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Improving electric vehicle utilization in carsharing: A framework and simulation of an e-carsharing vehicle utilization management system

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ABSTRACT

Rapid economic growth and urbanization have motivated economists and researchers to seek innovative solutions for the many challenges that accompany these trends. This can be observed in upcoming research in sustainable transportation services where potential solutions to urban mobility issues are being explored. For example, e-carsharing, which involves the joint ownership or use of battery electric vehicles (BEVs) does not only mitigate the environmental and infrastructural hazards of privately owned internal combustion engine vehicles (ICEVs) through reduction of emissions and urban traffic, but also alleviates many barriers such as high costs, battery life limitations, and suboptimal charging infrastructures that have prevented privately owned BEVs from reaching their full potential.

In response, we present a framework for a battery electric vehicle utilization management system (BEVUMS) for automated optimization of operational decisions regarding the usage of electric vehicles in mixed vehicle-type fleets. The framework consists of four modules: energy demand prediction, battery charge scheduling, vehicle selection, and vehicle relocation. We assess the validity and capabilities of the system by simulating an e-carsharing system with data sets of 2,000 and 20,000 vehicle rental data points. Our findings suggest opportunities for prevention of charging related problems, increased BEV rental ratios, and lengthened BEV rental periods. Thus, the proposed system leads to improved BEV utilization and prolonged BEV battery life. In addition to these opportunities for increased potential sustainability provided by our proposed BEVUMS, this study further contributes to current research in the field by providing a framework and a benchmark setting for future research.

1. Introduction

Global economic trends have witnessed an increase in urban population in recent years. According to the 2014 revision of the "World Urbanization Prospects", 54% of the world's population lives in urban areas. Furthermore, the same report estimates a rise in the proportion of the global population residing in urban areas by the year 2050 (UN-DESA, 2014). This presents new challenges for urban transportation infrastructures, including increased rates of urban traffic congestion, accidents, noise and harmful emissions (Nykvist and Whitmarsh, 2008; Pavone et al., 2012). Consequentially, demand for new mobility substitutes for privately owned vehicles has increased in recent years. However, in order to be considered valid alternatives, new mobility options should not only be

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sustainable, but also flexible enough to meet dynamic customer needs (Nykvist and Whitmarsh, 2008; KPMG, 2014).

Given the current structure of transportation systems, *battery electric vehicles* (BEV) can be a successful, environmental friendly addition to future mobility options, especially when combined with carsharing services (Bruglieri et al., 2014; Wappelhorst et al., 2014; Willing et al., 2016; Boyacı et al., 2017). This is particularly desirable as carsharing can be a means to introduce BEVs and e-mobility to the masses (Willing et al., 2016) and reduce any potential skepticism, e.g. range anxiety (Tate et al., 2008; Mueller et al., 2015). Range anxiety is defined as a "continuous concern and fear of becoming stranded with a discharged battery in a limited range" (Tate et al., 2008) and can exacerbate consumer perceptions of battery related limitations (Franke et al., 2012a; Franke et al., 2012b). However, positive driving exposure to BEVs can increase the comfort range and reduce range anxiety in people, making e-carsharing short distance rentals within urban or rural areas a valid strategy for facilitating mass BEV adoption (Franke et al., 2012b; Rauh et al., 2015; Willing et al., 2016). Furthermore, carsharing is a flexible short-term transportation service and it can complement traditional means of transportation by connecting individual mobility with existing public transportation options to form a coherent intermodal mobility chain (Willing et al., 2017). This makes carsharing a valuable asset of our future mobility (Nair and Miller-Hooks, 2011; King et al., 2013; Willing et al., 2016).

With regards to vehicle fleet composition, there are various ways to incorporate BEVs into carsharing. For example, the service provider can choose to operate a pure BEV fleet or a mixed fleet consisting of BEVs and *internal combustion engine vehicles* (ICEVs). Integrating BEVs in mixed fleets is beneficial as ICEVs can be used to counter the limitations of BEVs. BEVs suffer from two major drawbacks: short travel range per charging cycle and high costs (Wappelhorst et al., 2014; Boyacı et al., 2017). E-carsharing can mitigate the financial drawback of BEVs by distributing it among its customers, although initial investments are still higher than those necessary for conventional ICEVs (Firnkorn and Müller, 2012; Wappelhorst et al., 2014). Nonetheless, the short range remains a profound problem for long distance travel usage. However, in the context of inner city or rural mobility, this poses a negligible issue given that the distances traveled are predominantly short (Lützenberger et al., 2014; Wappelhorst et al., 2014), and customers can rent an ICEVs for longer distances from a mixed fleet. Thus, e-carsharing services employing a mixed vehicle fleet can match city driving patterns of potential customers (Rickenberg et al., 2013; Willing et al., 2016) as well as demand for longer trips.

In spite of BEVs being considered a sustainable improvement for carsharing, operating a fleet that includes BEVs can also pose new problems (Bruglieri et al., 2014). The dependency of e-carsharing on charger access between trips (Seign and Bogenberger, 2012; Ferrero et al., 2015) – makes free-floating formats difficult for e-carsharing providers. The dense charging network required throughout the system's operating area (Wappelhorst et al., 2014) and the significant time period needed to fully charge a BEV (Lee et al., 2011; Firnkorn and Müller, 2012; Seign and Bogenberger, 2012; Boyaci et al., 2014) are two of the many factors limiting BEV utilization. In contrast, ICEVs can be rented and quickly refueled by customers if needed (Seign and Bogenberger, 2012). In contrast, BEVs need to be recharged more frequently because of their limited capacity, which can make re-charging between consecutive rentals difficult (Wappelhorst et al., 2014; Seign et al., 2015). Thus, e-carsharing requires Level 3[1] fast charging points (Yilmaz and Krein, 2012) to enable longer trips and prevent charging related downtimes during a customer's trip (Seign et al., 2015). Consequently, the tradeoff between the costs for fast charging points and the idle time of the BEV remains a challenge (Seign and Bogenberger, 2012; Boyaci et al., 2014). In addition, BEV batteries have a limited life time (Seign and Bogenberger, 2012), which is further shortened by deep discharges and many charging cycles (Botsford and Szczepanek, 2009; Seign and Bogenberger, 2012; Yilmaz and Krein, 2012; Winston, 2016) among other factors (Schoch et al., 2017). Therefore, these issues must be addressed in order to enable high BEV utilization, increase vehicle booking frequency, and maximize the period of time rented between charges (Bruglieri et al., 2014). In order to overcome BEV usage limitations, a *BEV utilization management system* (BEVUMS) should provide sufficient charge for the next user while minimizing the number of charging cycles needed (Lützenberger et al., 2014; Seign et al., 2015). Slow charging remains a technical issue, but an efficient utilization management system minimizes charging required of customers, thereby increasing the acceptance and convenience of e-carsharing.

By answering the following research questions, we strive to design a system that addresses the prevailing operational problems of mixed vehicle fleets in e-carsharing:

1. *How can a BEVUMS be designed to counter limitations of BEVs while increasing utilization within mixed vehicle fleets?*
2. *What is the impact of such a management system on an e-carsharing system?*

To answer these questions, we developed a BEVUMS for station-based one-way e-carsharing. A system based on the proposed framework automates operational decisions in e-carsharing regarding charging, relocation and vehicle selection to increase BEV utilization. It is composed of charging management and vehicle management components.

We aimed to develop a framework which identified the essential tasks of BEVUMS while providing groundwork for future research. Regarding the individual components, we decided to give a heuristic solution to each module to allow for individual benchmarking and improvement of individual parts of the system (Rai, 2017). To analyze and evaluate its validity and impact on the e-carsharing system, we tested the framework in a station-based one-way e-carsharing system simulation performed across different scenarios and cases. Overall, a BEVUMS can improve the accessibility of BEVs, rental time of BEVs, the number of rentals per charging, and the charging schedules, successfully avoiding deep discharges and minimizing charging cycle frequency.

[1] According to the IEC 62196 standard, "Level 3" *fast charging points* are high-voltage (480–600 V), high-current (125–150 A), high-power (50–100 kW) charging points connected via a specific socket on a dedicated EVSE (electric vehicle supply equipment) circuit (Mode 3), or via direct current (DC) connection to a main power grid through an external charger.