annual HH income ($1,000)	89.10	62.08	5	62.5	250	24.60	28.51	5	17.5	225
Number of children 5 and younger	0.13	0.43	0	0	5	0.10	0.39	0	0	4
Number of children 6 to 17	2.64	1.38	1	2	8	1.77	1.24	1	1	8
Number of Millennials (Y Gen)	0.29	0.62	0	0	6	0.19	0.48	0	0	3
Number X Gen HH members	0.47	0.75	0	0	5	0.34	0.62	0	0	3
Number of Baby Boomers	0.94	0.84	0	1	4	0.62	0.61	0	1	3
Number of Silent generation HH members	0.31	0.60	0	0	4	0.26	0.49	0	0	2
Number of female adults in the HH	1.08	0.60	0	1	7	0.81	0.61	0	1	4
Number of employed HH members	1.29	0.88	0	1	6	0.52	0.65	0	0	3
Binary: 1= No high school [baseline]	0.03	0.17	0	0	1	0.19	0.39	0	0	1
Binary: 1 = High school	0.09	0.29	0	0	1	0.25	0.43	0	0	1
Binary: 1 = Some college	0.14	0.35	0	0	1	0.20	0.40	0	0	1
Binary: 1 = Associate degree	0.11	0.32	0	0	1	0.10	0.31	0	0	1
Binary: 1 = College/university degree	0.62	0.48	0	1	1	0.25	0.44	0	0	1

♠ These variables are measured at the block group level.

Note. Since built environment variables are measured at different scales in the Germany and California datasets, they cannot be compared directly. For example, although the median population density is higher in our California dataset than in our Germany dataset, it does not mean that California is more densely populated than Germany (it is not). This apparent discrepancy results on one hand from the higher concentration of Californians combined with the sampling of people (not the sampling of block groups) which leads to an over-representation of densely populated block groups in our California sample, and on the other hand from the measurement of population at the municipality level in Germany which leads to smaller density numbers because many German municipalities include parks and open spaces. This effect was amplified by the removal of observations with missing data as respondents with item non-

A.5 Research article #4: Optimization of carsharing networks: Increasing sustainability through heterogeneous fleets and emission control

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Optimization of carsharing networks: Increasing sustainability through heterogeneous fleets and emission control

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Abstract: Carsharing services are successfully implemented in an increasing number of cities worldwide. They offer a sustainable, environmentally friendly alternative to vehicle ownership. With a growing number of users, carsharing permits a reduction of pollution, traffic congestion, and parking problems in cities. The positioning and dimensioning of carsharing stations as well as vehicle relocation have already been addressed in several optimization models. However, the scientific literature typically focuses on homogeneous fleets. Existing carsharing organizations increasingly apply mixed fleets of vehicles with different propulsion methods.

We address this research gap and introduce a MILP, which permits a combination of the advantages of differently powered vehicles: while hybrid or electric vehicles reduce local pollution, combustion vehicles currently require lower initial investments. Our MILP supports decision-makers in their efforts to solve the multi-dimensional challenge of fulfilling demands and maximizing profit while satisfying customer expectations and governmental requirements regarding sustainability.

In an applicability check, the proposed model is evaluated and its capabilities are demonstrated by way of example for the city of San Francisco. Extensive sensitivity analyses within various areas of this city, including diverse fleet emission constraints, various energy and petrol costs, and different distances between demand and station locations are discussed. The results demonstrate the influence of slight parameter modifications and indicate how a profitable operation of heterogeneous fleets can be established and optimized. While leveraging the benefits of carsharing organizations as well as users, our MILP permits an increase in economic and ecological sustainability for today's station-based carsharing applications.

Keywords: OR in environment and climate change; transportation; carsharing; network and fleet optimization; sensitivity analyses.

1. Introduction

A growing level of eco-consciousness in public as well as business sectors evokes a rethinking of car usage and personal vehicle ownership (Shaheen & Cohen, 2013). In this context, carsharing addresses both the environmental and economic concerns of conventional vehicle usage (Alfian, Rhee, & Yoon, 2014). This leads to reduced emissions and grants carsharing clients access to a fleet of relatively new and thus environmentally friendly vehicles on a pay as-needed basis (Shaheen, Cohen, & Martin, 2010). As carsharing profitability depends on demand, carsharing services are typically offered in urban areas where car ownership can (partly) be dispensed with. With an increasing percentage of the world population living in cities and a rapidly rising number of people using carsharing, new opportunities for carsharing organizations arise (Dedrick, 2010).

Supported by technological progress and a variety of available optimization approaches, carsharing organizations are able to better plan their networks as well as their fleet sizes and offer simplified operational services at high service levels to their customers (Hayashi, Hidaka, & Teshima, 2014; Kaspi, Raviv, & Tzur, 2014). The scope of literature dealing with the functionality of different carsharing concepts, the analyses of these concepts, and investigations of use and users is manifold. Introduced optimization models focus on diverse goals and support the creation or expansion of carsharing networks. But even though potentially crucial to success, the implementation of a heterogeneous carsharing fleet has not yet been taken into consideration by existing models. The option of installing a heterogeneous fleet is deemed important as it allows a carsharing organization to leverage the benefits of diverse propulsion methods and thus address a larger customer pool. While a pure electric fleet contributes towards environmental protection, it creates high costs for vehicle charging infrastructures and leads to idle times during charging cycles under present-day conditions (Speranza, 2016). While a combustion engine fleet allows for increased capacity utilization, this results in higher emissions. The positive effects of reduced emissions and reduced energy consumption can thus be reinforced by including alternatively powered vehicles in the carsharing fleet (Shaheen, Cano, & Camel, 2013). In addition, many of these alternatively powered vehicles already meet the requirements of so far mostly voluntary environmental labelling programs, which in turn represent a beneficial marketing aspect for carsharing organizations (Millard-Ball, Murray, ter Schure, Fox, & Burkhardt, 2005).

Real-life application examples further support the concept of heterogeneity. Especially the combination of electric vehicles with petrol-powered vehicles is a growing mixture in today's carsharing fleets. Zipcar, the main provider in the U.S., already successfully applies a heterogeneous vehicle approach with vehicle type and propulsion method varying depending on the location of offer (Zipcar Inc., 2012). Car2go, the largest carsharing organization worldwide, has already begun to include electric vehicles in their fleet, as is the case for instance in San Diego (GreenCarReports, 2016).

While increasing the flexibility and availability of vehicles, electric fleets require vehicle charging infrastructures. Consequently, the integration of electric vehicles makes two-way carsharing (also called round-trip) most feasible for a carsharing network. This means that vehicles have to be returned to their designated parking lot or, in the case of electric vehicles, their respective charging infrastructure. This is in contrast to the one-way mode, in which vehicles can be driven between designated stations, or free-floating carsharing, which allows a vehicle to be left at any allowed parking space within a designated area (Wagner, Brandt, & Neumann, 2016). A summary of the above is given in Table 1, which shows the specific characteristics of the carsharing modes.

Table 1
Advantages and disadvantages of different carsharing operation modes

	One-way	Two-way	Free-floating
Network structure	Station-based; vehicle can be picked up and dropped off at any station	Station-based; vehicle needs to be returned to a designated station / parking lot	Vehicle can be picked up and dropped off at any allowed parking space in the area of operations
Advantages for the carsharing organization	• Relocation is predictable because of typically required pre-booking	• No relocation costs • Prevents crowded stations/areas • No operational management • Planning reliability (e.g., utilization, maintenance, cleaning)	• No station costs
Advantages for the customer	• Fixed location for vehicles • Pre-booking is limited possible • Cost reductions may be applied to support relocation • Spontaneous trips possible • Round trips possible	• Fixed location for vehicles • Pre-booking possible • Spontaneous trips possible • Predictable with regard to long-term scheduling	• Door-to-door service is possible • High flexibility
Disadvantages for the carsharing organization	• Station costs • Relocation costs (staff vs. user incentives) • Crowded/vacant stations	• Station costs • Loss of demand for door-to-door service	• Relocation costs (staff vs. user incentives) • Parking costs in some areas • Crowded/vacant areas
Disadvantages for the customer	• No vehicle available at nearest/preferred station • Preferred destination station may be occupied	• Lower flexibility than free-floating/one-way • Payment of idle times (e.g., for parking)	• No vehicle available in nearby area (limited availability) • No pre-booking possible • Search for parking lot
Implications regarding electromobility	• Unlimited suitability for pure electric fleet • Limited suitability for heterogeneous fleet → Limited availability of vehicle charging infrastructure → Relocation necessary	• Unlimited suitability	• Limited suitability → Ineffective and expensive → Relocations necessary for charging

With the goal of reducing the overall emissions of a carsharing fleet, while at the same time maintaining a customer friendly and yet profit maximizing approach, the above considerations favor a unified fleet deploying different propulsion methods, such as electric, hybrid, or combustion engine vehicles in a two-way mode. The objectives of this paper can consequently be divided into (i) the development of an optimization model that allows profit maximization for a combined fleet of differently powered vehicles, and (ii) the inclusion of a maximum carbon dioxide (CO_2) threshold that enables a carsharing organization to set, review, or reduce the maximum emission of their fleet.

In order to achieve the described objectives, this paper is structured as follows: work regarding the creation, design, and optimization of station-based carsharing networks is described the following Section. Section 3 introduces our optimization model and explains the underlying assumptions as well as the input parameters. Section 4 explains our approach towards dataset creation, defines values for input parameters, and provides conducted benchmarks, obtained sensitivities, and resulting evaluations with a special focus on expected economic and ecological effects. Generalizations derived from our benchmarks as well as a critical review of our approach are also presented in this Section. We complete our article with conclusions and an outlook.

2. Related work

Research on carsharing related topics and the number of respective publications have increased over the past years. Most of these address the history and development of carsharing organizations (e.g., Barth & Shaheen, 2002; Shaheen, Cohen, & Chung, 2009). Others analyze user characteristics and user habits as well as the environmental and social benefits of this mobility service (e.g., Shaheen & Cohen, 2013; Shaheen et al., 2013; Bardhi & Eckhardt, 2012). Besides, many articles deal with the description of different carsharing concepts, success factors, or analyses focusing on existing and running carsharing organizations (e.g., Costain, Ardron, & Habib, 2012; Celsor & Millard-Ball, 2007; Kek, Cheu, Meng & Fung, 2009; Stillwater, Mokhtarian, & Shaheen, 2009). Publications regarding the planning and optimization of station-based carsharing are summarized in the following.

The planning of a carsharing network is divided into three different levels (Boyaci, Zografos, & Geroliminis, 2015). The long-term or strategic perspective determines the allocation of stations regarding number, location, and size. A typical medium-term or tactical action is the designation of vehicles to these stations. The outcome of these planning stages is an established carsharing network. Following long- to medium-term objectives, operational strategies for daily business need to be considered. This includes elements such as pricing, re-fueling, or, if required, relocation techniques (Correia & Antunes, 2012). These three levels, especially long- and medium-term activities, overlap to a certain extent and are therefore often combined in existing models. This is feasible in many instances, but needs to be cautiously considered on a case-by-case basis. For instance, organizations tend to adjust their prices more often than closing or opening a station. The review given below therefore focuses on long- to medium-term strategies and considers operational aspects only as part of network planning and fleet assignment.

A first concept for the strategic selection of carsharing stations is presented by Awasthi, Breuil, Chauhan, Parent, & Reveillere (2007). Their analytical hierarchy process consists of a three-stage approach and can be applied for one-way or two-way modes. In a first step, decision criteria have to be selected and potential stations have to be identified. The suggested decision criteria are developed in cooperation with local planners as well as an established carsharing organization. These contain six indicators including demographic, geographic, and transportation elements. Secondly, the stations are scored by allotting weights to each decision criterion. Finally, the stations with the best overall weights are chosen, provided they exceed a predefined threshold value. Musso, Corazza, & Tozzi (2012) introduce a similar approach for strategic selection using decision criteria to expand an existing network. Three success factors are derived from the built environment forming the foundation of their approach. These factors are assigned to quarters without existing carsharing stations and compared afterwards. New stations are opened in the highest-rated regions. The concrete location, size, and vehicle assignment is not calculated. This approach is not limited to a specific mode of station-based concepts. Another article presents a framework determining the best expansion strategy for an existing carsharing network limited to the two-way mode: El Fassi, Awasthi, & Viviani (2012) develop a decision support system based on discrete event simulation. This combines strategic and tactical elements to react to demand variations. Possible strategies include the establishment of new stations, the expansion of existing stations, and the (de)merging of stations. The optimization objective is to minimize the number of vehicles and stations while maximizing user satisfaction. This is intended to lead to a high performance carsharing network with reduced vehicle idle times.

Focusing on two-way optimization approaches, Rickenberg, Gebhardt, & Breitner (2013) introduce a mathematical model for an optimal selection of number, location, and size of carsharing stations and the subsequent fleet assignment. Their model includes a maximum distance constraint between stations and demand points to satisfy customer needs. With the aid of a stochastically distributed demand, the costs for the installation of such a carsharing network are minimized. In addition, and to support local planners, a decision support system is presented. Sonneberg, Kühne, & Breitner (2015) extend this approach to establish a carsharing network consisting of an all-electric vehicle fleet. These are charged via selectable infrastructures with variable charging cycles. In order to satisfy customers, the demand has to be fulfilled completely. As an operational element, time windows throughout the week are introduced to simulate peaks and off-peaks. A mixed-integer model maximizes the profit of a carsharing organization. While annual leasing costs for vehicles, stations, parking lots, and different charging opportunities are incorporated in the model, expenses for staff or office spaces are not considered.

The following models tackle the optimization of one-way modes and thus integrate to some extent the simulation or optimization of arising relocation procedures. Boyaci, Geroliminis, & Zografos (2013) suggest an approach to optimize station locations and sizes as well as vehicle assignment. Their model is limited to electric vehicles operating in a one-way carsharing scheme and balances the trade-off between profit maximization and level of service. Relocation shifts are required (but not optimized) to satisfy both customer demand and customer satisfaction. Despite the use of electric vehicles, charging times are not taken into account, even though they negatively influence profit. Boyaci, Zografos, & Geroliminis (2013) extend this work by splitting the objective function into two discrete objectives in order to simplify the optimization procedure. Cepolina & Farina (2012) provide a cost minimization model for the distribution of small city-accessible electric vehicles used within pedestrian areas in the city of Genoa, Italy. Their concept includes a fully user-based relocation strategy. Stations are spread over the investigation area and located in densely populated areas or at access points to local public transportation or tourist attractions. A simulated annealing process determines the tactical fleet optimization of small electric vehicles. The user-based relocation is guided by operators offering different pick-up and drop-off locations determined by micro-simulations. The focus of these simulations is to minimize operator costs while not exceeding a maximum waiting time threshold limit. Correia & Antunes (2012) conducted an integration approach that optimizes network design, fleet assignment, and operational vehicle relocation. The authors present a mixed-integer problem, which employs a branch-and-cut algorithm to maximize the revenues of a carsharing organization operating in one-way mode. The relocation procedure is conducted by supervisors and is only possible after an entire period, for example one day. A relocation is carried out on the basis of reservations for the next period, thereby representing a non-dynamic relocation process. This approach is extended by Jorge, Correia, & Barnhart (2012) by including dynamic relocations throughout the day. This results in a mixed-integer linear problem with the objective of profit maximization. A further refinement by Jorge, Correia, & Barnhart (2014) considers different scenarios regarding operational relocation. Their model simulates user behavior based on information about intention to use other pick-up and drop-off locations. Boyaci, Zografos, & Geroliminis (2015) present an optimization framework refining their previous work concerning electric vehicles in one-way mode. This approach introduces an operative planning level and the inclusion of charging requirements additional to the previous ones. A multi-objective mixed-integer linear problem is developed to maximize the profit of a carsharing organization while at the same time maximizing the user net benefit as a monetary function. As the model is not found to be efficiently solvable for real-world situations, they derive an aggregated model. This model is solved via a branch-and-bound algorithm and optimizes an organization's profit. Subsequently, the model is validated by an existing carsharing network in Nice, France.

Reviewing these approaches, none of them permits the implementation of heterogeneous fleets. Another aspect not yet considered is the inclusion of maximum emission levels to fulfill customer expectations or potential future pre-requirements for carsharing fleets. The mathematical model introduced in the following solves the present problems relating to carsharing organizations. It supports the network generation of a mixed fleet and tackles the necessary planning horizons regarding station-based two-way carsharing.

3. Problem description and optimization model

3.1. Problem specification and assumptions

Before a mathematical model for carsharing network optimization can be introduced and applied, several requirements need to be considered. Preconditions for successful carsharing are related to demographic as well as geographic factors. The typical carsharer is thereby described as young to middle-aged, well-educated, and preferably lives in small non-family households in apartment buildings with an average of less than one vehicle per household (Burkhardt & Millard-Ball, 2006; Firnkorn & Müller, 2012; Morency, Trepanier, & Agard, 2011; Habib, Morency, Islam, & Grasset, 2012; Stillwater et al., 2009). Geographic factors include high population density as well as walkable and mixed-use urban areas (Cohen, Shaheen, & McKenzie, 2008; Celsor & Millard-Ball, 2007). These considerations include elements such as accessibility and distance to users' homes as well as a shortage of parking possibilities (Celsor & Millard-Ball, 2007). In addition, good coverage of local public transport plays an important role for the success of carsharing organizations and increases the ability to dispense with a car (Celsor & Millard-Ball, 2007; Cohen et al., 2008; Stillwater et al., 2009).

If these requirements are met, the key to a thriving carsharing organization is the optimum access, availability, and distribution of vehicles (Barth & Todd, 1999). All of these aspects are addressed in our mathematical model. Our model concentrates on strategic and tactical network optimization, allows for a heterogeneous fleet, and considers operation in the two-way mode. Throughout the investigation area, demand and supply points in the form of potential stations are assigned and characterized by geographical coordinates. Local conditions have to be considered for both demand points and potential stations. This includes, for instance, the limited capacity of parking lots. This is influenced by different parking conditions such as bilateral, parallel, and transverse parking as well as on-street and off-street parking. Furthermore, a demand level is assigned to each demand location. These levels are discretely modeled using the Poisson distribution, allotting a number of arrival processes within a timeframe. The complete process of dataset creation and assignment of supply and demand points is described in Section 4.1.

To avoid the establishment of unprofitable stations, the assigned demand is not required to be completely fulfilled. The model allows some demand points to be served only partially or even not at all, while others may be served completely. In order to achieve this, the optimization allows a minimum service level to be inserted. To delimit the optimization, this service level can be set to zero. To reach a maximum of fulfilled demand, the service level can be set to 100 percent. Furthermore, a maximum allowable distance between a built station and an assigned demand location is adjustable so as not to exceed a specific span and ensure customer satisfaction (Morency, Trepanier, & Martin, 2008; Costain et al., 2012; Celsor & Millard-Ball, 2007).

In addition, vehicles with various propulsion methods, such as combustion engine, hybrid, or electric vehicles can be implemented. These vehicles have to be differentiated with respect to costs, consumption, range, emission, charging process, and resulting charging time, if applicable. Vehicles operated with other than electric consumables are expected to be filled-up by carsharers, which is an efficient approach most carsharing operators adopt (e.g., Zipcar Inc., 2012). Annual leasing costs incur for each vehicle, station, and parking lot. These include expenses for acquisition, depreciation, amortization, administration, taxes, insurance, service, maintenance, repair, cleaning, and marketing. If electric vehicles are included, charging infrastructure also incurs expenses for grid connection. Trips are simulated based on a normal distribution regarding duration and distance driven. Respective durations are subdivided into driving time and parking time. The calculation of trips and the resulting consumption further considers local conditions in the investigation area, such as average speed.

In addition, an option is included to implement time windows to simulate demand peaks and off-peaks. If desired, these could be set per week, day, or a combination of both. Special attention must be paid to the Poisson distributed demand, which must be suitable for the time window selection. This means that when choosing a demand per week, time windows need to be set per week and must not be set per day. To fulfill local environmental labelling programs, a maximum average amount of CO_2-emissions in g/km over the entire carsharing fleet can be set. This results in a confinement of vehicle selection during the optimization process and leads to more vehicles with low emissions and lower allowable CO_2-emission levels.

3.2. Input parameters

Sets and indices:

$i = (1, \dots, I)$: *potential station location*

$j = (1, \dots, J)$: *demand location*

$p = (1, \dots, P)$: *propulsion method*

$w = (1, \dots, W)$: *time windows*

Decision variables:

d_{ijpw}: *satisfied demand at station i for demand location j of propulsion method p at time window w* [#]

v_{ip}: *number of vehicles with propulsion method p at station i* [#]

y_i: 1, *if station is built*; 0, *else*

z_{ij}: 1, *if demand location j is served by station i*; 0, *else*

Parameters:

C_p: $leasing\ cost\ of\ charging\ infrastructure\ for\ propulsion\ method\ p\ [US\$\ p.a.]$

e_p: $energy\ price\ per\ propulsion\ method\ p\ [US\$/kwh]\ or\ [US\$/l]$

f_p: $average\ energy\ consumption\ per\ propulsion\ method\ p\ [kwh/km]\ or\ [l/km]$

k: $expected\ distance\ driven\ [km]$

L_i: $leasing\ cost\ of\ a\ parking\ lot\ at\ station\ i\ [US\$\ p.a.]$

n_i: $maximum\ number\ of\ lots\ at\ station\ i\ [\#]$

Q: $maximum\ distance\ between\ station\ i\ and\ demand\ location\ j\ [km]$

q_{ij}: $distance\ between\ station\ i\ and\ demand\ point\ j\ [km]$

r^{km}: $revenue\ for\ renting\ [US\$/km]$

r^{min}: $revenue\ for\ renting\ [US\$/min]$

S_i: $leasing\ cost\ of\ station\ i\ [US\$\ p.a.]$

t: $expected\ duration\ of\ a\ rent\ [min]$

U: $average\ maximum\ carbon\ dioxide\ emission\ per\ vehicle\ [g/km]$

u_p: $carbon\ dioxide\ emission\ per\ vehicle\ with\ propulsion\ method\ p\ [g/km]$

V_p: $leasing\ cost\ per\ vehicle\ with\ propulsion\ method\ p\ [US\$\ p.a.]$

x_p: $possible\ trips\ per\ vehicle\ with\ propulsion\ method\ p\ [\#]$

Θ_{jw}: $Poisson\ distributed\ demand\ per\ time\ window\ w\ of\ demand\ location\ j\ [rents/time\ window]$

α: $considered\ demand\ period\ account\ for\ one\ year\ [\#]$

β: $minimum\ level\ of\ service\ to\ satisfy\ [\#]$

3.3. A MILP for carsharing network generation and fleet assignment

$$Max.F(v,y) = \overbrace{\alpha * \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{w=1}^{W} d_{ijpw} * \left((t * r^{min}) + (k * r^{km})\right)}^{revenue\ [US\$\ p.a.]} - \overbrace{\alpha * \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{w=1}^{W} d_{ijpw} * (k * e_p * f_p)}^{variable\ costs\ [US\$\ p.a.]} - \overbrace{\sum_{i=1}^{I}\sum_{p=1}^{P}\left(v_{ip} * (V_p + L_i + C_p) + y_i * S_i\right)}^{leasing\ costs\ [US\$\ p.a.]} \quad (1)$$

$$\sum_{i=1}^{I} z_{ij} \geq 1 \quad \forall\, j,w \quad (2)$$

$$y_i \geq z_{ij} \quad \forall\, i,j,w \quad (3)$$

$$\sum_{p=1}^{P} v_{ip} \geq y_i \quad \forall\, i \tag{4}$$

$$\sum_{i=1}^{I}\sum_{p=1}^{P} d_{ijpw} \leq \Theta_{jw} \quad \forall\, j,w \tag{5}$$

$$\sum_{p=1}^{P} d_{ijpw} \leq z_{ij} * \Theta_{jw} \quad \forall\, i,j,w \tag{6}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P} d_{ijpw} \Big/ \sum_{j=1}^{J} \Theta_{jw} \geq \beta \quad \forall\, w \tag{7}$$

$$v_{ip} * x_p \geq \sum_{j=1}^{J} d_{ijpw} \quad \forall\, i,p,w \tag{8}$$

$$\sum_{p=1}^{P} v_{ip} \leq n_i * y_i \quad \forall\, i \tag{9}$$

$$q_{ij} * z_{ij} \leq Q \quad \forall\, i,j \tag{10}$$

$$\sum_{i=1}^{I}\sum_{p=1}^{P} v_{ip} * u_p \Big/ \sum_{i=1}^{I}\sum_{p=1}^{P} v_{ip} \leq U \tag{11}$$

$$y_i \in \{0,1\} \quad \forall\, i \tag{12}$$

$$z_{ij} \in \{0,1\} \quad \forall\, i,j \tag{13}$$

$$v_{ip}, d_{ijpw} \geq 0 \quad \forall\, i,j,p,w \tag{14}$$

The objective function (1) maximizes the annual profit of a carsharing organization. This is carried out by calculating the revenues and subtracting the resulting variable and leasing costs; all of the leasing costs are on an annual basis. In detail, the revenue equals the product of the sum of minutes of rent and the sum of kilometers driven at every established station in each time window and for each vehicle type over the number of satisfied trips at each demand location. This enables a carsharing organization to generate the revenue on either a time-dependent and/or distance-dependent basis in the calculation. Aggregated time windows depict one whole week. Hence, we need to multiply one week of revenue by the number of operating weeks during one year, which is expressed by α. The subtracted variable costs incorporate the resulting vehicle consumption for these satisfied trips, while allowing for different propulsion methods. This leads to the requirement for variations of the type of consumption, the average consumption per kilometer, and the costs for one unit of the respective consumption for each propulsion method again multiplied by the number of weeks. In addition, annual leasing costs for different kinds of vehicles, required charging infrastructures, parking lots, and stations are subtracted.

The constraints (2) to (4) are necessary for the proper creation of the carsharing network and constitutional assignments. Constraint (2) ensures that every demand point is served by one or more dedicated stations. The interconnection of (3) denotes that a station has to be built before a demand location can be assigned to it. The sum of vehicles for all propulsion methods at each station built must be greater than the decision variable for station opening, as described by constraint (4). This guarantees the existence of at least one vehicle per established station.

The constraints (5) to (8) deal with demand-related characteristics and the resulting supply aspect. In constraint (5), the calculation of the satisfied demand per station has to be equal or smaller than the existing demand, which is modeled by a Poisson distribution. Constraint (6) ensures the assignment of demand to only established stations. As described in Section 3.1, the existing demand is not required to be completely fulfilled. Thus, constraint (7) expresses a share as an adjustable minimum service level, which implies a minimum percentage of demand that has to be satisfied. Based on the number of trips that need to be satisfied, a respective number of vehicles is necessary to fulfill this demand, as stated in constraint (8). Therefore, the parameter x_p defines the maximum number of trips possible for a vehicle powered by each propulsion method. This parameter is characterized by the following equation:

$$x_p = \frac{duration\ of\ a\ time\ window}{t * \left(1 + \frac{maximum\ charging\ time_p}{\left(\frac{range_p}{average\ speed}\right)}\right)} \tag{15}$$

The maximum number of trips within a time window is calculated using the range per propulsion method, the average speed within the investigation area, the maximum charging time (if applicable), and the duration of a trip proportioned according to the duration of a time window.

Furthermore, a number of threshold variables limit the optimization process, as expressed in equations (9) to (11). A limited number of parking lots for vehicles (9) is allocated to every station in order to account for local parking conditions around each potential station. Constraint (10) ensures that a maximum distance between a demand point and an associated station is not exceeded. To ensure sustainability aspects, an average emission limit regarding carbon dioxide assumed over the whole fleet is covered in constraint (11). Constraints (12), (13), and (14) set the specific value range of the decision variables of the underlying model.

4. Application, results, and sensitivities

4.1. Parameter definition and dataset development

The described MILP is developed to establish a profitable carsharing network at highest possible service rates. When applying the optimization approach, the quality and level of the input values strongly affect the results of the underlying model. This not only includes cost-related parameters, such as vehicle and station costs, but also the assumed demand, which considerably influences the solution. Accurate input values and realistic demand estimates are therefore crucial to the success of the carsharing network and fleet planning with the introduced model. Various approaches regarding demand and station dataset creation, as well as the choice of input parameters are explained and discussed in the following.

The establishment of a new carsharing network is often difficult due to missing data of acceptance and demand in the chosen investigation area. Many existing approaches, e.g., Boyaci et al. (2015), Lee & Park (2012), or Nourinejad & Roorda (2014), estimate the demand based on empirical values of carsharing organizations already in operation to evaluate and validate new optimization models. While accurate for a specific area, such procedures are not transferable to other areas or different carsharing approaches. This similarly applies to different network structures. Even though the approach helps to validate a model, a method to adapt this model to a new area is lacking. We therefore conclude that these approaches are neither flexible nor adequate enough for practical applications. In order to realize a model with wider applicability, we hence developed a new estimation approach to generate demand values irrespective of existing carsharing services.

Our demand estimation is based on carsharing user characteristics identified in the scientific literature. This refines and extends the approach of Sonneberg et al. (2015) by providing calculation models with an accurate derivation and description of these calculations. While many attributes of a typical carsharer differ between publications, five characteristics are consistently supported by the investigations. These serve as predictor variables for our demand estimation and describe the typical carsharer as young to middle aged, well-educated, living in small non-family households, in apartment buildings, with less than one vehicle per household (see Section 3.1). Other characteristics, such as (household) income, marital status, or gender are excluded due to inconsistent investigation results (e.g., Jorge & Correia, 2013).

The first step in our demand estimation approach is to subdivide the investigation area into smaller parts. Census criteria, such as the American classification into blocks by the US Census Bureau may be used to support this step. Such a block typically involves several buildings, which results in smaller subdivisions of approximately 500 to 3,000 individuals. The most densely populated point of each block is used as its center and serves as a demand point described by geographical coordinates. As a result, the whole investigation area is covered with demand points. The five characteristics of the typical carsharer are used to estimate the demand level per block. The respective values for these characteristics should be based on (forecasted) data published by governments or independent institutes. Before the potential user group of each block can be calculated, shares for each chosen characteristic need to be identified (equations (16) – (20)). These shares are determined for each block individually and then form the basis for calculating the potential user group per block.

$$\frac{\#\ inhabitants\ aged\ between\ 21\ and\ 44}{\#\ inhabitants} = \Delta\, age \tag{16}$$

$$\frac{\#\ inhabitants\ with\ at\ least\ a\ Bachelor's\ degree}{\#\ inhabitants} = \Delta\, education \tag{17}$$

$$\frac{\#\ small\ non-family\ households}{\#\ households} = \Delta\, household\ type \tag{18}$$

$$\frac{\#\ households\ with\ one\ or\ no\ vehicle\ available}{\#\ households} = \Delta\, vehicles \tag{19}$$

$$\frac{\#\ apartment\ buildings\ with\ more\ than\ 5\ housing\ units}{\#\ apartment\ buildings} = \Delta\, housing\ units \tag{20}$$

For the share of carsharers within the typical age range, equation (16) divides the number of inhabitants per block of the corresponding age group by the number of total inhabitants per block. Similarly, the comparatively high level of education of the typical carsharer is accounted for in equation (17). For the shares of vehicle availability and household type, the number of households per block serves as a basis for the calculation. Carsharers tend to live in small non-family households, as stated in equation (18). As indicated by equation (19), these households are equipped with one or no vehicle. As expressed by equation (20), these types of households are typically embodied into larger apartment buildings with more than five housing units.

Certainly, there is also a minor percentage of additional carsharers who do not fall into the typical profile described above, e.g., with regard to age structure. As this number is deemed to be negligible, however, it is not expected to significantly affect the overall demand estimation and is therefore not considered.

As shown in equation (21), the potential user group participating in carsharing services for each block is then determined by multiplying these five shares. As every potential user does not actually participate in carsharing, the absolute number of carsharers is much lower. This ratio (λ) depends on various regional aspects such as the infrastructure of the investigation area or attitudes towards the sustainability of inhabitants. Therefore, the assumed λ should be varied based on these conditions; in our calculations we assume a default λ of 0.05, which is varied between 0.01 and 0.10 in Section 4.2.5.

$$\lambda * (\Delta\, age * \Delta\, education * \Delta\, household\ type * \Delta\, vehicles * \Delta\, housing\ units) = potential\ user\ group \qquad (21)$$

Depending on the result obtained from equation (21), the potential user group can drop to zero in blocks with a majority of family households or elderly population, and the demand points can be eliminated. Based on the resulting potential user groups per block, the actual demand levels can be calculated. Diverse analyses of the behavior of carsharing users conclude that a carsharer requests three trips per month on average (Habib et al., 2012; Morency et al., 2011; Millard-Ball et al., 2005). When applying this value to the above user groups, a certain demand level results for each block. Our approach incorporates these demand levels on a weekly basis with the option to simulate peaks and off-peaks throughout the week. If required, a planner can adapt the demand structures and focus on different time spans via time windows. To simulate varying arrival processes of carsharing customers, the inputs are then modeled following the Poisson distribution within the optimization process. To satisfy the resulting demand levels, supply points need to be established which represent potential station locations. Due to the proven correlation between public transport and carsharing, possible station locations should be set close to public transportation access points (Celsor & Millard-Ball, 2007). The parking situation around each potential station location has to be considered as this limits the possible number of parking lots. Existing parking lots can be used as a basis for this determination.

In addition to the demand levels and potential station locations, parameters such as vehicle costs as well as vehicle consumptions or emissions are required for the optimization process. Representative input values are preset in the optimization model to facilitate completion of the optimization process. These values are summarized in Table 2 and explained in the following.

The composition of cost elements is described in Section 3.1. The values for the annual leasing costs of a vehicle, the related CO_2-emissions, and consumption are chosen on the basis of manufacturer's data[1]. For the following calculations, we choose identical annuals costs for each station and parking lot. To allow for comparability between the different propulsion methods, the Renault CLIO (petrol-driven) and the Renault ZOE (electrically powered), which are otherwise constructed identically, are chosen. The range of the electric vehicle is used for calculating the required charging cycles and therefore does not apply to the petrol-driven variant.

[1] Official brochure prices of Renault (available as hard copy); state: 03/2016

Table 2
Chosen values of input parameters

Parameter (vehicle-related)	Value	Parameter (operational)	Value
Petrol vehicle [US$ p.a.]	2,400	Revenue per minute [US$]	0.04
Electric vehicle [US$ p.a.]	4,200	Revenue per km driven [US$]	0.26
Parking lot [US$ p.a.]	2,400	Price per kWh [US$]	0.20
Cost per station [US$ p.a.]	600	Price per liter petrol [US$]	0.80
Charging infrastructure [US$ p.a.]	6,000	**Parameter (trip-related)**	**Value**
CO_2-emission (Petrol) [g/km]	127	Average trip duration [min]	120
CO_2-emission (Electric) [g/km]	0	Std. dev. trip duration [min]	60
Max. average CO_2-emission [g/km]	75	Average trip distance [km]	35
Parameter (demand-related)	**Value**	Std. dev. trip distance [km]	20
Monday [%]	10	Energy consumption per km [kWh]	0.07
Tuesday [%]	10	Petrol consumption per km [l]	0.1
Wednesday [%]	10	**Parameter (other)**	**Value**
Thursday [%]	10	Max. distance [km]	0.75
Friday [%]	15	Max. range of electric vehicle [km]	210
Saturday [%]	25	Charging time [min]	30
Sunday [%]	20	Average speed [km/h]	25
Potential user group λ [%]	5	Min. level of service [%]	75

Values for trip duration in terms of time and distance are based on previous investigations (Cervero & Tsai, 2004; Duncan, 2011; Morency et al., 2011), as is the chosen maximum distance (Celsor & Millard-Ball, 2007; Costain et al., 2012; Morency et al., 2008). The revenues per minute and kilometer driven result from a web-based comparison of different existing two-way carsharing organizations (Greenwheels, 2017; Stadtmobil carsharing, 2017). Similarly, the costs for a fast-charging infrastructure and the resulting charging times result from a market analysis. Consumptions for operational business are at current market price. Parking lot and station costs as well as average speed are adjusted to local conditions. The average CO_2-emission limit for the entire fleet is adjustable to fulfill local environment labelling programs. Our pre-set value of 75 g/km can only be attained when using a combined fleet of electric and petrol-driven vehicles. We selected seven time windows (Monday to Sunday; each 24 hours long) to depict peaks and off-peaks during a week. The demand-related distribution is determined from the real data of a German carsharing organization.

4.2. Benchmarks and sensitivities

4.2.1. Investigation area of San Francisco

The developed optimization model for the strategic and tactical planning of a heterogeneous carsharing fleet is applied and validated in this Section. Using the case example of San Francisco, the annual profit of a carsharing organization is optimized, compared, and elucidated for different scenarios. San Francisco is chosen due to its high population density of over 6,500 inhabitants per square kilometer, its parking shortage, the mix modes of transportation, and the resulting ability to dispense with a vehicle. The city consists of eleven districts, which form the basis for the comparison of differently populated areas in our benchmarks. It is further divided into 573 blocks in accordance with the U.S. Census Bureau for 2013 based on census data. The positioning of demand locations was set analogous to the subdivision of blocks, as suggested in Section 4.1.

Each block is characterized by a particular demand location at its center of settlement with assigned geographical coordinates. In addition, a total of 1,448 potential carsharing stations are distributed over the whole investigation area, likewise using precise geographical coordinates. Due to the well-developed public transport system covering the majority of the city, close proximity of potential stations to public transportation access points is easy to ensure. Our benchmarks are established using single districts and combinations of districts of San Francisco, which differ in size and population, as shown in Fig. 1 and quantified in Fig. 2 as well as in Table 3.

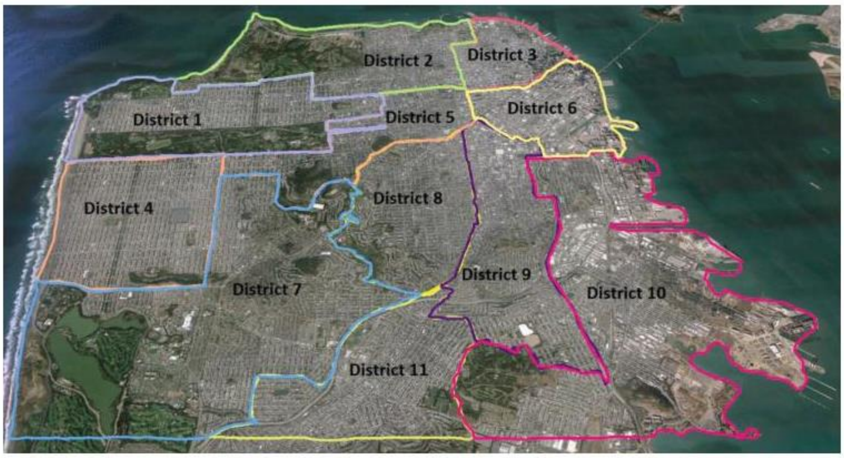

Fig. 1. Visualization of eleven districts of the investigation area San Francisco

As shown in Fig. 1, some areas such as districts 1, 2, and 7 include parks, lakes, or countryside areas, whereas others, such as districts 8 and 9 are completely urbanized. This leads to differences between the districts regarding demand points, demand level per week, and potential stations per district. Due to its relatively large area (measured on the basis of the surface occupied) with a combination of apartment blocks and the lake area, district 7 has a high number of potential stations assigned to it, while the overall demand is comparatively low. In contrast, districts 2 and 3 have a high estimated demand per week compared to their overall size due to their larger number of apartment buildings, which is typical for high carsharing demands. An overview of the number of demand points, potential stations and expected demand levels per week in the various districts is given in Fig. 2.

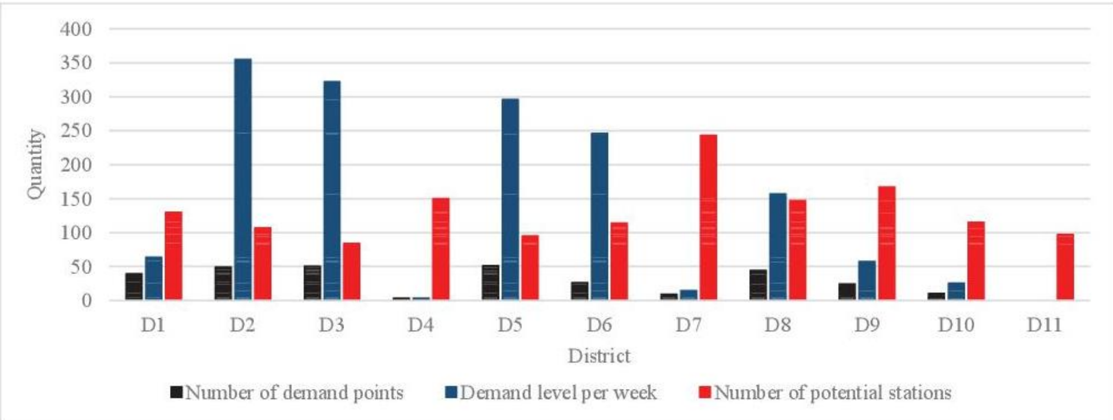

Fig. 2. Number of potential stations, demand points, and demand levels per district

Our benchmarks and sensitivity analyses are carried out using so-called clusters consisting of different combinations of districts. These clusters are defined in Table 3 with their respective overall numbers of demand points and potential stations. For classifying and allocating districts to the clusters, we follow the demand levels beginning with the most distinct ones. The objective of this procedure is to visualize to what extent the choice of the investigation area influences profit and service level of the carsharing organization. The first cluster consists of district 2 due to its highest existing group of potential users and the resulting high level of demand. The second cluster additionally includes district 3. Clusters 3 and 4 are similarly augmented. Cluster 5 finally contains all eleven districts representing the entire city of San Francisco. An overview is provided in Table 3. By adjusting diverse input values in the optimization model, these clusters are examined and compared to each other in the following in order to validate our optimization model.

Table 3
Distribution of clusters and contained districts

Dataset	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Contained districts	D2	D2 & D3	D2, D3, D5, & D6	D2, D3, D5, D6, D1, D8, & D9	D1 – D11
# Demand points	49	99	176	283	305
# Potential stations	107	191	400	844	1,448

4.2.2. Comparison of different clusters

Our initial set of benchmarks for all five clusters is based on the preset input parameters introduced in Table 2. The results are presented in Table 4 and include the overall profit, number of stations, electrically powered as well as petrol-driven vehicles, average CO_2-emissions, demand satisfaction, computing time in total (accumulated calculation times of all cores) and calculation time. Calculations were performed on a Linux cluster system (16 cores each @ 2.4 GHz CPU with 64 GB RAM) using GAMS 24.5.6 with CPLEX 12.6.2 and a set optimization gap of 3 %.

Table 4
Initial benchmarks for all clusters

Clustered districts [3% gap]	Profit [US$]	# Stations	# Vehicles		Av. CO_2-emission [g/km]	Demand satisfaction [%]	Computing time in total [mm:ss]	Calculation time [mm:ss]
			Petrol	Electric				
Cluster 1	165,567	5	4	3	72.57	99.7	00:10	00:05
Cluster 2	337,500	8	8	6	72.57	99.8	01:06	00:50
Cluster 3	611,785	18	15	11	73.27	99.8	08:15	04:06
Cluster 4	665,355	27	21	15	74.08	98.9	16:54	08:38
Cluster 5	629,405	36	25	18	73.83	99.6	18:49	10:06

Although profit increases with larger investigation areas, this only applies if the relation between demand and supply is balanced. In cluster 5, stations also need to be built for areas with lower demand levels, which implies a decrease in profit compared to cluster 4. When examined in more detail, the profit is found to almost double between the first and second as well as the second and third cluster, meaning that districts 2, 3, 5, and 6 are similarly profitable. This is in line with the demands shown in Table 3. The profit in cluster 4 increases less, as demands are lower, and eventually decreases in cluster 5. From an economic perspective, this implies that adding the last districts D4, D7, D10, and D11 is not worthwhile for carsharing organizations due to low expected demands in these areas.

The number of stations and overall vehicles increases with larger clusters, as this involves a larger operating area and hence more demand points are satisfied. The composition of the heterogeneous fleet changes with more included districts since the annual leasing costs are much lower for petrol-driven vehicles than for electrically powered ones. The electric vehicles are preferably deployed with a high occupancy rate because of the comparatively low operating costs (less consumption and less energy costs). With more included districts and reduced occupancy rates, more petrol-driven vehicles are selected due to lower fixed leasing costs and no costs for charging infrastructures.

The CO_2-emission limit depends on the shares of electric and petrol-driven vehicles and is set at 75 g/km as an initial value. The actual average CO_2 limit in all clusters is only slightly below this maximum level. This implies that electric vehicles are merely used to keep within the CO_2-emission limit. Although electric vehicles (including the necessary charging infrastructure) are indeed more expensive than petrol-driven vehicles, they use cheaper energy than petrol-driven ones and have a lower consumption. It is more cost-efficient to use electric vehicles at a high demand profile due to the above-mentioned energy price and consumption advantages of this propulsion method. The demand satisfaction is highest in clusters 2 and 3 (99.8 %) and is less in clusters 4 and 5 due to the addition of comparatively less economical districts. As expected, the computing time in total increases in larger clusters. This can be explained by the larger operating area with an increase in demand locations and more possibilities to install stations and vehicles. Our model is solved by CPLEX, which uses multi-threads to calculate the solutions. The results of our strategic and tactical optimization computations were obtained within a few minutes depending on the sizes of the underlying cluster and respective number of contained demand points and potential stations.

4.2.3. Comparison of heterogeneous and homogeneous fleet compositions

To ascertain the impact of our mixed fleet composition (M), we compare the initial benchmark of each cluster with calculations involving solely petrol (P) and electric (E) vehicles; CO_2-emission levels are ignored for these cases. The calculation findings for the number of necessary vehicles as well as the expected profit and demand satisfaction are visualized in Fig. 3.

The number of vehicles for the three considered fleet options is found to increase when more districts are added (see also Table 4 and its description). The number of used vehicles is the lowest in all clusters when a pure electric fleet is applied. The profit and demand satisfaction are lowest when compared to the other two fleet compositions. This is due to the higher initial costs of an electric vehicle and the required charging infrastructures compared to a petrol-driven one. Another aspect is the necessary charging cycle, which has to be considered as an additional operating factor. If electric vehicles have high occupancy rates, they are cheaper regarding the operation business owing to less and cheaper consumption and thus become worthwhile for a carsharing business.

The number of petrol-driven vehicles and the total number of vehicles within a mixed fleet are approximately equal over the five considered clusters, which is also reflected in demand satisfaction. When analyzing the distribution of vehicles, petrol-driven vehicles are found to be slightly predominant compared to electric ones in all clusters.

Profit is found to be slightly less for a mixed fleet composition due to the higher costs for electric vehicles. Nevertheless, when considering the pure electric fleet, demand satisfaction is found to be highest in the first cluster (95.6%) before it decreases (to below 92.8%) and finally rises again in cluster 5. The highest value in cluster 1 is associated with high expected demands and the resulting high occupancy rates for electric vehicles. The subsequent decrease depicts the weaker districts in terms of demand, and hence less demand is sufficient to still maximize the profits of the carsharing business. In cluster 5, demand satisfaction again rises to realize higher profits, even though less worthwhile districts are included. The impact of the less worthwhile districts can also be seen in the profit development. For a pure electric fleet, the profit is reduced by approximately US$ 60,000, but only by ~US$ 15,000 for a pure petrol vehicle fleet and ~US$ 36,000 for a mixed fleet. To conclude, cluster 4 is most profitable for heterogeneous and homogeneous fleets. For this reason, cluster 4 is chosen for the following benchmark calculations and sensitivity analyses performed for heterogeneous fleets.

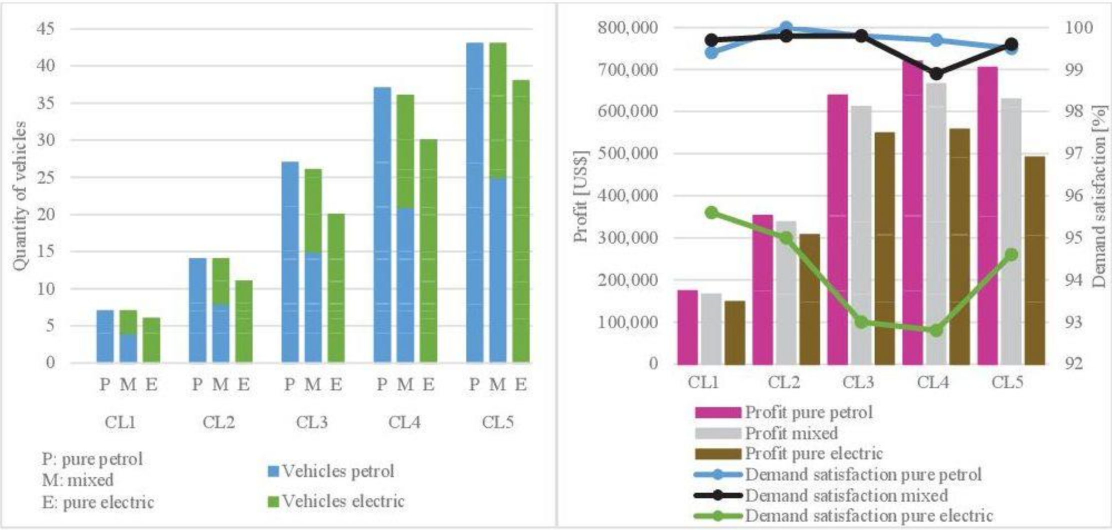

Fig. 3. Impact of fleet composition on number of vehicles, profit, and demand satisfaction

4.2.4. Impact of maximum distance on stations, vehicles, profit, and demand satisfaction

Ceteris paribus, we vary the maximum allowed distance between a demand point and the assigned carsharing station to demonstrate the impact on the number of stations and vehicles as well as on profit and demand satisfaction using cluster 4 due to its most profitable characteristics. The respective results are shown in both parts of Fig. 4, which is divided into five parts with 0.5 km, 0.75 km, 1 km, 1.25 km, and 1.5 km as the maximum allowed distance. For each distance, the corresponding annual profit, number of stations, and the number of vehicles are shown in the left part of Fig. 3. In the right part of the figure, the same is carried out for profit (primary vertical axis) and demand satisfaction (secondary vertical axis).

In general, with an increasing maximum distance, a tendency towards fewer overall vehicles and less established stations can be observed while demand satisfaction does not vary significantly. A lot more stations and vehicles must be provided within shorter distances to satisfy customer needs. Therefore, the occupancy rate of vehicles is less with lower distances and hence reduces profit. Correspondingly, a trend to an increase in profit with larger maximum distances is evident, as especially less stations as well as fewer vehicles are required to satisfy customer needs. However, higher distances can negatively impact customer satisfaction due to greater effort and more time required to reach the nearest station. These aspects are not considered in our approach. At a maximum distance of only 0.5 km, more than 50 stations equipped with just one vehicle per station have to be installed to generate a dense network of stations throughout the investigation area. The number of stations rapidly decreases with an allowed maximum distance of 0.75 km. The customer satisfaction of demanded trips is fairly high and slightly varies between 98.9 % and 99.5 %.

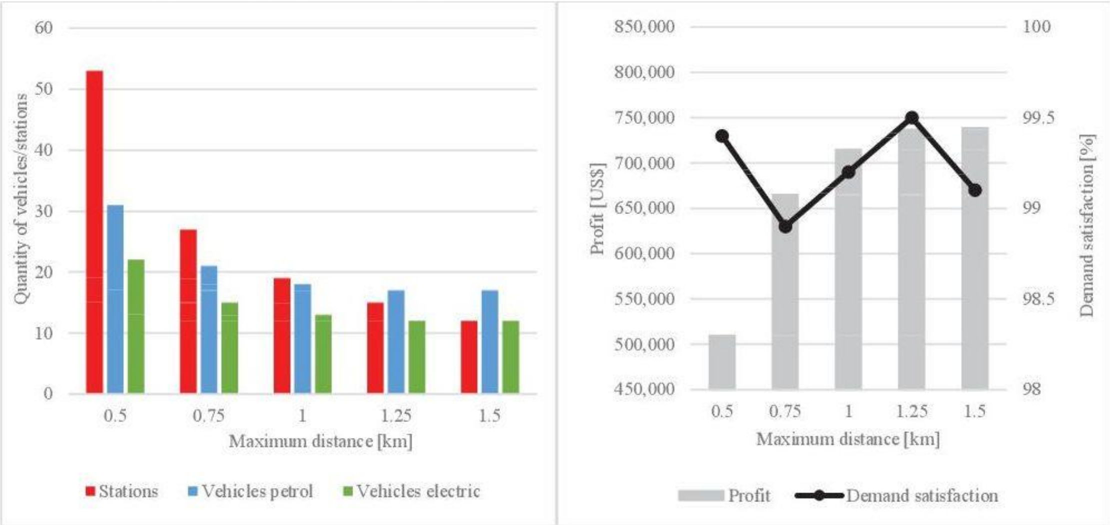

Fig. 4. Variation of maximum distance and impact on stations, vehicles, profit, and demand satisfaction (cluster 4)

These benchmarks are in line with expectations, as less stations and vehicles are required with larger maximum distances accompanied by an increase in profit. This results from the assignment of more demand points to one station due to the fact that customers are compelled to accept longer distance to the next station which increases the occupancy rate of vehicles. Regarding demand satisfaction, no clear trend is visible. It should be noted, however, that the overall demand might decrease if no carsharing station is available nearby.

4.2.5. Impact of demand levels on stations, vehicles, profit, and demand satisfaction

This Section examines the ceteris paribus impact of varying demand levels at a maximum distance of 0.75 km using cluster 4. Besides the impact on the required number of stations and vehicles, the significant influence of demand on overall profit and hence the success of a carsharing organization is visualized. The demand ratio λ of 5 %, which was initially chosen for the city of San Francisco, may not apply to cities with less public transport, lower public interest in carsharing, or a high number of competitors. λ is therefore varied between 0.01 and 0.10. The respective results are presented in Fig. 5.

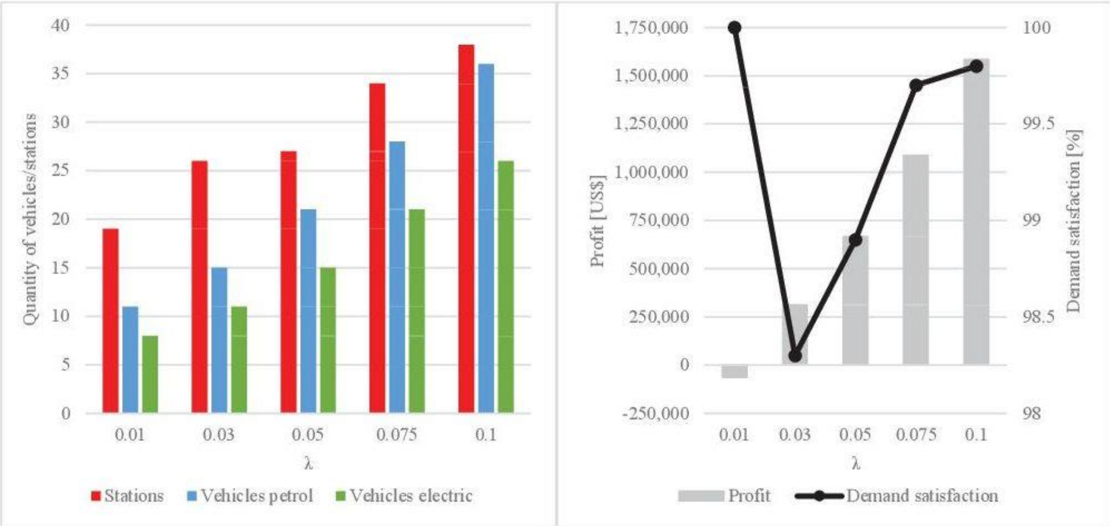

Fig. 5. Variation of demand levels and impact on stations, vehicles, profit, and demand satisfaction (cluster 4)

As evident in Fig. 5, the demand level strongly influences the expected profit as well as the number of stations and vehicles required. A λ of 0.01 results in a negative outcome of US$ 62,400, which means that a carsharing business is not worthwhile at this low demand value; for a λ of 0.1, however, the profit increases to more than US$ 1,500,000. This growth in profit is almost linear and in line with the rising demand profile. Similarly, the number of stations and vehicles almost linearly rises, starting with 19 stations and 19 vehicles for a λ of 0.01 and increasing to 38 stations and 62 vehicles for a λ of 0.1, also resulting in an increase of the vehicle per station ratio. The demand satisfaction fluctuates around 99%. With a λ of 0.01, the existing demand is fulfilled completely to avoid even more negative outcomes owing to unsatisfied trips. A λ of 0.03 results in a decrease of demand satisfaction but in an increase in profits. At subsequent demand levels, the demand satisfaction rate is found to increase.

This increase in profit with higher demand is in line with expectations. This highlights the importance of correctly assessing the habits of potential users in order to realistically evaluate demand. Small misjudgments in this regard can easily make the difference between business success and failure of a carsharing organization.

4.3. Impact of expected economic developments and future ecological prerequisites

4.3.1. Impact of CO_2 levels, as well as energy and petrol prices on network and fleet structure

In the following part of our sensitivity analysis, we vary the prices of petrol and energy for different CO_2-emission limits to demonstrate the respective influence on network structure. On the one hand, this takes into account recent developments on the energy market, leading to uncertainty of energy and petrol prices. On the other hand, it also includes potential future limitations regarding the maximum allowed emissions of a carsharing fleet, which can either be self-motivated and as a competitive advantage or externally required by way of a city or country directive.

The sensitivity analysis is again run on cluster 4. We include calculations on three different maximum levels of average CO_2-emissions (50, 100, and 150 g/km) for two possible energy price levels (US$ 0.10 and US$ 0.30 per kWh) and for four possible prices of petrol (US$ 0.50, US$ 1.00, US$ 1.50, and US$ 2.00 per liter).

The results of these calculations are presented, compared, and discussed in the corresponding diagrams for all six scenarios. Bars in the diagram illustrate the number of petrol-driven as well as electric vehicles. Additionally, the shift of the average CO_2-emissions is shown on the secondary vertical axis. The number of overall stations is not illustrated as this only varies marginally between the different scenarios with a minimum of 27 and a maximum of 33 stations and with no observable relation to price variations.

Our most important consideration concerns the change in composition of the heterogeneous fleet. Regarding the benchmarks, this means that the varying number of electric and petrol-driven vehicles in combination with different CO_2-emission levels is a focus of attention in the following.

At a first glance, it is apparent that the number of electric vehicles exceeds the number of petrol-driven vehicles for the lowest maximum average CO_2 level of 50g/km, irrespective of energy and petrol prices. In addition, the number of electric vehicles increases with rising petrol prices and a corresponding decrease in petrol-driven vehicles. In detail, we notice that in most scenarios with low petrol prices (0.50 US$/l), the CO_2 limit restricts the number of petrol-driven vehicles since electric vehicles are less profitable as long as the price of petrol is comparatively low. With a rising price of petrol, the number of electric vehicles is found to increase. Consequently, a tendency towards reduced average CO_2 levels can be observed. It is notable that even with a high maximum CO_2-emission level, electric vehicles are selected (with the exception of a petrol price of US$ 0.50 per liter) for the carsharing fleet, as these appear to be a profitable alternative in certain areas. Petrol-driven vehicles are deployed in every scenario of the sensitivity analyses with a tendency towards fewer vehicles for a rising petrol price, even though this tendency is only weak for the lower CO_2-emission level. Although average CO_2-emissions strongly depend on the maximum limits, these also show a clear decrease with rising petrol prices due to the deployment of more electric vehicles. In scenarios 3 to 6 and a price of petrol of only US$ 0.50 per liter the number of petrol-driven vehicles strongly dominates, since the maximum average CO_2 limit allows for this composition. Electric vehicles are almost eliminated at this petrol price within a limit of 100 g/km and are completely eliminated in the scenarios with a limit of 150 g/km. This indicates that the CO_2 limit has a significant impact on the composition of the carsharing fleet as long as the price of petrol is low. In this case, electric vehicles are unattractive in terms of profitability and are only selected to comply with CO_2 restrictions. Nevertheless, the distribution is found to change with higher petrol costs. Electric vehicles become more attractive due to the increasing gap between petrol and energy price as well as the lower consumption of an electric vehicle in comparison to a petrol-driven one. For an energy price of only US$ 0.10 per kWh and a high petrol price of US$ 2.00, electric vehicles even comprise the majority of the fleet regardless of the maximum allowed average CO_2-emissions. The high number of electric vehicles is primarily governed by the CO_2 limit while the price impact becomes negligible. However, in all other calculations, petrol-driven vehicles dominate due to their lower annual leasing costs and no costs for charging infrastructure. Some minor exceptions to the general tendencies exist and can again be explained by a combination of a varying demand satisfaction, normal variance of the calculation, and the set gap of 3 %.

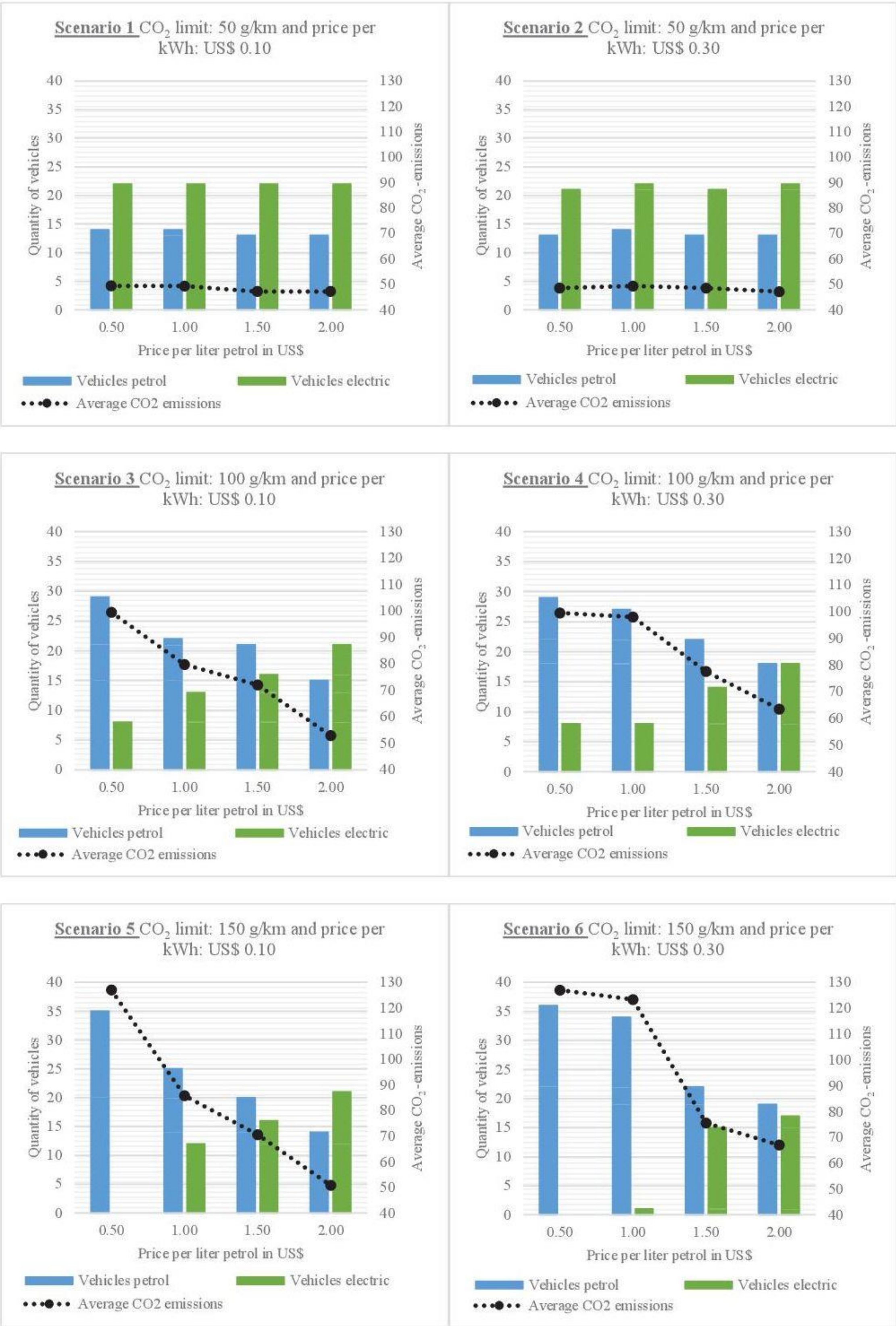

Fig. 6. Scenarios for variations of CO_2 levels, energy, and petrol prices and impact on fleet structure (cluster 4)

4.3.2. Impact of CO_2 levels, energy, and petrol prices on expected profit

In the following, we consider the impact of different CO_2 levels as well as petrol and energy prices on the expected annual profit for a carsharing organization. Similar to the above benchmarks, we compare three different maximum CO_2 levels and vary the prices of energy and petrol. The resulting expected profits are illustrated as two lines for the two different energy prices and show the development of four possible petrol prices. Fig. 6 shows the sensitivity analysis results for the six mentioned scenarios combined in three diagrams. The lines within the same maximum CO_2 level scenario show similar patterns. Additionally, the yellow lines for energy costs of US$ 0.10 per kWh (scenario 1, 3, and 5) are above the green lines for energy costs of US$ 0.30 (scenario 2, 4, and 6), as a higher profit can be achieved when energy costs are lower.

A general tendency can be perceived for decreasing CO_2 limits, which reduce the overall profit. Depending on the application area, electric vehicles appear to be less profitable compared to petrol-driven ones even though they represent the majority of the fleet as already shown in Section 4.3.1. Thus, profit depends on the composition of the fleet when CO_2 limits restrict the number of petrol-driven vehicles. Profits for different CO_2 limits correspond approximately to higher petrol costs. This is most evident for the highest assumed petrol price of US$ 2.00 per liter in every scenario, where the profit is almost identical for all CO_2 limits. A plausible reason for this is that the changing composition of the fleet is influenced rather by energy and petrol prices than by the CO_2 limit. This allows an optimization of profit independent of CO_2 requirements, implying that electric vehicles are deployed for economic reasons. It can be inferred that the consumption of each propulsion method as well as variable and fixed costs also have an influence on the composition of the fleet and the profit for carsharing organizations. This might influence single values, however, but not the overall tendencies presented.

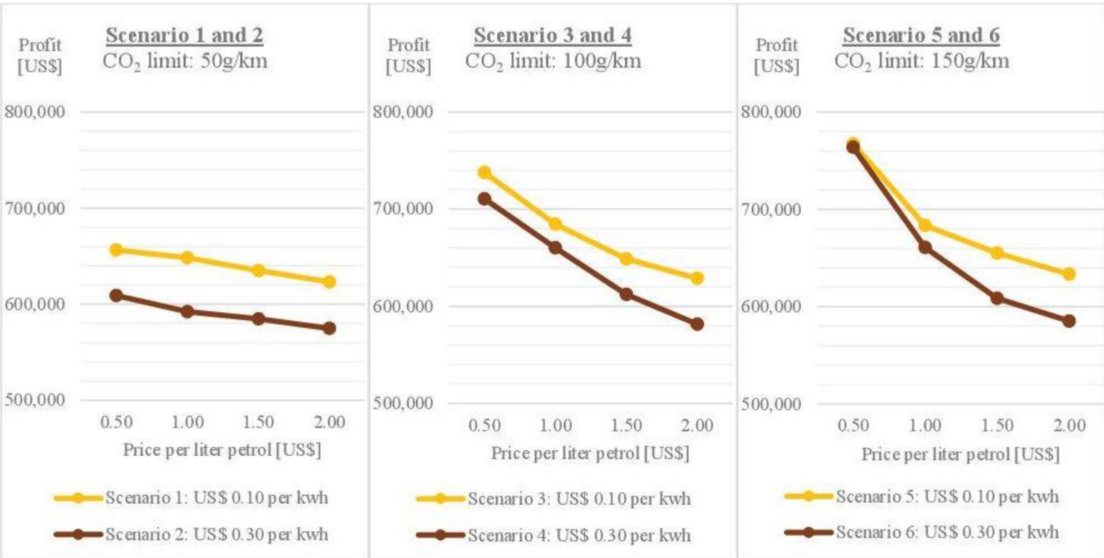

Fig. 7. Variations of CO_2 levels, energy, and petrol prices and the impact on expected profit (cluster 4)

4.4. Generalization of results

From the above benchmarks of the city of San Francisco, generalizations can be derived regarding the influence of various selected parameters ceteris paribus. As Speranza (2016) points out, electric vehicles are available on the market that now feature in several optimization approaches. Based on monetary and efficiency drawbacks compared with conventionally powered vehicles, a homogeneous electric fleet is not favorable for suppliers, e.g., carsharing organizations. When implementing a heterogeneous fleet, the advantages of conventionally powered vehicles (lower costs and a higher level of service) and electric vehicles (lower emissions) can be combined. If electric vehicles become affordable and the required charging cycles decrease in duration and range-dependent necessity, a fleet could be replaced gradually up to a prospective pure electric (carsharing) fleet.

Table 5 summarizes modifications with respective impacts on network, fleet, and profit of the carsharing optimization approach for a heterogeneous fleet. A generalization regarding different clusters in the investigated area is not reasonable because the number of demand points and demand levels vary per analyzed cluster, as indicated in Fig. 2, Table 3, and Table 4. In general, many demand points lead to a larger network, while high demand levels result in more vehicles for customer satisfaction.

Table 5
Generalizations of variations regarding network, fleet, and profit

Impact (ceteris paribus) of … on	Number of stations	Number of vehicles			Profit
		In total	Electric	Petrol	
Costs for stations ↑	→	→	→	→	↓
Costs for parking lots ↑	→	→	→	→	↓
Costs for electric vehicles ↑	→	→	↓	↑	↓
Costs for petrol vehicles ↑	→	→	↑	↓	↓
Demand ↑	↑	↑	↑	↑	↑
CO_2-emission limit ↓	→	→	↑	↓	↓
Price per kWh ↑	→	→	↓	↑	↓
Price per liter petrol ↑	→	→	↑	↓	↓
Max. distance ↑	↓	↓	↓	↓	↑

The cost increase of stations and parking lots does not impact the network structure but decreases profit. Similarly, a cost increase for a particular type of vehicle does not influence the number of stations but decreases the number of vehicle types subject to increased costs and increases the number of vehicles with unaltered costs. A higher demand has an increasing impact on all of the above variables. With a lower average CO_2 limit, the number of stations and overall number of vehicles does not change, whereas the number of electric vehicles increases and the number of petrol-driven vehicles as well as profit decrease. A rise in the price of petrol or energy has a comparable effect on the increase in costs for the designated vehicle type. A higher maximum distance between supply and demand points eventually decreases the number of stations, increases profit, and slightly decreases the number of both types of vehicles. Computing and calculation times increase with larger clusters; thus, a generalization based on single parameters is not feasible. The demand satisfaction does not show clear tendencies; variations can be explained by the preset optimization gap and the underlying network differentiations.

4.5. Critical considerations

The preceding benchmarks demonstrate the applicability of the introduced optimization model for the profit maximization of a two-way carsharing service equipped with a heterogeneous fleet. The model permits the integration of the characteristics of a city to solve the complex problem of determining optimal locations, vehicle compositions, and assignment to carsharing stations. As a result, the model provides a precise, practically applicable recommendation of station allocations within a city.

Despite the latter, certain limitations and potential enhancements need to be considered. Our optimization model can be used for any city worldwide with the restriction of data availability for necessary demand estimate. The city should fulfill the described geographic and demographic characteristics for appropriate and successful application. In this paper, the evaluation of the model and its applicability was limited to the city of San Francisco. Additional tests for cities of different size, structure, and population are required to further validate transferability and generalizability.

Our demand estimation based on demographic data supports realistic assumptions regarding the profitability of carsharing and can be adopted to other cities if the required data is available. Especially for cities with no actual carsharing data, this method allows carsharing organizations to evaluate the feasibility of offering their services in a designated area. Yet, the approach is simplified as it only considers the demand of the habitual abode of potential users and not the demand in business areas or at public transport stations due to a lack of data and research in this domain. Demand also depends on variables other than those discussed, including e.g., the price of carsharing, the structure of the city concerned, and the competitive market situation. While our model does not explicitly consider these aspects, a variation of λ can indirectly adjust the demand to lower values, e.g., when competitors are present. In addition, our model permits adjustments regarding the percentage of the demand, which has to be fulfilled to eliminate unprofitable stations due to low expected demands.

Differently powered vehicles can be included in the optimization model with respective average emissions. A maximum limit of overall CO_2-emission for the fleet can then be set to control the latter and achieve a certain sustainability level. This limit plays a crucial role in the calculations as it strongly influences the required number of alternatively powered vehicles and thus the overall profit of the carsharing organization. If the limit is set to a high value, only few alternatively powered vehicles are included in the fleet. In the future, it is expected that low emission levels will be supported or even required when offering a carsharing service. Today, such an emission limit is voluntary and typically used to support the environmentally friendly image of an organization.

In our benchmarks, we use the two extremes of possible propulsion methods, namely petrol-driven and electrically powered vehicles. We limit our analyses to only two methods to allow comparability of varying vehicle compositions. In addition, we assume 0 g/km CO_2-emission for electric vehicles, which require renewable energy not only for the charging process but also for the production of the vehicles. As such, this represents a simplification of real life situations.

Due to the requirement of charging infrastructures for electric vehicles, a station-based two-way carsharing approach is considered which takes into account all the advantages and disadvantages given in Table 1. One-way trips generate significantly more costs due to the requirement of additional charging infrastructures at each station as well as staff or user incentives for relocation. However, the implementation of a one-way option with higher prices to cover the additional costs could increase flexibility and attract additional users. This option may be limited to non-electric vehicles, as already offered by Zipcar (Zipcar Inc., 2012).

Further improvements of the set optimization gap of 3 % are possible with additional computing time. As our model addresses strategic and tactical planning, computing time is not a critical aspect. However, the set optimization gap used in our benchmarks may lead to small biases between the results.

5. Conclusions and outlook

Carsharing organizations offer their services in an increasing number of cities worldwide. With a growing public environmental awareness, the number of carsharing users continues to rise and the aspect of sustainability becomes more and more important. As a consequence, the integration of vehicles with alternative propulsion methods such as electric vehicles into existing fleets depicts an ongoing trend in this business sector. To successfully integrate differently powered carsharing vehicles into a city, station locations, their sizes, and an optimal number of different types of vehicles have to be determined.

We introduced a MILP to support the challenging task of network and fleet planning as well as optimization for heterogeneous fleets with the overall objective of profit maximization under consideration of ecological sustainability. We evaluated our model using the example of San Francisco. Our benchmarks reveal that the identification of realistic demand levels has a significant influence as to whether carsharing is profitable or not. They further show that slight adjustments in parameters can have a notable impact on how to optimally disburse the carsharing network of a heterogeneous fleet. Although certain limitations have been identified, it was possible to verify the applicability and usefulness of the optimization model.

Benefit could be drawn from more detailed empirical evaluation in this field; as demand represents the most crucial factor to success, additional information regarding typical carsharers and support for the currently used aspects could further validate and enhance our approach. The optimization model itself could be refined by adding aspects not yet considered, such as the implementation of additional multi-mobility constraints, demand-related prices, or a one-way option for non-electric vehicles. We emphasize that the potential of including alternative propulsion methods in carsharing applications is considerable, as this approach serves to increase sustainability while maintaining profitable installation. In conjunction with further enhancements, our work can therefore contribute to supporting a cleaner environment and a greener future.

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A.6 Research article #5: Ecological & profitable carsharing business: Emission limits and heterogeneous fleet

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ECOLOGICAL & PROFITABLE CARSHARING BUSINESS: EMISSION LIMITS & HETEROGENEOUS FLEETS

Research paper

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Abstract

Carsharing is a mobility concept that addresses the world's growing interest in sustainability. It reduces CO_2 emissions, traffic congestion, and noise in cities. Including electric and hybrid vehicles in the carsharing fleet supports these aspects even more. For a station-based carsharing organization (CSO), the distribution and availability of vehicles play a crucial role to satisfy the customers' needs as well as to obtain profits. We developed a tactical optimization model to determine the size and composition of a heterogeneous carsharing fleet while considering different emission limits with time-depended demand profiles. Different propulsion modes and vehicle classes represent the heterogeneity of the fleet. Using the application example of the city of San Francisco, results are presented, discussed, and analyzed. Our benchmarks for two different demand scenarios reveal the strong influence of a preset maximum level of CO_2 emissions on fleet composition and monthly net profit. The optimization model allows CSOs to provide a sustainable and profitable mobility concept; city planners are supported to evaluate influences of CO_2 emission thresholds on CSOs. The model thereby represents a Green IS approach, as it contributes to supporting a society's path towards a low emission and noise-reduced environment in urban areas where carsharing is feasible.

Keywords: Carsharing, Emission Limits, Decision Support, Green IS.

1 Introduction and Motivation

A growing level of eco-consciousness in both public and business sectors, combined with an increasing percentage of the world living in cities, evokes a rethinking of car usage and personal vehicle ownership (Dedrick, 2010; Shaheen and Cohen, 2013). According to estimates for the year 2030, it is expected that approximately 60 % of the world's population is living in cities (Shaheen and Cohen, 2013). Besides these factors, economic uncertainty, rising energy costs, and the wish to reduce CO_2 emissions are reasons why the means of transportation are being widely reconsidered. A comparatively new mobility concept that addresses this question is carsharing (Shaheen and Cohen, 2013). Carsharing means that individuals gain access to a fleet of shared-use vehicles in an urban area and pay on an as-needed basis (Shaheen et al., 2005). The development of the mobility market in general seems to be faster than ever before, which is reasonable especially due to technological progress and modern information and communication technologies. These facts also apply to the carsharing development. The availability, location, and status of each carsharing vehicle can be checked online at any time and any place. This greatly simplified carsharing services in recent years. Today a high service level can be offered to the customers (Hayashi et al., 2014; Kaspi et al., 2014). Owing to these circumstances, the number of people using carsharing is rising rapidly, which is observable all over the world. For example *zipcar*, which is one of the leading organizations in terms of carsharing, serves 950,000 members in seven countries by providing 12,000 vehicles on different vehicle types (Zipcar, 2016).

Regarding the environment, carsharing services can reduce negative impacts of vehicle usage, such as energy consumption, emissions, congestion, and inefficient land use (Shaheen and Cohen, 2008). In particular, the effects of reduced emissions and energy consumption from limited resources can be reinforced by including vehicles with alternative propulsion modes in the carsharing fleet. Vehicles with low fuel consumption and low emissions, in many cases hybrid or electric vehicles, are already used to meet requirements of different environmental labelling programs, which are mostly voluntary nowadays (Millard-Ball et al., 2005). To satisfy the demand for carsharing trips and to benefit from advantages of vehicles with alternative propulsion modes simultaneously, the task of planning carsharing fleets is crucial to success. In general, carsharing can be distinguished between station-based and free floating services. Station-based services provide a defined number of stations, which customers can access. Free floating systems operate without fixed stations and vehicles are accessible in the operating area. While offering increased flexibility to customer, this approach is disadvantageous when using electric vehicles, which require charging infrastructures. Our article therefore focuses on station-based carsharing. The respective planning process can be structured in three different planning stages (Boyaci et al., 2015). First, the strategic planning focuses on the establishment of stations in terms of number, location, and size. Second, the tactical planning assigns vehicles to the stations. Lastly, the operational level deals with elements such as pricing or relocation approaches.

We follow a design science research approach to develop an optimization approach for tactical fleet planning based on an existing carsharing network, fixed in number, location, and size of stations. The model as resulting artifact is classified as nascent design theory (Gregor and Hevner, 2013); an applicability check serves as instantiation to evaluate the model and its results. Regarding to Green IS, this approach supports solution-oriented research in the field of sustainable transportation. We contribute to Green IS in providing decision support to optimize a two-way carsharing system with a heterogeneous fleet and a time-dependent demand to determine the optimal fleet size and composition, while fulfilling pre-defined emission limits. This leads us to the following research question:

RQ: How can a heterogeneous carsharing fleet be optimized while considering emission limits and demand variations?

The remainder of this article is structured as follows; first, we describe carsharing and provide an overview of related research. In section 3 we presents our research. In the following section we explain and note our developed optimization model. Subsequently, we performed benchmarks for an application example. Also, we show and further discuss our results and observed sensitivities. In section 6 we describe limitations and recommendations of our approach. Finally, we provide conclusion and outlook.

2 Carsharing and Related Work

"Never before has world opinion been so united on a single goal as it is on achieving sustainable development" (Watson et al., 2010). Watson et al. (2010) appeal to the academic Information System (IS) community to use the "transformative power" of IS to ensure and enhance environmental sustainability and address the resulting challenges (Watson et al., 2010). The importance of IS to improve sustainability across the economy, defined as Green IS, is growing exponentially (Dedrick, 2010). The Green IS concept supports interactions of IT and humans with the prime goal of conserving resources and the environment (Watson et al., 2010; Butler, 2011). High-level modeling systems for mathematical programming and optimization represent a foundation for a variety of solver and provide user interfaces to solve complex optimization models related to environmental issues. However, studies examining Green IS research by Malhotra et al. (2013) and Gholami et al. (2016) reveal that conceptualization and analyses are overrepresented while the design and impact oriented research is lacking. With our solution-oriented research, we aim to react to these findings contributing to a further improvement of a green transportation concept. Our optimization model for carsharing fleets meets ecological and profitable demands to recently established sustainable transportation businesses.

Carsharing is a transportation mode that offers the use of vehicles to people who have the necessary permits and who pay trip-dependent fees. After they have registered at a carsharing organization (CSO), they can use a vehicle from the fleet by picking it up and returning it to the same location. This is how the two-way (also called round-trip) carsharing concept, considered in our article, operates. Members can utilize any available vehicle of the fleet as long and as often as they want to satisfy their mobility needs. To ensure availability, members may reserve a vehicle in advance; however, spontaneous rides are possible as long as no reservation exists. This is in contrast to one-way services, where vehicles can be driven between dedicated stations, or free-floating carsharing, which allows a vehicle to be left anywhere within a designated operation area (Wagner et al., 2016). The reasons for the growing popularity of carsharing are diverse; yet, they can predominantly be summarized using the three types of sustainability that carsharing addresses: social equity, economic efficiency, and ecological awareness (Boudreau et al., 2009). Social equity is achieved by anti-discriminatory registration, meaning that anyone can use a CSO vehicle independent of social background or income. Economic sustainability often represents the most important criterion for joining a CSO, as members can achieve tremendous savings with very calculable costs per ride when compared to a private vehicle. Costs, such as procurement or leasing, fueling, depreciation, residential parking, insurance, registration fees, maintenance, repair, and car-dependent taxes simply do not affect a carsharer (Duncan, 2011). The usage of low (or even zero) emission vehicles in particular, further leads to the third type of sustainability: ecological awareness. For instance, in North America a carsharing vehicle removes approximately 15 private cars from the road (Cohen et al., 2008). An online survey by Martin and Shaheen (2011) showed a decrease in the number of vehicles per household from 0.47 to 0.24 vehicles when becoming a carsharing member.

Carsharing vehicles are newer, create less pollution, and are much more fuel-efficient than most private ones; often hybrid or electrical vehicles are used to reduce the pollution even more (Millard-Ball et al., 2005; Barth and Todd, 1999). Moreover, the typical way people use cars changes; members usually use the shared vehicle less than they would use a private one. Instead they take more trips by walking, biking, or using local public transportation systems. When carsharing is integrated into the public transportation of a city, there is a large increase in potential customers and the concept of sustainable mobility can be realized. Resulting advantages affect the whole community, which profits due to less traffic, less pollution, and less noise. In addition, it frees up parking spaces, which can be replaced with green areas (Millard-Ball et al., 2005).

The typical carsharing user appreciates the above advantages, and accordingly, is ecology-minded, well-educated, socially engaged, does not own a vehicle, regularly uses public transportation, and is usually between 24 and 40 years old, irrespective of gender (Martin et al., 2010). Geographic factors such as high population density, walkability, and mixed used urban areas with a good coverage of public transportation are important for the success of a CSO (Cohen et al., 2008; Celsor and Millard-Ball, 2007). The competitive conditions as well as the potential and development of carsharing has been further discussed in many articles. For example, Shaheen (2013) provides a global perspective on carsharing growth and future developments and anticipates electric vehicles in fleets of CSO in the coming years. Furthermore, many articles deal with different carsharing concepts, demand-related topics, or other analyses focusing on existent and running CSOs (Duncan, 2011; Efthymiou et al., 2013). Articles focusing on the establishment and planning of carsharing networks have been frequently discussed in recent years. Thereby, several optimization models have been developed underlying different decision levels and different optimization foci. Based on the wide range of this literature, only articles dealing with tactical decisions will be presented and discussed in following. In some of these articles, the decision models do not only include the fleet optimization but also strategical or operative elements.

For our literature review we carefully reviewed carsharing optimization articles, but also closely related topics such as bikesharing and car rental, which similarly require identification of optimal locations. Most of the research on bikesharing considers one-way modes since a relocation can be conducted more easily compared to cars (Martinez et al., 2012; Askari et al., 2016). Several aspects are investigated such as the optimal location, number of stations, and routes of customers to optimize revenues, which can be partly applied to carsharing. Car rental is a similar service to carsharing which also needs several stations; however they mainly differ on the length of rental times, since traditional car rental organizations usually rent out their vehicles for whole days and even longer. The location of the stations can be determined through a mathematical model by analyzing the vehicle availability of existing rental companies, but the dimension of the fleet also must be considered to optimize profits (George and Xia, 2011). However, the circumstances of station-based carsharing differ from these businesses and hence the existing models can not immediately adopted. The distribution of stations and the number of vehicles is investigated by Cepolina and Farina (2012) who provide a cost minimization model for the distribution of personal intelligent city accessible vehicles (PICAVs) within the city of Genoa (Italy). A similar approach is the identification of points of interest to estimate the expected demand accurately and calculate the number of required vehicles or stations (Wagner et al., 2014).

The identification of optimal locations is a major topic of carsharing research. Awasthi et al. (2007) present a three-stage approach for the selection of carsharing stations and adjacent distribution of vehicles. They identify potential stations, assign allotted weights for each station, and then select the final stations for a case example in France. Musso et al. (2012) introduce a similar approach to extend an existing carsharing network by assigning three success factors to different regions and installing new stations and vehicles in the highest-rated regions. El Fassi et al. (2012) developed a decision support system for existing CSOs. It is based on a discrete event simulation, which determines the best expansion strategy for the desired investigation area. The optimization of carsharing stations locations can be assigned to strategical decisions, but in this article we consider the optimal fleet size, which is referred to tactical decisions (Boyaci et al., 2015). This concrete and specific research is very rarely investigated in recent articles. Rhee et al. (2014) provide a discrete event simulation for analyzing many different scenarios in terms of fleet size and its impact on acceptance ratio and utilization ratio to derive recommendations for fleet dimensions (Rhee et al., 2014). Costain et al. (2012) addresses the tactical decision level by proving an approach of operative allocation of rides to reduce the number of vehicles on the streets. Furthermore, optimization models for one-way carsharing services have been developed which combine strategical, tactical and even operational decisions by providing simplified mathematical models by satisfying the entire demand (Boyaci et al., 2015; Nourinejad and Roorda, 2015). The presented articles deal mostly with tactical problems, oftentimes for different travel mode businesses combined with other decision levels, which results in a lack of profundity regarding the fleet optimization for carsharing itself. The number and the allocation of vehicles to existing stations is the most crucial factor for meeting customers' demands and to reach profits. Hence, our model focuses strictly on tactical decisions to optimize the fleet size where different vehicles types (e.g. gas, hybrid or electric) and classes (e.g., small, medium or large) can be implemented whereby additionally, certain emission limits has to be met.

3 Research Design

Our research methodology is based on design science research (DSR) principles as proposed by Hevner et al. (2004) visualized through three cycles (relevance, design, and rigor). Our applied research methodology is presented in Figure 1. In contrast to behavioral science, the design science approach systematically seeks to create "new and innovative artifacts" (Hevner et al., 2004). This means it is the most suitable approach for creating, specifying, and evaluating a carsharing model, addressing both its relevance and its rigor. Regarding relevance cycle, our work is motivated by the increasing demand for alternative transportation modes, electric mobility, CO_2 emission reduction, and the associated decision making requirements. Our current research project focusing on electric mobility, provides further information and ensures the recent relevance and importance of the problem. The review of existing knowledge in the rigor cycle represents a second essential part of the research process (Peffers et al., 2007). We conducted a comprehensive literature review within the whole carsharing domain and presented important articles focusing on tactical optimization. The design cycle is an iterative process that uses several build-and-evaluate loops, and revises the design artifacts until they are ready for a real world application. The built-and-evaluate activities were already tested and confirmed by March and Smith (1995) to be an important dimension for research on information technology. We conducted several cycles to ensure that environmental requirements, scientific methods, and existing expertise were all taken into account. The emerged tactical optimization model as final artifact provides decision support for CSOs and is therefore classified as nascent design theory in the field of Green IS (Gregor and Hevner, 2013). We tested the optimization model extensively and present an application example as instantiation of the artifact to enable proper documentation and publication of research results.

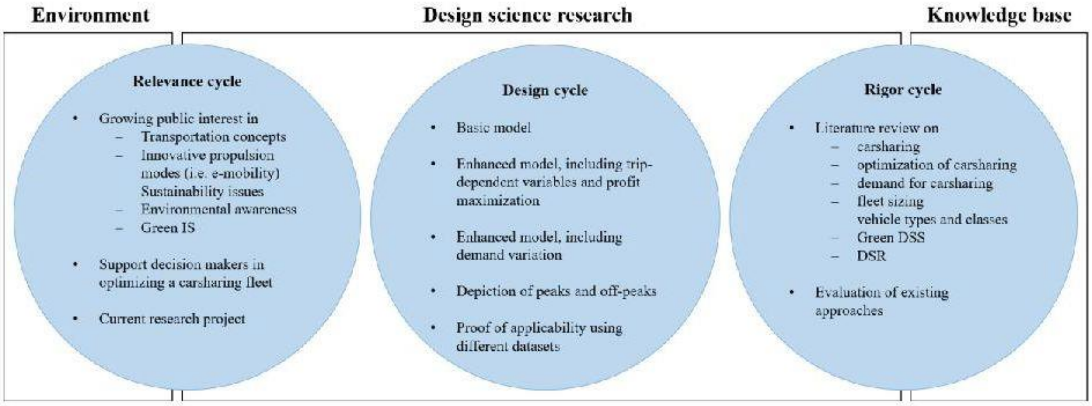

Figure 1. Applied research methodology based on Hevner (2007).

4 Optimization Model

4.1 Assumptions

The objective of the introduced model is to maximize the monthly net profit of a CSO. It takes into consideration a station-based two-way carsharing system. Following assumptions form the foundation of the tactical model for fleet size and composition optimization:

- The number and the locations of the established carsharing stations cannot be changed by the tactical planning process, because they are determined in advance by the strategic planning. Therefore, the monthly leasing costs represent the fixed strategic cost fraction of the monthly operating costs of a CSO.
- One demand represents one trip. The demand does not need to be satisfied completely. For each unsatisfied demand of a trip, penalty costs incur and increase squarely.
- Time frames are used to illustrate peak and off-peak times in the course of a day and a month. For simplification reasons one month is considered to have 28 days. Each day is separated in four time frames, which results in 112 time frames in total. The vehicles are available again after one time frame. Therefore, a trip has to be started and finished within one time frame and cannot be extended to the next.
- Since different propulsion methods are possible to implement, fast charging infrastructures to recharge potential electric and hybrid vehicles are considered. The charging process with a conventional power outlet would require a few hours and hence, the availability of an electric vehicle could not be ensured in each time frame.
- For charging infrastructures, vehicles, and parking lots monthly leasing costs are assumed.
- The possibility of renting parking lots, charging infrastructure and vehicles for a CSO exists at the beginning of each month. Thereby, it is possible to react to monthly fluctuations in demand.

- A maximum limit of parking lots is defined for each established station, and hence, the number of vehicles is also limited.
- Existing stations must be equipped with at least one vehicle to avoid customers' disappointment.
- Each demand for a vehicle class at each demand location is assigned to one or more established stations and a defined maximum distance between these two must not be exceeded.
- A maximum average amount of CO_2 emissions in g/km of the total fleet must not be exceeded due to meeting local emission prerequisites.
- The revenue for renting a vehicle is charged on a time and distance basis and is differentiated by the vehicle class.

4.2 Notation and Mathematical Formulation

We used several input data (see Table 1) for our mathematical optimization model, which can be distinguished between sets, parameters and decision variables.

Sets			
$c = \{1, \ldots, C\}$	vehicle class	$f = \{1, \ldots, F\}$	time frame
$i = \{1, \ldots, I\}$	location of station	$j = \{1, \ldots, J\}$	demand location
$t = \{1, \ldots, T\}$	vehicle type (in terms of propulsion mode)		
Decision Variables			
$s_{cift} \geq 0$	number of satisfied demand	$u_{cift} \geq 0$	number of unsatisfied demand
$v_{cit} \geq 0$	number of vehicles	$z_{cji} \in \{0, 1\}$	1, if demand is assigned to a station; else: 0
Parameters			
co_{ct}	CO_2 emissions of a vehicle (g/km)	dur_f	duration of a time frame
d_{cif}	Poisson distributed demand (# trips/ time frame)	g_f	factor of time frame
$dismax$	max. distance between demand location and assigned station (km)	$comax$	max. average admissible emission of CO_2 (g/km)
dis_{ji}	distance between demand location and station (km)	l_{ft}	leasing cost of charging infrastructure (US$/month)
lp	leasing cost of a parking lot (US$/month)	l_{si}	fixed cost of a station (US$/month)
lv_{ct}	leasing cost of vehicle (US$/month)	$maxp_i$	max. number of parking lots at a station (#)
n_t	number of possible trips of a vehicle type (#)	min	normal distribution of duration of a trip (min)
dd	normal distributed distance driven per trip (km)	p_{cj}	Poisson distributed demand (#)
ep_t	average price for energy (US$/l or US$/kWh)	ec_{ct}	average energy consumption (l/km or kwh/km)
$revm_c$	revenue for renting a vehicle (US$/min)	$revd_c$	revenue for renting a vehicle (US$/km)
ed	average duration of a trip (min)	sd	standard deviation of duration of a trip (min)
ek	distance of a trip (km)	sdk	standard deviation of distance of a trip (km)

Table 1. Used sets, decision variables, and parameters.

The assumptions and the above mentioned sets, decision variables, and parameters serve as a basis for our optimization model, which is formulated in the following. The objective function (1) maximizes the monthly net profit of a CSO. The first term contains the monthly revenues. For each satisfied trip, the charges for the customers are calculated per minute and distance travelled. The second term represents the variable monthly costs depending on the distances driven, the average energy consumption, and the energy price summed up for every satisfied trip. The third term contains the amount of penalty costs. For every time frame at all established stations each trip that will not be satisfied is squarely penalized. The fourth term is composed of the monthly leasing costs of built vehicles, parking lots, and charging infrastructures, if required. While the terms mentioned so far represent the tactical fraction of the monthly net profit, the last term depicts the strategic fraction. Since the stations are determined in advance by the strategic planning process, the leasing costs exist in every tactical decision level, no matter how many vehicles are included in the fleet or how much demand is satisfied or unsatisfied.

$$\textbf{Max}\, \boldsymbol{Z}(\boldsymbol{s},\boldsymbol{u},\boldsymbol{v}) = \sum_{c=1}^{k}\sum_{i=1}^{m}\sum_{f=1}^{l}\sum_{t=1}^{o} s_{cift} * (min * revm_c + dd * revd_c) - \sum_{c=1}^{k}\sum_{i=1}^{m}\sum_{f=1}^{l}\sum_{t=1}^{o} s_{cift} * (dd * ec_{ct} * ep_t) - \sum_{c=1}^{k}\sum_{i=1}^{m}\sum_{f=1}^{l}\sum_{t=1}^{o} u_{cift}^2 - \sum_{c=1}^{k}\sum_{t=1}^{o}\sum_{i=1}^{m} (lv_{ct} + lf_t + lp) * v_{cti} - \sum_{i=1}^{m} ls_i \tag{1}$$

The following restrictions (2) to (12) limit the optimization process:

$$\sum_{i=1}^{m} z_{cij} = 1 \qquad \forall\, c,j \tag{2}$$

$$\sum_{c=1}^{k}\sum_{j=1}^{n} z_{cji} \geq 1, \qquad \forall\, i \tag{3}$$

$$\sum_{c=1}^{k}\sum_{j=1}^{n} v_{cti} \geq 1, \qquad \forall\, i \tag{4}$$

$$\sum_{c=1}^{k}\sum_{t=1}^{o} v_{cti} \leq maxp_i, \qquad \forall\, i \tag{5}$$

$$dis_{ji} * z_{cji} \leq dismax, \qquad \forall\, c,j,i \tag{6}$$

$$\sum_{j=1}^{n} d_{cif} * z_{cji} = \sum_{t=1}^{o} s_{cift} + u_{cif} \qquad \forall\, c,i,f \tag{7}$$

$$d_{cjf} = g_f * p_{cj} \qquad \forall\, c,j,f \tag{8}$$

$$s_{cift} \leq v_{cti} * n_t \qquad \forall\, c,i,f,t \tag{9}$$

$$\sum_{c=1}^{k}\sum_{t=1}^{o}\sum_{i=1}^{m} v_{cti} * co_{ct} \Bigg/ \sum_{c=1}^{k}\sum_{t=1}^{o}\sum_{i=1}^{m} v_{cti} \leq comax \tag{10}$$

$$s_{cift};\ u_{cif};\ v_{cti} \geq 0 \qquad \forall\, c,i,f,t \tag{11}$$

$$z_{cji} \in \{0,1\} \qquad \forall\, c,j,i \tag{12}$$

Constraint (2) ensures that every demand value for each vehicle class c at a demand location j is assigned to exactly one established station i. Thus, we sum up the binary variable z_{ji}, which must be equal to one. Corresponding to our assumptions, at least one demand location has to be assigned to each established station, with one as the minimum number of vehicles v_{cti} per station. This is considered by constraints (3) and (4). The following constraint (5) denotes a maximum number of parking lots $maxp_i$ at each established station and, correspondingly, a maximum number of vehicles that must not be exceeded. Likewise, for (6), a defined maximum distance $dismax$ between a demand location and an assigned established station must not be exceeded. Constraint (7) indicates that the satisfied demand s_{cift} and the unsatisfied demand u_{cif} for a vehicle class in one time frame f at an established station (right side of the equation) has to be equal to all the assigned demand values for this vehicle class in this time frame (left side of the equation). Equation (8) expresses the expected demand d_{cif} which is defined through a specific time frame factor g_f (summed up to 100%) multiplied by the Poisson distributed demand p_{cj}. The time frame factor varies for each time frame to consider peak and off-peak times during the course of a day as well as of a month. In addition, the satisfied demand cannot be higher than all possible trips n_t offered by the vehicles included in the fleet, which is shown by constraint (9). The number of possible trips in each time frame considers the average travel time and the subsequent charging time for electric vehicles before the vehicle is available for the next customer. To ensure that a maximum average amount of CO_2 emissions $comax$ of the total fleet will not be exceeded, constraint (10) is included in the model. Equation (11) and (12) constitute the specific value range of the decision binary variable.

5 Application Example San Francisco

5.1 Initial Context and Benchmarks

We chose the city of San Francisco as an example for the application of the tactical optimization model we developed. The city meets geographic preconditions for a successful carsharing business, such as a high population density, parking pressure, and mix of transportation modes (Celsor and Millard-Ball, 2007; Cohen et al., 2008; Stillwater et al., 2009). For our investigation, we set the demand locations analogous to the subdivision of blocks according to the U.S. Census Bureau, which sums up to 573 demand points for the entire city. The center of each block represents our specific location indicated by geographical coordinates. Our demand estimation is based on exemplary characteristics of carsharing users. The five most frequently mentioned social-demographics are presented in Table 2.

Typical user characteristics	References
Age between 22 and 44 years	Andrew and Douma, 2006; Burkhardt and Millard-Ball, 2006; Firnkorn and Müller, 2012; Morency et al., 2011
Above-average education	Andrew and Douma, 2006; Burkhardt and Millard-Ball, 2006
Single non-family household	Burkhardt and Millard-Ball 2006; Habib et al., 2012; Stillwater et al., 2009
Availability of cars per household one or less	Andrew and Douma, 2006; Habib et al., 2012
Lives in housing unit with more than five apartments	Andrew and Douma, 2006; Burkhardt and Millard-Ball, 2006; Firnkorn and Müller, 2012

Table 2. User characteristics of the typical carsharer.

We used the latest forecasted data published by the U.S. Census Bureau, available on their homepage. Based on that data we first determined for each block the percentages of individuals who meet all of the five mentioned aspects and multiplied them with the number of inhabitants of this block. We assume an average trip frequency of three trips per user per month, in accordance with Burkhardt and Millard-Ball (2006), Habib et al. (2012), and Morency et al. (2011). As not every potential user who meets the five aspects, actually participates in carsharing, the absolute number of car sharers is lower. In addition, different months can have different demands for carsharing, and therefore, we consider two different demand scenarios (2.5% and 7.5% of potential users, who meet the five aspects) in our calculations. The following calculation summarizes the demand estimation for each block:

$$\begin{aligned}&\boldsymbol{demand\ per\ block}\\&= number\ of\ inhabitants * percentages\ of\ all\ five\ aspects * 3\ trips\ per\ months\\&* percentage\ of\ demand\ scenario\end{aligned} \quad (13)$$

The estimation for the demand results in less demand points for the whole city, since many demand points do not cover all five aspects and therefore no demand for carsharing exists. The demand points are spread throughout the city. To illustrate adequately the fluctuating demand in the course of the month and the day, it must be subdivided into time frames. An appropriate solution is chosen based on the duration of six hours for each time frame. Thus, a day is subdivided into four time frames and the whole month is considered to have 112 time frames in accordance to our assumption that one month has only 28 days. To consider peak and off-peak times, the demand is multiplied with a specific factor in accordance to real booking data of our nation-wide project partner CSO operating in two-way mode. During the night the demand is usually very low, hence, we set the demand in the first time frame of a day as the lowest. Later in the day, the demand increases slightly. The peak can be expected in the afternoon, where the value is the highest of the considered day. In the evening the demand usually decreases again (Millard-Ball et al., 2005). To simulate changing conditions throughout the month, potentially caused by vacation periods, weather conditions, or special events such as trade fairs, we assume that every week has a different demand level. As visible in Table 3, the first week has the highest demand level, the following two weeks have an average demand level, while the last week is considered as off-peak.

	Week 1				Week 2			
	0-6 a.m.	6-12 a.m.	12-6 p.m.	6-12 p.m.	0-6 a.m.	6-12 a.m.	12-6 p.m.	6-12 p.m.
Monday	0.0056	0.0084	0.0168	0.00224	0.0004	0.006	0.012	0.0016
Tuesday	0.0007	0.0105	0.021	0.0028	0.0005	0.0075	0.015	0.002
Wednesday	0.0007	0.0105	0.021	0.0028	0.0005	0.0075	0.015	0.002
Thursday	0.00084	0.0126	0.0252	0.00336	0.0006	0.009	0.018	0.0024
Friday	0.00105	0.01575	0.0315	0.0042	0.00075	0.01125	0.0225	0.003
Saturday	0.00175	0.02625	0.0525	0.007	0.00125	0.01875	0.0375	0.005
Sunday	0.0014	0.021	0.042	0.0056	0.001	0.015	0.03	0.004
	Week 3				Week 4			
	0-6 a.m.	6-12 a.m.	12-6 p.m.	6-12 p.m.	0-6 a.m.	6-12 a.m.	12-6 p.m.	6-12 p.m.
Monday	0.0004	0.006	0.012	0.0016	0.00024	0.0036	0.0072	0.00096
Tuesday	0.0005	0.0075	0.015	0.002	0.0003	0.0045	0.009	0.0012
Wednesday	0.0005	0.0075	0.015	0.002	0.0003	0.0045	0.009	0.0012
Thursday	0.0006	0.009	0.018	0.0024	0.00036	0.0054	0.0108	0.00144
Friday	0.00075	0.01125	0.0225	0.003	0.00045	0.00675	0.0135	0.0018
Saturday	0.00125	0.01875	0.0375	0.005	0.00075	0.01125	0.0225	0.003
Sunday	0.001	0.015	0.03	0.004	0.0006	0.009	0.018	0.0024

Table 3. Demand multiplier per time frame to consider peaks and off-peaks.

Furthermore, several input data must be chosen for the mathematical model, which is presented in the following Table 4. To ensure heterogeneity of the fleet we consider three vehicles types: gas, hybrid, and electric. We distinguish the demand by two vehicles classes in order to meet customer preferences with 70% for small and 30% for medium size vehicles to allow for varying trip purposes as for example, in San Francisco a carsharing trip is commuted with around 1.59 persons (Cervero and Tsai, 2004). The demand follows the Poisson distribution, since it is appropriate for the modelling of the frequency of an event over a certain period. We use the following differently powered vehicles: Honda FIT (gas, small), Honda Civic Sedan (gas, medium), Toyota Yaris (hybrid, small), Toyota Prius (hybrid, medium), Mitsubishi EV (electric, small) and Nissan Leaf (electric, medium).

Honda FIT [US$ p.m.]	200	Av. CO_2 emission Honda FIT [g/km]	120
Honda Civic Sedan [US$ p.m.]	230	Av. CO_2 emission Honda Civic Sedan [g/km]	148
Toyota Yaris [US$ p.m.]	250	Av. CO_2 emission Toyota Yaris [g/km]	75
Toyota Prius [US$ p.m.]	300	Av. CO_2 emission Toyota Prius (medium) [g/km]	90
Mitsubishi EV [US$ p.m.]	300	Av. CO_2 emission Mitsubishi EV (small) [g/km]	0
Nissan Leaf [US$ p.m.]	360	Av. CO_2 emission Nissan Leaf (medium) [g/km]	0
Fixed cost station [US$ p.m.]	50	Average trip length [min]	90
Charging infrastructure [US$ p.m.]	400	Standard deviation trip [min]	45
Parking lot [US$ p.m.]	200	Average trip distance [km]	25
Energy price per liter gas [US$]	0.80	Standard deviation distance [km]	15
Energy price per kWh [US$]	0.126	Revenue per minute (small) [US$]	0.15
Maximum distance [km]	0.75	Revenue per minute (medium) [US$]	0.20
Maximum average CO_2 emissions [g/km]	75	Revenue per km (small) [US$]	0.23
		Revenue per km (medium) [US$]	0.25

Table 4. Initial input values for the tactical optimization.

The costs for the vehicles are assumed as monthly leasing rates and are determined by the recent leasing costs. They consist of initial and running costs for purchase, battery, insurance, taxes, maintenance, cleaning, administration, and depreciation. The monthly costs for parking lots, stations establishment, and charging infrastructures cover the entire running cost such as maintenance and cleaning, as well as parking signage. The revenues are charged on a time and distance driven basis and are distinguished between the two vehicle classes. Trip durations and trip distances are normal distributed. The mean

values are chosen based on the findings of recent articles. The distance driven per trip varies between 20 and 60 kilometers (Duncan, 2011; Morency et al. 2011). The whole duration of a trip varies between half an hour and four hours (Alfian et al., 2014). The average CO_2 emission values are chosen in compliance with manufacturers' information for each vehicle type and class explicit not taking into account the incidental emissions for production. The prices for the energy are based on mean values over the last year.
Since we optimize the fleet size and composition of an already existing carsharing business, we assume a basic scenario for established carsharing stations using the strategical optimization model of Sonneberg et al. (2015). We assume 55 carsharing stations in total, and use their geographical coordinates for our tactical optimization model. The distribution of stations is visualized in Figure 2. The stations are located in the inner districts of San Francisco (except for one), as only worthwhile stations are considered. The demand in the other areas either drop to zero or are too small for a CSO to implement a station in this area. All of our considered demand points can be served by at least one station with a maximum distance of 0.75km.

Figure 2. Distribution of stations as basic scenario for tactical optimization of San Francisco.

Our example of application uses the mentioned parameters from Table 4. Calculations are conducted on a standard laptop (Intel Core i5, 2.5 GHz CPU, 16 GB RAM) using GAMS 24.5.6 with the solver IBM ILOG CPLEX and a set optimization gap of 3%. The results of the benchmarks are presented in table form, which contains of CSO profit, number of each vehicle type t (1=gas; 2=hybrid; 3=electric) and class (small; medium), total number of vehicles, average CO_2 emission, percentages of satisfied trips of small and medium classes and percentage of total demand satisfaction. For our benchmarks (Table 5), we varied the maximum average CO_2 emissions of 0g/km, 75g/km, and 150g/km in two possible demand scenarios (low and high) to demonstrate its impact on fleet composition as well as on profits of CSOs.

	CO_2 emission limit	Profit in US$	Small			Medium			# total vehicles	Av. CO_2 in g/km	Demand satisfaction in %		
			# t1	# t2	# t3	# t1	# t2	# t3			Small	Medium	Total
Demand scenario 1 (low: 2.5%)	0g/km	-39,952	0	0	52	0	0	3	55	0	99.52	95.71	99.14
	75g/km	-16,026	1	51	0	0	2	1	55	75	99.52	95.71	99.14
	150g/km	-13,063	52	0	0	3	0	0	55	121.53	99.52	95.71	99.14
Demand scenario 2 (high: 7.5%)	0g/km	25,096	0	0	49	0	0	10	59	0	90.99	73.26	87.61
	75g/km	49,738	2	51	3	0	14	1	71	75	94.61	88.27	93.40
	150g/km	52,423	55	3	0	8	9	0	75	118	95.52	89.56	94.38

Table 5. Benchmarks: Variation of CO_2 emission limit and demand profiles.

5.2 Discussion of Results

Regarding the presented benchmarks for demand scenario 1 in the previous section, it is notable that the profit is negative for all three considered limits of CO_2 emissions, though the loss decreases the higher the CO_2 emission limit. This can be explained by looking at the vehicle composition. For all three levels, the total number of vehicles remains the same, but due to the strict limit of 0g/km of CO_2 emissions, only electric vehicles can be used, which are more expensive in comparison to hybrid and gas. These vehicles need charging infrastructure, which the CSO has to pay for, and adds to the already slightly higher monthly leasing costs for the electric vehicles. Considering the limit of 75g/km the majority of vehicles are hybrids due to their efficient consumption in combination with low average CO_2 emissions. They fulfil the need to not exceed the set limit. Setting the emission limit higher than the average of all considered vehicles, it does not influence the composition and only worthwhile vehicles are deployed, which leads to a homogeneous fleet of only gas vehicles. The average limit of CO_2 emissions is calculated by the number of vehicles and their average CO_2 emissions. Our benchmarks reveal that the limit is followed exactly, since for CSOs it is more profitable to use gas or hybrid vehicles instead of CO_2 neutral electric ones. Furthermore, the satisfaction of demand is striking as it does not change for the three considered CO_2 limits. The CSO satisfies most of the demand to achieve as little loss as possible from unsatisfied trips, since with every unsatisfied demand the penalty costs increase. This means that in the low demand scenario it is not worthwhile to run a carsharing business, but since following months may have higher demands, customer needs are satisfied instead of cancelling the whole business.

For the assumed higher demand in scenario 2 the CSO will reach a positive net profit irrespective of the maximum CO_2 limit. Even with a limit of 0g/km and a homogeneous fleet consisting of only electric vehicles, the monthly net profit can be about $25,000. The higher the CO_2 limit, the more profit for the CSO, since gas and hybrid vehicles are again cheaper than electrics. Considering the 75g/km limit, the majority of vehicles are hybrid, and yet electric and gas vehicles are still included to fulfil customer needs on the one hand and meet the CO_2 limit on the other hand. A limit of 150g/km allows an unconditional composition and thus the fleet compositing consists of a lot of gas and a few hybrid vehicles. As the number of total vehicles and therefore also the demand satisfaction percentage increases, the higher the limit for the CO_2 emissions. When gas and hybrid vehicles are allowed to be used, the result is lower costs which leads to higher demand satisfaction. The satisfaction of one demand (or trip) becomes profitable earlier for a CSO and hence it will satisfy more demand with higher emission limits. This means that for an electric vehicle the utilization must be higher than for gas and hybrid vehicles before becoming profitable. Hence, for the low emission level it is more profitable to not satisfy the demand instead of providing more electric vehicles.

Comparing both demand scenarios, the profit is remarkable, which also stands in line with the findings of Jorge et al. (2012) who conclude that a reduction in the demand leads to a reduction of the profit. With lower expected demand, the CSO is not able to achieve positive profits, since the utilization of vehicles seems not to be high enough for a successful carsharing business. However, some months might have less demand and the CSO can have better months with higher expected demands, where the profit is positive. Comparing the 0g/km CO_2 limits, there must be in sum more months with a high demand level to cover the loss in the lower demand months, as otherwise the business would not be worthwhile. The total number of vehicles is higher in the demand scenario 2, since more demand exists, although the demand percentage is even lower. The lower percentage of demand satisfaction is caused by the greater assumed demand. The CSO can obtain more revenues and hence less profitable demand is not weighted as high as in scenario 1, where the demand and thus the revenues are much lower. For both scenarios it can be observed that the percentage of demand satisfaction is always higher for the small size vehicles. The overall demand for medium size vehicles is lower, and hence especially in off-peaks the demand may drop to zero whereas for small size vehicles even in off-peaks there is at least a low demand level.

To conclude, the applicability check demonstrate the functionality of the artifact. In general, lower CO_2 limits lead to higher costs and consequently to a decrease of the CSOs' profit caused by higher number of electric and hybrid vehicles. Thus, from a business perspective, it is not advisable to include electric vehicles in the carsharing fleet, since they are not profitable yet. Electric vehicles and partly also hybrids are solely necessary for image and prestige reasons or to fulfill law requirements regarding CO_2 emission limits.

6 Limitations and Recommendations

We created, refined, and evaluated research artifacts in order to provide decision support for the optimization of composition and size of a carsharing fleet. We followed the structure of Gregor and Hevner (2013) by the development of a nascent design theory that contributes to the IS research domain. With the instantiation by means of an applicability check, we could identify the influence of the variation of crucial input values to the results. As advised for DSR, deeper empirical evaluation in the field forms a major part of the relevance cycle and will increase practicality, rigor, and generalizability of our approach. As in 86.5% of the decision support related DSR artifacts, no complete field trial has been realized here (Arnott and Pervan, 2012). As opposed to an application based on our model, we recommend a further cooperation with existing carsharing companies though in order to validate and evaluate our approach.

Our research is positioned within the Green IS domain and addresses issues of eco-friendly transportation allowing for improved sustainability through easy and self-explanatory usage of monthly tactical optimization for carsharing services. We developed a solution-oriented artifact that reacts to the lack of design and impact oriented research (Malhotra et al., 2013; Gholami et al., 2016). While increasing their profits, CSOs can use the developed model to countervail ecological issues through optimizing the composition and size of a heterogeneous carsharing fleet for a greener operating business. As carsharing and especially carsharing with heterogeneous fleets including electric and hybrid vehicles, focuses on a clean environment with state-of-the-art technology, the introduced model contributes to enhanced ecological sustainability. The model serves as decision support for managers, planners, and decision-makers. Characteristics of a city, in our example the city of San Francisco, can be easily integrated as input values to help planners solve the complex problem of determining the composition and size of the carsharing fleet. Theoretically, the applicability of the model is not limited, that means it can be used for any established carsharing organization worldwide operating in a station-based mode. The evaluation of the model and its applicability, however, has so far only been carried out for San Francisco. Further test for different cities are required. The model should also be applied on other exemplary cities to ensure transferability and generalizability.

Certainly, the model is based on various assumptions and simplifications. Especially the demand plays a crucial role. The time-depended demand with the chosen peaks and off-peaks, although partly based on data shared by an operating CSO is still an estimation. The Poisson distribution was a reasonable decision since this probability distribution is appropriate for the modelling of the frequency of an event over a certain time period. Nevertheless, queueing theory could be taken into account in future research with the focus on Markov chains. An arrival process at each established station instead of demand locations could improve the optimization results. However, the disadvantages that would come up are increasing computing time and the problem that in reality, carsharing customers would not wait at the station until the carsharing process can begin. A limitation of our model refers to the assumption that time frames cannot overlap each other. We presume that each vehicle is always available at the beginning of each time frame. Consequently, it is prescribed when the customer has to finish the trip at the latest which is not practicable in reality. If overlapping time frames are considered in future research, the chosen length of six hours can be reconsidered as well. The shorter the time frames, the more accurate is the modelling of the fluctuation in demand in the course of a day. An additional aspect that can be discussed as a limitation is that the model considers only station-based carsharing operating in two-way mode. Especially the electric vehicles cause challenges (e.g. implementation of charging infrastructure at any station) for the one-way mode. Besides additional charging infrastructure and additional parking lots, which have to be determined, relocation techniques have to be considered to address possible imbalances in the carsharing network. Also, free floating does not seem to be a reasonable and profitable approach for electric vehicles. However, the proposed two-way model represents an effective way for the monthly tactical planning of heterogeneous carsharing fleets to maximize the profit of CSO while considering emission limits. In our example, only three types of vehicles in terms of propulsion mode are used. Nevertheless, it is feasible to integrate an infinite number of types to provide a heterogeneous carsharing fleet. Furthermore, we considered only two vehicle classes (small and medium). In the use of the optimization model, further classes can be regarded, for instance, large vehicles, which represents operational aspects. Further research could combine both, tactical with operation optimizations. With the developed optimization model, CSOs have the possibility to react to any month with different expected demand. At the same time, they are able to maximize their profit and accomplish the goal of conserving resources and environment in accordance to the Green IS concept by setting limits for the CO_2 emissions.

An aspect not yet mentioned is the potential value of the model for city planners or governments. They are supported in defining reasonable CO_2 emission thresholds to ensure CSOs are required to include alternative propulsion methods in their fleets. It also gives an indication of monetary disadvantages with decreasing emission levels and can help to define required subsidies to support environmental sustainability while ensuring profitable business of the CSO.

7 Conclusions and Outlook

Increased environmental awareness and a growing number of people living in cities induce the population to reconsider their current modes of transportation and their need for personal vehicle ownership. Carsharing serves as an attractive transportation alternative to conserve resources and the environment, especially when including electric or hybrid vehicles in the fleet; at the same time it represents an appealing economic option that relieves its users from any running vehicles expenses. This makes the carsharing concept an inclusive approach of Green IS, as it allows any person possessing a driver's license to use a vehicle at moderate, trip-dependent costs. Taking the perspective of the CSO, the presented tactical optimization model allows them to provide a sustainable mobility concept without compromising profitability. It also allows city planners to contribute to a clean local environment by refining their CO_2 emission thresholds, while understanding and addressing potential profitability concerns of the CSO. These aspects further substantiate the Green IS concept applied in the introduced tactical carsharing optimization model. Our model, integrated in current software, enables an interaction of IT and humans and supports thereby the prime goal of conserving resources and the environment of Green IS. Much research on carsharing optimization consider strategical or operational planning. However, including also a tactical stage with CO_2 emission limits might help to optimize the stated objectives even further and completes the three necessary stages for an entire optimization of carsharing businesses (Boyaci et al., 2015). Hence, we contribute with our model to the Green IS research field by providing a solution approach at a tactical level from an optimization perspective by considering crucial CO_2 emission levels and different vehicles types to ensure customer satisfaction on the one hand but also profitability for CSO on the other hand.

The focus of our article was to provide decision support through the development and provision of a mathematical optimization model determining the composition and size of a heterogeneous carsharing fleet while considering emission limits with time-dependent demand. All of the input values can be adjusted for any city worldwide by having forecasted and experienced values for the demand. We support decision makers by providing the possibility to react to monthly demand fluctuations focusing on customer satisfaction and profitability. We chose the city of San Francisco as an example for the application of our tactical optimization model. Our benchmarks for two different demand scenarios reveal the strong influence of the set maximum level of CO_2 emissions with regards to fleet composition and monthly net profit. The optimization model itself can and should be further refined by the scientific community to achieve constantly increasing sustainability through Green IS. Along with further enhancements, our work contributes to supporting society's path towards a low emission and noise-reduced environment in agglomerations where carsharing is feasible.

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A.7 Adoption Determinants of XML-Based Invoices: an Exploratory Investigation

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Adoption Determinants of Xml-Based Invoices: an Exploratory Investigation

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Abstract

The digitalization of all business processes along the supply chain is a crucial method for cutting down administrative costs, improve productivity, and achieving transparency. One major business document being exchanged in almost any business transaction in the invoice. Electronic invoices are of great potential especially when automatically processing structured data (e.g., XML data).We conducted a qualitative study du understand the adoption determinants of XML-based invoice standards. Therefore, we analyzed interview material and organized the results in the technological, organizational, and environmental (TOE) framework. Within the technological element the simple XML special characteristics play a crucial role for its adoption. The organizational element is characterized by internal aspects like monetary and technical resources as well as available knowledge and expertise. Network effects and competitive pressure are adoption determinates set exogenous and are depicted in the external task environmental element.

Keywords: Electronic invoice, XML-based invoice standard adoption, critical success factor, qualitative study, expert interview

1 Introduction

The automated creation and procedure of electronic invoices (e-invoices) increase the efficiency of invoice business processes and is seen as a key factor for an economic growth for large as well as for small and medium sized organizations (Cuylen et al. 2012). An e-invoice can be received, transmitted and processed digitally which leads to no media discontinuity and thus optimizes and streamlines the business process. Legal requirements and the lack of knowledge how to deal with e-invoices were only some challenges to initiate the e-invoice process.

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In Germany, the law of Simplifying Tax in 2011 with the objective of equal treatment of paper and e-invoices and a lot of effort and enlightenment of the government, the European Union (EU) as well as independent organizations are reasons for the debate about e-invoices and their acceptance. Many transmission protocol, structure data formats and standards are used for the data exchange (Kuehne et al., 2015). This involves many challenges for the adoption and acceptance since the effort is high to unify the business processes of invoice procedure.

E-invoices do not only save time and money but also protect the environment by using less paper and avoiding the actual transportation. Organizations rethink their behavior on the environment and owning therefore a positive aspect at the side of the employees (Base ware, 2012). The key advantages can be realized when the e-invoice is not only an electronic document, like a PDF file sent via e-mail but rather when structured data sets, e.g., EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) or XML (Extensible Markup Language) are used. Larger organizations are more likely to adopt e-invoices and play a pioneering role in initially persuading their large business partners and thereafter also their smaller business partners follow suit (Koch, 2016). Nevertheless, the expected market penetration for 2017 in the B2B sector differs from country to country with the highest rates of more than 40% in Denmark, Finland, Norway, Sweden, Estonia, Brazil, Chile and Mexico (Koch, 2017).In Germany, 46% of the organizations prefer to send e-invoices and even 53% of the organizations prefer to receive invoices in an electronic format (Seidenschwarz et al., 2017). This implies much room for improvement since the majority of organizations have not adopted e-invoices.

The vision of the German Federal Ministry for Economic Affairs and Energy is that the market provides software and information systems to support e-invoices like the already established electronic banking transactions. However, a uniform standard is a key requirement for adoption of e-invoices (Haug, 2016). An XML-based standard, developed in Germany of the organization FeRD (Forum fuer elektronische Rechnung Deutschland "Forum for electronic invoicing Germany") is the "ZUGFeRD" (Zentraler User Guide des Forums elektronische Rechnung Deutschland) standard. The forum has the task and target to support the acceptance and adoption of e-invoices. For that reason they have elaborated one standard which can be used easily by any organization (FeRD, 2017). Another example is "Finvoice" (also XML-based), which is a frequently used standard in Finland for B2B, B2C and B2G transactions related to bank transactions (Finvoice, 2015). Another format is EDIFACT, which is part of the well-established EDI (Electronic Data Interchange). It includes not only invoices but also orders and other business documents along the entire supply chain. EDI is especially prevalent within value added networks because the data is only machine-readable and can therefore be processed at high speed. Thus, EDI is not affordable for every organization and not worthwhile for every business relationship due to high implementation and transmission costs (Balsmeier & Borne, 1995; Kabak & Dogac, 2010). To involve any company, an easier standard with fewer contractual agreements and lower investment is necessary. Therefore, an XML-based invoice might be suitable for business transactions and shows frequently application for example ebInterface (national standard in Austria) or UBL (universal business language developed for and with participants of various types of industries and businesses). From this background, the following central research question of this paper is derived:

What are the adoption determinants of XML-based invoice standards?

2 Literature Review

Much discussed in scientific literature is the adoption of e-invoices in general. Many challenges and barriers are identified to be factors for the non-adoption of e-invoices in Germany (Mai & Meyer, 2010). Often the advantages like cost saving, more accurately procedure, higher transparency, cutting lead times and efficient business processes are not evaluated very high so that many organizations are not willing to modify their invoicing processes (Haag et al., 2013; European Commission, 2010). In addition, the adoption is associated with costs, especially with creation and procedure of structured data like XML. Software and IT systems are required, which is not available in any organization (Koch, 2016; Bernius et al., 2013).

Research in the field of e-invoices or EDI in general has been carried out for several decades. Most research studies address e-invoice performance and national diffusion (Edelmann &Sintonen, 2006; Hernandez-Ortega & Jimenez-Martinez 2013), influence factors (Penttinen et al. 2009; Haag et al. 2013), or EDI adoption (Iacovou et al., 1995; Chau & Hui, 2001). For example, in 1995 Delhaye & Lobet-Maris focused on EDI and open standard adoption as well as standard message choice pointing out that coordination and cooperation structure are the most relevant factors for EDI adoption.

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Iacovou et al. (1995) considered small and medium sized enterprises and studied their EDI adoption behavior. Organizational readiness, external pressure and perceived benefits are identified adoption determinants. In 2003 Zhu et al. developed a conceptual model to study the adoption of electronic business in general. Edelmann & Sintonen (2006) have studied the reasons for the slow adoption rate of general e-invoices by small and medium sized organization in Finland. Their identified reasons are, e.g., perceived uncertainty or business partner using no e-invoices. A further study but focusing on open standard adoption is the paper of Zhu et al. (2006). They developed a conceptual model and showed that network effects, expected benefits and adoption costs are the main reasons for a standard diffusion. A further study in Finland is published by Penttinen & Hyytiänen (2008).

They studied factors which affect the adoption rate using a qualitative research method. In the Netherlands, Arendsen & Wijingaert (2011) have studied the impact of the government as a launching customer on e-invoice adoption and showed that organizations doing business with governmental organizations are more likely to adopt e-invoices. Juntumaa & Öörni (2011) showed with their study that a positive attitude towards adoption and an intention to adopt e-invoices are not sufficient for an overall adoption. Hernandez-Ortega (2012) has studied the Spanish market and came to the conclusion that organizations working already with IT and digital business documents will adopt e-invoices faster. However, the highest rated key factors are perceived usefulness and compatibility. Hernandez-Ortega &Jimenez-Martinez (2013) concentrated on performance of organizations which regularly use e-invoices. They explained a successful use of e-invoices by a general IT affinity of organizations and resulting habits to work with digital business processes. One explorative study concentrating on XML-based standard succeed is published by Kuehne et al. (2015). They addressed internal as well as external adoption determinants like for instance the available portfolio of documents in the format or the current market situation. Kreuzer (2017) studied the German market using empirical data of 126 business small and medium sized organizations. He pointed out that coercive pressure and degree of technology readiness are the most important influence factors of e-invoice inter-organizational information systems adoption.

3 Research Design and Data Collection

Since little research has been carried out on XML-based invoice standards, we undertook a qualitative exploration to identify influence factors of an adoption in this field. As qualitative methods are able to provide deep insights into organizational contexts and especially for new or unknown areas (Palvia et al., 2003), they are also useful for analyzing the adoption of XML-based invoice standards. Interviews with every age and social group are a typical instrument of data collection in empirically-oriented business sciences. Such interviews are widespread and mostly modelled as guided interviews. Preparation of guided interviews requires time, quality and a certain knowledge level of the interviewer. We developed a structured list of questions to study critical factors of XML-based invoice standard adoption. The experts were from diverse organizations and had a wide knowledge of the adoption of XML-based invoices. The experts were contacted by visiting the large computer fair CEBIT 2016 in Hannover, thereby permitting personal interviews. With the permission of the expert in question, each interview was recorded and the recorded file was used for transcription. These were assessed in accordance with the structured content analysis of Mayring (2014). Table 1 presents an overview of the participants.

The Technology – Organization – External Task Environment (TOE) frame work developed by Tornatzky & Fleischer (1990) serves as deductive categories for the interview analysis and interpretation. We decided to use this model due to its frequently application in empirical research of business process standard adoption (e.g., Kreuzer et al., 2014), EDI standard adoption (e.g., Premkumar et al., 1997), and e-business adoption (Zhu et al., 2006). It is useful to cluster and organize factors influencing the adoption of an innovative technology (in our case XML-based invoice standards). The technology element contains the relevant technologies of an organization (internal as well as external) to adopt an innovation. The organizational element, however, describes the internal situation and characteristics of an organizations. The last element (external task environment) cannot be influenced by the organization and is set exogenous. All three elements together describe the restrictions and chances of a technological innovation, such as an XML-based invoice standard.

For the tool-based content analysis, the MAXQDA software was applied. The uploaded text material provided an opportunity to define the deductive categories accurately in accordance to the TOE-model and add a category description. Through the appropriated coding of the deductive categories, a paraphrase and a generalization for every code was formulated. The paraphrases structured the code by shortening and reforming the quotations of the experts. The generalization formulated a general statement for every paraphrase.

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In some cases it was possible to summarize two or more paraphrases to one generalization and thus to form the adoption determinant. Table 2 provides an extract of the definition, code, paraphrase and generalization.

4 Discussion of Results

We enhanced the traditional TOE-model with our specific adoption determinants of XML-based invoice standard. Since we use the TOE-model for our empirical investigation, the results of the expert interviews are organized according to the same pattern.

4.1 Technology

The technology element of the model describes the characteristics of an innovation, which in our case represent the characteristics of an XML-based invoice standard. For instance, the German-designed ZUGFeRD standard is one hybrid standard, which integrates XML data based on UN/CEFACT CII into a PDF (FeRD, 2017). By way of a combination organizations are able to conduct transactions with both business partners who implemented IT-systems to process the XML data as well as business partners who are unable to process the structured data and just use the invoice image (the PDF file). This approach unifies the process and increases productivity as well as raises the rate of adoption by business partners as a whole (Experts 1; 2; 5). Furthermore, an XML-based standard is simply applicable and transferable to further business documents (e.g., order confirmation or delivery notification) due to its clear syntax and interchangeability of elements. This allows to set this format as a standard. The XML code is machine-readable and is also easily comprehensible for humans due to the text format, even though this is not necessary when it comes to an automated process. The creation as well as the interpretation of XML files are basic functions of current software and are very common among employees in IT departments and is a well-known language (Bohannon et al. 2002), as also confirmed by the majority of our experts. One specific characteristic of XML-based invoice standards is the possibility to develop interfaces to others systems and standard software. Since the complexity of an invoice standard in general is a critical factor for its adoption (Chen et al. 2003; Jeyaraj et al. 2006; Penttinen & Hyytiäinen 2008), the simplicity of an XML-based standard permits an easy integration into current systems. All of our six experts have mentioned the simplified manageability of XML files and thus its suitability to use this format for an invoice exchange.

4.2 Organization

An XML-based invoice standard provides the opportunity of a simple solution of an invoice exchange. However, organizations must invest effort and money to implement and realize the electronic processing. The four experts from organization using already XML-based invoices explain that they have the technical expertise and knowledge in IT so that a successful adoption was possible (Experts 1; 2; 4; 6). But they also point out that some organizations have no IT in use and thus show now willingness to adopt XML-based invoices since they need interfaces to process the data automatically. The experts all agree that in times of digitalization more IT landscape and diverse systems become available and affordable to all kind of organizations (in terms of size and industry) which leads to a simple integration possibility of XML-based invoices. Some experts (2; 4; 6) mentioned that much monetary effort is necessary especially when the entire business process has to be modified and new IT architecture has to be implemented. Working already in digital environment and with IT systems reduces the monetary necessary resources and is therefore a significant adoption determinant for an XML-based invoice exchange. It thereby promotes the adoption rate of XML-based invoice standards. One additional aspect in this respect is that some organizations do not handle enough invoices and therefore avoid an electronic procedure. The effort is evaluated as too high in comparison to the processed low number of invoices (Experts 1; 2; 4; 6). Sufficient high volumes of invoices thus increases the adoption rate of XML-based invoices.

4.3 External Task Environment

Every organization also has external circumstances which may determine the adoption of XML-based invoice standards. Much discussed in studies on innovation adoption (e.g., EDI adoption) are the network effects. If enough business partner use one specific standard, the organization is more likely to follow and adopt the same standard (Zhu et al., 2003; Zhu et al., 2006; Haag et al., 2013). Our experts agree to this statement. They all pointed out that many organizations are skeptical as long as they have not many business partners who use the same XML-based invoice standard. The more user an XML-based standard has, the more organizations are likely to adopt it, too. This represents one of the largest adoption determinants of an XML-based invoice standard. A standard always needs pioneers who start to dispatch or even send requests for the invoice receive.

This can not only occur by organizations but rather public authorities should also be involved and implement processes for an XML-based invoice exchange for a successful adoption.

5 Limitations and Outlook

Reflecting the preliminary nature of our exploratory study, our investigation has some limitations that offer interesting future research directions. A desirable benefit of the chosen design of our study is the ability to isolate particular factors of interest, however, a weakness of the research design is its inability to truly capture other dynamic processes concerning the adoption of XML-based invoice standards within a complex organizational environment and its interfaces with the external environment. Future research should employ other research methods (e.g., a quantitative investigation) in order to provide a triangulation with the presented findings. Furthermore, the study was only conducted with German experts; for that reason cross-national studies to achieve higher level of the generalizability of the results are recommended. Such studies may provide new insights into the diffusion, adoption, and use of XML-based invoice standards.

6 Conclusions

Although recent studies mentioned standard adoption in general, academic research do not properly consider XML-based invoice standard adoption and their determinants. To shed light on this issue, we set forth to answer the question: What are the adoption determinants of XML-based invoice standards? In this context, we have conducted a qualitative study to identify factors that are relevant not only from the perspective of current research but also from practice. We depicted our results in the TOE framework. Within the technological element the simple XML specific characteristics play a crucial role for the adoption of XML-based invoice standards. The organizational element is characterized by internal aspects like monetary and technical resources as well as available knowledge and expertise. Network effects and competitive pressure are adoption determinates set exogenous and are displayed in the external task environmental element. By identifying the underlying mechanism and boundary conditions of XML-based invoice standard adoption, our study serves as a basis for future research in this important and growing area of research. Our study demonstrates a well-founded framework for a successful adoption of XML-based invoices in organizations and additionally provides a basis for future research.

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Tables and Figures

Table 1: Overview of the interviewed experts and relevant data

Expert	Organization size	XML-based standard in use	Experts position	Industry	# codes[1]
1	SME	yes	CEO	Software Provider	18
2	SME	yes	CEO	Management Consulting	20
3	SME	n/a	Member of Standardization council	Public Organization	15
4	SME	yes	Head of research & development	Software/Service provider	11
5	SME	n/a	Advisor	Government Institution	10
6	SME	yes	Consultant	Software/Service provider	9

Table 2: Overview of the interviewed experts and relevant data

Category	Definition	Code	Paraphrase	Generalization
Technolo gy	current situation of IT systems, standardization, XML characteristics	XML is a long established and well know language. It is future-oriented and can be used for any business document exchange, like PDF. Combining both is also an opportunity.	XML is a suitable technology for business document exchange	XML is an easy language to exchange structured business documents.
Organizati on	Internal factors such as monetary and technical resources, number of processed invoices, internal knowledge	The organization which is sending XML-based invoices has to make sure that the standard requirements are fulfilled and that is a lot of work and effort. It always sounds easy but in reality there is much technical effort to realize it.	Sending XML-based standards requires technical knowledge and needs effort in preparation phase.	Technical knowledge and expertise is a prerequisite for XML-based invoice standard exchange.
External Task Environm ent	External factors such as legal requirements, business partner etc.	If you want to become successful in electronic procedure then you always need business partners supporting you how to send XML-based invoices in the preferred standard.	Business partner who support and provide opportunities to create and send XML-based invoices is useful.	Business partners' support increases the adoption of XML-based invoice standards.
…	…	…	…	…

[1] Codes can be understood as statements or interpretations of segments of the interview

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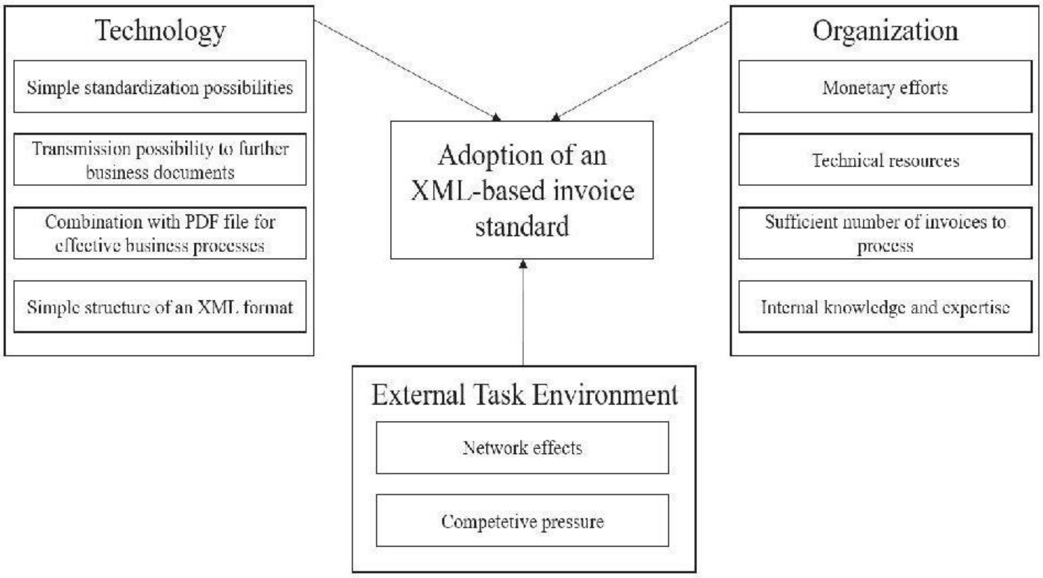

Figure 1: TOE-model for XML-based invoice standard adoption

A.8 Revenue Management meets Carsharing: Optimizing the Daily Business

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Revenue Management meets Carsharing: Optimizing the Daily Business

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Abstract Carsharing is a transportation alternative that enables flexible use of a vehicle instead of owning it by paying trip-dependent fees. In recent years, this service denotes a considerable increase of new providers, which face an exponentially growing number of customers worldwide. As a consequence, rising vehicle utilization leads providers to contemplate revenue management elements. When focusing on station-based carsharing concepts, these are typically based on advance reservations. This makes them perfectly suitable for the application of demand-side management approaches. Demand-side management allows providers to optimize their revenues by accepting or rejecting certain trips. We respectively develop an optimization model for revenue management support. Based on an existing model of the hotel business, special consideration is drawn to carsharing related features. For instance, the implementation of a heterogeneously powered fleet allows providers to choose a certain limit of emissions to fulfill local requirements. We implement the mathematical model into the modeling environment GAMS using the solver Couenne. Conducted benchmarks show sensitivities under the variation of different input values, for example risk tolerances. In contrast to the often used first-come first-serve-principle, the results indicate the usefulness of the developed model in optimizing revenues of todays carsharing providers.

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1 Introduction

Mobility is one major need of today's society. According to a survey by *BMVI* [2], 90% of the interviewed persons left a house at the reference day for various reasons whereas most of the distances (58%) were traveled by car. In large cities with highly developed public transportation systems, vehicle ownership is not always necessary and profitable. Furthermore, environmental awareness is a steadily increasing need [8] and raised the demand for carsharing in recent years [9]. However, carsharing providers are usually focused on profitability. Years of research and empirical knowledge point out that revenue management practices are an essential tool to successfully manage a company [1]. Accordingly, this paper addresses the following research questions:
RQ 1: How can revenue management practices be adapted to carsharing concepts?
RQ 2: How do the decision variables change, if local emission prerequisites vary?

2 Research Background and Optimization Model

Our literature review reveals that there is no published research on revenue management in combination with carsharing and a limited number of publications in combination with car rental. Respective models cover capacity management, pricing and reservation (*Geraghty and Johnson* [4]), assignment of vehicles to random customer requests by accepting or rejecting trips (*Guerriero and Olivito* [5]) and fleet distribution between rental stations, including capacity management at stations and the aspect of demand uncertainty (*Haensel et al.* [6]). Yet none of these models fully matches our focus on the combination of operator's risk aversion, customer satisfaction and demand uncertainty, which are deemed equally important aspects for the emergent business segment of carsharing. A more suitable model is introduced by *Lai and Ng* [7], who address demand uncertainty, operator's risk aversion, and customer satisfaction in the hotel business. Similarities between hotel and carsharing sectors include the availability of rooms or vehicles, the parallels in booking processes and the possibility of reservation purchase. We therefore transfer and adapt their model to suit our carsharing application.

To do so, several assumptions are necessary. The developed model considers different time frames with an interval duration of three hours. Thus, a total of eight time frames per day result. Every started time frame must be paid entirely by the customer. A trip duration limit of 24 hours is set. The revenue can be set individually per time frame by the provider. When the demand is low, the resulting revenue should be low as well, whereas the revenue increases with rising demand. A customer is able to make a reservation for a vehicle in advance. At the beginning and the end of the observation period all vehicles must be available. To allow for overnight trips, such bookings are divided into two bookings.

The optimization model considers six indices. The indices $i = \{1, \ldots, T-1\}$ and $j = \{2, \ldots, T\}$ indicate the starting and ending time frame of the renting period.

$k = \{2,\dots,T-1\}$ represent any time in the observation period while $s = \{1,\dots,S\}$ is the amount of several demand scenarios. We specify three scenarios with a low, middle and high demand level. The stations to be optimized are given by $z = \{1,\dots,Z\}$ and the different vehicle types in terms of propulsion methods are given by $t = \{1,\dots,N\}$. Vehicle type 1 represents a diesel-engined vehicle system, whereas vehicle type 2 is electrically powered. To limit the number of vehicles at any station, $C_{z,t}$ is the capacity at station z for each vehicle type t. A threshold concerning ecological needs is represented by CO_{max}, the maximum average admissible amount of CO_2-emissions over the whole fleet. The emission of the individual vehicle types, based on the propulsion method, is given by the parameter E_t. λ is a trade-off factor between expected revenue and deviation that gives the risk aversion of the management. The probability of a scenario is represented by p_s. A booking with starting and ending time i and j in scenario s delivers a revenue $R^s_{i,j}$. The corresponding demand at station s is given by $U^s_{i,j,z}$. $w_{i,j}$ is a parameter that weights the number of bookings with starting and ending time i and j. If $w_{i,j}$ is low, more bookings with the corresponding starting and ending times are satisfied. Finally, the decision variable $x_{i,j,z,t}$ provides the total number of accepted bookings for vehicle type t at station z with starting and ending time i and j. Due to the optimization of the operational planning level of a carsharing organization, costs for stations and vehicles are not considered. The values for the external parameters, which are obtained in corporation with a carsharing organization are given in Table 1.

Table 1 Parameters - Initial solution

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
$C_{1,1}$	25	$C_{1,2}$	13	$C_{2,1}$	20	$C_{2,2}$	10
CO_{max}	2,184g	E_1	3,302g	E_2	0g	λ	1
p_1	1/3	p_2	1/3	p_3	1/3	$w_{i,j}$	1

$$\begin{aligned}\text{Max}\quad & \textstyle\sum_{s=1}^{S}\left(p_s\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}(j-i)R^s_{i,j}x_{i,j,z,t}\right)\\ & -\lambda\textstyle\sum_{s=1}^{S}\left(p_s\left|\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}(j-i)R^s_{i,j}x_{i,j,z,t}\right.\right.\\ & \left.\left.-\textstyle\sum_{s=1}^{S}\left(p_s\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}(j-i)R^s_{i,j}x_{i,j,z,t}\right)\right|\right)\\ & -\textstyle\sum_{s=1}^{S}\left(p_s\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}w_{i,j}|U^s_{i,j,z}-x_{i,j,z,t}|\right)\end{aligned} \tag{1}$$

$$\text{s.t.}\quad \textstyle\sum_{i=1}^{k-1}\sum_{j=k+1}^{T}x_{i,j,z,t}+\sum_{j=k+1}^{T}x_{k,j,z,t}\le C_{z,t}\quad \forall k,z,t \tag{2}$$

$$\textstyle\sum_{j=2}^{T}x_{1,j,z,t}\le C_{z,t}\quad \forall z,t \tag{3}$$

$$\textstyle\sum_{t=1}^{N}x_{i,j,z,t}\le \max\{U^s_{i,j,z}\}\quad \forall i,j,z, \tag{4}$$

$$\frac{\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}(j-i)E_t x_{i,j,z,t}}{\sum_{i=1}^{T-1}\sum_{j=i+1}^{T}\sum_{z=1}^{Z}\sum_{t=1}^{N}(j-i)x_{i,j,z,t}} \leq CO_{max} \quad (5)$$

$$\sum_{i=1}^{T-1}\sum_{z=1}^{Z} x_{i,8,z,2} = 0 \quad (6)$$

$$x_{i,j,z,t} \geq 0 \quad \forall i,j,z,t \quad (7)$$

$$1 \leq i < j \leq T \quad \forall s \in \Omega \quad (8)$$

The objective function (1) consists of four terms to maximize the daily revenues of the carsharing provider. The first term of this function maximizes the expected revenue in dependence of the occurrence of a certain scenario s. The average absolute deviation of the revenue is subtracted in the second term and is calculated by the absolute value of the difference of actual and expected revenue. The absolute deviation of the demand is subtracted in the third term and is calculated by the absolute value of the difference of demand and number of accepted bookings. Constraint (2) is the capacity restriction for the vehicle types and secures that the number of rented vehicles does not exceed the fleet size. (3) ensures that the number of accepted bookings does not transcend vehicles available at the beginning of the observation period. According to constraint (4), the number of accepted bookings must be smaller than the maximum demand of all scenarios. A maximum level of the CO_2-emissions is expressed in constraint (5) and secures that an average emission of all vehicles within the fleet is not higher than certain thresholds. To recharge electric vehicles, equation (6) guarantees that the number of accepted bookings of vehicle type 2 in time frame eight is equal to zero to ensure the recharging process of the electric vehicles, to be available at the beginning of an operating day. Furthermore, the number of accepted bookings must not be negative (7), (8) specifies the validity range of starting and ending times frames.

3 Results, Sensitivities and Benchmarks

In this section, we present the results which are obtained by solving the mathematical model from section 2 using GAMS 24.7.1 and the solver COUENNE 0.5 with a preset gap of 0%. Table 2 shows the number of accepted bookings for every combination of starting time and end of rental for station 1 and 2 with respect to propulsion method. In time frame 3, 18 diesel-engined vehicles are rented at station 1. 13 of these rentals are returned at time frame 5 and the remaining five vehicles end at time frame 8. The objective function value amounts to 6,831.74 €. Compared to the often used first-come first-serve-principle, the presented model increases the objective function value by more than 49% (2,271.64 €) per day. The explanation for this significant difference lies is the improved resource utilization: profitable trips take precedence over less profitable or short term reservations. The initial solution comprises overall 339 rented time frames. 224 are served by diesel-engined vehicles and 115 by electric vehicles. 184 rented time frames are operated at station 1 whereas the remaining 155 are operated at station 2.

Table 2 Accepted bookings - Initial solution

	Station 1														Station 2													
	Diesel							Electric							Diesel							Electric						
Starting Time Frame \ Ending Time Frame	2	3	4	5	6	7	8	2	3	4	5	6	7	8	2	3	4	5	6	7	8	2	3	4	5	6	7	8
1	3	3	1	-	-	-	-	11	2	-	-	-	-	-	6	4	2	-	-	-	-	10	-	-	-	-	-	-
2		3	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
3			-	13	-	-	5			-	-	-	11	-			-	7	-	-	7			-	-	-	10	-
4				-	-	-	6				-	-	2	-				-	-	-	4				-	-	-	-
5					-	-	1					-	-	-					-	-	2					-	-	-
6						-	13						-	-						-	7						-	-
7							-							-							-							-

Table 3 Accepted bookings - Sensitivities and Benchmarks

CO_2 low	Station 1														Station 2													
	Diesel							Electric							Diesel							Electric						
Starting Time Frame \ Ending Time Frame	2	3	4	5	6	7	8	2	3	4	5	6	7	8	2	3	4	5	6	7	8	2	3	4	5	6	7	8
1	-	-	-	-	-	-	-	11	2	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
2		-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-		-	-	-	-	-	-
3			9	-	-	-	-			-	-	-	11	-			9	8	-	-	-			-	-	-	10	-
4				-	-	-	-				-	-	2	-				-	-	-	-				-	-	-	-
5					-	-	-					-	-	-					-	-	-					-	-	-
6						5	1						-	-						4	2						-	-
7							-							-							-							-

In order to derive the model sensitivities we reduce the parameter for the maximum CO_2 emission across the whole fleet to 1,000g per time frame. This equals a reduction by approx. 55%. As a consequence, a decrease in the number of rented time frames for diesel-engined vehicles is observed. The results are presented in Table 3. A decrease in rented time frames of vehicle type 1 by 175 to 49 with regard to both stations is obtained. The objective function value decreases to 3,032.29 € which is, compared to the initial solution, a reduction of approx. 44% (3,799.45 €). Compared to the first-come first-serve-principle a 69% (1,241.98 €) improvement in the CO_2 low case can be achieved using the presented revenue management model.

4 Discussion and Conclusions

The objective of this paper was to optimize the daily revenue of a carsharing organization. An existing mathematical model to optimize the room occupancy of hotels was adapted to station-based carsharing. This was possible through similarities between the operating modes of both business segments. The resulting model allows to implement differently structured networks with regards to stations and vehicles. To fulfill (future) local prerequisites in terms of emissions, a CO_2 threshold over the average fleet can be set. This results in an assignment of differently powered vehicles to the existing stations without exceeding the predefined threshold. To demonstrate the general functionality and the influence of the parameter modifications with regards to emissions, we used the two extrema of possible propulsion methods, diesel-engined and electrically powered vehicles. In addition, we assume 0 g/km CO_2-emission for the electric vehicles. Future research should address certain limitations of our approach. Possible enhancements include the creation of shorter time frames and a minute- and/or kilometer-based billing. Additionally, the charging process can be optimized by allowing charging as needed rather than at the end of a period. To conclude, our developed model shows the applicability of revenue management to optimize the daily business of station-based carsharing services operating with heterogeneous fleets.

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A.9 Comparison of Standard and Electric Carsharing Processes and IT Infrastructures

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Comparison of Standard and Electric Carsharing Processes and IT-Infrastructures

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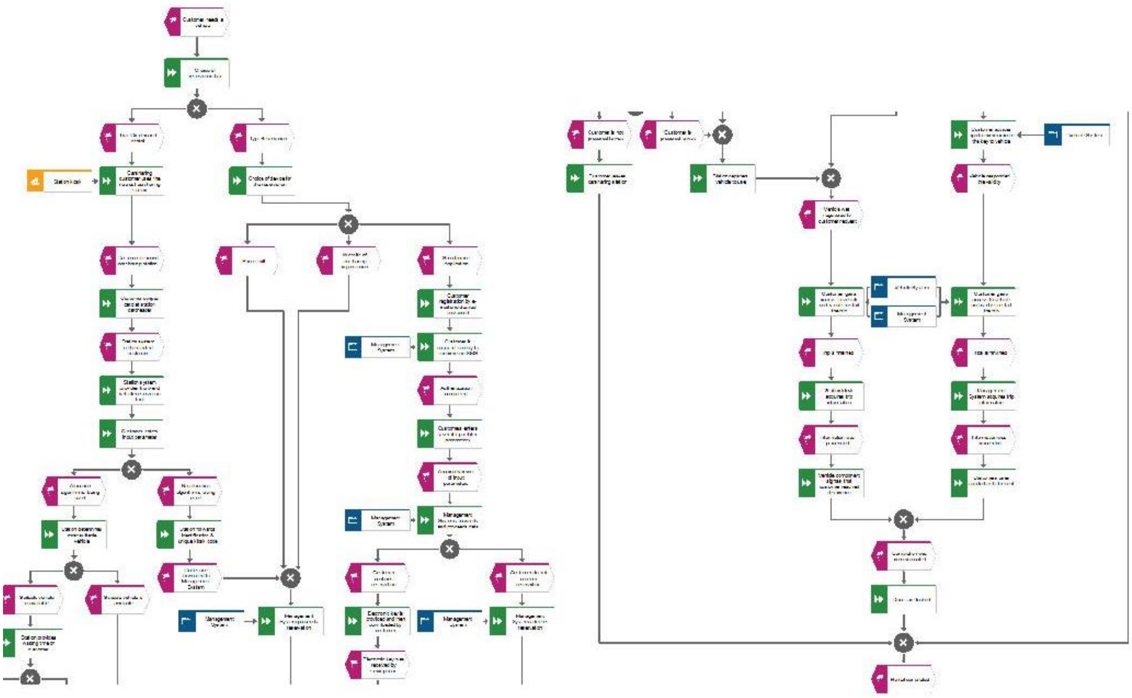

Business Process: Trip Registration

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Abstract

In the last decades, carsharing became increasingly popular as a sustainable alternative to privat car ownership. Carsharing is particularly suitable to cover mediumrange distances and can be linked to the public transport of major cities (intermodal mobility). Within this context, the integration of electric vehicles represents an opportunity to further protect the environment and potentially save energy cost. In order to introduce coherent and successful electric carsharing, the business process has to be developed. Thus five categories (Relocation, Distribution, Evaluation and Simulation, Incentives and Billing, and Infrastructure) are analysed and illustrated in business processes to compare standard carsharing concept with electric carsharing concept. However, as its differences are so minor and therefore hardly representable, the comparison is only verbal presented. The differences mainly concerned the structure of the sub processes, such as the choice and setup of mathematical models and respective algorithms concerning the relocation and distribution of vehicles and the evaluation of the carsharing system itself. The general business processes, which can be used for both concepts, are illustrated as event-driven process chains by the modelling software ARIS. The processes Trip Registration System, Vehicle System and Management System are illustriated in the appendix.

Keywords

Carsharing, business process, electric carsharing, comparison, Trip Registration, Vehicle System, Management System, event-driven process chain

1 Introducation

In the last decades, carsharing, which describes "a distinct business process wherein CSOs [carsharing operators] typically provide their members with short-term vehicle access" (Stillwater et al., 2008), became increasingly popular as an alternative form of transportation. Carsharing providers around the world recorded impressively rising numbers of active members. Within a period of five years, between 2006 and 2010, the worldwide number of registered members almost tripled to a total of about 1.25 million, whereas the fleetsize almost doubled to 31,000 vehicles in 2010 (Shaheen and Cohen, 2013). This development may mainly be accredited to an increasing environmental consciousness and sense of responsibility of vehicle users towards nature, as well as financial factors (Buchinger and Braet, 2013; Shaheen and Cohen, 2013). Including economic uncertainty, rising energy and private car ownership costs, as well as efforts for increasing vehicle efficiency in order to reduce greenhouse gas emissions, those factors are encouraging drivers to actively seek alternatives to a regular vehicle ownership. Therefore, as one of these alternatives, carsharing allows individuals to remain mobile and flexible, thus gaining the advantages of a private automobile, while avoiding responsibilities and costs that result from owning a private vehicle (Shaheen and Cohen, 2013; Markel, 2010; Stillwater et al., 2008; Katzev, 2002). Furthermore, research has shown that carsharing also actively contributes to reduce one's greenhouse gas emissions by 55 percent, while also helping to avoid other negative side-effects of an increased traffic density, for instance unsolicited congestions or air pollution in cities (Shaheen and Cohen, 2013; Lee et al., 2012; Parent and Gallais, 2002).

As worldwide greenhouse gas emissions grow nonetheless due to a continuous increase in overall transportation, the interest in so called smart or innovative mobility solutions like electric vehicles and respective carsharing concepts has grown even further (Alli et al., 2012; Barth et al., 2003; Figueiredo et al., 2002). Therefore, since electric vehicles produce little to none emissions at all, carsharing companies have deployed electric vehicles worldwide in order to test their applicability and economic viability in real environments (Shaheen and Cohen, 2013; Alli et al., 2012). However, the electric vehicle industry and e-carsharing providers are facing various obstacles in penetrating the market (Buchinger and Braet, 2013). Besides economical and organisational challenges, electric vehicles are critically renowned by customers as a result of their short driving ranges, the extensive charging times, or their high acquisition costs (Buchinger and Braet, 2013). Likewise, carsharing companies are facing issues incorporating electric vehicles in their services, since they supposedly require adjusted IT-infrastructures and Intelligent Transportation Technologies, which in turn allow for a maximisation of returns by fully exploiting the vehicles resources and the companies capacities. This is especially important for both conventional and, moreover, e-carsharing companies, considering that they have to think and act economically in the first place (Buchinger and Braet, 2013; Markel, 2010). Furthermore, as electric vehicles are comparably expensive in their acquisition, they consequently reach their amortisation point later than conventional vehicles and thus, require a frequent utilisation by customers, which can only be guaranteed by adjusting and optimising the carsharing companies IT infrastructure and associated business processes (Alli et al., 2012). Yet, since any intrusions, changes, and additions to IT systems used also have an impact on the underlying business processes, the applicable sub processes presumably have to be adapted to the new structures as well.

Despite this urgent need, research has confined itself to mostly analysing and describing essential information technologies and respective carsharing systems, subsequently creating a research gap. In order to fill this gap, this paper tries to analyse the common conventional and e-carsharing infrastructures, based-on which the business processes will be modeled and compared. Therefore, after the introduction and the description of the purpose and value of this paper in chapter one, the differences be-tween casual car rental and carsharing, as well as a brief distinction of the common carsharing systems will be provided in chapter two. The first section of the third chapter, however, deals with specific intel-ligent transportation technologies that are typically being deployed in carsharing systems and the mo-tives for their utilisation, thus allowing for a more universal comprehension regarding the structure of these initiatives. The consecutive section builds on these previous findings and relates the individual technologies with one another, thus establishing a general IT-infrastructure, based on which the model-ing of the business processes will be conducted, although due to their extent, the respective results will be presented in the appendix of this paper. In the fifth and second to last chapter, the actual compari-son of the business processes of conventional and e-carsharing systems will be conducted, therefore giving answers to the initial research question, whereas the last chapter provides both a critical acclaim concerning the results of the paper and a final conclusion.

2 Carsharing: A Distinction

As mentioned in the introduction, the term carsharing describes and encompasses the provision of a variety of vehicles by a company that can be rented by a broad range of customers for either cooperative or profit-oriented purposes, thus presenting an alternative to privately owned vehicles, since customers can easily access and use vehicles if needed without owning them (Katzev, 2002; Barth and Shaheen, 2002; Parent and Gallais, 2002). In this way, carsharing differs notably from casual car rentals, as users don't have to pay for a whole day, but for the actual time or mileage they were using the vehicle (Parent and Gallais, 2002; Katzev, 2002). Moreover, by participating in carsharing projects, individuals can avoid the majority of fixed costs that come with vehicle ownership. Usually, the carsharing companies pay insurance costs, taxes, maintenance and repairs and levy them partly onto the fees that subscribers have to pay per mile or hour (Katzev, 2002; Stillwater et al. 2008). Subsequently, members still pay these fixed costs indirectly, but since shared-vehicles are commonly used by 10 to 15 individuals, these costs are split accordingly (Katzev, 2002). Nevertheless, using shared-vehicles is solely cost-effective, if an individual drives less than 10,000 kilometers a year (Mannan, 2001). However, as the term carsharing is relatively general in nature, often used interchangeably, and gives no further information about the different concepts that companies or groups of individuals might apply; it also complicates the analysis, description, and comparison of shared-use vehicle programmes (Barth and Shaheen, 2002). In order to provide a classification, Barth and Shaheen (2002) came up with a framework that allows for an easy distinction between the commonly applied concepts. According to their framework, shared-use vehicle systems can generally be separated into station based concepts, casual carsharing concepts and a variety of hybrid models in between (Barth and Shaheen, 2002). As for this paper, a rough distinction between both will suffice, since for the purpose of this paper, carsharing and respective systems will be in the focus, whereas the station based concept was omitted.

The main purpose of station based concepts is to support commuters in their daily routine by providing them with vehicles, facilitating their commute to and from local public transport stations, thus providing a comfortable way of transport (Barth and Shaheen, 2002; Parent and Gallais, 2002). Thereby, operators initially intended not only to increase the number of bus or train passengers by providing a comfortable manner of transportation, but also to decrease parking shortages. Typically, individuals use these station vehicles to get from home to a nearby transit station, take the bus or train to their desired destination, and then commute to their workplace by renting another station vehicle or by taking any other alternative form of transportation (Barth and Shaheen, 2002). However, as station vehicles are mostly intended to improve transit connectivity, the user-to-vehicle ratio is lower compared to carsharing, which runs between ca. 10-15 users (Barth and Shaheen, 2002; Katzev, 2002). The latter of both concepts, carsharing serves a more general purpose than station based systems. Instead of solely supporting public transportation and transit, carsharing companies offer their vehicles for a broader range of their subscribers' needs. Although in both concepts the vehicles are usually rented for local trips several times a day by different individuals, carsharing vehicles are being used for rather infrequent needs, such as shopping or the transport of goods (Parent and Gallais, 2002; Katzev, 2002; Barth and Shaheen, 2002). Yet, since varying tasks often require different types of vehicles and carsharing organisations are inclined to satisfy their customers' needs, they commonly proceed to diversify their fleets (Katzev, 2002). This fleet is usually distributed and stationed around strategic spots throughout the city to shorten walking distances, thus providing a convenient access that in turn increases customer satisfaction (Barth and Shaheen, 2002). Once a vehicle is chosen and rented, the carsharing procedure can differ notably between the various organisations according to the type of rental they provide. Historically speaking, carsharing operators almost exclusively offered so called two-way-rentals or round-trips (Weikl and Bogenberger, 2012). Here the user starts his trip at a parking lot or a station, proceeds to finish his business, and once he is done, is obliged to return the vehicle at the exact same station where he started (Jorge et al., 2012; Clemente et al., 2013). As follows, these two-way rentals offer decreased flexibility for customers, but, apart from that, it also facilitates the management of the fleet. Since demand patterns can be more easily assessed and stocks more easily planned, sophisticated relocation strategies and respective systems will not be necessary, which in turn leads to lower prices (Jorge et al. 2012; Clemente et al., 2013). One-way rentals on the other hand allow a more flexible utilisation of the vehicles, because customers do not have to return the vehicle at a specific station, but at any station or parking lot provided by the carsharing organisation (Clemente et al. 2013; Weikl and Bogenberger, 2012; Barth and Shaheen, 2002). An even more flexible form of these one-way systems is the so called free-floating system. Free-floating systems eliminate the constraint that customers have to return their vehicles at a parking station and enables them to leave the vehicles anywhere within the vicinity of a certain district where the carsharing organisation has rented parking lots, thus further promoting flexibility (Weikl and Bogenberger, 2012).

In conclusion, one-way and especially free-floating systems also result in increased managerial requirements (Clemente et al., 2013; Barth and Shaheen, 2002; Weikl and Bogenberger, 2012). As customers can park at any desired station or parking lot, neither an even distribution nor the availability of a vehicle can be guaranteed. This is primarily caused by the customers' demand that can differ strongly between the various spots and throughout the day. So it can come to pass that shared-vehicles are sometimes parked at stations and locations that are far from strategic points of interest where the demand is high. As a consequence, those vehicles might become stranded in these areas of low demand, which in turn might lead to a shortage of vehicles at the other stations (Weikl and Bogenberger, 2012; Clemente et al., 2013; Barth and Shaheen, 2002). In order to tackle these logistic problems, carsharing organisations have to deploy certain relocation strategies which will be discussed later in the paper, as they are important when it comes to modeling the business process.

3 Carsharing-Relevant Intelligent Transportation Systems and Technologies

One of the most important factors that determine the success, economic viability, and user acceptance of carsharing concepts is the use of intelligent transportation systems (ITS) and technologies (Barth et al., 2003). Especially in multi-station, one-way or free-floating shared-use vehicle systems, the application of ITS is crucial. Although these systems are more attractive to the customers since they offer more flexibility, they also complicate the management of the operator's fleet (Barth and Todd, 2000). Considering that in most of these cases, the relocation is passively conducted by the customer and consequently depends solely on their utilisation pattern and only in rare cases, the vehicles are relocated manually by the operator, one-way rentals often result in vehicle stock imbalances among the various available stations (Bruglieri et al., 2013; Weikl and Bogenberger, 2012). This in turn can greatly influence the customer satisfaction, since in case no vehicles are available, a customer request cannot be fulfilled and therefore, he is obliged to take an alternative means of transportation (Lee et al., 2012; Clemente et al., 2013; Barth et al., 2003; Barth and Todd, 2000). Moreover, this so called service-ratio is, according to various studies, the most critical factor for the satisfaction of a carsharing subscribers with their providers and thus, the distribution must be effectively managed to promote carsharing as a feasible alternative to privately owned vehicles (Lee et al. 2012; Barth and Todd 2002; Clemente et al., 2013).

Furthermore, besides an increased service-ratio leading to a higher customer satisfaction, the application of ITS also improves the overall convenience and user-friendliness of the whole rental process, consecutively leading to an expanding market growth (Lose, 2010; Barth and Todd 2002, p. 52; Shaheen and Wipyewski 2003, p. 10). Various processes, such as recording the driven distance or the reservation of and access to shared-use vehicles, that would otherwise have to be documented or conducted manually, can be automated with ITS. For instance, the utilisation of an in-vehicle tracking system in Car Link II, a carsharing pilot programme from the San Francisco Bay Area, replaced the customer's former obligation to manually fill out the travel log after each rental. This in turn not only saved some of the customers time, it also allowed for an automated, accurate billing procedure (Shaheen et al., 2000; Shaheen et al., 2004; Shaheen and Wipyewsk,i 2003). Furthermore, reservation systems allow customers to rent their vehicles in advance, giving both operators and customers planning security, while also allowing management systems to maximise the vehicle usage (Barth et al. 2003). Customers also profit from vehicle access systems that facilitate the check-in and access procedures, as customers nowadays can, provided that the system is very advanced, even access vehicles by solely using their smartphones (Cugola and Rossi, 2012). Moreover, the application of ITS allows an improvement of the overall efficiency of the service and reduces accruing costs. Since respective technologies not only permit determining the optimal fleet size and their distribution based on simulations that estimate the mobility demand, they can also help to manage these resources more economically (Clemente et al., 2013; Barth and Todd, 2000). By constantly logging all vehicle data and data from station kiosks via ITS, a more detailed analysis of the system can be performed. This in turn provides more accurate information on vehicle operation and the effectiveness of the system management techniques, as well as improving the accuracy of the initial simulation through experience (Barth and Todd, 2000). Furthermore, technologies such as ignition immobilisation when a user finished his trip or devices that allow vehicle tracking while the customer is still driving, can lead to insurance discounts, whereas an automated billing procedure reduces labour costs, because the system replaces the task usually being performed by employees (Clemente et al., 2013; Shaheen and Wipyewski, 2003).

All in all, these technologies are very important for carsharing systems and operators, not just because they determine their success, but also because they influence the choice of systems in-use, as well as the system architecture and the underlying processes. Since this paper focuses on modeling the business process of e-carsharing systems and its comparison to conventional carsharing systems, an analysis of the system architecture as well as the pertaining system and technologies is crucial for an understanding of the process. For that reason, both technologies and existing architectures will be described briefly in the following sections.

3.1 Technologies and Function

The following section will concentrate on introducing the various technologies and the reasons for their common appliance in carsharing systems, which in turn results in a better comprehension of the status of the carsharing infrastructures nowadays.

3.1.1 Reservation

The reservation procedure, which comes after the registration of a new user, strongly depends on the applied technology as well as management decisions of the respective carsharing service provider. However, the main purpose of these reservation technologies, such as a reservation software, is to maximise the operators' financial revenues by minimising the unused time of each vehicle (Barth et al., 2003). This is usually accomplished through the application of a selection algorithm that chooses the most suitable vehicle for a certain task or trip (e.g. depending on the estimated distance and the fuel levels or the state of charge (SOC) of the available vehicles) as well as it tries to balance the distribution of vehicles across the various stations or parking lots a company deployed or rented (Barth et al., 2003). These functions are, however, located in station kiosks, or in an integrated management system.

Usually, when a user wants to reserve a vehicle, he has to specify certain parameters, for instance the date and time, his current location and destination, as well as special requests, such as baby seats (Fukuda et al., 2003; Mannan, 2001; Cugola and Rossi, 2012). At this point, the application of intelligent reservation systems can further promote user convenience after multiple reservations by analysing these specifications and identifying preference patterns of the customers. These preferences can then be displayed as trip suggestions the next time the customer logs in (Lose, 2010). In general, reservation systems can be distinguished by whether they are operated manually, automatically or, the most common approach, which is through a combination of both (Barth et al., 2003; Fukuda et al., 2003). Systems relying solely on manual reservations (e.g. via phone) are operated by designated employees of the carsharing organisation that check the availability of each vehicle according to the customer's specifications and reservations of other clients (Barth et al., 2003). Reservations from automated systems on the other hand do not particularly require staff, since the search is mostly automated through the aforementioned allocation algorithms. Customers are consequently provided with a list of suitable vehicles after entering the specifications and thus, can choose their vehicle on their own (Barth et al., 2003; Cugola and Rossi, 2012). However, as reservations sometimes require spontaneous adjustments (e.g. in case of technical problems), they can still be monitored and adjusted by employees (Barth and Todd, 2002). Furthermore, reservation systems allow two different approaches of renting a vehicle. These can either be exclusively in advance, on-demand reservations, or a combination of both. Advance reservations enable customers to reserve a vehicle for a particular date and time, thus blocking its availability for other customers. Yet, there are examples of carsharing systems, where a reservation does not necessarily imply that it is blocked for other customers (see Shaheen et al. 2004). In these systems, the carsharing operator has to offer incentives to other potentially interested users in order to prevent them from taking the vehicle without paying heed to the customer who came first (Shaheen et al. 2004, p. 70). In some systems, customers also have to confirm a reservation up to 15 minutes before the rental period starts. This allows the system to make vehicles available once again in case a customer changed his mind last-minute, which, as follows, facilitates the maximisation of vehicle usage, and additionally provides a certain protection from misuse, as of course vehicles are rented but never paid for (Cugola and Rossi, 2012; Shaheen et al., 2004). On-demand rentals, which can also be regarded as immediate reservations, lead to increased requirements concerning the system and fleet management. Customers can simply choose and rent a vehicle right before the trip, which especially comes in handy, when one could not foresee the need for a vehicle beforehand, hence increasing the overall user-friendliness of the service (Barth et al., 2003). However, charging different fees for both on-demand and in advance rentals can facilitate an even distribution between both types of reservations. When a carsharing system offers on-demand rentals, a so called check-out process takes the place of the reservation process. Users can simply walk up to a station kiosk and use the kiosks terminal or, in more modern systems, using mobile applications instead. In order to successfully rent a shared vehicle, users are then supposed to work through various input data screens entering the required information (Barth and Todd, 2000; Barth et al., 2003). After the check-out procedure, the user can obtain vehicle access and start the trip (Barth et al., 2003; Shaheen et al., 2004; Hara et al., 2000).

3.1.2 Vehicle Access

In carsharing systems, various technologies, including hardware and software solutions, exist that allow customers to obtain vehicle access, while also providing certain degrees of security to the carsharing operators (Barth et al., 2003). These are both external solutions at the proximity of the vehicle and station, as well as internal solutions placed in the vehicle itself, that conduct the authentication procedure.

One of the easiest ways to grant customers access to shared-use vehicles is placing a casual lockbox near the operating carsharing stations (Khan, 2012). This lockbox contains the keys of the vehicles that are parked nearby. When a customer wants to use one of these vehicles, he is required to carry a special key with him that he initially received from the carsharing company upon registration. This key allows access to the lockbox and thus, the vehicles themselves (Barth et al., 2003). An even easier, but less secure technique is to replicate a vehicles key and to distribute these copies among all members, hence allowing anyone access without further requirements. This, however, undermines the security reservations should provide, since the availability of a reserved vehicle can not be guaranteed, because anyone can take the vehicle at anytime. As a consequence, honorary systems have to be introduced that enforce customers to omit already rented vehicles, possibly through monetary incentives (Barth et al., 2003).

A more advanced access technique is the employment of so-called smartcards as a substitute for key-based solutions, thus dispensing the need for both a lockbox and its access key. The smartcard allows access either to the station kiosks, or directly to the vehicles (Barth and Todd, 2000). In order to start the registration procedure, users generally swipe their smartcard at a station kiosk. This, in turn, starts an internal process, in which the station checks and usually validates the owner's card (Barth and Todd, 2000). Afterwards, the user is required to swipe the card next to the card reader, which is usually installed under the windshield. However, there are three different approaches of how users gain access via smartcards. The first approach, which is similar to the common key solution, generally allows all customers to gain access to any vehicle at any time. The second approach grants access exclusively to specific users, which is achieved through an additional personal identification number (PIN). This PIN is transmitted to the smartcard after the checkout and prior to the vehicle access. The desired vehicle can be accessed only when the PIN coincides with the reservation data (Barth et al., 2003). In both of these cases, the smartcard solely grants access to the vehicle, the ignition is usually started via casual keys that are physically chained to the car (Alli et al., 2012). Securitywise, the third approach goes even further, as for the ignition process the user is also required to enter a specific PIN code on a terminal in the vehicle. If both codes, the one being transmitted by the system and the one being entered by the customer, coincide, the ignition starts and the user can begin the trip (Shaheen et al., 2004). In some cases, vehicle access is required multiple times during a trip. Solely when a user leaves the vehicle at his destination, the system will log him out permanently. Otherwise, the user can always gain access anew via the smartcard (Fukuda et al., 2003).

3.1.3 Vehicle Data Acquisition and Supervision

Another essential feature being provided by the application of ITS is the supervision of the shared-use vehicles. Technologies such as special micro-controllers, or Embedded Electronic Boards, are both solutions that are connected with diverse sensors being placed in the vehicle. These integrated and mutually interacting technologies automatically record information like remaining battery charge, current voltage and vehicle location, driven distance, and even door statuses. This in turn enables other systems to process this vehicle-related information for the daily business (Fukuda et al., 2003; Barth and Todd, 2000; Cugola and Rossi, 2012). For example, supervision technologies allow systems or the operating staff to recognise unwanted incidents, such as motor and tire problems or dangerously low fuel and battery levels, early on (Fukuda et al., 2003; Hara et al., 2000). This facilitates the premature taking of preventive measures, consequently avoiding more severe problems. For example, if the battery of an electric vehicle is almost depleted, an employee of the carsharing operator can establish a connection to the respective vehicle and communicate its need to recharge to the user. Otherwise, without supervision, the vehicle would have eventually stalled, hence requiring a road service needing to tow him to the next fuel or recharge station.

These automated supervision processes not only increase the convenience of customers since they do not have to record information such as the driven distances themselves, but they also support and enable additional functions. Monitoring the door statuses for example allows the operators or the operating system to notice when a customer forgot to lock the vehicle, which then can be resolved by manually sending a command that eventually locks the doors (Fukuda et al., 2003). In the UCR Intellishare carsharing system, the micro-controller replaced a card reader, hence controlling vehicle access, as well as not only realised when a user reached his destination, but it also turned off the ignition and locked the doors. Furthermore, the supervision facilitates an automated billing process, because most carsharing operators charge monthly fees both for subscription and based on the duration of vehicle-usage and the driven distance (Shaheen et al., 2004; Barth et al., 2003). However, one of the most important aspects of vehicle supervision is that by providing vehicle information, supervision enables other systems to determine vehicle availability (Shaheen et al., 2004; Barth and Todd 2002, p. 54). As for electric vehicles, their trip range greatly depends on the current state of charge (SOC), thus influencing the availability of the vehicles (Barth and Todd, 1999). Without its monitoring and displaying, many customers would probably be stalled mid-trip once the battery is depleted, which in turn would strongly influence their satisfaction with the service. Therefore, monitoring fuel levels and other parameters allows evaluating whether a vehicle suits a trip or not. Moreover, since the current location of a vehicle can help a system to determine the vehicles time of arrival, vehicle supervision also supports the overall fleet management, because based on this information, the system can estimate the time a vehicle will be available for rental once more (Karbassi and Barth, 2003). Furthermore, constantly monitoring the location of each vehicle by including GPS devices or radio transponders enables relocation systems or the operating staff to identify and prevent an uneven distribution of vehicles (Barth et al., 2003; Clemente et al., 2013; Karbassi and Barth, 2003). Moreover, by tracking vehicle locations during the trips, organisations can analyse driving pat-terns, which facilitates the identification of popular spots where customers regularly make intermediate stops while using the service. This in turn allows carsharing operators to identify suitable places for new carsharing stations. Besides this, tracking technologies could also be used to compare the actual user behavior, demand patterns and trip length with those being predicted by the simulation models, thus providing possibilities to improve the overall accuracy of the latter (Karbassi and Barth, 2003; Barth and Todd, 2000; Millard-Ball and Murray, 2005).

3.1.4 Vehicle Navigation and In-Vehicle Messaging

Beyond vehicle location tracking, GPS and similar devices can also actively assist customers during their trip. Navigation systems relying on these technologies can provide various functions, for instance navigational aids that increase a customer's convenience by consequently directing them to their chosen destination or by displaying points of interests such as filling stations (Barth et al., 2003; Barth and Todd, 2000).Furthermore, carsharing operators can apply additional systems such as Advanced traveller infor-mation systems (ATIS). These systems provide customers not only with more detailed real-time traffic information, allowing them to avoid traffic congestions and to choose the most favourable route to their destination, but they also offer additional public transportation information, which enables them to chose alternative means of transportation (Figueiredo et al., 2001; Kitamura et al., 2000). However, in-vehicle devices (e.g. casual LCD screens) that can display this information are required to enable these functions.

The vehicle data acquisition systems described previously can be connected with those LCD displays, thus adding additional functions such as displaying billing information i.e. rental fees. Moreover, the display can show both messages from the staff or automated warnings, for instance when a user leaves the designated service area or the fuel level is considerably low (Hara et al., 2000). Additionally, as the connection between the in-vehicle device and the operating system is not solely one-sided, the users can also use the display to send messages to the operating staff. This could become useful in case the vehicle has unexpected issues (e.g. flat tires), or when the user has questions concerning their exact location (Kitamura, 2002; Barth et al., 2003). However, in-vehicle messaging can also be arranged by the application of stationary smartphones that can establish a connection with the operating center at any desired time (Hara et al., 2000; Fukuda et al,. 2003). Latest carsharing concepts like the Green Move system are even going as far as that they almost refrain from applying any in-vehicle devices for reasons of communicating, since most of the interactions between the vehicle, the operation center and the users can be arranged via their own smartphones and the respective app (Alli et al., 2012).

3.1.5 Simulation and Relocation

As mentioned at the beginning of this chapter, forecasting and simulation systems play an integral role in the success of carsharing systems. The simulations can help to drastically improve the efficiency of the carsharing system, since they can both aid in planning and determining the best configuration of a carsharing system in advance or by constantly analysing the overall performance of the system (Barth and Todd, 1999; Xu and Lim, 2007; Kitamura, 2002). Moreover, through forecasting the demand and supply of the shared-use vehicles, these simulations could help to save initial setup costs, which emerge from their buying. Thus, by determining the optimal fleet size in advance, carsharing companies could avoid the acquisition of too many vehicles in the first place, which then would supposedly be idle most of the time due to the exceeding supply (Cepolina and Farina, 2012; George and Xia, 2011). Furthermore, simulation models could help to actively ease vehicle imbalances by suggesting relocation strategies; while others can help to identify the best depot locations (Clemente et al., 2013). For example, Clemente et al. (2013) proposed that by applying a user-based relocation strategy drawing from suggestions of a simulation using real-time monitoring of shared-use vehicles, the availability and distribution of the operators fleet could be improved significantly (Clemente et al., 2013). By simulating the future demand and monitoring the current distribution, the simulation system could provide users with incentives (e.g. discounts on their rental fees) that would influence their travel behaviour to such a degree that they would eventually follow the systems suggestions by parking their vehicles at less frequented stations, thus effectively minimising distribution imbalances (Clemente et al., 2013).

Although based on the same idea of simulating the demand and supply, Xu and Lim 2007 suggested a different relocation strategy that involved the companies own staff. If the simulation anticipated an exceeding demand or vice versa, employees would move a vehicle from one station to another, which is also commonly known as operator-based relocation strategies because of the involvement of the operators staff (Xu and Lim, 2007; Weikl and Bogenberger, 2012). Hence, as these simulations improve both the daily business and the initial configuration of the carsharing system, these simulation models can and should be applied throughout the whole carsharing process.

3.2 Integrated Systems Infrastructure

Because of the undeniable importance for the economic viability of carsharing systems, most of the modern carsharing companies have integrated the individual technologies and systems described in section 3.1 into more sophisticated systems that help in facilitating their individual interactions and thus, optimise the whole process (Barth and Todd, 2002). Therefore, in the following chapter a general system infrastructure drawing from the descriptions about the structure and setting of five different carsharing programmes as well as their corresponding findings is proposed. This infrastructure in turn serves as the basis of the carsharing business processes, which will be derived accordingly. However, due to their spatial proportions, these processes will be displayed in the appendix of this paper. Furthermore, both the knowledge about a general infrastructure, as well as the processes occurring within, are vital for the accurate modeling of the business processes, which is one of the main purposes of this paper. In general, many carsharing programmes are comprised of three highly integrated systems that mostly assist different stages of the rental process, which is why they can roughly be divided into a trip regis-tration system, a management system, and a vehicle system. However, although they are seen as dis-tinct, these systems strongly interact with one another and sometimes even share functions (e.g. regis-tration) to provide the most efficient, user-friendly, and easily manageable service (Barth and Todd, 2000).

3.2.1 Trip Registration and Return System

The trip registration system's infrastructure is comparably simple, showing high similarities between the different carsharing programmes, though the input devices can differ considerably. In general, a mixture of phone, Smartphone, web and station kiosk based options were offered for registration and return, thus mainly supporting the beginning and end phase of the business process. However, many of the older carsharing systems used station kiosks both for rental of shared-use vehicle and authentica-tion of customers, whereas modern systems mostly depend on phone plus internet for registration and smartphones plus in-vehicle devices for authentication (Cugola and Rossi, 2012). Since reservations via phone or the company's web site are handled separately by the management system, the process being conducted by the static carsharing stations and smartphone apps will solely be described in the following.

Both the UCR Intellishare as well as the Kyoto Public Car programmes used static carsharing stations, which are generally used for check-out and check-in purposes, thus enabling spontaneous on-demand rentals as well as reservations (Barth and Todd, 2000; Kitamura 2002). After an initial registration for the carsharing programme, users can simply walk up to the station of interest, swipe their smart card at the station kiosk, consisting of a card reader besides a touch screen display, and start the check-out procedure. In order to register a vehicle, after swiping the smartcard at the kiosk, the customer has to enter various trip related information as described in 3.1.1 (Barth and Todd, 2000; Fukuda et al., 2003; Mannan, 2001). Depending on whether the station has a selection program at its disposal or functions solely as an input device, the search request is processed. Concerning the first case, using an allocation algorithm, the station chooses the appropriate vehicle according to fuel-level or state of charge of the battery and frequency of use (Barth et al., 2003). However, if there is no suitable vehicle available, the station will show an additional screen that displays the estimated waiting time (Barth and Todd, 2000). In case the station does not incorporate an allocation algorithm, it solely serves as a host for a web-browser that enables access to the company's website via http, hence providing online registration features. The respective vehicle selection is then carried out via the management system. However, only if the identification codes from the smart card as well as the station kiosk match the ones being saved on the server database, will the registration finally be completed and the user can proceed to retrieve his car (Barth and Todd, 2000; Hara et al., 2000). As for the vehicle access, it is handled by either the vehicle system, or the smartphone app, whereby both are in close communication with the management system (Alli et al., 2012). Concerning return, most carsharing stations only play a subsidiary role, since it is commonly handled by the in-vehicle system. Just in case the in-vehicle system cannot establish a direct connection with the management component, or the station itself manages vehicle registration and selection, a carshar-ing station will be required. Trip information or information indicating that a user finished his trip, such as the keys were placed in the glove box, can then be uploaded from the vehicle system to the station, which in turn can lock the vehicle (Barth et al., 2003; Hara et al., 2000). However, when it comes to carsharing systems using electric vehicles, the deployment of carsharing stations is also essential, since they provide the required infrastructure for recharging the shared-use vehicles (Fukuda et al., 2003; Hara et al., 2000). Furthermore, after the user finished a trip with an electric vehicle, the latter can supposedly signal to the management system that they are being recharged.

An even more advanced technology to both register and unlock shared-use vehicle is the use of external devices such smartphones. One of these examples is provided by the Green Move project from the Politecnico di Milano University. After an initial registration and authentication, which includes the creation and confirmation of the account, the customer can download a smartphone app. This provides a search function, which the customer can utilize to search for and reserve, if successful, suitable vehicles (Alli et al., 2012). Furthermore, the smartphone app accelerates the search process, since it automatically determines information that is required for reservation, such as the current position of the user (Alli et al., 2012). After this procedure, the Green Move Center, which can be seen as a management system, confirms the reservation and issues an electric key. This key is directly associat-ed with the specific reservation and contains all data that is relevant for identifying the rented vehicle, e.g. date, time, as well as an encrypted ticket (Alli et al. 2012; Cugola and Rossi, 2012). Thus, an internet connection is mandatory during the initial reservation process. The user then proceeds to download this key via his smartphone. Once he finishes downloading, he is free to go to the specified vehicle and unlock its doors. This is enabled via communication technologies (e.g. Bluetooth or near-field communication) that establish a connection between the vehicle and the smartphone, where the smartphone sends the key that was previously downloaded to the vehicle sys-tem and its access system that is being integrated in the vehicle. In return, this in-vehicle system downloads the reservations from the management system and unlocks the doors, provided the information and the keys from both systems match (Alli et al., 2012; Cugola and Rossi, 2012). Once the registration is finished, the smartphone is not required to communicate with the Green Move Center anymore but with the vehicle system, which is why the initial internet connection is replaced by a blue-tooth connection that enables the exchange between smartphone and in-vehicle system (Alli et al., 2012). During the trip, the user can leave and access the vehicle at any time, using only his smartphone (Cugola and Rossi, 2012). However, once the user wants to terminate the trip and return the vehicle, he can use a special command being provided by the smartphone app. The smartphone then issues a message to the in-vehicle system which invalidates the user's reservation ticket, thus depriving him from the possibility of opening the vehicle anew (Alli et al., 2012).

3.2.2 Vehicle System

The vehicle system combines a variety of ITS technologies that enable various essential functions, which are primarily related to the trip itself. Besides vehicle supervision and data acquisition, it allows for an external and internal communication, vehicle navigation and access, as well as user authentication, and it strongly interacts both with the management system and the user. As with the Trip registration system, the set-up as well as the functions and processes being supported by the Vehicle system are quite common among the various carsharing companies, despite minor differences concerning the hardware utilised. In general, the first process being supported by vehicle system is vehicle access. Usually, a device like a simple smart card reader is placed within the vehicle. When a customer walks up to the car and swipes the card above the windshield, the card reader automatically checks the specific user ID, estab-lishes a connection with the management system, and compares it with the one being saved in a data-base (Barth and Todd, 2000; Shaheen et al., 2004; Kitamura, 2002). However, as mentioned in the previous chapter, vehicle access can also be performed by the customer's smartphone. Therefore, card readers are not specifically mandatory, as these customised solutions such as the Green Box from the Green Move programme or the so called On-Board Communications unit from the Rent-a-car sys-tem, Japan, can handle authentication as well (Cugola and Rossi, 2012). Nonetheless, in all carsharing programmes an onboard unit assessed user specific identification criteria, established a connection to or received a message from the system management and compared them with those that were either received beforehand or that were saved separately on a database (Barth and Todd, 2000; Shaheen et al., 2004; Fukuda et al., 2003; Hara et al., 2000; Cugola and Rossi, 2012). Once a user is authorised for access, the doors will unlock and, depending on the system, the user either simply starts the engine or can retrieve the required keys from the glove box inside the vehicle (Fukuda et al., 2003; Alli et al., 2012).

The next process being supported by the vehicle system is gathering vehicle information. Vehicle supervision can be seen as the main process, besides vehicle access, of the vehicle system, since it is important for both the management system and respective processes, as well as it enables further functions and thus processes during the trip (Bianchessi, 2013). As said before, a close monitoring of the shared-use vehicles allows for an efficient fleet management, such as determining vehicle availability or relocation strategies, by the management system (Barth and Todd, 2000). In order to do so, devices like the ones mentioned in 3.1.3 can either be connected to sensors that regularly check for the required information or, as for electric vehicles, directly to the electric core unit (Alli et al., 2012). The provided information usually encompasses fuel levels or state of battery charge, charging signals, vehicle miles driven, time of use in and out of the vehicle, vehicle location (usually via GPS) and destination, and door as well as motor statuses (Barth et al., 2003; Alli et al., 2012; Shaheen et al., 2004; Hara et al., 2000). However, some management systems constantly monitored these factors during the whole trip; some deemed it sufficient to download the data at the beginning and end of each trip, while others retrieved it every 30 minutes (Fukuda et al., 2003; Hara et al., 2000; Cugola and Rossi, 2012). Having GPS-based or similar devices installed for reasons of supervision opens further areas of appli-cation of the vehicle system and comprises of another process. A navigational device can, if desired, determine the most advantageous route to a target, as well as provide additional information concern-ing traffic or specific points of interest (Kitamura et al., 2000; Barth et al., 2013). Thus, once a customer enters his destination, the navigational system leads him there by constantly monitoring the vehicle location and calculating the route. Besides facilitating fleet management and user trips, vehicle supervision also allows for an indirect, incident-based communication between user, vehicle, and man-agement system. Since management systems constantly monitor the state of the vehicle, users can either be warned in advance, e.g. in case the battery is low, or when an acute problem occurs (Kitamura, 2002; Cugola and Rossi, 2012). In both cases, management systems can react promptly by conducting effective measures such as calling external services, sending emails or other kinds of alerts.

Apart from an indirect communication between user and vehicle, the vehicle system often comprises of means that enable external communication and thus support another important process. As described before in the assertion of the respective technologies, users can often establish a direct contact to the operating staff of the carsharing provider. By using stationary in-vehicle devices such as cell phones or built-in LCD screens, users can ask for guidance, assistance and even extend the time of rental if needed (Barth and Todd, 2000; Fukuda et al., 2003; Cugola and Rossi, 2012). Since the vehicle system controls vehicle access, it is also responsible for locking the doors once the user reaches his destination. In most cases, the user is simply obliged to return the vehicle keys to the glove box and take his personal belongings. This is registered by the vehicle system, which then locks the doors and, furthermore, sends relevant information such as trip data or current position to the management system (Mannan, 2001; Hara et al., 2000).

3.2.3 Management System

The management system is the most integrated and complex system being used in carsharing infrastructures. Since its functions span fleet management, handling of reservations and vehicle supervision, accounting, simulation and forecasting, and because it is partly required for vehicle access, the management system can also be seen as the core system of the carsharing programme (Hara et al., 2000; Barth et al., 2003; Cugola and Rossi, 2012; Milliard-Ball, 2005). Regarding the various carsharing concepts, the management system is consistently linked to and interacts with a database that saves all the relevant administrative and operative information (e.g. registration, user, and vehicle data) required for the supported processes (Shao and Greenhalgh, 2010; Cugola and Rossi, 2012; Barth and Todd, 2000). Comparing the registration and return component, as well as the vehicle system with the management system, the latter assists processes all over the various stages of the rental and even before. Furthermore, contrary to the vehicle system that merely serves the purpose of collecting vehicle data and granting vehicle access, the management system interprets this information based upon decisions will be made (e.g. initiate relocation procedures or change associated strategies). Thus, the processes are far more complex than the ones taking place in the other system components.

The initial process that is supported by the management system and belongs to the general fleet management process is the interpretation of overall vehicle data, upon which the management system intelligently determines the optimal fleet size, the distribution of vehicles, and relocation strategies (Weikl and Bogenberger, 2012; Clemente et al., 2013). In this regard, dual or single modules can be applied, whereas the first approach consists of utilizing both an offline planning and an online optimization module. The purpose of the offline module is to identify repeating demand patterns by analysing historical vehicle position and booking data that was gathered between each analysis. After finishing the analysis, the results will indicate the demand for each station ranging from highest to lowest. Furthermore suggestions concerning the ideal amount of vehicles per station will be made and therefore, the overall fleet size can be determined (Weikl and Bogenberger, 2012; George and Xia, 2012). However, since the offline module does not continuously monitor vehicle data, these analyses are conducted in chronological, such as daily, weekly, annual and event-based, intervals. Based upon these analyses, the management system then preselects a case-sensitive and viable relocation strategy for each station exhibiting a mismatch between demand and supply with the intention to reach an even distribution of vehicles (Weikl and Bogenberger, 2012). For instance, the system could determine general incentives irrespective of the current vehicle distribution, thus applying a user-based relocation strategy, which would be an effect for the whole day. The goal of these incentives would be to induce a shift of demand from stations of high demand to stations of low demand and vice versa (Weikl and Bogenberger, 2012). After preselecting appropriate relocation strategies, the aforementioned online optimisation module is required to determine and, finally, to choose the most efficient strategy out of these feasible options. Instead of using historical data, the online module continuously monitors the distribution of vehicles and compares the current with the nominal state, which was previously computed by the offline module (Weikl and Bogenberger, 2012). Depending on whether this comparison reveals that a station generally exhibits a surplus or a lack of vehicles, the system operator takes further measures. In the latter case, the operator needs to intervene in order to restore a balanced distribution, whereas in the first case no further actions are required, since the supply is greater than the demand. However, when an intervention and thus, relocation is necessary, the online module compares the suggestions that were made by the offline module. During this comparison, the online module evaluates the cost of each suggestion through the application of a specific cost function, whereby the strategy with the lowest costs will eventually be chosen (Weikl and Bogenberger, 2012). After this initial process, which is to be seen more or less independently from the actual rental procedure, since it is a general process not being bound to a specific rental, the reservation process begins. Provided that the customer previously conducted the registration procedure, where he is required to fill-in a form concerning personal data on the provider's website, he can start the reservation. The management system runs a server that provides a website and, more specifically, an online search function where the customer is required to state the date and time of rental, as well as the desired vehicle, the location and whether he needs further services (Barth and Todd, 2000; Fukuda et al., 2003; Mannan, 2001; Cugola and Rossi, 2012). Therefore, this process resembles the one being supported by the trip registration procedure, provided the carsharing stations dispose of a selection program. However, some of the management systems can identify these preferences (e.g. station and vehicle) and, after some reservations, can show them as suggestions the next time the customer wants to rent a vehicle, thus facilitating the rental process (Lose, 2010). Nonetheless, in case the customer immediately requires a vehicle, the system computes his request automatically and in real-time. Otherwise, the Management System commences the search for an appropriate vehicle using a vehicle allocation algorithm that considers the previously entered specifications, although it is limited to vehicles that are parked nearby the user (Cugola and Rossi 2012; Barth and Todd 2000). This process of distributing available vehicles as a function of specifications also belongs to the overall fleet management function and process. However, further search parameters that were not actively specified by the customer but which are nonetheless considered in the choice of vehicle are, when it comes to electric vehicles, current battery state or when the user wants to rent the vehicle at a later time, the estimated battery charge (Cugola and Rossi, 2012). Additionally, the system determines the distance of the trip, as it is quite important to assess the overall battery consumption and thus, the expected recharge time after rental (Fukuda et al., 2003; Barth and Todd, 2000). In case that at least one shared-use vehicle with the defined parameters is available at the nearest station, a reservation is both issued to the customer, as well as saved in the reservation section of the database (Fukuda et al., 2003; Cugola and Rossi, 2012; Barth and Todd, 2000). Depending on the system in use, some carsharing programmes require the user to confirm the reservation, since it would otherwise be erased (Cugola and Rossi, 2012; Shaheen et al., 2004). However, in most systems the reservation would then be sent to the vehicle system or, in other cases, the vehicle-component would retrieve the reservations itself as soon as that customer approaches the vehicle (Fukuda et al., 2003; Hara et al., 2000). As follows, at this point of rental the management system also plays an integral role for vehicle access because the system indirectly manages it through the vehicle system, as the latter will solely grant access to customers with valid reservations.

After determining relocation strategies, providing and handling the reservation and vehicle distribution, as well as granting vehicle access, the management system also deals with the accumulation and interpretation of vehicle data (Barth et al., 2003; Fukuda et al., 2003). As mentioned before, vehicle information is required to both choose viable relocation strategies and to handle customer requests. However, although these functions can mostly be provided by simply supervising various vehicle parameters, their sole observation sometimes does not suffice to manage a huge vehicle-fleet. Additionally, the great amount of data that accompanies this supervision also needs to be interpreted by native software such as the "T-Rex system", which is deployed at the Green Move project. This software not only enables the management system to identify recurring events and situations, allowing certain actions to be taken for prevention or solutions, but it also facilitates further functions provided by other systems (Alli et al., 2012). For this purpose, so called "event observers" such as the vehicle system send the data to the T-Rex system. Afterwards, the system analyses and processes these observations based on a certain predefined set of rules and automatically forwards them to other systems known as "event consumers" that require this information. These rules are more or less the heart of the event processing engine, since they define certain scenarios and thus, specify how the data is to be interpreted (Cugola and Rossi 2012,. For example, the event observers forward position as well as speed-related event data to the system, upon which it can identify certain events such as traffic congestions or accidents, since the rules imply that in case many vehicles stop abruptly on the same route, the latter occurred (Cugola and Rossi, 2012). Having identified similar situations, the management system can therefore advise the customer to change his route, consequently helping him to avoid these time consuming incidents.

As one of the last processes, the management system is required to calculate the fees of each trip (Fukuda et al., 2003; Hara et al., 2000). However, since the vehicle system constantly supplies the management system with trip related data, this process is less complex than fleet management processes. Usually, the fee is determined automatically by considering both the driven distance and the rental duration and can be displayed either constantly during the trip or upon reaching the destination (Fukuda et al. 2003; Hara et al., 2000). Moreover, since the customers are rarely required to immediately pay for the trip after their rental, the management system is obliged to save the billing information of each customer in the respective section of the operator's database. This information is then used and summed up each month to determine the fees to be paid by the customer (Shaheen et al. 2004, p. 43).

In conclusion, the management system can be seen both as front-end, as well as back-end system. On the one hand, it directly interacts with the customer since it provides the web-content (front-end) and direct means of communication (e.g. user interface in the vehicle) and on the other hand, it is comprised of underlying sub processes (e.g. fleet management and vehicle supervision), where it interacts with the vehicle system, thus exhibiting back-end system features (Bianchessi et al., 2013; Alli et al., 2012).

4 Comparison of Carsharing vs. E-Carsharing Business Processes

In general, the process being depicted in the previous chapter can be seen as a generic business process. It could easily be adapted for both conventional as well as e-carsharing initiatives, since the applied systems, the infrastructure, as well as the underlying processes are very common amongst the various carsharing programmes that were analysed in this paper. This distinctive overlapping can be ascribed to the circumstances that the application of ITS is a crucial factor for the success of all carsharing programmes, as it not only notably improves the efficiency and manageability on the part of the carsharing providers, but corresponding technologies and systems also increase the customer's convenience before, during, and after the rental process (Lose, 2010; Barth and Todd, 2002; Shaheen and Wipyewski, 2003). Regardless of the vehicle in use, providing customer services such as enabling reservations, implementing vehicle navigation devices, automated billing procedures, and means of communication is very important for the overall customer satisfaction. Moreover, monitoring tools that contribute vehicle data, respective systems that can interpret and process this information, as well as fleet management systems that use this data to continuously determine appropriate relocation strategies, evaluate and improve the systems effectiveness, and handle customer requests are also crucial for these types of carsharing environments. Thus, as the technology and the systems architecture of electric vehicle carsharing programmes can be applied to conventional carsharing initiatives and vice versa, the business process is valid for both cases (Bianchessi et al., 2013; Barth and Todd, 2000). However, although the general business process is quite similar, both types of carsharing exhibit minor differences that primarily can be related to fundamental fleet management processes provided by the management system and, secondarily, more superficial processes located in the vehicle and trip registration system. Furthermore, although it does not affect the processes, some of the specified tasks are more important for e-carsharing than for conventional carsharing concepts and therefore require more attention or they take place in different system due to infrastructural differences. Consequently, as the following chapter aims at comparing these differences, it will be divided into the five sub-sections "Relocation", "Distribution", "Evaluation and Simulation", "Incentives and Billing", and "Infrastructure".

4.1 Relocation

As for the choice of viable relocation strategies, which is a process being provided by the management system, it is also greatly influenced by the selection of the vehicles being used in a carsharing programs. In general, determining the most suitable relocation strategy is achieved by solving optimisation problems which aim at maximizing specific key figures. Concerning carsharing, optimisation features a two-fold issue, in which the aim lies both at increasing the number of fulfilled requests, consequently improving the vehicle availability being especially important for customer satisfaction, as well as reducing the costs accruing from vehicle relocation (Touati and Jost, 2011; Barth and Todd, 1999). However, whereas the availability of conventional vehicles between rentals is only restricted by customer reservations and possible maintenance, further constraining factors have to be considered regarding electric vehicles. One of these additional factors is the remaining charge of the electric vehicle's battery after each rental and/or relocation process. Generally, it can be stated that the residual battery charge directly influences the potential of the distance driven in an electric vehicle in a proportionally linear fashion. This in turn implies that by each missing percent of battery charge, the maximum range decreases by the exact same amount. Following this logic, a vehicle being halfway charged can only cover half the distance (Bruglieri et al., 2013). Since the possible travel range strongly depends on residual battery charge and the travel range determines once again whether a vehicle is suitable for a certain request, it is especially important for e-carsharing operators to choose a relocation strategy that positively affects the battery charge in order to increase vehicle availability and to shorten recharging times (Bruglieri et al., 2013; Touati and Jost, 2011). Therefore, in the paper from Bruglieri et al. (2013), they tested a feasible operator-based relo-cation approach by modifying a common, so-called Rollon-Rolloff Vehicle Routing problem (RRVRP) for the setting of e-carsharing systems (see Bodin et al. 2000). Usually, these Rollon-Rolloff Vehicle Routing problems are optimisation problems, thus belonging to the field of combinatorial optimization, where the target is to minimise the total travel time being required of a certain entity in order to fulfill all the required tasks, consequently also leading to lower costs (Bodin et al., 2000). Although this problem and the pertaining mathematical solution, the mixed integer linear programmeming, were initially developed to minimise the travel time of tractors moving a single trailer from a cer-tain destination to disposal factories, it could easily be transferred to the setting of conventional carsharing and, more specifically, to distribution and relocation. In the latter case, instead of focusing on tractors, one would now aim at operator-based relocation schemes and consequently an employee or sets of employees that can only relocate one vehicle at a time. However, whereas the standard RRVRP and pertaining mathematical solutions would also apply for conventional vehicles, it had to be modified in order to allow for evaluating e-carsharing relocation strategies (Bruglieri et al., 2013). As a consequence, the authors added a specific variables such as one representing the residual charge. In both cases, pickup and delivery, the request would be defined by a certain location (i.e. the carsharing station), time and the residual charge. Regarding delivery request, where a vehicle is relocated to a location lacking available vehicles, this request could either be served when the residual charge was high enough for the trip succeeding the relocation (delivery), or when the minimum required charge level would be achieved through recharging before the vehicle would be required a new by a customer (Bruglieri et al., 2013). However, by modifying the initial problem by adding variables like the residual charge, the authors were not only able to eventually determine that their relocation approach would suit to the setting of e-carsharing programmes, but they were also able to conclude how much staff would be required to serve a given amount of requested relocations, thus helping to reduce operational labour costs (Bruglieri et al., 2013).

In conclusion, the evaluation of the economic feasibility of relocation strategies for electric shared-use vehicle requires the consideration of additional factors, such as recharging times and the remaining battery charge, in order to provide reliable as well as valid results on which carsharing operators can make appropriate decisions. Thus, the process of choosing respective strategies has to and does vary slightly between conventional and electric carsharing programmes. Nonetheless, it has to be mentioned that these differences in most cases solely concern the process of evaluating relocation strategies. Otherwise, the applied strategies are quite analogous among the different observed carsharing programmes and vary between user-based (i.e. incentives) and operator-based strategies (i.e. staff).

4.2 Distribution

The distribution of vehicles, which in fact is the underlying process of reservation systems, also displays various minor differences between e-vehicle and conventional carsharing programmes. One of the more general differences concerns fundamental decisions regarding the type of trips that are allowed for the customers. Although these decisions have the identical outcomes respecting the underlying processes of both kinds of carsharing programmes, they are worth mentioning, since they have rather drastic effects on the overall business process. One of the major disadvantages of electric vehicles is their relatively low travel range which, as mentioned beforehand, ranges from about 40 miles to 140 miles (Cugola and Rossi, 2012; Barth et al., 2003). Additionally, since the battery charge defines electric vehicles possible travel range, respective vehicles experience limitations regarding the customer requests they can serve (Barth and Todd, 1999). However, these limitations are in fact the reason why there is an almost perfect fit between electric vehicles and carsharing. In general, it has been observed in various studies that shared-use vehicles are predominantly used to make trips that take place in the relative vicinity of the customers. For example, Fukuda et al. (2003) observed, that the distances driven by electric vehicles rarely exceeded 15 miles, which lies well within the supported maximum travel range, whereas the mileage driven averaged around nine miles per trip (Fukuda et al., 2003). Because of this, electric vehicles are especially suitable for short one-way rentals, where customers can drop off the vehicle at any desired station, since it guarantees plenty of recharging opportunities while the vehicles are idle between rentals (Barth and Todd, 1999; Fukuda et al., 2003; Shaheen and Wright, 2001).

In contrast, conventional vehicles do not suffer from limited travelling ranges, since they can be refueled during the trip without having to conduct prolonged recharging procedures. This, in turn, is one of the main reasons, why the application of two-way rental schemes especially fits the use of conventional vehicles depending on fossil fuels. Two-way rentals are often characterised by longer trip distances, as customers are required to return the vehicle to the station, where they initially started this trip and not to the station which is close to their destination (Bruglieri et al., 2013). Therefore, the distance of each trip approximately doubles, when carsharing operators only allow for two-way rentals (Shaheen et al., 2004). Although both types of carsharing programmes could apply to two or one-way rentals, it is, respectively, necessary to state these differing applicability's of electric vehicles and conventional vehicles. The decision on which kind of rental should be allowed has strong impacts on the underlying business processes. Since vehicles are to be returned to their starting station when it comes to two-way rentals, corresponding carsharing systems do not require relocation strategies. One-way rentals, by contrast, are often disadvantaged vehicle distributions, since customers can return the vehicle to a station wherever they desire (Weikl and Bogenberger, 2012; Clemente et al., 2013; Barth and Shaheen, 2002). As follows, because conventional carsharing processes often apply two-way rentals, they differ from their respective electric vehicle counterparts in that respect, that they do not dispose of processes that both evaluate and determine appropriate relocation strategies and processes facilitating these relocations. Nonetheless, as carsharing operators have freedom of choice regarding their type of rentals, these disparities are not by default.

Besides these very general differences based upon the distinct applicability of electric vehicles and conventional vehicles, the distribution process of both types of shared-use vehicle programmes also further enact more minor dissimilarities. These are, again, due to the fact that electric vehicles run on electric energy and batteries to drive and thus, are subject to a limited range and need constant recharging. As these factors have to be taken into account while handling customer requests and trip planning, the distribution process has to be adjusted. In conventional carsharing systems, managing the distribution of vehicles is fairly simple. Since the vehicle system constantly provides the management system with vehicle data (i.e. desired destination, current location, vehicle miles travelled, fuel level) and the management system receives, manages, and therefore knows all future reservations, the latter can easily determine the availability of the shared-use vehicles (Barth and Todd, 2003). Unless a vehicle needs to relocated, requires maintenance because of technical issues or is already reserved in the period required by the customer, a vehicle allocation algorithm will intelligently evaluate vehicles suitability for rental and, eventually, will assign it to a customer request (Barth et al., 2003). Albeit most of the parameters of this vehicle allocation algorithm overlaps with the ones being considered in e-carsharing programmes, the use of electric vehicles nonetheless adds further requirements to the distribution process and, consequently, to the allocation algorithm in-use. As for electric vehicles, it is, previous to the trip, a premise for the management system not only to calculate the travel distance that is to be expected from the request, but also to determine the current drain caused by electronic devices and air conditioning, as these factors are linked with battery consumption and, therefore, the ensuing recharge procedure (Barth and Todd, 1999). Considering these variables, the management system can ascertain whether the vehicle disposes of sufficient charge to supply the requested trip. When the charge level matches the estimated travel range, the reservation will be accepted (Fukuda et. al, 2003). Furthermore, when a customer request lies farther in the future, trip time calculations can be conducted and taken into consideration by the management system to determine the future availability of the shared-use vehicles for the requested timeframe. These trip time calculations generally include variables such as boarding, transit, and unloading times as well as the time required to prepare a vehicle for another trip (Barth and Todd, 1999). Furthermore, whereas for conventional vehicles the time required for preparing them anew for another trip is focused on maintenance or relocation procedures, for electric vehicles this variable should also include recharging times. However, the recharging times would presumably only be taken into account regarding availability, when the residual battery charge does not suffice to satisfy a request, otherwise the electric vehicle would not require a recharging procedure. In order to ensure a sufficient battery level as well as an increase of the average battery charge, e-carsharing operators could establish a time-buffer between each reservation, consequently implying an additional process compared to conventional carsharing systems (Barth et al., 2003).

Besides these differences in the vehicle distribution process, the management system also should dispose of additional processes that, otherwise, would not be required in conventional carsharing systems and corresponding business processes. These vehicle routing processes originate from Energy Shortest Path Problem and aim at maximising the battery charge after each rental, therefore increasing the operational profitability and customer satisfaction, both being especially important for e-carsharing initiatives (Touati and Jost, 2011). This so called Energy Shortest Path Problem (EnSPP) is, in general, alike the Shortest Path Problem with Resource Constraints (SPPRC), which could also be applied to conventional carsharing systems. However, instead of being constrained to time resources, one is constrained to battery charge (Touati and Jost, 2011; Irnich and Desaulniers, 2005). Consequently, this problem again belongs to the field of combinatorial optimisation, whereas in this case of ESPP, the feature of electric vehicles to recharge batteries during deceleration phases is considered and used to determine as well as to provide the most appropriate route that would achieve the initial aim of maximising trip related battery charging (Touati and Jost, 2011). In short, the problem can be modeled as a directed graph, in which a set of nodes (representing actual geographical locations) is introduced and connected by a set of arcs. Each arc (representing the route taken), in turn, is related to a certain value, which is either positive or negative, depending on whether the battery loses or actually gains charge. Regarding the conventional SPPRC, this value would represent i.e. the cost and/or the time that is required to take a certain path (Irnich and Desaulnier, 2005). Eventually, the aim would consist of finding an origin-destination route that optimises the travel time while also complying with a set of predefined resources along each node of the path (Irnich and Desaulnier, 2005). Therefore, in case of the EnSPP, the resource constraint is the battery charge, which cannot fall below zero, and, serving as an additional side constraint, specific time windows. Consequently, when the vehicle would be returned to a customer after the designated time window, a path would be deemed unfeasible and therefore, would, eventually, not be considered (Touati and Jost, 2011).

All in all, the major differences between conventional and e-carsharing systems and their distribution processes lie within the underlying fleet management. Processes such as vehicle allocation, which deal with choosing appropriate vehicles for customer requests or planning their routes, have to consider the particular characteristics of electric vehicles. Since factors such as the residual battery charge and recharging schemes strongly influence the availability either through a limited travel range or the constraint to recharge a vehicle, need to be included in corresponding allocation algorithms and processes. Furthermore, through finding routes that maximise the residual battery charge after each rental, the overall vehicle-availability and, consequently, the profitability and customer satisfaction of e-carsharing systems can further be improved, whereas respective procedures of conventional carsharing systems would solely aim at reducing the resources required to handle a request.

4.3 Simulation and Evaluation

Besides varying processes concerning the reallocation and allocation of vehicles, e-carsharing systems comprise of further differences dealing less with the daily tasks and operational processes, but more with initial configuring and continuous evaluating of the system itself. As the limited travel distance of electric vehicles still entails the major drawbacks concerning customer satisfaction with electric vehicles and pursuing carsharing systems, carsharing operators need to ascertain that future customers can draw on an appropriately planned station infrastructure and vehicle fleet (Cepolina and Farina, 2012). This is especially important for electric vehicles, since establishing such an infrastructure is comparably expensive, but nonetheless mandatory for providing sufficient recharging opportunities (Tuoati and Jost, 2011). Furthermore, because the number of vehicles at each station can easily become imbalanced due to a varying demand throughout the day, it is even more important to maintain an appropriate number of stations and parking spaces with rechargers; otherwise customers would periodically not be able to recharge their vehicle, therefore limiting its travel range (Clemente et al., 2013). As for the respective mathematical model, this issue, also known as facility location problem, requires a slightly different approach when adapting it to electric vehicles (Wang, 2008). Although up to now there is a significant lack of literature tackling this issue, certain papers, however, can give an impression of which adjustments might be necessary when projecting the facility location problem on e-carsharing systems. In general, these adjustments consist of changing some of the various parameters and side constraints to fit the new scenario. Usually, the aim of minimising the set-up costs would remain the same for both types of carsharing (Wang, 2008). Nonetheless, additional variables describing the remaining amount as well as maximum battery charge and, moreover, the electric energy that was being recharged, were introduced to evaluate the situation at each station. Hence, a configuration that decreases the set-up costs while providing an appropriate infrastructure was to be found (Wang, 2008; Cepolina and Farina, 2012). As for the side constraints, they also mostly cover aspects pertaining to the required or the remaining battery charges, as well as energy consumption ascribed to recharging processes. Some more general constraints concern the stations service capacities or restrictions that define location capacities, consequently restraining the number of respective recharging stations that ultimately being considered (Wang, 2008).

Besides differences in processes that enable carsharing operators to determine the ideal set-up configuration of carsharing systems through minimising their set-up costs, further distinctions can be identified relating to continuous performance evaluation processes of this system, therefore often being a daily task. In order to test a systems effectiveness, several measures have to be developed providing details about the conditions of the system in-use. These performance indicators usually refer to three categories: "internal", "output", and "outcome" measures (Millard-Ball and Murray, 2005). Internal measures, primarily being used for internal management issues, encompass performance indicators such as vehicle utilisation and vehicle availability, whereas output measures quantify the number of vehicles in-use as well as active and inactive members (Millard-Ball and Murray, 2005; Barth and Todd 1999). Last but not least, outcome measures such as vehicle miles travel (VMT) or vehicle ownership, indicate the progress and impact of carsharing systems in achieving certain targets (i.e. reducing vehicle ownership) that are mainly being tied to and serve the common good (Millard-Ball and Murray, 2005). However, when operating an e-carsharing system, it is advisable to introduce further measures of effectiveness (MOE) that help to capture all additional aspects being entailed when using electric vehicles. For example, as conventional combustion engines use fossil fuels, while electric vehicles require an electrical current being provided by batteries, the deployment of the latter demands the introduction of a MOE that measures the average battery state of charge of all the shared-use vehicles. This, in turn, is very important, since it facilitates the evaluation of the effectiveness regarding the overall energy management of the system, consequently enabling operators to identify potential, respective issues (Barth and Todd, 1999). Besides this "internal" performance indicator, further MOEs can be introduced belonging either to the output measures or outcome measures. Additional output measures could quantify the share of low-emission vehicles of a carsharing system, provided both conventional and electrical vehicles are used. Furthermore, the impact of electric vehicles on the environment could be evaluated by adding an outcome measure called "emissions" that captures changes referring to the overall production of pollutants of the carsharing system (Millard-Ball and Murray, 2005).

In conclusion, most differences between conventional and e-carsharing systems of both simulation and evaluation processes rarely affect the choice of general procedures and methodologies, but rather the underlying parameters that are being used to solve them.

4.4 Infrastructural Differences

Although it was concluded that the applied technologies of both types of carsharing initiatives are largely identical, the deployment of electric vehicles entails additional technological requirements concerning the overall infrastructure, which in turn leads to distinctive processes. In conventional carsharing programmes, carsharing operators commonly used vehicles that either entirely depend on fuel, or utilize hybrid engines (Shaheen et al., 2004). Companies which provide shared-use vehicles solely relying on fossil fuels, such as natural gas or petrol, as well as fuel cards, offer the advantage of increasing flexibility. Thus, the customer's convenience of the whole rental process is greatly enhanced. Since the respective vehicles can easily and swiftly be refueled at any gas station and point of time during rental, customers enjoy fewer boundaries on the supported travel range and consequently, the destinations they can travel to (Shaheen et al.; 2004). Contrarily, electric vehicles cannot provide the same degree of flexibility as conventional vehicles. Since the range of electric vehicles is comparably low and ranges from 40 to 150 miles, customers would either have to refrain from making long trips or they would be forced to make stops for recharging, albeit this recharging procedure is characterised by its slow pace (Cugola and Rossi, 2012; Barth et al., 2003). Either way, because electric vehicles depend on electric energy that is being stored in batteries, they also require a battery charging infrastructure. Therefore, carsharing operators relying on electric vehicles cannot go without the use of recharging stations which can be equated to casual station kiosks on a functional level, albeit they are equipped with charging devices (Kitamura, 2002; Markel, 2010; Tuoati and Jost, 2011). However, although station kiosks may seem a bit outdated, considering that alternative check-out devices like smartphones exist, they can still offer some advantages, especially when it comes to electric vehicles. Provided their internal system operates with a system management algorithm, recharging stations can take additional vehicle-related information into account, which is, since the station is directly connected to the vehicle, more up to date than when the vehicle is solely supervised in fixed intervals (Barth et al. 2003). Since the factor "availability" presumably will not suffice to determine the most appropriate vehicle, considering aspects, such as the current battery level or the frequency of use, as a frequent rotation is desirable, can thus offer advantages (Barth et al., 2003). Now, since the registration and reservation would not necessarily be provided by the management system but the recharging station, the corresponding processes would also differ notably or would be located elsewhere. Additionally, recharging stations can support further smart processes that would otherwise be located in the vehicle system. For instance, features such as user authentication, locking and unlocking the cars as well as providing vehicle information could be handled by the recharging station (Alli et al., 2012).

All in all these infrastructural differences, provided the conventional vehicle programmes do not make use of station kiosks, solely imply a shift regarding the responsibility and location of the underlying processes. Thus, the processes themselves would not differ considerably, although instead of being handled by the management system, they would be managed by the recharging stations.

4.5 Incentives and Billing

When it comes to the billing process, both conventional and e-carsharing systems have very similar procedures commonly being performed by the management system. Due to vehicle supervision technologies, the management system can monitor trip related parameters such as the traveled distance and the length of rental, which, in turn, is able to calculate and display the fee to be paid both during the rental and after finishing the trip (Kitamura et al., 2000). Furthermore, besides analogous billing practices, the choice of financial incentives when applying user-based relocation strategies is, again, quite complementary. As the respective pricing strategies in most cases solely aim at balancing the distribution, the factor "battery" can, for the most part, be excluded. Nonetheless, for instance when a customer wants to reserve a vehicle for a trip in the distant future at a station that lacks appropriate vehicles, it might be advantageous to have a user-based relocation strategy and pertaining algorithms that would also consider the required battery charge for a trip as well as the overall battery charge of all vehicles. This could be helpful since considering the battery charge of all vehicles would allow the system to identify trips and corresponding vehicles that would both be terminated before the aforementioned reservation would be due and where the vehicle would still have a sufficient charge to serve this future request. Now, by offering financial incentives to the respective customer, he possibly would prefer to terminate his trip at the station that lacks vehicles, thus providing the initial request with an appropriately charged electric vehicle. However, as mentioned before, electric vehicles are at disadvantage due to significant range limitations either stemming from limited battery capacities, or because the residual battery charge is insufficient to serve a customer's request after a previous rental. Consequently, electric vehicles are very well suited for short-term rentals, because these trips not only imply small traveling distances, but also an increase in recharging opportunities, since the electric vehicles can be recharged comparably often whilst being idle between each rental (Barth and Todd, 1999). On behalf of the vehiclesharing operators, it thus might be advisable to implement pricing mechanisms and incentives that encourage customers to rent electric vehicles only for short periods of time. One of these possibilities was presented by Barth and Todd (1999). The authors proposed that carsharing operators can implement so-called retention periods that reward customers with fairly low prices per mileage and minute when they remain under these predefined limits. Otherwise, in case customers exceed these periods and drive longer than, for instance, 60 minutes, these fees become very expensive (Barth and Todd, 1999). Nonetheless, applying such pricing mechanisms might also yield some disadvantages on behalf of the operators and customers, since they not only decrease the flexibility of the system and thus lessen the customer satisfaction, but can also increase the waiting time. This can supposedly be accredited to the circumstances that the shorter a trip is, the faster the distribution of shared-use vehicles can become imbalanced. Now, as an imbalanced distribution means that some stations lack vehicles whereas others display an abundance of the latter, some customers are required to wait until some vehicles are either sufficiently loaded or a vehicle gets relocated. Either way, as both processes take up time, the average waiting time may increase when introducing retention periods (Barth and Todd, 1999).

Furthermore, as explained in subchapter 4.2, management systems are able to determine the most viable origin-destination routes for maximizing the residual battery charge after each rental. However, since providing the most viable routes supposedly would not suffice to actively influence the customer's behavior to the extent that they would actually follow these instructions, carsharing operators could and possibly should offer additional financial incentives. By adding respective incentives, the probability of customers taking these routes would probably rise, thus increasing the average battery charge of all vehicles and, consequently, their availability. Another chance of providing incentives would be to vary the mileage fees according to the customers driving pattern. Since higher velocities also require comparably more battery charge, carsharing operators could sanction customers exceeding the advisory speed limit (e.g. 130km/h), by charging more per every mile where the customers did not adhere to the latter. Besides influencing the user's trip behaviour, carsharing operators could also deploy incentives that would influence the customer's choice of their initial starting station. As mentioned before, an imbalanced distribution of shared-use vehicles is an undesirable situation for both customers and carsharing providers, since occasionally some stations would lack vehicles to serve customer requests, whereas at another station there would be an abundance of vehicles. Considering that this problem is especially more complicated when it comes to electric vehicles due to their need for finding free parking lots with recharge opportunities, e-carsharing operators need to find means to respond to these problems that exceed the sole application of relocation strategies. Thus, by providing financial incentives concerning the choice of starting point, carsharing operators could induce a shift in demand from hot spots (stations of high demand), to cold spots (stations of low demand), therefore improving the overall distribution of vehicles.

5 Discussion

The main issue throughout this analysis was to provide an appropriate degree of detail concerning the depiction of the business processes, while also illustrating a rather universal process that would constitute and be comprised of most of the characteristics and systems of the various carsharing programmes. At first, it was intended to outline both conventional and e-carsharing processes separately, based upon which a comparison would have been delineated, wherein the differences would have been discussed in greater detail. However, while consulting the various case studies, it became apparent that the infrastructure and systems of both types of carsharing systems did not differ notably and therefore, could have been used almost interchangeably. Nevertheless, a choice had to be made regarding whether the detail of the pertaining business processes to be modeled should have been increased, thus allowing a graphical comparison, or if the latter should be conducted in writing. Yet, as the differences are quite minor and located in underlying processes such as vehicle distribution, relocation, and simulation, their holistic depiction would have meant such a severe increase in detail that the illustration of both processes would have scarcely fit in this paper. Furthermore, some differences are so minor (e.g. slightly varying variables) that their graphical depiction would have been unnecessary, but nonetheless tedious. Therefore, the choice fell on modeling a universal process, while subsequently discussing the various disparities in the following chapter. However, reducing the complexity of the overall process consequently means lowering its explanatory contribution and value. This lack of detail constitutes a problem and it would, nonetheless, still be of peculiar interest and importance for researches, practitioners, and carsharing operators alike to graphically model the respective business processes in greatest illustrative detail. Therefore, future papers could venture deeper and focus on individual tasks. By specialising in, for instance, relocation processes, it would become viable not only to completely model a representative process, but also to compare it visually to both analogous conventional carsharing procedures, as well as alternative practices being applied in e-carsharing systems.

Another issue of this paper might be the choice of studies that were examined in the course of the paper. Since the initial research was solely limited to German and English research papers, the existence of further relevant studies cannot be ruled out. This could bias the results of this paper, as the studies were conducted in well-developed industrial countries, where the infrastructure of both the road network and electrical grid are highly advanced. As follows, other countries with a less developed infrastructure could require adjustments regarding the infrastructure of the carsharing system itself, as well as respective business processes. Hence, future researchers focusing on carsharing business processes should resolve this issue by either evaluating the additional challenges in these environments, or by comparing carsharing initiatives of industrial with less developed countries.

Furthermore, not only the choice of studies might have biased the depiction of the business process, but also that solely scientific papers, which focused on rather experimental carsharing systems and initiatives, were observed. As business processes highly relate to and have a foundation in reality, examining the carsharing initiatives from a customer's perspective could have provided further insights towards an integrated business process. This is especially true when it comes to subsidiary processes that are relatively unimportant in scientific evaluations, but, nevertheless, have a high relevance for carsharing operators and customers alike. One of those examples could be the billing process, as in the research papers, it was - if ever - merely described. In most cases, the respective description was reduced to the reference that customers are obliged to pay monthly, as well as fixed fees per mile and minute. Therefore, further information on common and potential pricing mechanisms and corresponding incentives were omitted, since they were not deemed important in the first place. As for the business process, by going through an actual rental and billing process of an established carsharing provider, further knowledge could be contributed.

6 Conclusion

As the business processes of both conventional carsharing companies and their electric vehicle counterparts have probably never been illustrated holistically, the purpose of this paper was, on the one hand, to examine respective and common carsharing infrastructures, their systems in-use, and finally, on the other hand, to model and compare the associated business processes. Therefore, after the definition of terms and distinction of the various forms of carsharing programmes in the first and second chapter, the diverse intelligent transportation technologies and reasons for their implementation in carsharing initiatives were discussed. This was accomplished by including the findings of carsharing concepts being described in a variety of assorted case studies that encompassed both electric and convential carsharing programmes. Thereupon, it has been shown that applying intelligent transportation technologies is highly advisable and very common, since it not only strongly impacts the economic viability of carsharing initiatives through an increased efficiency, but also improves the customers' convenience and satisfaction thereof.

Furthermore, as the potential of these technologies cannot fully be realized when being utilised individually, they usually are integrated as technology bundles into bigger systems. Generally, these systems would be separated as per their functions and the localisation of the processes being supported by them. Thus, in most studies the carsharing operators applied trip registration, vehicle, and management systems. The vehicle system usually provided data being used by the management system, supported the customer's trip by enabling navigational aids and means of communication, and partly managed vehicle access. Moreover, the management system comprised of the most processes, also constituted as the prime processes, thus being the heart of the carsharing infrastructure, since it facilitated the general fleet management, as well as vehicle access, billing, and evaluation of the carsharing system itself. Last but not least, the trip registration system, which is localised in either carsharing stations or modern smartphone apps, was found to support processes that generally could be handled by the management system itself, but in some cases is conducted by the former due to certain advantages. Based-upon these systems, their infrastructure, and functions, the underlying business processes were derived in the second part of the third chapter. However, as it was found during the examination of case studies that both types of carsharing programmes tend to apply the systems and technologies, these associated business processes were designed to fit both settings.

Anyhow, the initial purpose of this paper was to conduct a comparison between the business processes of both carsharing systems. However, as their differences were so minute and therefore hardly representable, the comparison was conducted not graphically but written in chapter four. These differences mainly concerned the structure of the sub processes, such as the choice and setup of mathematical models and respective algorithms concerning the relocation and distribution of vehicles and the evaluation of the carsharing system itself. Notably, one should refrain from generalising the discussed findings, as the setup and choice of systems still depends strongly on both contextual and environmental factors, as well as preferences of the carsharing providers and the general purpose of the system. Nonetheless, this paper contributes to a general understanding of what characterises carsharing programmes and which systems and functions might be necessary to operate them sustainably and user-friendly.

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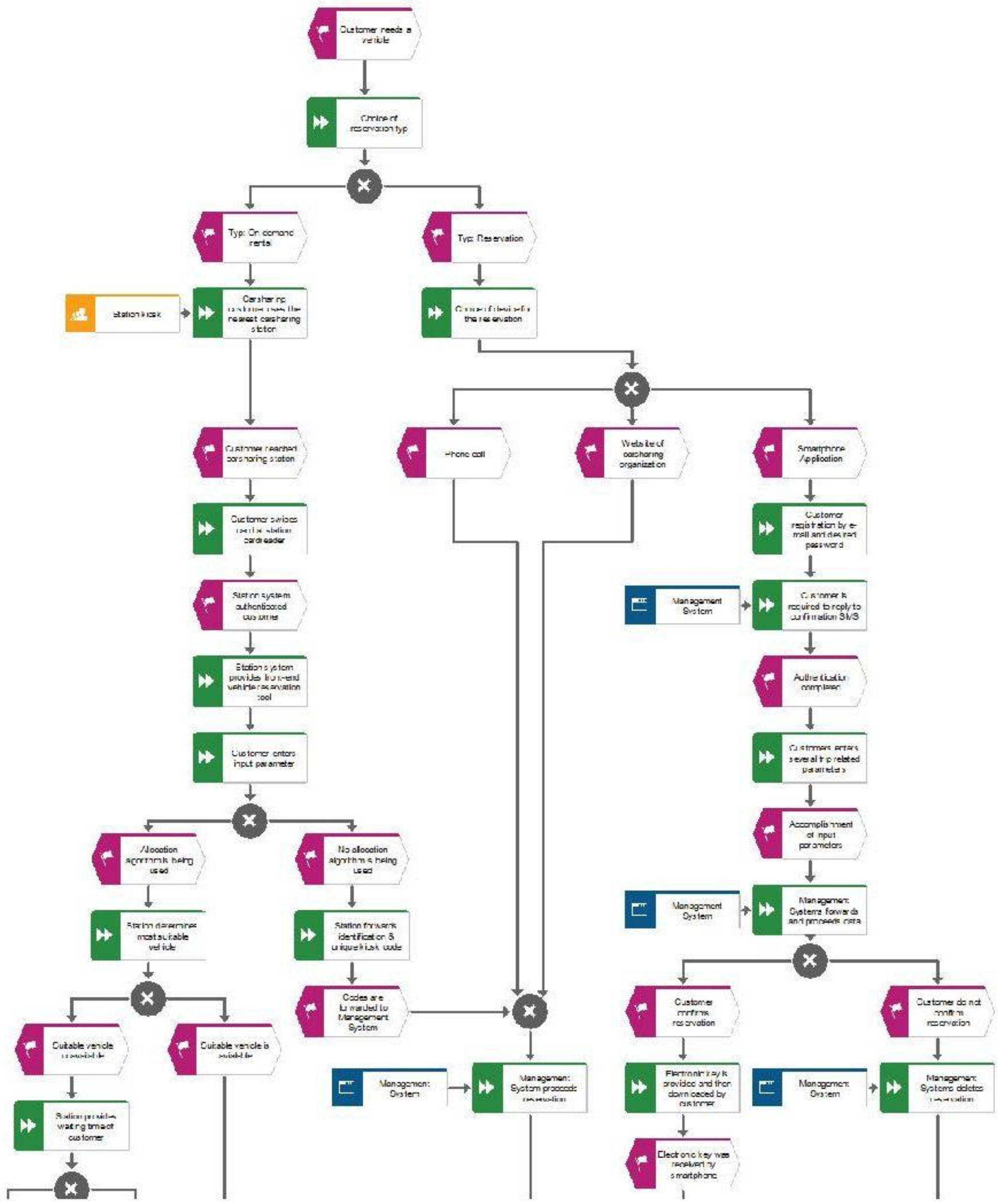
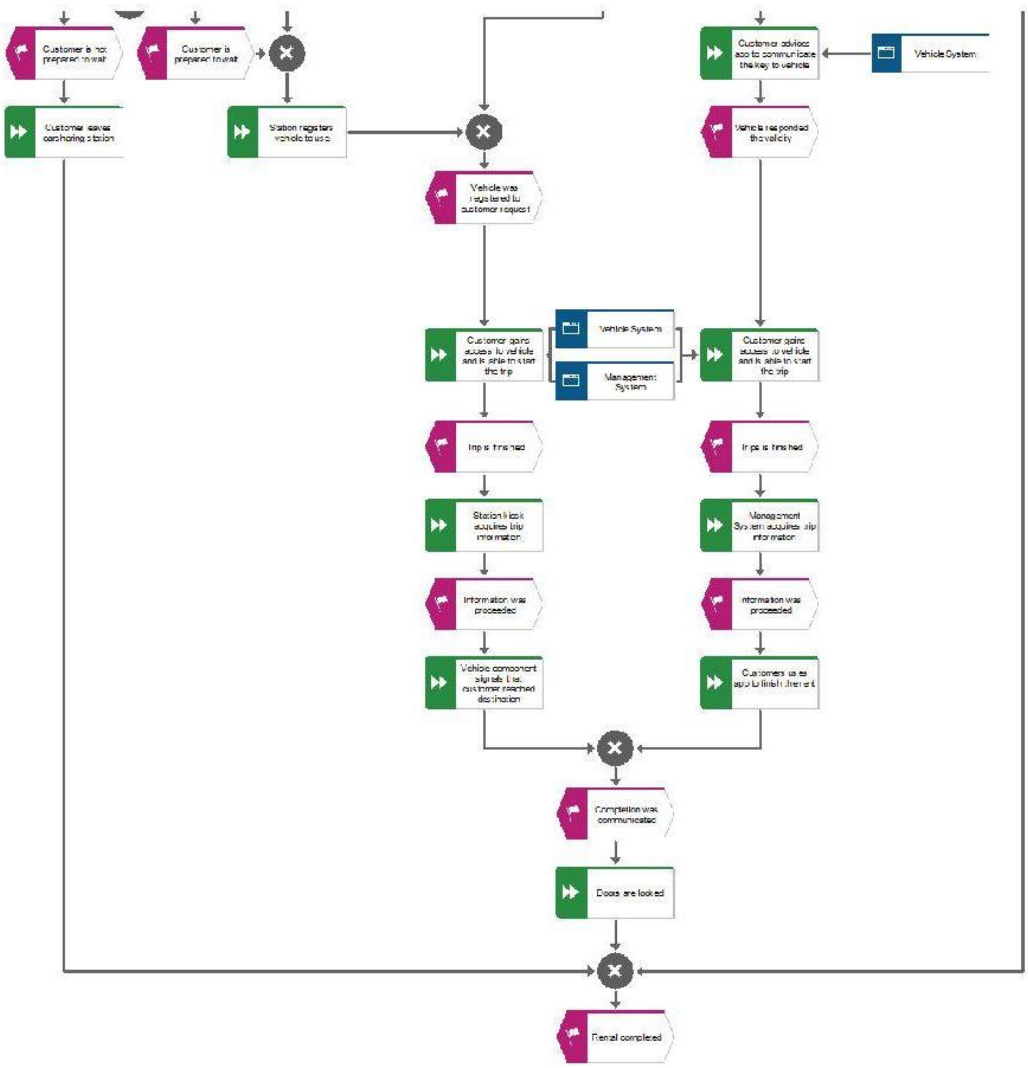
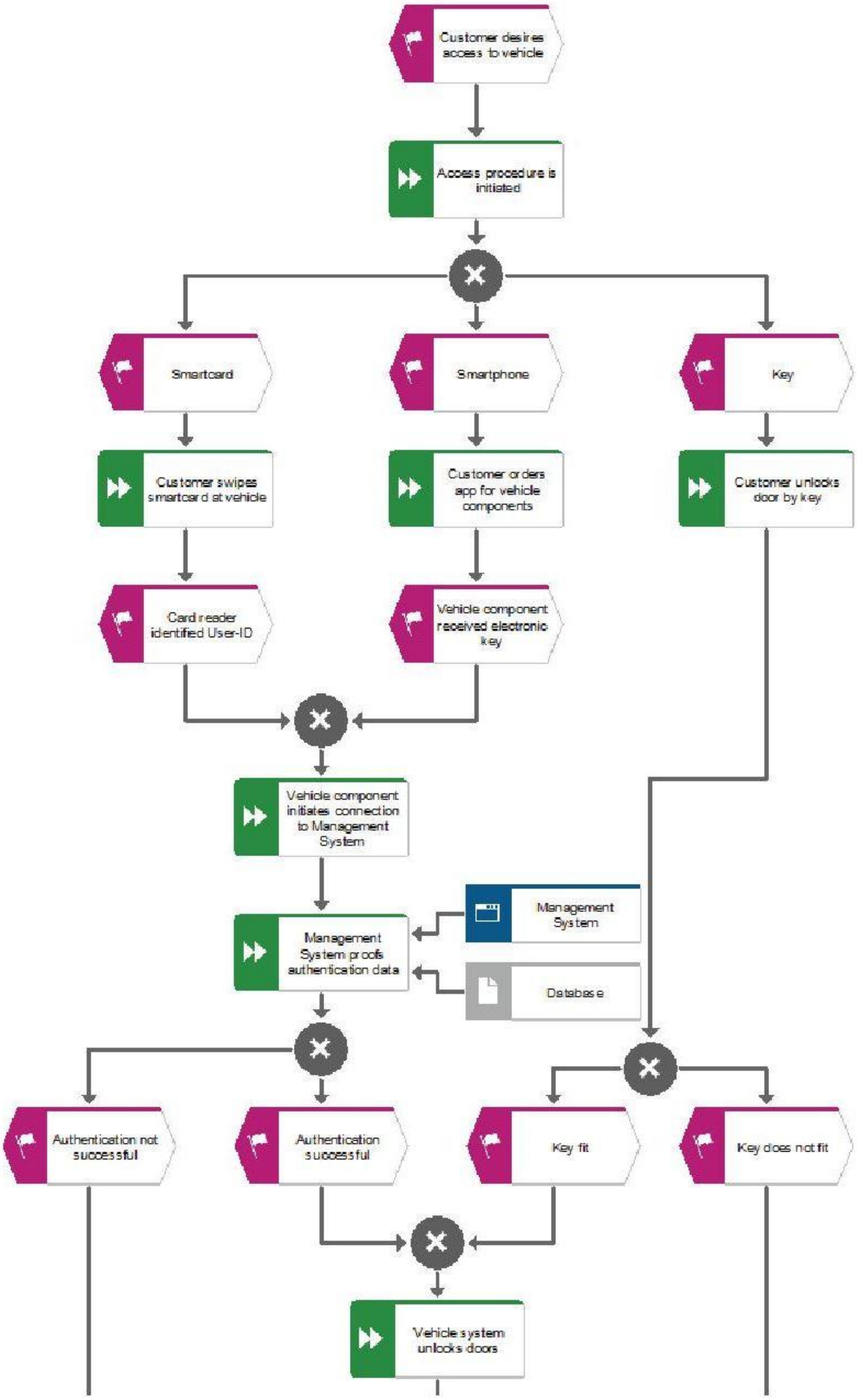
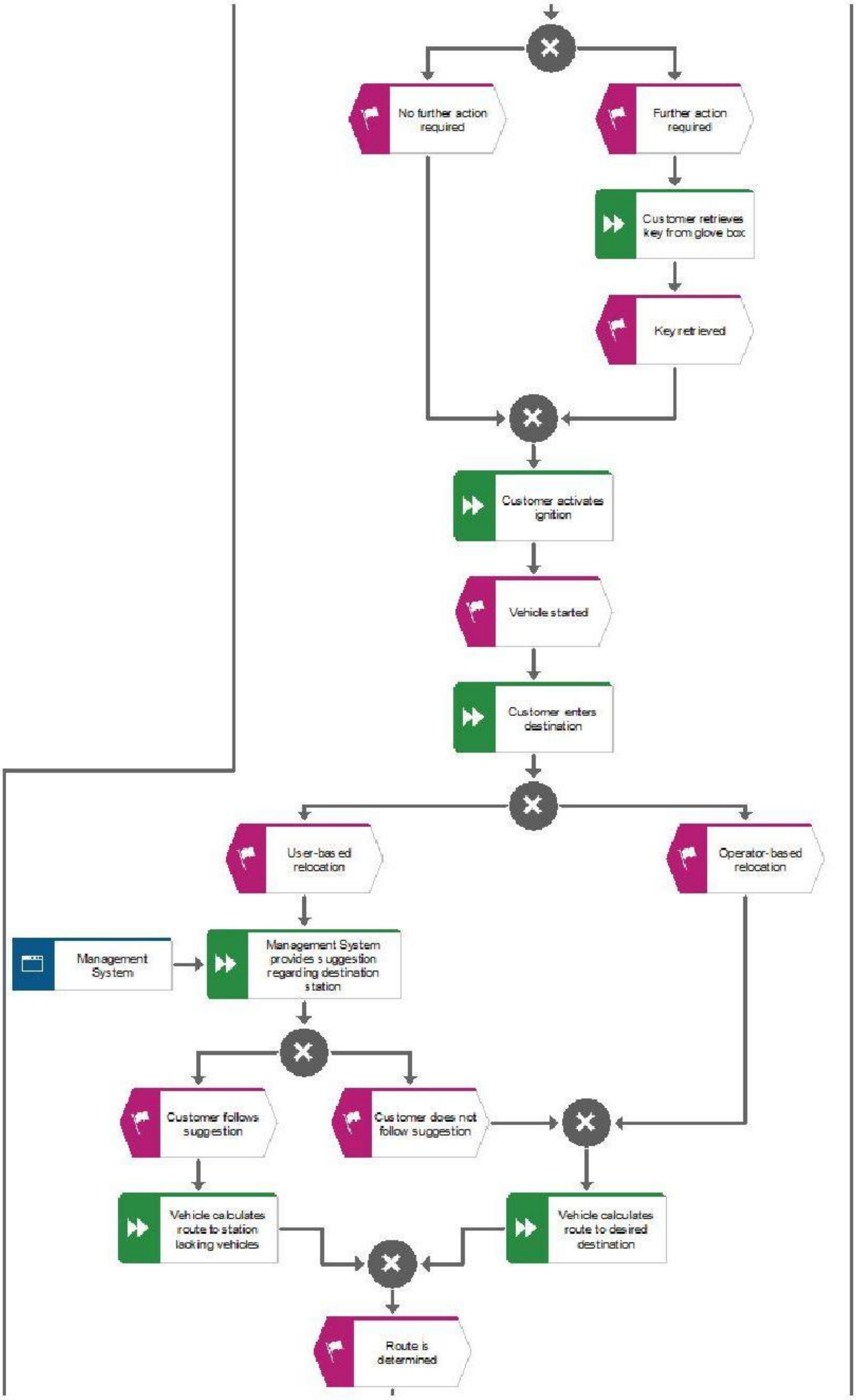
Appendix A: Trip Registration System

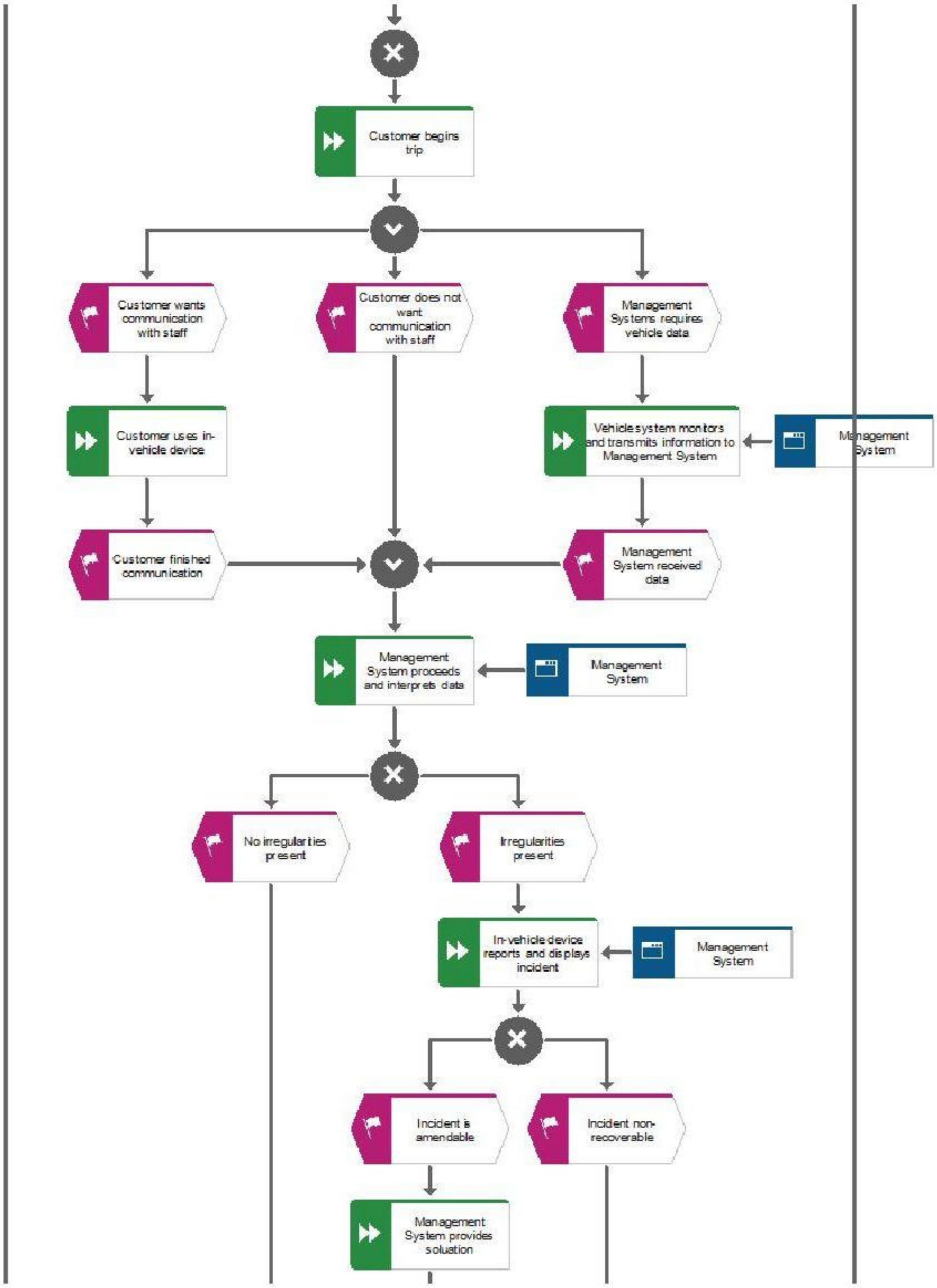


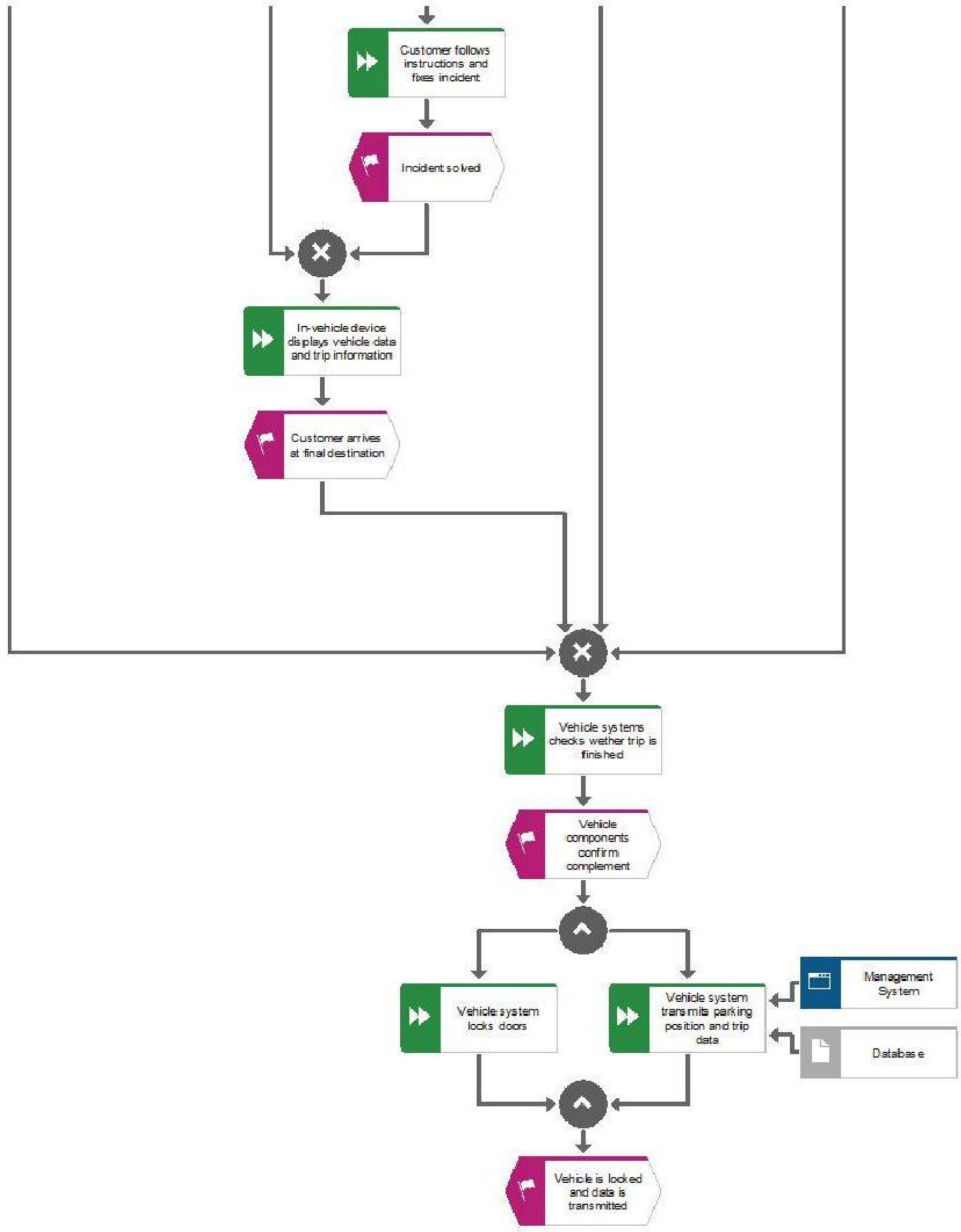

Customer is prepared to wait
Customer leaves carsharing station
Vehicle System
Vehicle was registered to customer request
Vehicle System
Management System
Information was proceeded
Information was proceeded
Completion was communicated
Doors are locked
Rental completed

Appendix B: Vehicle System



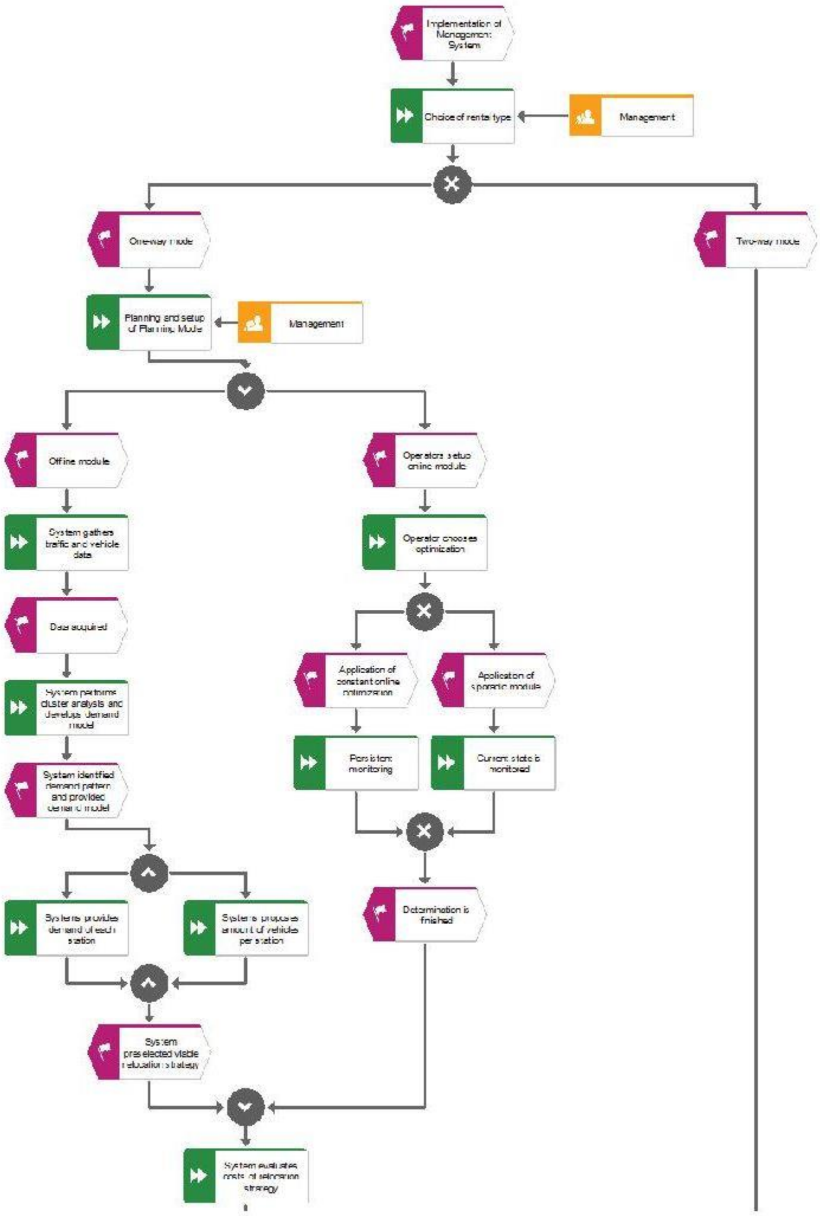

No further action required
Further action required
Customer retrieves key from glove box
Key retrieved
Customer activates ignition
Vehicle started
Customer enters destination
User-based relocation
Operator-based relocation
Management System
Management System provides suggestion regarding destination station
Customer follows suggestion
Customer does not follow suggestion
Vehicle calculates route to station lacking vehicles
Vehicle calculates route to desired destination
Route is determined

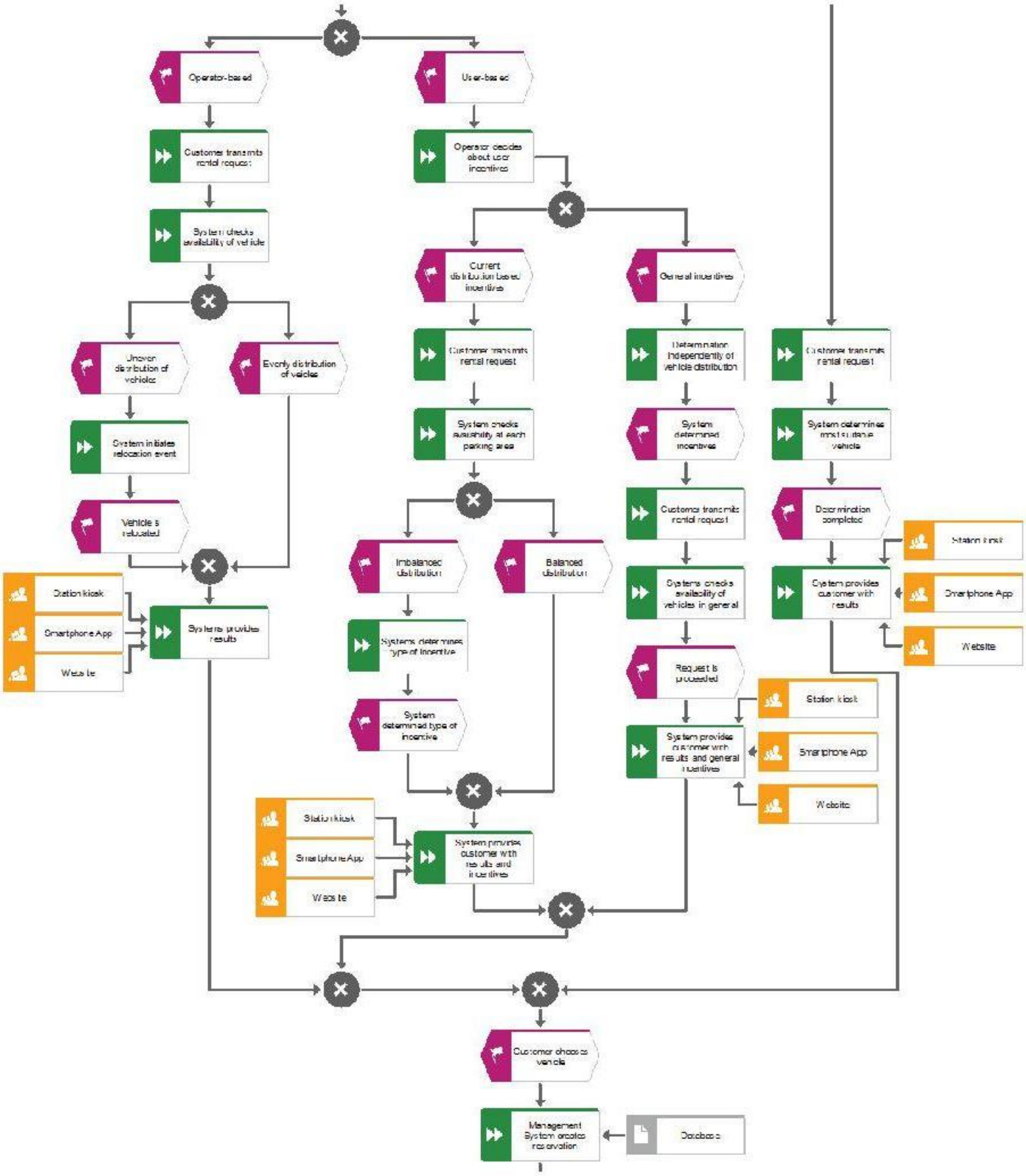

Customer begins trip
Customer wants communication with staff
Customer does not want communication with staff
Management Systems requires vehicle data
Customer uses in-vehicle device
Vehicle system monitors and transmits information to Management System
Management System
Customer finished communication
Management System received data
Management System proceeds and interprets data
Management System
No irregularities present
Irregularities present
In-vehicle device reports and displays incident
Management System
Incident is amendable
Incident non-recoverable
Management System provides soluation

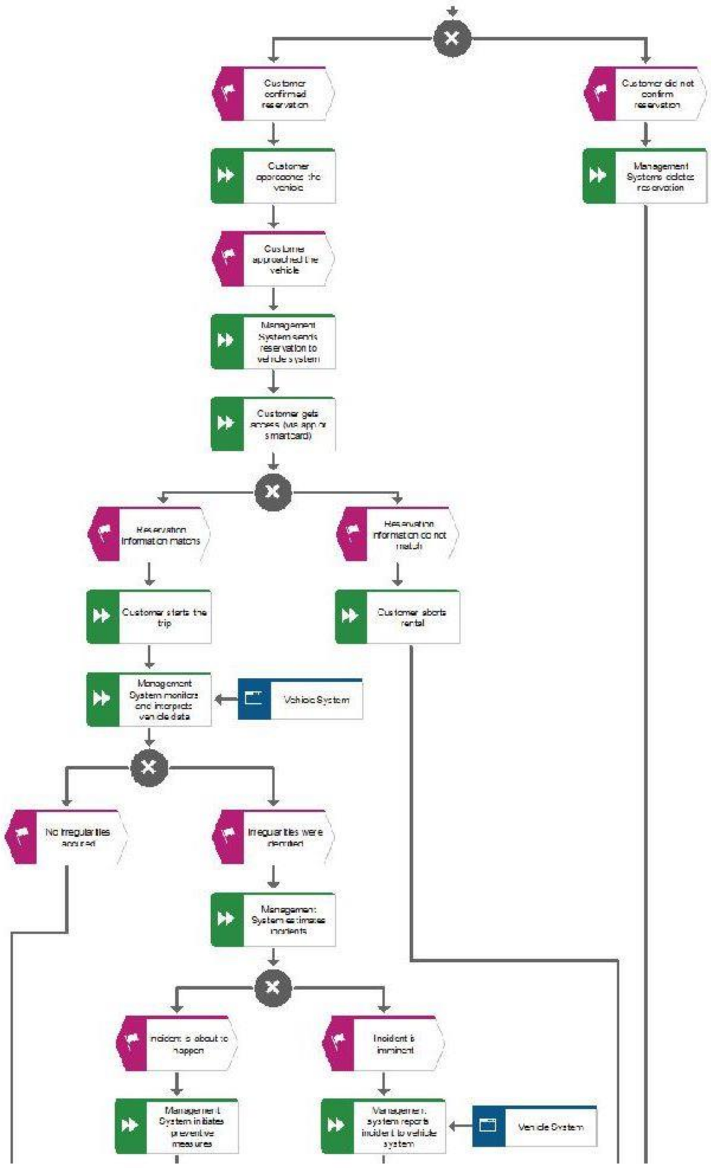


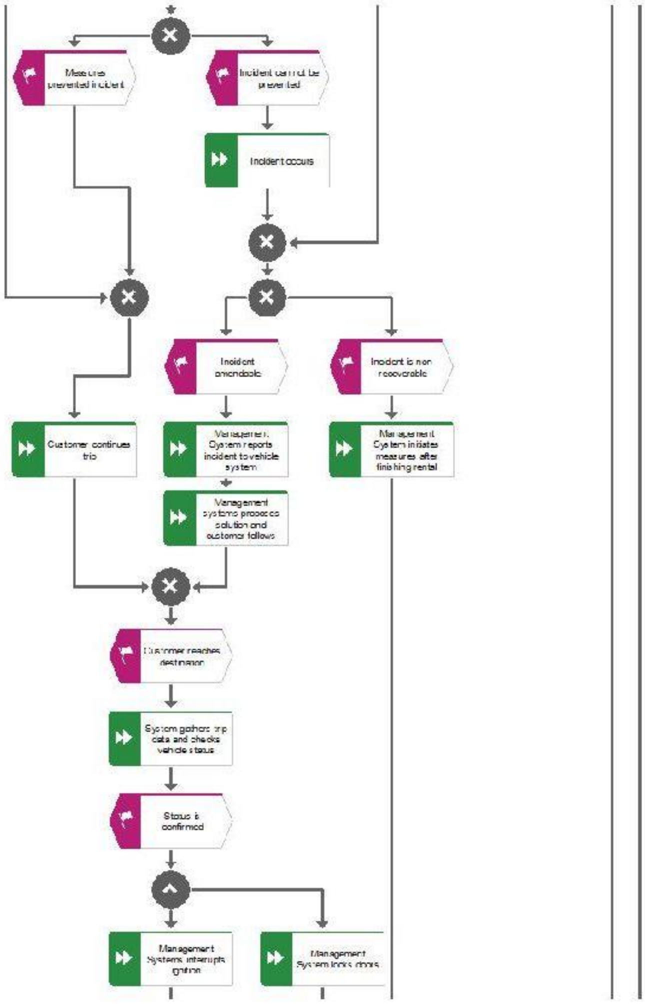
Customer follows instructions and fixes incident
Incident solved
In-vehicle device displays vehicle data and trip information
Customer arrives at final destination
Vehicle systems checks wether trip is finished
Vehicle components confirm complement
Vehicle system locks doors
Vehicle system transmits parking position and trip data
Management System
Database
Vehicle is locked and data is transmitted

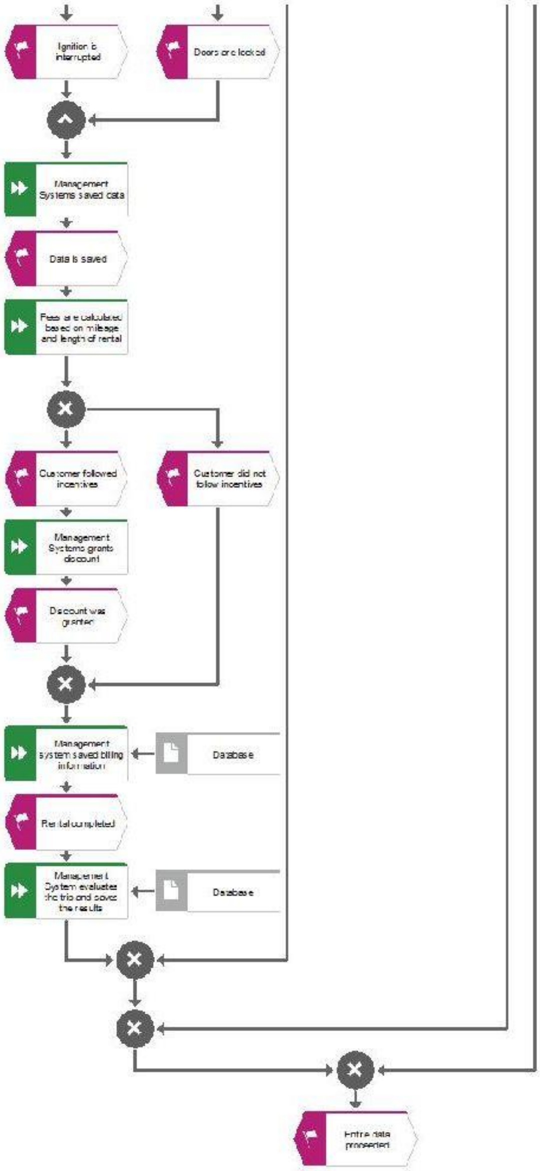
Appendix C: Management System




Operator-based
User-based
Customer transmits rental request
Operator decides about user incentives
System checks availability of vehicle
Current distribution based incentives
General incentives
Uneven distribution of vehicles
Evenly distribution of veicles
Customer transmits rental request
Determination independently of vehicle distribution
Customer transmits rental request
System initiates relocation event
System checks availability at each parking area
System determined incentives
System determines most suitable vehicle
Vehicle is relocated
Customer transmits rental request
Determination completed
Station kiosk
Imbalanced distribution
Balanced distribution
Station kiosk
Smartphone App
Systems provides results
Systems checks availability of vehicles in general
System provides customer with results
Smartphone App
Website
Systems determines type of incentive
Website
Request is proceeded
Station kiosk
System determined type of incentive
System provides customer with results and general incentives
Smartphone App
Website
Station kiosk
Smartphone App
System provides customer with results and incentives
Website
Customer chooses vehicle
Management System creates reservation
Database


Customer confirmed reservation
Customer did not confirm reservation
Customer approaches the vehicle
Management Systems deletes reservation
Customer approached the vehicle
Management System sends reservation to vehicle system
Customer gets access (via app or smartcard)
Reservation information matches
Reservation information do not match
Customer starts the trip
Customer aborts rental
Management System monitors and interprets vehicle data
Vehicle System
No irregularities occured
Irregularities were identified
Management System estimates incidents
Incident is about to happen
Incident is imminent
Management System initiates preventive measures
Management system reports incident to vehicle system
Vehicle System


Measures prevented incident
Incident can not be prevented
Incident occurs
Incident amendable
Incident is non recoverable
Customer continues trip
Management System reports incident to vehicle system
Management System initiates measures after finishing rental
Management systems propose solution and customer follows
Customer reaches destination
System gathers trip data and checks vehicle status
Status is confirmed
Management Systems interrupts ignition
Management System locks doors


Ignition is interrupted
Doors are locked
Management Systems saved data
Data is saved
Fees are calculated based on mileage and length of rental
Customer followed incentives
Customer did not follow incentives
Management Systems grants discount
Discount was granted
Management system saved billing information
Database
Rental completed
Management System evaluates the trip and saves the results
Database
Entire data proceeded

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A.10 Ein Smartphone-Bonussystem zum energieeffizienten Fahren von Carsharing–Elektrofahrzeugen

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Ein Smartphone-Bonussystem zum energieeffizienten Fahren von Carsharing–Elektrofahrzeugen

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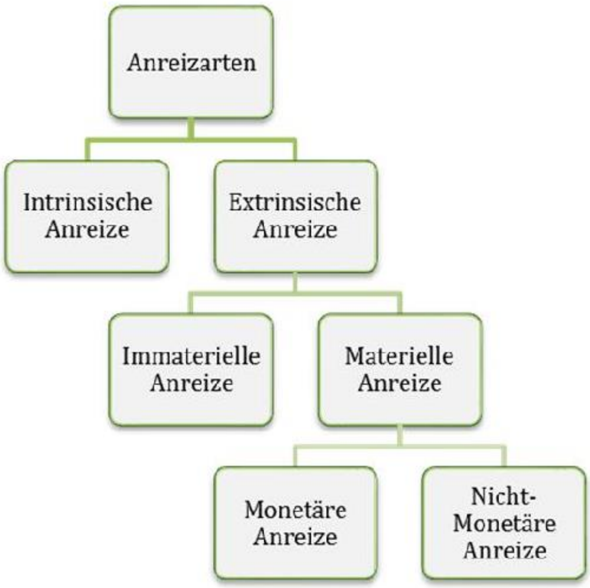

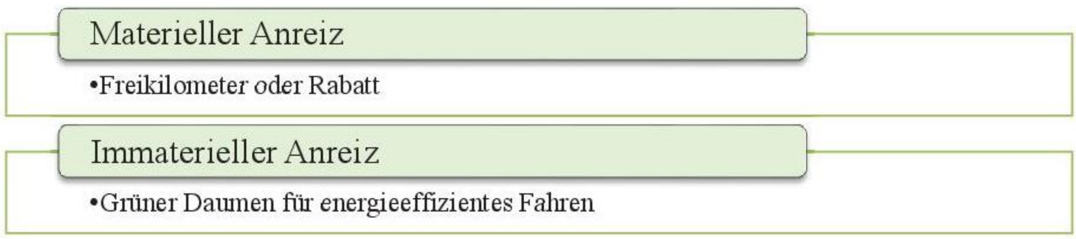

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1 Einleitung und Motivation

Aufgrund der zunehmenden Überlastung urbaner Straßennetze kommt alternativen Mobilitätskonzepten eine immer größere Bedeutung zu. Einer der wichtigsten Trends ist in diesem Zusammenhang das Carsharing (Costain et al. 2012, Habib et al. 2012, Morency 2008). Die stetig steigenden Rohölpreise und die sich immer rasanter entwickelnde Technik für mobile Antriebssysteme, werden im Bereich des Carsharings jedoch zu Veränderungen führen. Zurzeit bestehen die Carsharing-Flotten überwiegend aus Fahrzeugen mit Verbrennungsmotor. In Zukunft werden jedoch immer mehr Elektrofahrzeuge erwartet (Shaheen und Cohen 2013). Die Nachteile von Elektrofahrzeugen, wie die geringe Reichweite oder die hohen Anschaffungskosten (Busse et al. 2013, Flath et al. 2012, Wagner et al. 2013) stellen eine große Herausforderung für die Anbieter dar. Damit sich Elektrofahrzeuge in Carsharing-Flotten durchsetzen können, müssen Anreize zur ökologisch und ökonomisch verantwortungsbewussten Nutzung geschaffen werden. In diesem Artikel wird ein Anreizsystem entwickelt, das den energieeffizienten Gebrauch von Elektrofahrzeugen unterstützen soll. Da viele Carsharing-Anbieter die Distribution ihrer Fahrzeuge mit einer App unterstützen, soll das Anreizsystem in Form eines Smartphone-Bonussystems konzipiert werden. Die Smartphone-Betriebssysteme Android, iOS und Windows Phone decken gegenwärtig ca. 99% des Weltmarktes ab (IDC Corporate 2014). Zur Auswertung der relevanten Fahrzeugdaten aus den Fahrzeugen der Carsharing-Unternehmen, ist eine entsprechende Schnittstelle in den Infotainment-Systemen der Fahrzeuge notwendig. Die Softwarehersteller bieten hier jeweils eine eigene Schnittstelle zur Fahrzeughardware.

In diesem Artikel wird ein konzeptioneller Entwurf eines smartphonebasierten Bonussystems vorgestellt, welches Anreize zum energieeffizienten Fahren von Carsharing-Elektrofahrzeugen geben soll. Dabei stellt sich die Frage, welche Anreizfaktoren die größte Wirkung bei Nutzern von Carsharing erzielen. Zur Untersuchung dieser Frage werden die wesentlichen Anreizfaktoren hinsichtlich ihrer Wirkung auf den Nutzer betrachtet. Dementsprechend wird folgende Forschungsfrage untersucht:

> *Welche Anreizarten können in einem Smartphone-Bonussystem zum energieeffizienten Fahren von Carsharing-Elektrofahrzeugen beitragen?*

Dieser Artikel ist wie folgt aufgebaut: Zunächst werden Grundlagen zum Carsharing und zu Anreizsystemen im zweiten Kapitel gegeben. Anschließend werden die Anreizsysteme im dritten Kapitel vertieft und für den Anwendungsbereich Carsharing dargestellt. Hierbei erfolgt eine Unterteilung in materielle und immaterielle Anreize. Aufbauend hierauf wird ein Bonussystem hergeleitet und konzeptionell entworfen. Im anschließenden vierten Kapitel wird das Bonussystem diskutiert und Limitationen präsentiert. Abschließend wird in Kapitel fünf ein Fazit gezogen und ein Ausblick gegeben.

2 Grundlagen

2.1 Carsharing

Bei dem Konzept Carsharing gibt es die Möglichkeit, unter bestimmten Voraussetzungen, gebührenpflichtig ein Fahrzeug eines Carsharing-Unternehmens für einen bestimmten Zeitraum zu nutzen (Duncan 2011). Im Gegensatz zur traditionellen Vermietung kann hier spontan und für kurze Zeitabschnitte ein Fahrzeug geliehen werden. In der Regel erfolgt zunächst eine Buchung (meist online), danach kann das Fahrzeug an der gewählten Station abgeholt werden. Nach der Fahrt wird das Fahrzeug wieder zurückgebracht oder an einer anderen Station abgestellt. Dies hängt von der Politik des Carsharing-Unternehmens ab, ob nur Two-Way-Fahrten oder aber auch One-Way-Fahrten gestattet sind. Die Abrechnung erfolgt meist nach den gefahrenen km oder nach der gemieteten Zeit. Die Bezahlung kann entweder sofort erfolgen oder im Rahmen einer monatlichen Abrechnung (Kiermasch 2013).

Der Automobilverkehr ist einer der größten Faktoren im Bereich Luftverschmutzung und Lärmbelästigung in großen Städten. Rund 70% der Kohlenstoffmonoxide (CO) und 45% der Stickoxide werden von den Fahrzeugen verursacht (Katzev 2003). Hier ist es wichtig anzusetzen. Carsharing mit Elektrofahrzeugen könnte eine gute Lösungsmöglichkeit darstellen, welches sich auch bereits in einigen Städten wie Düsseldorf und Berlin etabliert hat (E-Carflex 2015, Multicity Citroen 2015). Grundsätzlich haben diese jedoch den Nachteil, im Vergleich zu konventionell betriebenen Fahrzeugen, dass die

Ladezeit für die Batterie des Fahrzeugs mit einkalkuliert werden muss, und daher das Fahrzeug nicht sofort für den nächsten Kunden zur Verfügung steht. Durch energieeffizienteres Fahren der Carsharing-Nutzer, können die Ladezeiten, und somit die ungenutzten Standzeiten des Fahrzeugs, reduziert werden. Mit Carsharing kann daher nicht nur die Umwelt geschont werden (weniger CO2, Lärm und benötigte Parkfläche), sondern es kann für die Nutzer eine Kostensicherheit bedeuten. Sie müssen nicht mehr mit unkalkulierbaren Kosten, wie bspw. Reparaturen rechnen und müssen nur für genau die Fahrten bezahlen, die sie auch tätigen. Es wird mehr darüber nachgedacht, ob die Fahrt mit dem Fahrzeug wirklich notwendig ist, oder ob der Weg eventuell mit einem anderen Verkehrsmittel machbar wäre. Laut einer Umfrage von Martin und Shaheen (2011) reduziert sich die Anzahl eigener Fahrzeuge von Carsharing-Nutzern deutlich. Für weniger Fahrzeuge wird auch weniger Parkfläche benötigt, daher können die Schwierigkeiten bei Parkplatzproblemen verringert werden. Carsharing macht daher insbesondere in großen Städten mit einer hohen Bevölkerungsdichte Sinn, da hier viele potentielle Kunden vorhanden sind und die Nachfrage dementsprechend vorhanden ist. Um den meist ohnehin umweltbewussten potentiellen Kunden entgegenzukommen, kann ein anreizbasiertes Bonussystem zum energieeffizienten Fahren, mit dem sich die Kosten für den Carsharing-Nutzer noch weiter reduzieren, zu einer zufriedeneren Nutzergruppe führen und gleichzeitig Kosten und Ladezeiten für das Carsharing-Unternehmen eingespart werden.

2.2 Anreizsysteme

Ein Anreizsystem kann als Menge von positiven oder negativen Anreizen im Zusammenspiel mit den entsprechenden Bezugsobjekten, Bemessungsgrundlage oder Bewertungskriterien, gesehen werden (Kossbiel 1994). Damit ein solches Anreizsystem das Verhalten der gewünschten Personen erfolgreich beeinflusst, müssen die Anreize eine entsprechende Relevanz für diese Person haben. Je nach Kontext kann hier eine Belohnung, Bestrafung oder Unterlassung für ein bestimmtes Verhalten vereinbart werden. Zur Beurteilung, ob es zu einem der genannten Szenarien kommt, sind eine Bemessungsgrundlage und entsprechende Kriterien von Nöten. Anhand dieser kann der Grad der Zielerreichung gemessen werden. Ein variabler Anreiz, wie z.B. ein Bonus oder eine andere Vergünstigung, wird nur im Erfolgsfall ausgeschüttet. Der variable Anreiz führt in der Regel zum Erfolg des Anreizgebers, sofern dieser für den Adressaten erstrebenswert ist. Dieser Zusammenhang wird auch als Belohnungsfunktion bezeichnet. Wird das Ziel erreicht und es kommt zur Belohnung, ist die Ausschüttungspolitik ein weiterer Gestaltungsfaktor eines Anreizsystems (Hungenberg 2006). Zur Ausschüttungspolitik gehört bspw. ob die Belohnung sofort ausgeschüttet wird oder nicht. Der letzte wichtige Aspekt bei der Erarbeitung eines Anreizsystems ist der Adressatenkreis. Aus dem Adressatenkreis ergibt sich letztlich die Auswahl der Anreize um die Wirkung des Anreizsystems zu gewährleisten. Ein Anreizsystem lässt sich anhand der fünf Grundkomponenten Anreiz, Bemessungsgrundlage, Belohnungsfunktion, Ausschüttungspolitik und Adressatenkreis modellieren (Kossbiel 1994, Huber 2014).

Ein Anreiz kann in vielerlei Hinsicht ausgestaltet werden, sodass nach mehreren Anreizarten unterschieden werden kann. Zum einem nach intrinsischen Anreizen, welche durch die Handlung selbst entstehen und nach extrinsischen Anreizen, welche von außen auf den Adressaten einwirken. Die extrinsischen Anreize können weiterhin noch aufgegliedert werden nach materiellen und immateriellen Anreizen. Immaterielle Anreize zielen größtenteils auf die gesellschaftliche Stellung der Adressaten ab. Wohingegen materielle Anreize noch weiter nach monetären und nicht-monetären unterschieden werden können. Unter nicht-monetäre Anreize fallen z.B. ein größeres Büro, ein eigener Firmenwagen oder dergleichen (Huber 2014). Abbildung 1 stellt die Anreizarten in Anreizsystemen dar.

Der entscheidende Vorteil monetärer Anreize liegt in der fast universellen Möglichkeit mit Geld Bedürfnisse zu befriedigen. Allerdings nimmt dieser Effekt mit steigender Häufigkeit und Höhe der Anreize ab. Ab diesem Punkt werden eher immaterielle Anreize wie z.B. Statussymbole attraktiv (Huber 2014, Hungenberg 2006). Finanzielle Anreize sollten außerdem nur in sehr begrenztem Maße verwendet werden, da diese auf Dauer die intrinsische Motivation der Adressaten verschwinden lassen. Bei übermäßigem Einsatz monetärer Anreize wird diese nur noch in Verbindung mit dem monetären Anreiz erreicht. Man nennt dieses Verhalten auch Korrumpierungseffekt (Frey und Osterloh 2000). Um einen möglichst effektiven Anreiz zu schaffen, ist es möglich, die Adressaten aus einem Set möglicher Anreiz-Alternativen wählen zu lassen. Diese Variante wird als Cafeteria-Modell bezeichnet (Hungenberg 2006).

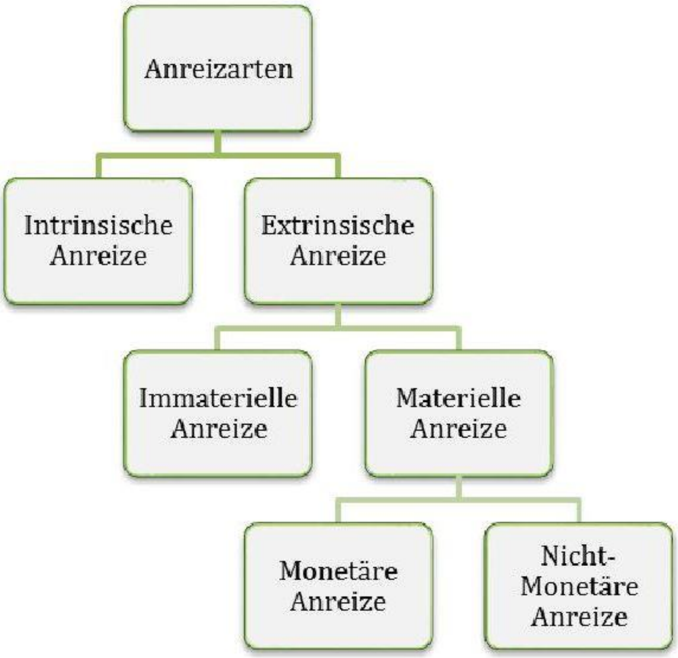

Abbildung 1 : Anreizarten im Anreizsystem (Huber 2014)

3 Methodik und konzeptioneller Entwurf

3.1 Herleitung des Bonussystems

In der Literatur wird derzeit viel diskutiert wie Elektrofahrzeuge optimal und kostengünstig, in die Carsharing-Flotte mit eingebunden werden können (Fournier et al 2014, Heim und Hoettl 2012, Lue et al 2012). Oftmals werden diese eher aus Prestigegründen und nicht zur Gewinnmaximierung eingesetzt, da Elektrofahrzeuge den Gewinn eher negativ beeinflussen. Dies ist auf die hohen Anschaffungskosten sowie die Kosten für den Aufbau einer Ladeinfrastruktur zurückzuführen. Weiterhin sind aber auch die Ladezeiten der Elektrofahrzeuge von großer Bedeutung. Diese führen zu Standzeiten während denen das Fahrzeug nicht genutzt werden kann (Boyaci et al. 2015, Die Bundesregierung 2011). Um diesem Problem entgegenzuwirken, ist die Einführung eines Bonussystems zur Förderung energieeffizienten Fahrens von großer Bedeutung und kann helfen diese Standzeiten zu reduzieren.

Für das Bonussystem zum energieeffizienten Fahren empfiehlt sich ein Anreizsystem, welches sowohl eine materielle als auch eine immaterielle Komponente enthält. Als immaterieller Anreiz bietet sich für das zu entwickelnde System eine Effizienzanzeige an. Diese zeigt, je nach Fahrverhalten, ein Lob für eine besonders umweltbewusste und energieeffiziente Fahrweise oder eine Warnung bei einer energieintensiven Nutzung. Eine solche Anzeige soll auf die negativen Auswirkungen energieintensiven Fahrens auf Natur, Mensch und Umwelt aufmerksam machen und könnte in Form eines Daumens ausgestaltet sein. Der Daumen soll bei einer energieeffizienten Fahrweise eine grüne Farbe annehmen und nach oben zeigen, bei einer energieintensiven Fahrweise soll er eine rote Farbe annehmen und nach unten zeigen. Die Visualisierung soll die extrinsische Motivation der umweltbewussten Carsharing-Nutzer anregen.

Da eine rein immaterielle Belohnung nicht ausreichend sein wird, gibt es zudem eine materielle Komponente, welche auf dem Cafeteria-Modell basiert, bei dem Adressaten aus einem Set möglicher Alternativen wählen dürfen (Hungenberg 2006). Daher soll der Carsharing-Nutzer die Wahl zwischen Freikilometern und einem Rabatt auf den Standardtarif haben. Mit diesem materiellen Anreiz können bspw. Neukunden und Fahranfänger motiviert werden am Carsharing teilzunehmen, da in der Regel Fahranfänger eher jung und wenig vermögend sind. Die Ausgestaltung mit Wahlmöglichkeit hat zudem den Vorteil, dass regelmäßige Nutzer und auch Gelegenheitsnutzer gleichermaßen angesprochen werden. Um langfristige Kunden zu binden, sollten die erhalten Freikilometer einen höheren Wert als die Rabattierung besitzen.

Das Bonussystem für energieeffizientes Fahren basiert auf den dargestellten Anreizen. Es sollen die extrinsischen Anreize durch materielle und immaterielle Komponenten angesprochen werden. Das energieeffiziente Fahren soll anhand eines grünen Daumens (immateriell) und Vergünstigungen für die Fahrt (materiell) honoriert werden. Diese Anreize sind der folgenden Abbildung 2 zusammenfassend zu entnehmen.

Materieller Anreiz

- Freikilometer oder Rabatt

Immaterieller Anreiz

- Grüner Daumen für energieeffizientes Fahren

Abbildung 2: Anreize des Bonussystems

Als Bemessungsgrundlage für das Bonussystem bietet sich der durchschnittliche Energieverbrauch je gefahrenem Kilometer an. Hier muss unterschieden werden, ob sich das Fahrzeug im Stadt-, Landstraßen-, oder Autobahnverkehr befindet. Aus dem Einsatzszenario ergeben sich unterschiedliche Fahrprofile. Im Stadtverkehr muss häufiger gebremst und wieder angefahren werden. Daher ergibt sich ein höherer Energieverbrauch je gefahrenem Kilometer, wie bspw. im Vergleich zu der Landstraße, auf der mit konstanter Geschwindigkeit gefahren werden kann. Daraus ergibt sich die erste Anforderung an das spätere Bonussystem, welches anhand von Karten- oder Bewegungsdaten auswerten muss, welches der drei genannten Fahrprofile zutreffend und wie der gemessene Energieverbrauch zu bewerten ist. Die Nutzung der Rekuperation wirkt sich positiv auf den Durchschnittsverbrauch aus und belohnt somit den Fahrer.

Im hier vorgestellten Bonussystem werden Punkte anhand der Ausrichtung eines Daumens vergeben, aus denen sich dann die Belohnung ergibt. Bei einer besonders energieeffizienten Fahrweise ist der Daumen grün und zeigt nach oben. Je energieintensiver die Fahrweise, desto mehr verschiebt sich die Farbe des Daumen ins Rote. Seine Ausrichtung dreht sich dabei immer weiter nach unten. Der Daumen kann dabei fünf unterschiedliche Positionen annehmen. Die nachfolgende Tabelle 1 zeigt alle Ausrichtungen des Daumens und eine mögliche Ausgestaltung des Bonussystems.

	Daumen	Punkte	Freikilometer	Rabatt
Optimale Fahrweise		1 km = 2 Punkte	20 Punkte = 1 Freikilometer	20 Punkte = 1 x Rabatt auf 1 km (80%)
Gute Fahrweise		1 km = 1 Punkt		
Neutrale Fahrweise		1 km = 0 Punkte		
Energieintensive Fahrweise		1 km = -1 Punkt		
Besonders energieintensive FW		1 km = -2 Punkte		

Tabelle 1: Ausgestaltung des Bonussystems

Bei einer optimalen Fahrweise können maximal zwei Punkte je gefahrenen Kilometer gesammelt werden. Für 20 Punkte erhält der Carsharing-Nutzer einen materiellen Anreiz, welchen er aus zwei Alternativen wählen kann. Es kann ein Freikilometer gewählt werden, der erst bei der nächsten Fahrt genutzt werden kann, oder ein sofortiger 80%iger Rabatt auf einen gefahrenen Kilometer. Negative Punkte können zwar während der Fahrt gesammelt werden, haben aber keinen Einfluss, falls die Fahrt mit einem negativen Punktestand beendet wird. So werden nur die energieeffiziente Fahrweisen belohnt und keine Fahrweise bestraft. Als Grundlage für die Fahrweisen dienen die ermittelten Durchschnittswerte für Stadt-, Landstraßen- und Autobahnbetrieb, sodass eine dem Nutzungskontext entsprechende Bewertung des Fahrverhaltens ermöglicht wird. Eine Unterschreitung des üblichen Durchschnittsverbrauchs für einen Tesla Model S (ADAC 2013) von fünf bzw. zehn Prozent, wird mit einer Punktevergabe von einem bzw. zwei Punkten belohnt. Eine Überschreitung zwischen fünf und zehn Prozent wird mit einem Minuspunkt bewertet und mit zwei Minuspunkten, falls sogar mehr als zehn Prozent überschritten werden. Es könnte hilfreich sein, auf der Monatsabrechnung des Carsharing Kunden einen Graph über den Verlauf der Fahrten anzufügen, welcher jede Fahrt mit einem Datenpunkt erfasst und darstellt, wie energieeffizient bzw. umweltfreundlich die jeweilige Fahrt war. Wie ein solcher Graph aussehen könnte wird in der folgenden Abbildung 3 veranschaulicht.

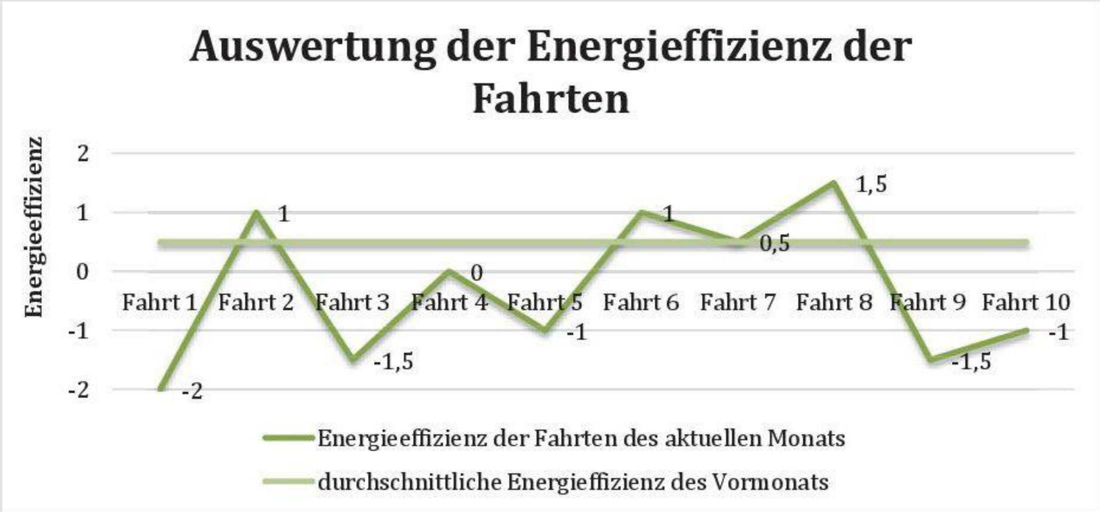

Abbildung 3: Darstellung einer möglichen Effizienzauswertung der Fahrten

3.2 Visualisierung und Aufbau des Bonussystems

Das konzeptionelle Bonussystem zum energieeffizienten Fahren sollte als App auf den üblichen Smartphone Betriebssystemen (Android, iOS, Windows) zur Verfügung stehen. Native Apps stellen eine professionelle Lösung dar und überzeugen mit einer hohen Performance und Stabilität. Mit nativen Apps ist die Hardwarekompatibilität gegeben und es ist keine Onlineverbindung bei der Nutzung der App notwendig. Daher sollte das Bonussystem in eine native App integriert werden, welche sich über den jeweiligen App Store vertreiben lässt. Aufgrund des geringeren Entwicklungsaufwands und der einheitlichen Programmiersprache ist eine Lösung mittels cross-platform-compiling optimal. Die Programmierung mittels cross-platform-compiling ermöglicht die kostengünstige Entwicklung einer App, da diese nur einmal erstellt werden muss und sich dann für das jeweilige Smartphone-Betriebssystem portieren lässt. Zudem ist es sinnvoll, die App mit dem Infotainmentsystems des Fahrzeugs zu verbinden. Der Fahrer wird somit nicht durch das Smartphone abgelenkt, da er alle Funktionen mit den Bedienelementen des Fahrzeugs steuern kann. Da es sich um eine App zum energieeffizienten Fahren von Carsharing-Elektrofahrzeugen handelt, ist der Name der App „sharefficient". Die folgenden Mock-Ups in Abbildung 4 werden aus der User-Perspektive unter iOS vorgestellt.

Zunächst einmal wird beim Start der App ein Start-/Ladebildschirm angezeigt. Der Startbildschirm zeigt das Logo sowie den Namen und Slogan der App. Das Logo der App ist der bereits genannte grüne Daumen. Dieser findet sich auch später bei der In-Car-Lösung wieder. Darauffolgend erscheint die Anmeldemaske. Diese ist in Abbildung 4 als erstes Mock-Up dargestellt. In die Anmeldemaske müssen die E-Mail Adresse sowie das persönliche Kennwort eingegeben werden. Durch das Bestätigen des „Login" Buttons wird der Nutzer zu den Funktionalitäten weitergeleitet. Des Weiteren besteht die Möglichkeit, in der App angemeldet zu bleiben. Wird diese Option gewählt, erscheint die Anmeldemaske beim nächsten Aufruf der App nicht mehr. Außerdem gibt es noch einen Hyperlink für den Fall, dass das Passwort vergessen wurde. Das Passwort lässt sich mit Hilfe der E-Mail Adresse zurücksetzen. Nachdem die E-Mail Adresse in das dafür vorgesehene Textfeld eingegeben und der Bestätigungsbutton betätigt wurde, erhält der Nutzer eine E-Mail mit der sich ein neues Passwort erstellen lässt. Als neuer Nutzer muss zuerst die Registrierung für „sharefficent" stattfinden. Hierzu muss eine E-Mail Adresse sowie ein persönliches Passwort eingegeben werden. Zur Vermeidung von Fehlern ist eine doppelte Eingabe erforderlich. Nachdem die Daten gesichert wurden, erhält der Nutzer eine E-Mail in der die weitere Vorgehensweise erklärt wird. Die Eingabe der weiteren persönlichen Daten sowie der Abschluss der Registrierung kann sowohl Online als auch persönlich in einer Geschäftsstelle des Carsharing-Anbieters erfolgen.

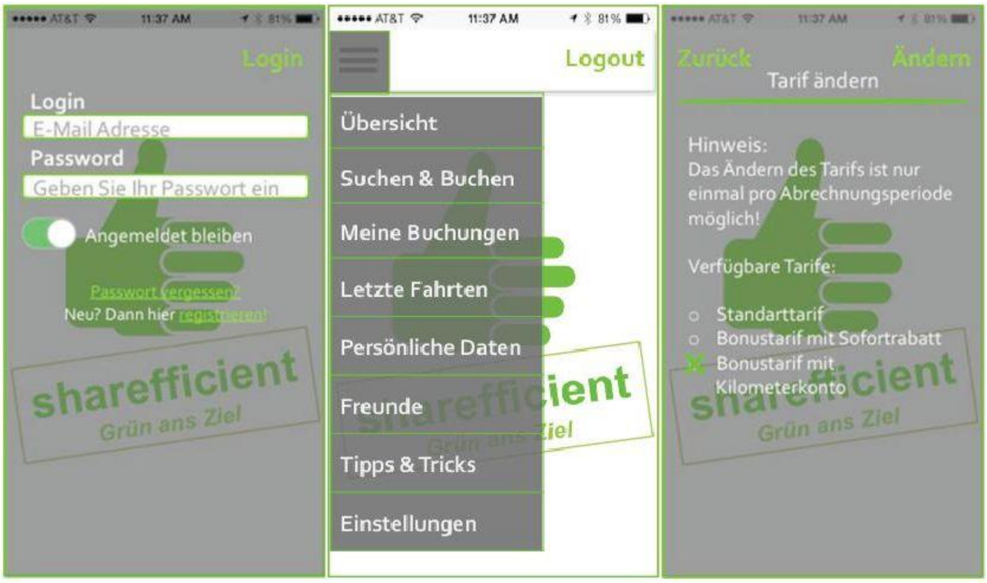

Abbildung 4: Mock-Ups der Funktionen des Bonussystems

Nach der Anmeldung oder Registrierung öffnet sich das Hauptmenü. Ein Pfeil mit dem Hinweis „Hier geht's los" zeigt auf den Button zum Öffnen der Menüleiste. Zusätzlich gibt es oben rechts einen Button der direkt zum Logout führt. Wurde die Menüleiste geöffnet, erscheint eine Liste mit verschiedenen Unterpunkten. Ein Klick auf den jeweiligen Unterpunkt öffnet den entsprechenden Bildschirm, welches als Mock-Up in Abbildung 4 in der Mitte zu sehen ist.

In dem Übersichtsmenü lassen sich Daten zu den insgesamt gefahrenen Kilometern, den gesammelten Bonuspunkten sowie zu der Gesamtanzahl an Fahrten einsehen. Des Weiteren gibt es eine Anzeige der Gesamtbewertung in Form des Daumens nach bekanntem Schema. Die Übersicht kann für einen Monat oder für die gesamte Nutzung der App eingesehen werden. Der „Suchen & Buchen" Button unterstützt dabei schnell ein Fahrzeug in der Umgebung zu finden und zu buchen. Angaben zu der Reichweite, dem Batteriestand und den verfügbaren Zeiten werden zu den jeweiligen Fahrzeugen angezeigt. Ein Klick auf den Hyperlink „Buchen" führt zum Buchungsbildschirm. Der Hyperlink „Starten" aktiviert eine Navigation zum Auto. Im Menüpunkt „Letzte Fahrten" sind alle Informationen zu den bisher getätigten Fahrten gespeichert. Es wird das Datum, die zurückgelegte Distanz sowie die Bewertung der Fahrt angezeigt. Durch das Betätigen der „Persönlichen Daten" können Daten, wie bspw. die E-Mail Adresse oder das Geburtsdatum des Nutzers eingesehen und geändert werden. Weiterhin gibt es hier die Möglichkeit den Tarif auszuwählen, welcher den materiellen Anreiz für das Bonussystem darstellt. Das zugehörige Mock-Up ist in Abbildung 4 ganz rechts zu sehen. Unter dem Menüpunkt „Freunde" kann ein Ranking für die getätigten, energieeffizienten Fahrten stattfinden und Nachrichten ausgetauscht werden. Die App zeigt unter dem Menüpunkt „Tipps & Tricks" Hinweise an, welche den Fahrer beim energieeffizienten Fahren unterstützen. Mit den Schaltflächen „Vorheriger Tipp" und „Nächster Tipp" lässt sich zwischen den Tipps hin und her blättern. Unter Einstellungen können allgemeinen Einstellungen der App, wie bspw. die Aktivierung von Push-Mitteilungen vorgenommen werden.

Die Funktionen der App für das energieeffiziente Fahren werden im Rahmen des Infotainmentsystems für Apple CarPlay dargestellt. Mit dem Start der App, erscheint die Anzeige des eigentlichen Bonussystems. Die Lösungen wurden in einem dunklen Farbton gestaltet, damit sie den Fahrer möglichst wenig ablenken und nicht blenden. Das Bonussystem greift auf das Navigationssystem des Smartphones zurück. Dies ist sinnvoll, da es dem Fahrer ermöglicht die kürzeste Strecke zu nutzen. Außerdem können Staus oder sonstige Verkehrsbarrieren angezeigt werden, damit der Nutzer diese effizient umfahren kann. Das Herzstück des Bonussystems ist die Effizienzanzeige in Form des Daumens. Die Fahrzeugdaten werden in Echtzeit im Hintergrund ausgewertet. Die Ausrichtung des Daumens ist abhängig von der Fahrweise des Fahrers. In Abbildung 5 ist dieses für die gute und die energieintensive Fahrweise grafisch dargestellt.

Abbildung 5: Mock-Ups der verschiedenen Fahrweisen im Bonussystem

Je weiter der Daumen nach unten zeigt, desto energieintensiver ist die Fahrweise des Fahrers. Neben der Bewertung der Fahrweise liefert die App noch Informationen zu den Kosten der aktuellen Fahrt sowie zu den gesammelten Bonuspunkten. Weiterhin wird je nach Tarifwahl die Anzahl der Freikilometer bzw. der Sparbetrag angezeigt

4 Diskussion und Limitationen

Das vorgestellte Konzept zum Bonussystem „sharefficent" gibt einen ersten Einblick, wie eine App aufgebaut sein könnte, um Nutzern von Carsharing-Elektrofahrzeugen zu motivieren, energieeffizienter zu fahren. Die Verbindung von Carsharing mit Elektrofahrzeugen und einer mobilen Anwendungen, wie bspw. hier auf dem Smartphone, stellen ein effizientes und effektives Carsharing-System dar (Lee et al. 2011). Um eine möglichst hohe Motivation der Nutzer zu erreichen, werden hier die extrinsischen Anreize angesprochen. Durch monetäre und nicht-monetäre Anreize werden diese innerhalb des Bonussystems abgedeckt. Die intrinsische Motivation ist bei jedem Carsharing-Nutzer individuell ausgeprägt und nur schwer zu quantifizieren. Gewöhnlich bezahlen die Carsharing-Nutzer einen festen Preis je gefahrenen Kilometer oder je gemieteter Stunde. Sie würden durch energieeffizientes Fahren keine Einsparungen erhalten und daher eher den Fahrspaß in den Vordergrund stellen. In diesem Fall gäbe es keine intrinsische Motivation des Fahrers das Fahrverhalten zu ändern. Daher wurde in dem Bonussystem Wert auf die extrinsischen Anreize gelegt, um unsere Forschungsfrage zu untersuchen. Der Daumen (von grün bis rot) sowie die finanziellen Vorteile (Freikilometer oder Rabatt) bilden die Anreizfaktoren mit größt möglicher Wirkung, um energieeffizientes Fahren zu fördern. Die festgelegten Anreize sind lediglich literaturbasiert und es hat keine Evaluierung dieser stattgefunden, was eine Limitation unserer Arbeit darstellt. Weiterhin wurden vornehmlich nur die Anreize auf Basis der Anforderungen für private Nutzer betrachtet. Weniger preissensitive Kundengruppen, wie z.B. Businesskunden wurden nicht behandelt, da für diese Nutzergruppe eher Aspekte wie Zuverlässigkeit und Verfügbarkeit relevant sind. Hinzu kommt, dass Carsharing vornehmlich von Privatpersonen genutzt wird und somit der Anteil der Kunden im Business-Bereich noch relativ gering ist (Schaefers 2013, Efthymiou et al. 2013). Dennoch sind die nicht-monetären und monetären Anreizfaktoren, die in diesem Artikel erarbeitet wurden, eine erste Grundlage und können als Basis für eine weitere Präzisierung des Bonussystems genutzt werden. Im Rahmen der Realisierung der App mit dem hinterlegten Bonussystem müssten die jeweiligen Carsharing-Unternehmen noch eine Wirtschaftlichkeitsanalyse auf Basis ihrer Kostenstruktur erstellen. Anhand dieser Analyse sollten die Höhe der Freikilometer und der Rabatt gewählt werden. Da es sich hier aber um einen konzeptionellen Entwurf handelt, wurden die Präzisierungen und auch die technische Ebene, wie bspw. die Programmierung der App nicht behandelt. Es hat somit nur eine Betrachtung des Front-End der App stattgefunden. Es wurden keine Aussagen über die Einbindung von Kundendatenbanken und Back-Endsystemen gemacht. Diese Systeme sind bei den meisten Carsharing-Unternehmen bereits vorhanden. Sie müssten dementsprechend angepasst werden, um das Bonussystem zu integrieren. Die Verarbeitung von drahtlos empfangenen Daten, wie sie von einem Smartphone zu erwarten sind, stellt für die Carsharing-Unternehmen keine Neuheit dar. Beispielsweise ist die drahtlose Verifikation des Kunden am Fahrzeug oft über die in der Windschutzscheibe platzierten Scanvorrichtung ausführbar.

Ein Ziel für Carsharing-Unternehmen, die Elektrofahrzeuge in ihre Flotte einbinden, ist die Reduzierung der Ladezyklen der Fahrzeuge. Das Bonussystem kann dazu beitragen, Energie und somit auch Zeit für die Ladung der Batterie einzusparen, da mit der App und dem hinterlegten Bonussystem an die extrinsischen Anreize der Nutzer appelliert wird. Die Einsparungen der benötigten Energie haben zusätzlich noch einen positiven Einfluss auf die Umweltbilanz des Unternehmens und bieten den Carsharing-Nutzern eine nachhaltige und individuelle Mobilität (Hanelt et al. 2015).

In dem vorgestellten Konzept wird die App bzw. das Smartphone mit dem Infotainmentsystem des Elektrofahrzeugs verbunden. Es gibt aber zusätzlich noch die Möglichkeit, die App nur auf dem Smartphone laufen zu lassen und somit das Infotainmentsystem gar nicht anzusprechen, falls dies nicht gewünscht ist, oder nicht verfügbar ist. Ein Auslesen der relevanten Fahrdaten ist mit der vorgeschriebene OBD 2-Schnittstelle möglich. Mittlerweile wird fast jedes Fahrzeug mit einem OBD 2-Anschluss ausgeliefert (Wtec-Systems 2015). Diese Adapter bieten einen detaillierte Einblick in den aktuellen Leistungs- und Funktionszustand des Fahrzeugs (Barth und Huch 2014). Über die Programmierung einer entsprechenden App könnte dieser Datensatz als Grundlage für die Erhebung eines Fahrprofils genutzt werden. Da Smartphones sowohl über Bluetooth als auch über GPS-Chips verfügen, lassen sich diese Daten kombinieren und somit Profile erstellen, welche sowohl den Leistungszustand des Fahrzeugs als auch den Umgebungskontext des Fahrzeugs berücksichtigen (wie bspw. Stadt- oder Landstraßenfahrt).

5 Fazit und Ausblick

Diese Arbeit hat gezeigt, wie ein Bonussystem gestaltet werden kann, um Anreize zum energieeffizienten Fahren von Carsharing-Elektrofahrzeugen zu schaffen. Ein solches Bonussystem kann den Prozess der Integration von Elektrofahrzeugen in Carsharing-Flotten unterstützen. Durch energieeffizientes Fahren können sich Einsparpotentiale auf Seiten der Nutzer sowie auf Anbieterseite ergeben, darunter eine Erhöhung der Reichweite der Elektrofahrzeuge, eine Reduzierung der Stromkosten und eine Senkung des Fahrzeugverschleißes für die Carsharing-Unternehmen. Bezugnehmend auf die Forschungsfrage, hatte dieser Artikel das Ziel, Anreizarten in einem Smartphone-Bonussystem zu identifizieren und zu analysieren, um einen Beitrag zum energieeffizienten Fahren von Carsharing-Elektrofahrzeugen zu leisten. Hierfür wurden Anreizarten im Anreizsystem systematisch untersucht und als Basis für die Herleitung und Visualisierung eines Bonussystems verwendet. Insbesondere materielle Anreize, wie etwa Freikilometer oder Rabatte im Carsharing-Programm, und immaterielle Anreize, wie etwa ein grüner Daumen für energieeffizientes Fahren, können hierbei als Anreize in einem Smartphone-Bonussystem eingesetzt werden. Es wurde ein konzeptioneller Entwurf eines Smartphone-Bonussystems mit dem Namen „sharefficient" vorgestellt und diskutiert, welches das energieeffiziente Fahren von Carsharing-Elektrofahrzeugen fördern soll.

Im Zuge des Markteintritts der großen IT-Konzerne wie Apple, Google und Microsoft wurden neue Infotainment-Standards eingeführt. Das Engagement dieser IT-Konzerne schafft neue Anwendungsmöglichkeiten, wie z. B. die Integration von smartphonebasierten Bonussystemen. Insbesondere die CSOs können von dieser Entwicklung profitieren, da sich durch die neu eingeführten Softwarestandards diverse neue Problemlösungs- und Einsatzmöglichkeiten ergeben. Die Automobilbranche hat bereits auf die neuen Technologien reagiert, wie sich am Beispiel von Opel sehen lässt. So unterstützt der neue Opel Astra alle Smartphone-Infotainment-Plattformen. Auch Ford hat angekündigt, dass bis Ende 2015 in allen Modellen serienmäßig Android Auto und Apple CarPlay verfügbar sein werden (Macerkopf 2015). Auch das zukünftige Engagement von Opel auf dem Carsharing-Markt unterstreicht das hohe Potential. Google arbeitet aktuell daran, dass Android als eigenständiges Betriebssystem in Fahrzeugen eingeführt wird. Das Projekt läuft unter dem Namen Android M. Damit geht Google einen Schritt weiter, indem es eine eigenständige, handyunabhängige Software bereitstellen möchte. Ob sich dieser Ansatz durchsetzt, ist nach der bisherigen Strategie der Automobilbauer fraglich. Denn bisher wollen diese sich nicht auf eine Lösung festlegen, da Kunden ihre Kaufentscheidung nicht vom Smartphone abhängig machen sollen. Ähnlich wie Opel hat auch VW bereits eine Baukastenlösung parat, mit der alle Smartphone-Betriebssysteme arbeiten können. Nach dem Markteintritt von Google und Apple sowie der Ankündigung von Microsoft sich ebenfalls auf dem Markt engagieren zu wollen, lässt sich festhalten, dass die Einführung der bisherigen Systeme erst den Anfang in der Entwicklung neuer vernetzter Infotainment-Systeme darstellen wird.

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A.11 A Decision Support System for the Optimization of Electric Car Sharing Stations

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A Decision Support System for the Optimization of Electric Car Sharing Stations

Completed Research Paper

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Abstract

Electric car sharing is a mobility alternative addressing the world's growing need for sustainability and allowing to reduce pollution, traffic congestion, and shortage of parking in cities. The positioning and sizing of car sharing stations are critical success factors for reaching many potential users. This represents a multi-dimensional challenge that requires decision makers to address the conflicting goals of fulfilling demands and maximizing profit. To provide decision support in anticipating optimal locations and to further achieve profitability, an optimization model in accordance to design science research principles is developed. The integration of the model into a decision support system (DSS) enables easy operability by providing a graphical user interface that helps the user import, edit, export, and visualize data. Solutions are illustrated, discussed, and evaluated using San Francisco as an application example. Results demonstrate the applicability of the DSS and indicate that profitable operation of electric car sharing is possible.

Keywords: *Electric car sharing, decision support system, optimization model, design science research.*

Introduction and Motivation

Over the last several decades, rising energy and vehicle ownership costs, sensitivity to environmental sustainability, and social responsibility have caused people to take advantage of transportation alternatives (Dedrick, 2010; Katzev, 2003). Car sharing is one alternative that can satisfy the mobility needs of the modern urban population. Besides the possible monetary savings that a car sharer can achieve, a change of the society toward access-based consumption instead of ownership is a decisive factor that positively affects the demand for car sharing (Shaheen and Cohen, 2013; Bardhi and Eckhardt, 2012). The environmental advantages of car sharing include a decrease in the shortage of parking, a reduction in the number and age of private vehicles, and a decrease in mileage per person (Alfian et al., 2014; Burkhardt and Millard-Ball, 2006). Since electric vehicles cut down emissions and reduce noise as compared to conventionally powered vehicles, they are perfectly suitable for a car sharing concept and further enhance ecological sustainability (Shaheen et al., 2013; Lee et al., 2012). However, state-of-the-art electric vehicles are still associated with high acquisition costs, require a charging infrastructure, and have a limited range compared to conventionally powered vehicles. Theoretically these points work well with car sharing, yet only station-based approaches can appropriately accommodate charging infrastructures and suitably account for range limitations and charging cycles.

For car sharing organizations, the most critical success factor is the challenging task of positioning and sizing car sharing stations to reach the largest possible amount of potential users (Costain et al., 2012). The accessibility and the distance to users' homes as well as to public transport stations play an important role in attracting potential users (Celsor and Millard-Ball, 2007). Moreover, different demographic and geographic characteristics such as high population density, shortage of parking, mix of public transportation uses, and the ability to live without a vehicle affect car sharing usage and need to be considered (Celsor and Millard-Ball, 2007; Cohen et al., 2008; Stillwater et al., 2009). These factors have to be addressed by decision makers when setting up a car sharing network. While trying to allocate the optimal number of stations and vehicles, the organizational objective of profit maximization must be kept in mind. Best practice so far appears to be a trial-and-error concept: stations are randomly opened and then monitored. If not frequently used, they are closed after a trial period. Otherwise they remain unchanged or the number of vehicles is increased. We suggest supporting the planning process with a web-based application that takes several important parameters into account. This tool enables decision makers to execute different scenarios and eventually find the optimal network for their specific application. In addition to its supportive function in implementing car sharing in an economically successful way, our approach helps achieve direct and indirect conservation of resources, and thus leads to increased sustainability. At the same time, it is part of the Green IS concept, as it applies an interaction of information technology (IT) and people to enable the optimization of processes and products and to raise resource efficiency (Watson et al., 2010; Butler, 2011).

Our suggested decision support system (DSS) and the underlying optimization model are based on the model from Rickenberg, Gebhardt, and Breitner (2013). We modified and expanded their model to accurately forecast the expected demand and to maximize the profit of car sharing organizations. The graphical user interface (GUI) of the DSS helps decision makers import and edit data, set parameters, trigger numerical solving of the underlying model, and visualize optimization results. This enables instant validation, comparison, and assessment of results and scenarios. This is exemplarily demonstrated by means of a major city in the US and includes the creation of a specific dataset based on census data and local conditions. The described challenges lead to our research question:

> *RQ: How can decision makers be supported in finding an optimal car sharing network of electric vehicles?*

To answer this question, the remainder of this paper is structured as follows: first the research background is described, covering our research design and related work about car sharing. In the next section, the optimization model is explained and formally noted. Subsequently, the DSS, which employs the underlying model, is presented. The applicability of the model is checked, benchmarks are performed, and the results are shown together with corresponding sensitivities. The next section discusses the presented model, DSS, and corresponding results, followed by the limitations and recommendations of our research. We complete our article with a conclusion and outlook regarding this field of research.

Research Background

Research Design

Methodologically our research is based on design science research (DSR) principles as proposed by Hevner et al. 2004. In contrast to behavioral science, the design science approach systematically seeks to create "new and innovative artifacts" (Hevner et al., 2004). This means it is most suitable for the tasks needed to be accomplished when creating, specifying, and evaluating a car sharing model, addressing both its relevance and its rigor.

Regarding relevance, our work is motivated by the increasing demand for alternative transportation methods, e-mobility, and the associated decision making requirements. A current research project focusing on e-mobility provides further information and ensures the actual relevance and importance of the problem. The review of existing knowledge in the rigor cycle represents a second essential part of the research process (Peffers et al., 2007). We conducted a comprehensive literature review within the car sharing domain, including optimization models, demand estimations, and electric vehicles. Furthermore, we carried out a targeted review of the DSS and DSR domains. The design cycle is an iterative process that uses several build-and-evaluate loops, and revises the design artifacts until a feasible level is reached. We conducted several cycles to ensure that environmental requirements, scientific methods, and existing expertise were all taken into account. As final artifacts, a further enhanced optimization model and the DSS "OptECarShare 1.5" emerged. We tested the DSS and the underlying optimization model extensively to enable proper documentation and publication of research results. The application of DSR in the context of our research as described in the above is visualized in Figure 1:

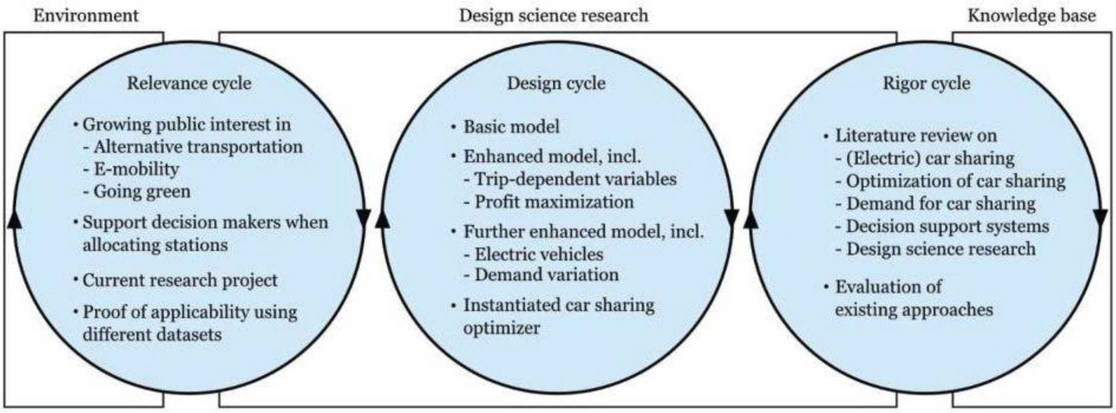

Figure 1. Design science research as applied in our approach based on Hevner (2007)

Car Sharing and Related Work

Car sharing is a transportation strategy that offers the usage of vehicles in an organized manner by paying variable trip-dependent fees. After registration at a car sharing organization (CSO), users can utilize any available vehicle of the fleet as long and as often as required to satisfy their mobility needs. The payment structure differs between organizations, and is usually regulated via varying minute-by-minute fees. Some organizations charge additional fees for mileage or minimal monthly basic fees. In any case, car sharing users pay only for trips they actually take and have no unexpected costs such as maintenance, repairs, or continuous costs such as taxes.

Car sharing organizations offer their services in three main variations. The free-floating system enables the user to pick up and drop off a vehicles anywhere within a determined area (Weikl and Bogenberger, 2012; Firnkorn and Müller, 2011). Station-based car sharing services either require the users to do round-trips and return the vehicle to the same station it was picked up at (two-way car sharing), or allow for one-way trips between different stations. To ensure that there is no imbalance, relocation techniques are needed in this case (Jorge and Correia, 2013; Shaheen and Cohen, 2013). As our work considers electric vehicles with a specific charging infrastructure, station-based car sharing in a two-way mode is the most suitable concept and represents the basis of our model.

Research on car sharing related topics and the number of respective publications increased over the past few years. Many of these address the history and the development of car sharing organizations. A few also analyze locations, typical users and their habits, or the environmental and social benefits of car sharing. While a broader overview on related literature can be found in the article from Degirmenci and Breitner (2014), we focused our review on optimization approaches for car sharing, electric car sharing, estimation of demand, and DSS. The following section succinctly outlines the most applicable articles, to provide a state-of-the-art view on the topic of car sharing.

Publications on optimization of car sharing networks are manifold, yet they emphasize different aspects. Within our literature review we therefore categorize all relevant articles based on their main focus into one or more of six categories (Table 1). The first category, "location optimization", refers to the allocation of stations into a car sharing network and typically represents a strategic approach. The "vehicle optimization" category designates the tactical decision level with corresponding approaches that assess the optimal number of vehicles at each station. In addition to these long-term perspectives, articles also review operational business with goals such as optimizing the service or relocating vehicles. These are consolidated into the "operative optimization" category. Articles concerning the demand for car sharing, at times including profiles of typical car sharing users, fall into the "demand" category. The "DSS" category includes articles introducing decision support systems regarding various aspects of car sharing. "Electric car sharing" is considered separately from traditional car sharing approaches because both charging infrastructures and charging cycles have to be taken into account.

A representative example for the first category is Awasthi et al. (2007), who present a three-stage approach to the selection of car sharing stations. They identify potential stations, assign allotted weights for each station, and then select the final stations. Musso et al. (2012) introduce a similar approach to extending an existing car sharing network by assigning three success factors to different regions and installing new stations and vehicles in the highest-rated regions. De Almeida Correia and Antunes (2012) consider one-way car sharing and combine the strategic perspective of planning locations and size of car sharing stations with the operative aspect of profit maximization per period for different relocation procedures. The model from Boyaci et al. (2015) has a similar focus. It explores the best location, fleet size, and relocation techniques in a one-way car sharing application with the aim of maximizing profit. Cepolina and Farina (2012) provide a cost minimization model for the distribution of personal intelligent city accessible vehicles (PICAVs) within the city of Genoa (Italy), including a fully user-based relocation strategy. Many operative models introduced in the literature fully focus on daily service. One example is Fan et al. (2008), who develop a multistage stochastic linear model to maximize the daily profit by means of a dynamic daily allocation of vehicles. The model calculates a relocation scheme by means of fixed reservations for the next day. Kek et al. (2009) present an optimization model and DSS to reduce the cost for the relocation of one-way car sharing services by considering operational costs. Compared to approaches regarding conventional car sharing, research and applications in the "electric car sharing" category are still relatively limited. Khanna and Ventors (2013) provide a prototype concept to integrate electric car sharing into the public transport system and state that information and communication technology innovation is a key component to success. A field study presented by Steininger and Bachner (2014) investigates the provision of electric vehicles by a rail company and indicates that the service can succeed. Potential demand for electric car sharing is reviewed in a survey by Shaheen et al. (2013), who report that 66% of all participants of the population in San Francisco are interested or at least maybe interested in electric car sharing. Literature also suggests that critical success factors exist to reach those potential car sharing users. Andrew and Douma (2006) identified population density, age, residents commuting, household type, and parking situation as critical success factors. Results of a study from Costain et al. (2012) show that car sharing is preferably used during the weekend, with a rising trend throughout the week. An overview of demand estimation and defined operations is provided by Jorge and Correia et al. (2013). Due to the criticality of the success factors and the related demand, decision support appears to be reasonable and can be found in several approaches. An example for the "DSS" category is represented by an article of El Fassi et al. (2012), who developed a DSS based on a discrete event simulation, which determines the best expansion strategy for the desired investigation area. Possible strategies, for instance, consist of the establishment of new stations, the expansion of existing stations, and the merging and demerging of stations.

Table 1. Car sharing related literature categorized by focus

Author	Year	Focus on: Location optimization	Vehicle optimization	Operative optimization	Electric car sharing	Demand	DSS	Content
Alfian et al.	2014			x				Simulation tool to evaluate the service model in car sharing systems
Andrew and Douma	2006					x		Study of car sharing market in US. Success factors are: density, age, residents commuting, household type, parking situation
Awasthi et al.	2007	x	x					Optimization of car sharing location based on a case example in France
Bardhi and Eckhardt	2012					x		Analysis of access-based consumption in the context of car sharing
Boyaci et al.	2015	x	x	x	x			Generic model for supporting the strategy (station location and size) and tactical decisions of one-way car sharing systems
Burkhardt and Millard-Ball	2006					x		Analysis of car sharing users
Celsor and Millard-Ball	2007	x				x		Tool to identify neighborhoods that can support car sharing in the US
Cepolina and Farina	2012		x		x			Optimization of distribution of electric vehicles (PICAVs) in Genoa
Cervero	2003					x		Analysis of car sharing users in the first year of a CSO in San Francisco
Cervero and Tsai	2004					x		Analysis of car sharing users in the second year of a CSO in San Francisco and positive developments within the city
Costain et al.	2012					x		Analysis of user behavior: case example Toronto
de Almeida Correia and Antunes	2012	x		x				Maximize daily profit by an optimization approach to depot location in one-way car sharing services
Di Febbraro et al.	2012			x				Simulation and optimization of the relocation problem of one-way car sharing: case example Turin
El Fassi et al.	2012		x	x			x	Optimization of car sharing stations and vehicles within existing CSO (operative planning)
Fan et al.	2008			x				Multistage stochastic linear model to maximize the daily profit by relocating the vehicles
Habib et al.	2012					x		Development and validation of an econometric model for behavior of car sharing users to provide support for car sharing planners
Jorge and Correia	2013					x		Literature review of demand estimation of car sharing systems
Jorge et al.	2014			x				Mathematical model to optimize relocation operations to maximize the profit and a simulation tool to study different real-time relocation policies
Kek et al.	2009			x			x	Optimization model and DSS to determine a set of near-optimal manpower and operating parameters for the vehicle relocation problem
Kek et al.	2006			x				Simulation model on operator-based relocation techniques
Khanna and Venters	2013				x			Case study in Berlin to integrate electric car sharing into the public transport system
Millard-Ball et al.	2005					x		Analysis of the market, barriers, impacts, and critical success factors
Morency et al.	2011					x		Analysis over three years of car sharing members in Montreal
Musso et al.	2012	x	x					Expansion plan of car sharing services in new districts in Rome
Nobis	2006					x		Survey of the awareness and market potential of car sharing service in Germany
Rodier and Shaheen	2003					x		Scenario analysis using an advanced travel demand model in the Sacramento region
Schaefers	2012					x		Analysis of motives of car sharing usage in the US
Shaheen and Cohen	2008					x		International comparison of car sharing
Shaheen and Martin	2010					x		Explorative study of demand for car sharing systems in Beijing
Shaheen et al.	2013				x			Study of electric vehicle car sharing in San Francisco
Steininger and Bachner	2014				x			Evaluating costs, market potential and environmental merits of implementation of car sharing in Austria
Stillwater et al.	2009					x		IS-based study of influencing factors of car sharing demand
Ter Schure et al.	2012					x		Impacts of parking situation and car sharing demand
Wagner et al.	2014		x				x	Decision support of points of interest in free-floating car sharing system
Wang et al.	2012					x		Survey of profile of car sharing members in Shanghai

However, none of these articles provide support for strategic optimization of location, number, and size of stations. Neither considers electric vehicles in their optimization approaches. However, many publications emphasize the importance of a well-planned network that optimally addresses the demand. They further indicate the suitability of electric vehicles for car sharing. We therefore consolidated many of the above ideas in our approach. We developed a mathematical model that optimizes an electric car sharing network and maximizes the organization's profit as objective function. Critical conditions discussed in many of the articles are combined in the constraints of this model. We also gave a lot of critical thought to our dataset and diligently implemented the existing background knowledge into our supply and demand datasets. We implemented this model to provide valuable insight for real-life decision makers.

Optimization Model

The presented optimization model is based on the basic model from Rickenberg, Gebhardt, and Breitner (2013) and maximizes the annual profit of a car sharing organization. The following assumptions form the basis of the optimization model:

- The object in consideration is the classic two-way car sharing scheme. Every vehicle has its designated parking lot, meaning vehicles have to be picked up and returned to the same location.
- The objective of the optimization model explicitly concerns strategic planning of a car sharing network; operational aspects are not considered.
- Stochastic and normal distributed demand points for car sharing exist.
- The demand points are allocated within the investigation area and are provided on a punctual basis by geographic coordinates.
- The demand has to be fulfilled completely to reach the maximum customer satisfaction.
- Possible supply points in the form of car sharing stations are spread over the specific investigation area to satisfy the demand. These points are also characterized by exact geographic coordinates.
- For each of the potential stations, a maximum limit of parking lots is defined to reflect local land-use conditions in the surroundings of the respective station.
- Annual leasing costs for vehicles, parking lots, and stations are introduced. These contain all incidental expenses, and explicitly not only the initial costs.
- Subject matter is electric vehicles, which are completely battery powered and require trip-dependent charging cycles.
- Two different options of the charging process can be simulated for the otherwise homogenous fleet. Firstly, regular charging can be used through the conventional local grid-connection. As an alternative, more efficient fast chargers via special 50 kW DC charging elements can be chosen. Depending on the option, different charging times and adjusted leasing costs are being considered.
- The implementation of electric vehicles into the car sharing fleet requires additional parameters. Charging condition and influencing elements such as range, average speed, and power consumption are therefore considered. The power consumption depends on the duration of a trip and the distance driven. Hence, these are integrated as trip-dependent parameters and modelled stochastically by a normal distribution.
- A maximum number of possible trips per day results from the choice of trip-dependent parameters and the corresponding fast or regular charging times.
- The charging time is linearly correlated to the travel time. This means that one hour of travel time is always associated with a fixed time to recharge the battery.
- Variations in demand typically do not represent a part of a strategic, i.e., long-term problem. To grant decision makers a certain degree of variation, the suggested model allows the demand to be varied throughout the week by determining peak and off-peak weekdays. An additional variation of the demand (e.g., throughout the day or year) is not expected to add further value to the strategic allocation of stations and vehicles and should rather be included in operative approaches.

Table 2. Parameters used

Sets:	
$i = (1, \dots m)$: *potential station location*	$j = (1, \dots, n)$: *demand location*
Parameters:	
d_j: *normal distributed demand* [*rents/week*]	*min*: *expected duration of a rent* [*min*]
rev: *revenue for renting* [*USD p.a.*]	*trip*: *expected distance driven* [*km*]
energy: *average energy consumption* [*kwh/km*]	*price*: *price* [*USD/kwh*]
cv: *leasing cost of a vehicle* [*USD p.a.*]	*cp*: *leasing cost of a parking lot* [*USD p.a.*]
cc^{reg}: *leasing cost of regular charger* [*USD p.a.*]	cc^{fast}: *leasing cost of fast charger* [*USD p.a.*]
cs: *leasing cost of a station* [*USD p.a.*]	
x^{reg}: *possible trips regular* [*units*]	x^{fast}: *possible trips fast* [*units*]
dmax: *demand of busiest interval* [*rents/day*]	
$maxl_i$: *max. lots at station i* (#)	*maxlfast*: *max. lots with fast charger* (#)
$dist_{ij}$: *distance betw. station i and demand point j* [*km*]	*maxdist*: *max. distance betw. i and j* [*km*]
Decision variables:	
v_i^{reg}: *number of vehicles regular charged at station i*	y_i: 1, *if station is built*, 0 *else*
v_i^{fast}: *number of vehicles fast charged at station i*	z_{ij}: 1, *if demand location j is served by station i*, 0 *else*

$$\boldsymbol{Max.F}\left(\boldsymbol{v}^{reg}, \boldsymbol{v}^{fast}, \boldsymbol{y}\right) = \overbrace{\sum_{j=1}^{n} d_j * (min * rev)}^{revenue} - \overbrace{\sum_{j=1}^{n} d_j * (trip * energy * price)}^{variable\ costs}$$
$$- \overbrace{\sum_{i=1}^{m} \left(v_i^{reg} * (cv + cp + cc^{reg}) + v_i^{fast} * (cv + cp + cc^{fast}) + y_i * cs\right)}^{leasing\ costs} \quad (1)$$

$$\sum_{i=1}^{m} z_{ij} \geq 1 \quad \forall j \quad (2)$$

$$y_i \geq z_{ij} \quad \forall\, i\ and\ j \quad (3)$$

$$v_i^{reg} * x^{reg} + v_i^{fast} * x^{fast} \geq \sum_{j=1}^{n} (dmax_j * z_{ij}) \quad \forall i \quad (4)$$

$$v_i^{reg} + v_i^{fast} \leq maxl_i \quad \forall i \quad (5)$$

$$v_i^{fast} \leq maxlfast \quad \forall i \quad (6)$$

$$dist_{ij} * z_{ij} \leq maxdist \quad \forall\, i\ and\ j \quad (7)$$

$$y_i \in \{0, 1\} \quad \forall i \quad (8)$$

$$z_{ij} \in \{0, 1\} \quad \forall\, i\ and\ j \quad (9)$$

$$v_i^{reg}, v_i^{fast} \geq 0 \quad \forall i \quad (10)$$

Figure 2. Underlying mathematical model

The objective function (1) maximizes the profit of a car sharing organization by calculating the revenue and subtracting the resulting variable and the annual leasing costs. Demand points can be served by one or more stations to split the expected demand (2). Constraint (3) ensures that every demand point can only be assigned to a station that is actually built. The existing demand has to be satisfied completely in compliance with corresponding charging times (4). The factors x^{reg} and x^{fast} are used to calculate the possible number of trips per day, taking into account the average speed, trip duration, and corresponding charging times. Every station has a limited number of parking spaces for vehicles (5) to consider local parking conditions at that station. To prevent a grid overload, constraint (6) sets a maximum amount of fast charging infrastructures at all stations. Constraint (7) ensures that a maximum distance between a demand point and an associated station is not exceeded. Equations (8), (9), and (10) set the specific value range of the decision variables of the model.

DSS

In addition to the developed mathematical model that optimizes the network of car sharing stations, a decision support system (DSS) is constructed. The developed DSS is a Java-based web application that enables decision support for the optimal placement and size of car sharing stations. It integrates the optimization model and additional applications into one system. As principles of usability and comprehensible visual appearance are applied, it enables decision makers to easily run their own case studies. After the desired datasets are developed and imported and after parameters are selected, the DSS solves the equations of the underlying model and displays the appropriate results in an illustrative way. As a result it contributes to less pollution and a more sustainable environment in accordance with the Green IS/DSS concept. The basic requirement for the optimization is the software GAMS, a modeling system for mathematical programming. Further software used to develop the DSS is Eclipse Luna with the actual Java Development Kit and Notepad++. The resulting system architecture and data flow is shown in Figure 3.

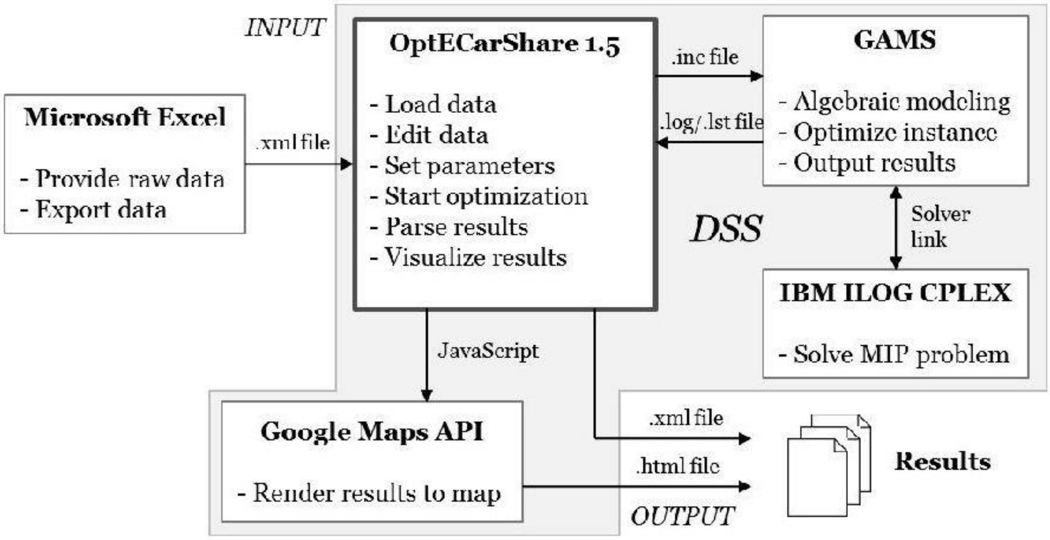

Figure 3. Dataflow of the decision support system

As illustrated above, a dataset for the respective investigation area needs to be developed by decision makers as external input in the form of an .xml file. The DSS provides the option to both load and edit data, such as potential car sharing stations. Furthermore, parameters of the mathematical model can be set and varied by the user to simulate different scenarios. When starting the optimization, an .inc file that contains the input data including the values of parameters is written. GAMS and the connected solver IBM ILOG CPLEX then calculate the optimal solution of the mathematical model. GAMS automatically generates a .log and a .lst file which are used to display the optimization process and the results. For an additional graphical visualization, the resulting car sharing network can be exported to an .html file via Google Maps API.

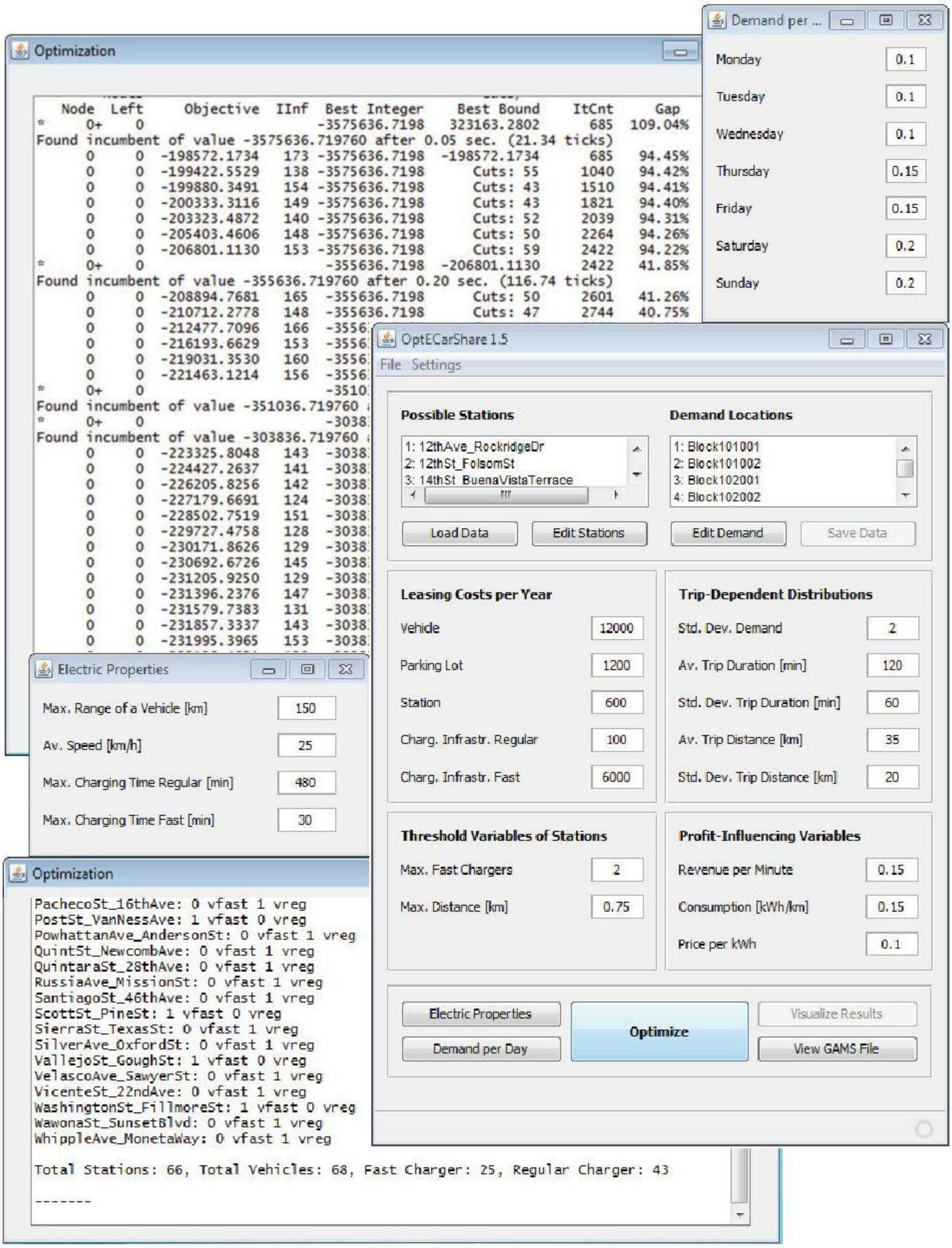

Figure 4. Design and functionality of the decision support system

Figure 4 provides an overview on the respective windows of the GUI. The main GUI "OptECarShare 1.5" is grouped into six graphically separated sections and a menu bar. In the menu bar, users can define the GAMS path and the working directory, as well as optimization accuracy, which is preset to five percent. The first section enables loading and modification of a dataset. The two vertical scrollbars can be used to quickly review the stations and demand points, which are displayed in numerical order. The stations and demand locations, as well as their specific properties, can be viewed in detail and easily edited via the "Edit Stations" and "Edit Demand" buttons. The next four sections contain the basic parameters. The first section contains different incidental costs that are described as leasing costs per year. This includes the leasing cost for a vehicle, parking lot, and station, as well as costs for the regular and the fast charging infrastructures. The second section of the main GUI contains different trip-dependent distributions. The dataset assigns mean values to every demand location that are normal distributed with an adjustable standard deviation. In addition, the normal distributed trip duration and the trip distance with their corresponding deviations can be set. In the third section, the threshold variables for the maximum number of fast charging infrastructures and the maximum distance between supply and demand locations can be adjusted. The fourth section includes the variables that directly affect profit, including revenue per minute, consumption per kilometer, and energy price. The last section at the bottom of the application contains six buttons. The "Set Electric Properties" and "Demand per Day" buttons are used to modify preset values, as shown in Figure 4. The "Optimize" button starts the optimization through the linkage to GAMS, as explained before. The "Optimization" window illustrated above displays the running process. As GAMS and CPLEX work with the branch and cut algorithm, every line shows one single branch with information about the related objective, best integer, best bound, and the gap to the optimal solution. Only those branches are displayed that are better than the solution found before. At the end of the optimization process, the results are displayed in the Optimization window. The "Visualize Results" button activates the linkage between the DSS and Google Maps. The resulting network of car sharing stations is shown in Figure 5. The "View GAMS File" button opens the corresponding mathematical model. The DSS further includes error messages that prevent the start of the optimization when input is incorrect or missing, e.g., if the overall weekly demand exceeds 100 percent. They quickly take decision makers to the error so that it can be fixed quickly. The final "OptECarShare 1.5" web application, the optimization model, and sample data sets are available at 130.75.63.115/OptECarShare.

Dataset Creation, Applicability, and Benchmarks of San Francisco

In order to evaluate the developed DSS, we provide an application example together with benchmarks. An additional application example supporting our results is available at 130.75.63.115/OptECarShare to show transferability. The success of a car sharing organization depends on different demographic and geographic characteristics such as high population density, parking pressures, mix of transportation means, and the ability to live without a vehicle (Celsor and Millard-Ball, 2007; Cohen et al., 2008; Stillwater et al., 2009). For this purpose, we chose the city of San Francisco, which satisfies all required characteristics and already successfully accommodates car sharing networks. San Francisco has an appropriate population of more than 825,000 inhabitants within an approximately quadratic urban area with an edge length of about eleven kilometers. With the resulting population density of more than 7,000 people per square kilometer, San Francisco is one of the most populated cities in the US, leading to a lack of parking space. Within the mostly rectangular oriented streets, a well-developed public transport system covers the complete city. In addition to train and bus connections to the adjoining San Francisco Bay Area, there are networks of light rails, cable cars, historic streetcars, trolley coaches, and buses. With only one operating company supervising all of these means of public transportation and with co-resident expansion plans in place, the ability to live without a vehicle continues to improve. After choosing an operation area, the positioning of demand and supply points is the most crucial factor for a car sharing organization (Costain et al., 2012). For our validation, we set the demand locations analogous to the subdivision of blocks according to the U.S. Census Bureau. With the exception of five sparsely populated blocks (e.g., the Golden Gate Park) which are not considered, San Francisco is divided into 573 blocks. Each block is characterized by a particular demand location in its center of settlement indicated by geographical coordinates. A total of 1,448 potential supply points is distributed consistently over the whole investigation area and, likewise with precise geographical positions. Due to the proven correlation between public transport and car sharing, possible stations are set close to access points of public transportation (Celsor and Millard-Ball, 2007).

The estimation of demand levels for car sharing is summarized in a literature review published by Jorge and Correia (2013). As stated in recent studies and investigations, so me generalizations about car sharing participants are feasible. Correspondingly, we base our demand estimation on several population characteristics. The by far highest share of people conducting car sharing are those between 22 and 39 years old (Andrew and Douma, 2006; Burkhardt and Millard-Ball, 2006; Firnkorn and Müller, 2012; Morency et al., 2011). A typical car sharer is above-average educated (at least to bachelor degree level) and often lives in small non-family households with a maximum of two people (Andrew and Douma, 2006; Burkhardt and Millard-Ball, 2006; Habib et al., 2012; Stillwater et al., 2009). Equipped with less than one vehicle per household, a car sharer generally lives in an apartment building with more than five housing units (Andrew and Douma, 2006; Burkhardt and Millard-Ball 2006; Firnkorn and Müller, 2012; Habib et al., 2012). Several other criteria such as typical income levels are not considered due to ambiguous information. Based on these findings, we determined a group of potential car sharing users for each block that complies with all of these requirements. We used the latest forecasted data published by the U.S. Census Bureau for 2013 based on Census 2010, available on their homepage. Based on that data, we calculated the weekly demand per block as input for the mathematical model as follows.

First, we determined five population characteristics for each block, by assigning typical age, education, housing unit, available vehicles, and household type. We then allocated the number of potential car sharing users per block in accordance with these characteristics. Depending on the respective characteristics, the number of potential users may drop to zero, for example in blocks with family households or elderly people who are not typical car sharing users. As not every potential users actually participates in car sharing, the absolute number of car sharers is much lower. Different surveys suggest inconsistent values, therefore we vary the percentage between 1% and 10% in the benchmark section. In accordance with Burkhardt and Millard-Ball (2006), Habib et al. (2012), and Morency et al. (2011), we assume an average trip frequency of three trips per user per month. Hence, we calculated the demand per week for each block as follows:

$$\frac{number\ of\ potential\ users * percentage\ of\ focus\ group * 3\ trips\ per\ months}{30\ days\ per\ month} * 7\ days\ a\ week \quad (11)$$

The potential station locations within the optimization model are characterized by a particular limit of parking lots. These numbers result from local conditions such as bilateral parking, parallel or transverse parking, on-street, or off-street parking. Table 3 summarizes the initial values used for the required parameters to execute the DSS. We chose the distinct values based on the following explanations. The first values refer to the various annual leasing costs. The leasing costs for one vehicle include initial and running costs for purchase, battery, insurance, taxes, maintenance, cleaning, administration, depreciation, and amortization over the year. Leasing costs for parking lots correspond to rental charges of the ground. Cost for maintenance and cleaning of a parking lot as well as parking signage are incurred within the costs for a station. The leasing costs for a regular charging infrastructure unit contain the establishment and maintenance of a power line to the grid of the infrastructure. The annual leasing cost for a unit of fast charging infrastructures consider the installation, connection, and maintenance of high voltage power lines to the power mains.

Table 3. Applied values for parameters

Parameter	Value	Parameter	Value
Vehicle [USD p.a.]	12,000	Max. number of fast chargers per station	2
Parking lot [USD p.a.]	1,200	Max. distance [km]	0.75
Station [USD p.a.]	600		
Regular charging infrastructure [USD p.a.]	100	Max. range of a vehicle [km]	150
Fast charging infrastructure [USD p.a.]	6,000	Average speed [km/h]	25
		Charging time regular [min]	480
Std. dev. of demand	2	Charging time fast [min]	30
Average trip duration [min]	120		
Std. dev. trip duration [min]	60	Monday	0.1
Average trip distance [km]	35	Tuesday	0.1
Std. dev. trip distance [km]	20	Wednesday	0.1
		Thursday	0.15
Revenue per minute [USD]	0.15	Friday	0.15
Consumption [kWh/km]	0.15	Saturday	0.2
Price per kWh [USD]	0.1	Sunday	0.2

The discussed demand levels per block serve as mean value within a normal distribution. Likewise, the trip duration and the trip distance are normal distributed. The mean values are chosen based on findings of recent studies. The distance driven per trip varies between 20 and 60 kilometers (Cervero and Tsai, 2004; Duncan, 2011; Morency et al. 2011). The whole duration of a trip, including driving and parking times, varies between half an hour and four hours (Alfian et al., 2014). To limit the solution, thresholds are considered. The threshold of a maximum number of fast charging infrastructures restricts the solution regarding the capital expenditure and the securing of network coverage. One of the strongest factors of influence on the solution is the maximum distance between demand and station location. Various surveys and observations deviate between 250 meters and two kilometers, others state a maximum walking distance of 10.75 minutes (Morency et al., 2008; Costain et al., 2012; Celsor and Millard-Ball, 2007). The revenue per minute includes both driving and parking times. The energy consumption per kilowatt hour of the vehicle is computed per kilometer. Besides these adjustments, some additional parameters related to the charging cycles were chosen. The maximum range of the vehicle is set to a typical range of the average electric vehicle. The average speed is set to a typical city locomotion of 25 km/h in accordance to Kriston et al. (2010). Recharging of an empty battery with a regular charging infrastructure via a standard outlet such as a charging station connected to the grid takes about eight hours. The 50 kW DC high voltage fast charging infrastructure significantly increases the process. We chose a value of 30 minutes to recharge a battery based on the specifications of different manufacturers. Literature states that the demand level varies between weekdays and weekends, which is adjustable via a corresponding button (Millard-Ball et al., 2005). Values are chosen to simulate that the usage of car sharing rises slightly but constantly throughout the week and achieves its maximum at the weekend (Costain et al., 2012; Cervero, 2003; Alfian et al. 2014).

The application example uses the above parameters from Table 3. Calculations were conducted on a standard laptop (Intel Core i7 2.5 GHz CPU with 16 GB RAM) using GAMS 24.1.3 with CPLEX 12.5.1 and a set optimization gap of 10% or a maximum computing time of 6,000 seconds. Figure 5 visualizes the resulting station network for the city of San Francisco in Google Maps. When users of the DSS click the markers, the properties of the respective station are shown, i.e., the specific number of regular and fast chargers. In order to avoid an information overload in the illustration, markers for the demand are not directly shown. However, when users click on an area close to a station marker, the demand locations and their respective properties are displayed.

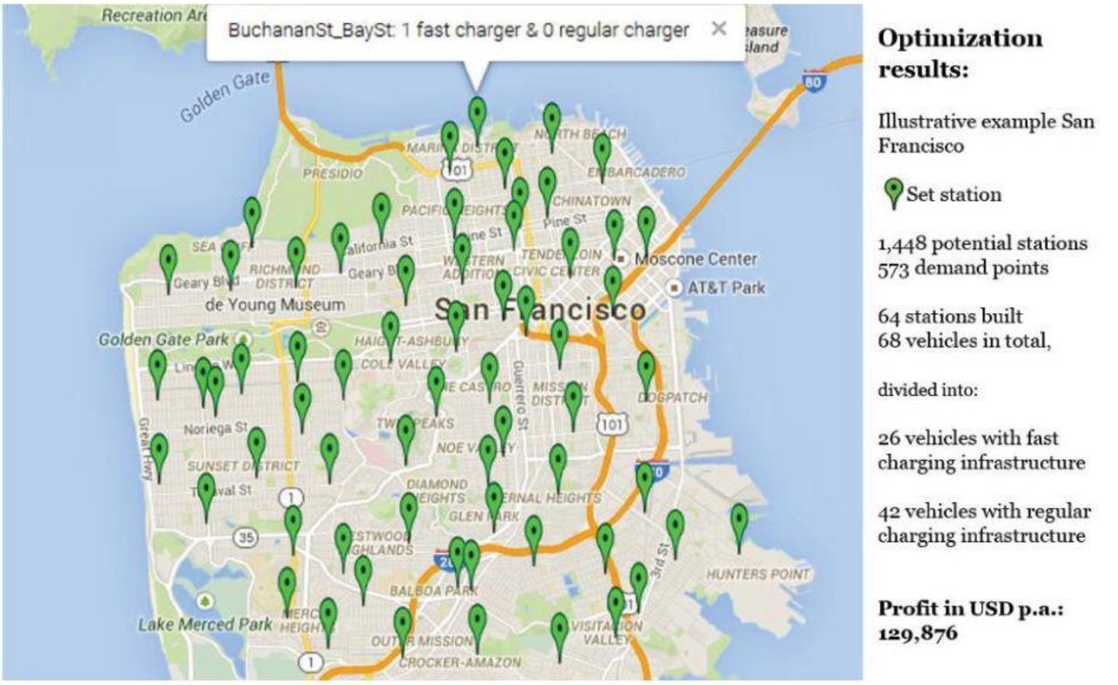

Figure 5. Optimization results

The results indicate that a car sharing organization can gain a profit of USD 129,876 when reaching 5% of the potential users in the identified focus group. In this example, a total of 64 stations are built. The number of required vehicles to satisfy the existing demand is 68, including 26 vehicles with fast and 42 with regular charging infrastructure. In general, the optimal values to maximize profit depend on the settings and parameters used. Different alternatives can be calculated and visualized to allow decision support for the process of finding the solution that best meets the actual budgetary or strategic goals of the car sharing organization.

With the applicability of the model demonstrated in the above example, the section below varies certain parameters and provides corresponding benchmarks. Table 4 is divided into three parts, with 0.5 km, 0.75 km, and 1 km as maximum distance between each demand point and the next car sharing station. Each part illustrates the respective annual profit and provides the indicated number of stations and vehicles (as the sum of regular and fast charging infrastructures). With a higher maximum distance, fewer vehicles and stations are necessary to satisfy the demand. This also means that the average utilization per vehicle is higher and the profit increases. It should be noted though that the overall demand might decrease if potential users do not have a car sharing opportunity nearby. We tested the model with five different demand profiles (1%, 3%, 5%, 7.5%, and 10% usage of the identified focus group). The results show the necessary minimum number of car sharing users to establish profitable electric car sharing. In combination with an additional market analysis, decision makers therefore get a good idea of their business case. As expected, with a higher percentage of users, the car sharing organization needs more stations and vehicles, but also generates a higher profit or reaches its break-even point. Moreover, the number of vehicles with fast charging infrastructure increases with more users to satisfy the additional demand. We also considered two different average trip durations, which presumably depend on local conditions and thus differ between cities. With longer trip durations, the profit of the car sharing organization increases markedly although more vehicles are required. In many cases the profit more than doubles when comparing the 3-hour trip duration to the 2-hour duration. This again shows the decision makers the importance of knowing the specific demand of their respective investigation area and urges them to cautiously examine their business case. Results also show that the number of vehicles with fast charging infrastructure usually increases with a higher trip duration to ensure quick availability of the vehicle for the next user. The number of vehicles with a regular charging infrastructure consequently declines since vehicles with fast chargers can serve more users. In summary our benchmarks validate DSS and model. They also highlight the importance of knowing the potential users, as the tool is only as good as the data used for the calculations. Especially the demand is one of these critical success factors. The tool supports decision makers in evaluating their business case and points out the fine line between success and failure.

Table 4. Benchmarks

Average trip duration of 2 hours	Max. dist. = 0.5 km				Max. dist. = 0.75 km				Max. dist. = 1 km			
	profit (USD)	stations (#)	vfast (#)	vreg (#)	profit (USD)	stations (#)	vfast (#)	vreg (#)	profit (USD)	stations (#)	vfast (#)	vreg (#)
1% of focus group	-1,263,348	123	1	122	-425,148	61	5	56	-156,848	40	9	31
3% of focus group	-909,476	121	9	112	-208,175	68	15	53	83,824	42	20	25
5% of focus group	-527,120	117	17	102	134,579	66	25	43	279,580	51	29	27
7.5% of focus group	-94,709	115	29	90	403,191	71	37	43	588,091	56	41	24
10% of focus group	272,686	121	41	84	758,186	73	47	41	872,186	58	54	23
Average trip duration of 3 hours	**Max. dist. = 0.5 km**				**Max. dist. = 0.75 km**				**Max. dist. = 1 km**			
	profit (USD)	stations (#)	vfast (#)	vreg (#)	profit (USD)	stations (#)	vfast (#)	vreg (#)	profit (USD)	stations (#)	vfast (#)	vreg (#)
1% of focus group	-1,001,207	125	5	120	-259,307	66	16	51	-84,907	44	27	23
3% of focus group	-348,149	115	25	90	133,250	69	36	40	333,250	51	40	20
5% of focus group	146,707	118	40	82	563,909	78	49	38	719,606	60	57	17
7.5% of focus group	687,456	124	58	79	621,456	86	65	45	1,147,856	86	74	23
10% of focus group	1,240,667	130	75	79	1,502,266	108	87	43	1,731,366	81	96	14

Discussion

We created, refined, and evaluated research artifacts in order to provide decision support for the optimization of the location and size of electric car sharing stations. We based our introduced optimization model on existing OR models and integrated it into a DSS. In doing so, we provide for additional usability by creating an intuitive interface for managers, planners, and decision-makers. We further explained the creation of the required dataset using the application example of San Francisco. Respective benchmarks completed our demonstration and show feasibility of model and DSS.

The developed decision support system "OptECarShare 1.5" answers our research question by providing a DSS that optimizes the allocation of electric car sharing stations while maximizing the profit. The model allows users to easily integrate the characteristics of a city to solve the complex problem of determining optimal locations and sizes of car sharing stations. It enables car sharing organizations to plan and implement car sharing within a new city in one big step to demonstrate extensive market presence from the beginning as compared to common trial-and-error concepts. Numerous parameters such as electric properties of vehicles or various leasing costs are included to help fine-tune the strategic optimization. This feature eases the inclusion of different scenarios and accounts for alternative vehicles, such as subcompact or mid-range electric vehicles, or the use of different charging infrastructures as is shown in our examples. It also enables decision makers to perform sensitivity analyses to evaluate the effects of different input parameters and thus helps to ascertain a profitable solution for their individual case. In order to achieve low computing times, a gap can be set, so that a result is found quickly. With additional computing time further improvements of the gap are possible. However, since the model addresses strategic planning as compared to operative control, for example, computing time does not represent a critical aspect. This also applies to other operative factors, such as demand variations throughout the day or year (e.g., peaks due to events), cleaning cycles, or vehicle inspection, which are not considered. The applicability and feasibility of the developed DSS were tested using the city of San Francisco as an example. The city fulfills the required prerequisites to theoretically allow for profitable car sharing and has a proven track record of successful car sharing implementation. The benchmarks suggest that the approach of electric car sharing can be profitably realized. As expected, in addition to the optimal allocation of stations and vehicles throughout the city, the demand plays an important role in our results and is the key to a successful implementation. An additional case example regarding the city of Portland further supports our results and is available at 130.75.63.115/OptECarShare. Overall results indicate that our DSS and the underlying optimization model can be applied beyond these two examples and can help decision makers to evaluate the profitability of their respective case. Results further emphasize the importance of accurate data, specifically regarding demographics, to ensure a sound dataset allowing for realistic demand estimations.

Since car sharing, and especially electric car sharing, aim for a clean environment with state-of-the-art technology, the introduced model also contributes to enhanced ecological, social, and economic sustainability. Moreover, the model and DSS allow car sharing organizations to plan their station arrangements in a time-saving, yet optimal manner. This makes the artifacts a part of the Green IS concept, as IT is utilized to achieve environmental enhancement. As the DSS provides the main user interface and incorporates the underlying model, it may also be called a Green DSS.

Limitations and Recommendations

Our model and DSS create a precise recommendation of station allocation throughout a city. However, certain limitations and possible enhancements need to be considered. Theoretically, the applicability of the model is not limited, i.e., it can be used for any city worldwide that fulfills the discussed conditions with regards to geographic and demographics characteristics. The evaluation of the model and its applicability was limited to the city of San Francisco in the course of this article. Additional benchmarks were carried out for the city of Portland, and are available online. Further tests for other cities with different structure or population are required to ensure transferability and generalizability.

Our model is based on many simplifications and assumptions. A realistic estimation of the demand is crucial to success. We consolidated a number of articles and created an image of the typical electric car sharing user. In combination with census data, a reasonable first demand estimation can be calculated without financial impact. However, the demand depends on many different variables, such as the price of car sharing, structure of the city, and public transport, but also on the competitive market situation.

Demographic data for the considered area allows for a first estimation of the demand. Additional criteria can help further refine the group of potential users. Our model does not explicitly consider competition, yet a variation in the percentage of the focus group can indirectly adjust the demand to lower values when competitors are present. To underline their business case we would still encourage decision makers to gain additional data, for example, from questionnaires or interviews in the corresponding areas.

Not only are further parameters such as average trip duration, speed, and distance related to the expected demand, they also strongly depend on individual characteristics of the respective city, including density of traffic and expansion of the local public transport. Although the model facilitates station allocation, it cannot replace a sound evaluation by decision makers. Also, we only considered deterministic data and not a stochastic distribution. In any case, the application example shows that the modelling of the demand is adequate by using literature to identify a potential user group and thereby distribute the potential demand. Further, the implementation of additional multi-mobility constraints, i.e., emphasizing the importance of stations near public transportation and especially the central station might improve the model. We only consider the demand of the habitual abode of potential users and not the demand around business areas or public transport stations due to a lack of data and research in this realm. In addition, only one average price for all car sharing users is assumed. In future amendments of the model, the price elasticity of demand should be considered as it has an influence on the demand and the profit of a car sharing organization. The model could also be expanded by creating timeframes throughout the day and the week and combining them with demand-related prices. These suggestions already considerably overlap with operational approaches and fine-tune our strategic model rather than significantly changing it. Since the demand for car sharing in a one-way and free-floating mode is increasing (Ciari et al., 2014), the two-way service suggested in our model is not optimal to reach the highest demand. Due to the requirement for charging infrastructures for electric vehicles, the free-floating service is not a suitable approach though. However, our model can be enhanced to include station-based one-way car sharing. A relocation algorithm has to be developed or adopted from an operative approach and constraints for the parking lots or charging infrastructures at each station would also have to be modified. At stations that are preferably used to return vehicles, more charging infrastructures and parking lots need to be provided. Even though possible, one-way trips generate significantly more costs by requiring additional charging infrastructures at each station and staff for the relocation. Thus the proposed two-way model represents an effective way of implementing electric car sharing strategically using today's technology.

Despite the applicability and performance of the introduced model and DSS, certain refinements may enhance the quality of the model. The most promising adjustments can be achieved in the context of demand. The constraint to satisfy demand completely forces the installation of a station even if that station is then used by only a few people. This means that the specific station is actually non-profitable. In contrast to this, demand can decrease due to dissatisfaction of potential users. The reputation of the car sharing organization can deteriorate and therefore less demand accrues, which means that profit decreases. To further optimize profit, assumptions can be made regarding the charging infrastructures by assigning two or more vehicles to one infrastructure. For these assumptions, a safety parameter should be included to cover the risks so that more vehicles are available in case one vehicle cannot be charged on time. Also, the demand as a constant parameter could be logically connected to the supply using a factor that depends on the distance between supply and demand: the closer the supply is to the demand, the higher the demand. Likewise, due to the constant demand, the model also assumes that the client would pay whatever the car sharing provider charges. This missing interconnection between price and demand is likely to cause issues when practically applying the model. Currently, the model will calculate a rising profit with increased prices, not taking into account that less people would use the service. Costs for stations and corresponding parking lots should be amended by choosing more realistic values for the respective location. This means that a parking lot next to the central station is more expensive than one farther away. However, the costs for a parking lot is only a minor part of the overall cost so that this differentiation would not have a significant influence on the profit, settings, and size of stations. The profit calculation in our model focuses on revenue and expenditure. No taxes or other country-specific duties are included.

As advised for DSR, deeper empirical evaluation in the field forms a major part of the relevance cycle and will increase practicality, rigor, and generalizability of our approach. As in 86.5% of the DSS related DSR artifacts, no complete field trial has been realized here (Arnott and Pervan, 2012). As opposed to an application based on our model, we recommend a cooperation with existing car sharing companies though in order to further validate and evaluate our approach.

Conclusions and Outlook

Increased environmental awareness and possible cost savings are making people reconsider their current modes of transportation and the need for personal vehicle ownership. Car sharing, and especially electric car sharing, represents an attractive alternative. To successfully implement car sharing within a city, station locations, their sizes, and an optimal number of vehicles to satisfy the demand have to be found.

In this article, we introduced a model to provide decision support for the complex task of planning the optimal locations and sizes of electric car sharing stations. The integration of the model into a DSS enhances the applicability and usability of our approach. The DSS provides a user-friendly interface, allows data import, and triggers the optimization and visualization of results. The DSS and the underlying model were evaluated and demonstrated using the example of the city of San Francisco. The benchmarks reveal that the identification of realistic demand levels can separate profitable from non-profitable car sharing. Although certain limitations have been identified, the applicability and usefulness of the optimization model and the DSS were evaluated and shown. Noticeable benefit could be drawn from deeper empirical evaluation in the field and a more profound quantitative analysis, which is suggested to be carried out in the context of the DSR relevance cycle. Especially when discussing the model, implications, and recommendations for additional research can be derived. The optimization model itself can and should be further refined by the scientific community to achieve constantly increasing sustainability through Green DSS. To conclude, we emphasize that the potential of electric car sharing is considerable, with regard to both sustainability and profitable installation. The developed model thereby supports the strategic planning phase by providing decision support. Along with further enhancements, our work can contribute to supporting society's path towards a low emission and noise-reduced environment.

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A.12 An Optimization Model and a Decision Support System to Optimize Car Sharing Stations with Electric Vehicles

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An Optimization Model and a Decision Support System to Optimize Car Sharing Stations with Electric Vehicles

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Abstract An increasing environmental awareness, rising energy cost, progressing urbanization, and shortage of space cause to rethink individual mobility behavior and personal car ownership in cities. Car sharing is a sustainable mobility concept that allows individuals to satisfy their mobility needs without owning a car and addresses modern mobility. Car sharing is particularly suitable to cover medium-range distances and can be linked to the public transport of major cities (intermodal mobility). Within this context, the integration of electric vehicles represents an opportunity to further protect the environment and potentially save energy cost.
In order to create an efficient car sharing transportation network, the location of stations, the number of vehicles and the availability of electric fast charging infrastructure are critical success factors. We provide a decision support system (DSS) to plan and optimize car sharing stations for electric vehicles. An optimization model and the DSS OptCarShare 1.1 enable to optimize stations and visualize results. Parameters, such as the annual lease payment for charging infrastructure, the expected travel time of consumers, the charging time of electric vehicles dependent on available charging infrastructure, affect the decision variables such as the number of car sharing stations, vehicles and fast chargers. On the basis of evaluations and benchmarks for the cities of Hannover and Zürich, we establish generalizations for the parameters of the model. The results show a high impact of fast chargers (half an hour to fill 80% of the battery) on the current model and the optimal solution.

1 Introduction

Automobile traffic is one major factor of air pollution and noise annoyance in cities. A good alternative to private cars is car sharing which allows to remain mobile

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without owning a car while saving cost and emissions. In this concept, individuals, especially young adults share vehicles which are property of an organization [3]. Car sharing is particularly suitable to cover medium-range distances and can be linked to the public transport of major cities such as e.g. Hannover or Zürich. It thus fills the gap between public transport and private automobile [7].
Car sharing in connection with electric vehicles has great potential with regard to sustainability. It can not only protect the environment (less CO2, noise and required parking area), it represents cost security for customers and their mobility needs [4]. Since 2005 with the increase in the sales figures, electric cars have become a serious alternative to conventionally propelled vehicles. [1]. Electric vehicles differ in the range and the maximum speed, many of them have an average of around 150 km range with a maximum speed of about 130 km/h [2]. An important component of a pure electric car is the battery (lithium-ion) which typically needs to be charged for eight hours on a conventional wall socket. These batteries may also be subjected to a fast charge, which takes about 0,5h to fill 80% of the battery, but this is associated with high investments. With regard to the cost of a car sharing organization and the satisfaction of the customer demand, the limited range and long charging times respectively expensive fast charging infrastructure represent challenges.
The protection of the environment and scarce natural resources as well as limited parking space caused by urbanization are urgent topics and are basis for the idea to refine an optimization model for car sharing stations by Rickenberg et al. [6]. The question, how many fast chargers need to be positioned will be addressed with an enhanced optimization model. We pursue the following research questions:
RQ 1: What factors of electric vehicles need be considered to optimize the location and size of car sharing stations? and
RQ 2: What influence do exogenous parameters have on the decision variables?

2 Optimization Model and Decision Support System

The objective of this model is to determine optimal locations of candidate car sharing stations i $(i = 1, \ldots, m)$ as well as to optimize the number of vehicles with fast charging $(f_i^{fc} \in \mathbb{N})$ and with regular charging infrastructure $(f_i^{rc} \in \mathbb{N})$. The minimization of total cost and the satisfaction of the customer have the highest priority. The maximum distance of any demand point j $(j = 1, \ldots, n)$ to the next car sharing station must not exceed a definite limit $(maxd)$. In our case, any period (t^{period}) is 24 hours and is related to the normal-distributed demand n_j, which is also given for one day (24h). A vehicle is available when the travel time (t_i^t) and the appropriate charging time (tc_i) is over. To calculate the charging time a coefficient (γ) and the expected travel time (normal-distributed) are needed. There are two varieties for γ, one for the fast charging and one for regular charging infrastructure. At any station are limited parking lots $(maxp_i)$ available and limited fast chargers $(maxfcs)$ possible. Since electric cars of one single type are used in this model, a homogenous fleet is assumed. The mathematical problem can be formulated as follows:

$$Min.\, Z = \sum_{i=1}^{m} [f_i^{rc}(kf + ka + kl^{rc}) + f_i^{fc}(kf + ka + kl^{fc}) + y_i * ks] \quad (1)$$

$$d_{ij} * z_{ij} \leq maxd \quad \forall i; j \quad (2)$$

$$\sum_{i=1}^{m} z_{ij} = 1 \quad \forall\, j \quad (3)$$

$$y_i = z_{ij} \quad \forall\, i; j \quad (4)$$

$$f_i^{rc} \frac{t^{period}}{t_i^t + tc_i^{regular}} + f_i^{fc} \frac{t^{period}}{t_i^t + tc_i^{fast}} \geq \sum_{j=1}^{n} n_j * z_{ij} \quad \forall\, i \quad (5)$$

$$f_i^{rc} + f_i^{fc} \leq maxp_i \quad \forall\, i \quad (6)$$

$$f_i^{fc} \leq maxfcs \quad \forall\, j \quad (7)$$

$$y_i * v_i \leq a \quad \forall\, i \quad (8)$$

$$w_i \geq minb * y_i \quad \forall\, i \quad (9)$$

$$z_{ij};\, y_i; \in \{0,1\} \quad \forall\, i; j \quad (10)$$

$$f_i^{rc};\, f_i^{fc} \quad \in \mathbb{N} \quad \forall\, i \quad (11)$$

The objective function (1) describes the incurred cost of a car sharing organization which are to be minimized. The cost is accumulated annual fees for renting vehicles (kf), parking lots (ka), charging infrastructure (kl^{rc} and kl^{fc}) as well as annual cost to maintain stations. Restriction (2) implies that the distance between a demand point and a station must not exceed a maximum value and constraint (3) assigns every demand point to a station but only if the station is actually built (4). The fulfillment of the demand is ensured by restriction (5). The variables $tc_i^{regular}$ and tc_i^{fast} are calculated as follows: $tc_i^{regular} = \gamma^{regular} * t_i^t$ and $tc_i^{fast} = \gamma^{fast} * t_i^t$. The coefficient γ describes the charging time per travel hour dependent on the maximum range of electric vehicles, the average speed and the charging time. It is calculated as follows: $\frac{max\ range}{average\ speed} = max\ travel\ time$ and accordindly $\gamma^{regular}$ and $\gamma^{fast} = \frac{max\ charging\ time}{max\ travel\ time}$.

The total number of vehicles (also the number of associated parking lots) must be smaller than the maximum number of parking lots for each station (6) [5]. Restriction (7) guarantees the electricity supply. Parameter v_i is defined as follows: v_i = free parking lots around station i / registered vehicles around station i * 100%. The smaller parameter v_i, the higher is the shortage of parking. Due to (8), the actual shortage of parking cannot be bigger than the default shortage of parking (a). Parameter w_i is defined as follows: w_i = population at station i /area at station i [6]. Because of (9) a minimum level of population density within an area is reached. In equations (10) and (11) are the binary variables and decision variables defined.

Based on the optimization model, we implement the decision support system (DSS) OptCarShare 1.1 to enable the optimization of stations and visualization of results. The DSS, the underlying model, and sample data pools are available online at http://archiv.iwi.uni-hannover.de/CarSharing/.

3 Benchmarks in Hannover and Zürich

Influence of charging-infrastructure – charging time and infrastructure cost: We run several benchmarks by using different values for the parameters and show thereby the applicability of the optimization model. We choose the German city Hannover and the Swiss city Zürich since both have an appropriate size, population density and well public transportation to allow efficient car sharing [5, 6].

The initial values for the benchmarks are $i^{Hannover} = 100$, $j^{Hannover} = 30$, $i^{Zürich} = 200$, $j^{Zürich} = 50$, $kf = 25{,}000€$, $ka = 7{,}000€$, $t^{period} = 24h$, $GAP = 3\%$, $maxp_i = 5$, $maxfcs = 2$, $minb = 1{,}200$, $maxd = 1km$. Parameter γ is not a fixed value and varies with the average speed, maximum range or required charging time. Our initial values are: $\gamma^{regular} = \frac{4}{3}$ and $\gamma^{fast} = \frac{1}{12}$ with a maximum range of 150km, average speed of 25km/h and a required charging time of 0.5h or 8h. We ignore the low cost of regular charging infrastructure and consider only the annual fees of fast charging infrastructure. There are different providers and types of charging infrastructure, which is still in development phase and therefore the cost of the fast chargers could decrease within the coming years. It is even possible that the regular charging infrastructure could improve and thus the gap between these two possibilities could diminish. Here, the smaller the charging coefficient, the more efficient the regular charging infrastructure works. We vary the charging coefficient $\gamma^{regular}$ and the cost kl^{fc} to investigate their influence, which can be seen from the following table.

Table 1 Influence of charging coefficient $\gamma^{regular}$ and cost of fast charging infrastructure kl^{fc}

Hannover	kl^{fc} = 5,000EUR				kl^{fc} = 26,000EUR				kl^{fc} = 35,000EUR			
	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost
$\gamma^{regular} = 4/3$	8	12	0	452,000	8	10	3	684,000	8	7	9	765,000
$\gamma^{regular} = 3/3$	8	12	0	452,000	9	5	11	651,000	8	2	17	686,000
$\gamma^{regular} = 2/3$	9	11	1	474,500	9	2	14	573,000	8	0	18	584,000
Zürich	kl^{fc} = 5,000EUR				kl^{fc} = 26,000EUR				kl^{fc} = 35,000EUR			
	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost
$\gamma^{regular} = 4/3$	14	18	3	776,000	17	18	3	1,181,000	16	10	18	1,262,000
$\gamma^{regular} = 3/3$	16	17	4	773,000	17	12	12	1,157,000	18	1	32	1,141,000
$\gamma^{regular} = 2/3$	16	16	5	768,000	17	3	24	959,000	19	0	30	979,000

A reduction of $\gamma^{regular}$, which implies shorter charging time, results in less total cost, since less vehicles with fast charging infrastructure are needed to meet customer demand. For example in Zürich and annual fees of the fast chargers of 26,000€, the amount of car sharing stations always remains equal at 17, while the number of vehicles related to fast or regular charging infrastructure varies. For $\gamma^{regular}$ = 4/3, the total cost is 1,181,000€, but the cost decrease to 959,000€ for $\gamma^{regular}$ = 2/3. Because of less charging time for vehicles even with regular charging infrastructure, more vehicles of this type will be deployed. The effect is higher, the higher the annual fees of the fast chargers are.

Influence of different driving time profiles and max. distance to station: The distance to the next car sharing station is an important factor since consumers do not want to walk a long way, e.g. from public transport stations and also from home, to satisfy their mobility needs [8]. For that reason, we vary the parameter *maxd* and compare it against three different expected travel time profiles.

Table 2 Max. distance to station *maxd* and expected travel time

Hannover	*maxd* = 0.5km				*maxd* = 1km				*maxd* = 1.25km			
	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost
low travel time	11	2	9	373,000	5	1	4	170,000	4	1	3	137,000
med. travel time	14	10	3	479,000	7	7	1	298,000	4	7	0	263,000
high travel time	14	16	2	670,000	9	14	0	527,000	7	13	1	520,000
Zürich	*maxd* = 0.5km				*maxd* = 1km				*maxd* = 1.25km			
	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost	s	f_i^{fc}	f_i^{rc}	cost
low travel time	26	4	21	846,000	11	1	10	368,000	9	1	7	270,000
med. travel time	29	12	16	985,000	14	11	3	517,000	11	9	1	413,000
high travel time	31	24	11	1,470,000	15	19	3	814,000	14	19	1	934,000

The total number of vehicles increases, the higher the average travel time is. The vehicles are longer on the roads and therefore need longer charging time which results in a lower availability of the vehicles. The more vehicles are deployed, the higher the total cost for the car sharing organization. For low average travel time, significantly more vehicles are used with regular charging infrastructure, because the vehicles only need a brief time to be charged even with regular charging infrastructure to be available for the next customer. However, with higher travel time, more vehicles with fast charging infrastructure are required. To meet the demand, a certain number of vehicles is needed. For low *maxd*, e.g. 0.5km for Zürich at the medium travel time, the total cost is 985,000€, but for higher *maxd* (1.25km), the cost decrease to 413,000€, although the demand and travel time are still the same.

4 Generalization, Limitations and Conclusion

Concerning RQ2 and based on the benchmarks of Hannover and Zürich, the influences of selected parameters can be generalized to establish a general relationship between the exogenous parameters and the resulting effect on decision variables.

Number of car sharing stations: With higher expected travel time as well as an increasing coefficient of regular charging infrastructure, the number of car sharing stations increases since more vehicles are needed. If the coefficient of the fast charging is lower, the number of car sharing station is reduced by having less vehicles.

Charging infrastructure: Analogous to the number of stations, the number of vehicles with fast charging infrastructure increases with higher travel time since the efficient fast chargers allow to reduce the charging time. However, the more expensive the fast charging infrastructure is, the less vehicles will be deployed with this infrastructure and in consequence the amount of regular charging infrastructure increases. If the coefficient $\gamma^{regular}$ decreases, the number of vehicles with regular charging infrastructure increases and the number of vehicles with fast charging infrastructure decreases due to their higher cost. With less fast chargers or more efficient regular charging infrastructure, the total cost decreases. The effect of γ^{fast} is opposed to $\gamma^{regular}$. The more vehicles are required, the higher is the total cost. While minimizing total cost, it is affected by the mentioned parameters. If $\gamma^{regular}$ increases, less vehicles are needed and in consequence the total cost decreases.

$$t_i^t(\uparrow) \Rightarrow \sum_i y_i(\uparrow) \quad \gamma^{regular}(\downarrow) \Rightarrow \sum_i y_i(\uparrow) \quad \gamma^{fast}(\uparrow) \Rightarrow \sum_i y_i(\downarrow) \tag{12}$$

$$t_i^t(\uparrow) \Rightarrow \sum_i f_i^{fc}(\uparrow) \quad \gamma^{regular}(\downarrow) \Rightarrow \sum_i f_i^{fc}(\downarrow) \quad kl^{fc}(\uparrow) \Rightarrow \sum_i f_i^{fc}(\downarrow) \tag{13}$$

$$t_i^t(\uparrow) \Rightarrow \sum_i f_i^{rc}(\downarrow) \quad \gamma^{regular}(\downarrow) \Rightarrow \sum_i f_i^{rc}(\uparrow) \quad kl^{fc}(\uparrow) \Rightarrow \sum_i f_i^{rc}(\uparrow) \tag{14}$$

$$t_i^t(\uparrow) \Rightarrow Z(\uparrow) \quad \gamma^{regular}(\downarrow) \Rightarrow Z(\downarrow) \quad kl^{fc}(\uparrow) \Rightarrow Z(\uparrow) \tag{15}$$

Concerning the limitations, this model can be used for strategic and tactical planning since a homogenous fleet is assumed and no operative factors (booking management, max range, etc.) are considered. Furthermore, we regard a normal distributed demand and do not consider peaks and off-peaks. Here, only one vehicle can be assigned to a fast charger, but in reality it could be possible to share a fast charger.

To conclude, the optimization model and the DSS are a first approach to support the planning of car sharing stations for electric vehicles. The results of the benchmarks of Hannover and Zürich show that fast chargers and the charging infrastructure in general heavily determine the amount of stations, cars, and total cost.

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