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Electric bike sharing: simulation of user demand and system availability

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ABSTRACT

This paper describes the operational concepts and system requirements of a fully automated electric bike (e-bike) sharing system demonstrated through a pilot project at the University of Tennessee, Knoxville (UTK) campus (deployed in September 2011). This project is part of a movement to develop a sustainable transportation system, and is one of the green initiatives on UTK campus. E-bikes are more energy efficient and produce fewer greenhouse gas (GHG) emissions per person compared to other transport modes such as car, bus, and motorcycle. Without empirical demand information for an e-bike sharing system, we simulated the operations of such a system to gain insights during the design process before field deployment. The simulation exercise focused on three critical demand parameters – distributions of trip rates, trip lengths, and trip durations – and coupled them with supply parameters – number of e-bikes, number of swappable batteries, and battery recharging profiles. The primary purpose of these simulations is to evaluate the efficiency of an off-board battery recharging system, where the depleted battery is removed from an e-bike upon its return and inserted into one of the charging slots at the kiosk. We tested various scenarios with different number of batteries always maintaining an initial condition with the battery to e-bike ratio greater or equal to 1.0 to ensure battery availability. We applied empirical battery recharging rates and system operations rules to determine the number of e-bikes and batteries available under different potential demand situations, with a focus on optimizing the number of batteries to meet user demands. By adjusting input parameters, numerous scenarios were simulated for sensitivity analysis. Based on the results of the simulation, this paper presents a cost constrained e-bike sharing system design that can maintain a high level of system reliability (e-bike and battery availability) through optimal battery charging and distribution management. We found that high demand scenarios require multiple swappable batteries per e-bike to reasonably meet the maximum demand. Trip duration has the most influence on e-bike and battery availability, followed by trip rate, and then trip length.

1. Introduction

Bike sharing is a new provision model of public/private transportation that has emerged in the past several years. As of January 2012, there are 15 automated bike sharing programs in the U.S. involving 5238 bicycles and 172,070 users (Shaheen et al., 2013). Bike sharing is among the most environmentally sound models of transport that provides public transportation services for short trips that are often inadequately served by other modes of fixed-route public transit (Hampshire and Marla, 2012; Shang et al., 2010). Bike sharing systems have been overcoming many operational challenges in the past decade to provide fully automated, secure, and cost-effective systems and have been deployed in over 100 cities worldwide (Kim et al., 2012). Traditional bicycles in bike sharing systems range in price, with mainstream systems offering bicycles for about US$1000 (Shaheen et al., 2013). Electric bikes (e-bikes) range in price as well but typically carry a price premium of approximately 2× for a similarly equipped bicycle.

Formal bike sharing systems have existed for nearly half a century, with various levels of success. Few studies have systematically estimated demand or defined operational parameters (Kaltenbrunner et al., 2010). There have been three generations of evolution, driven mostly by advances in technology. The first generation began in Amsterdam in 1965, where stationless bicycles could be borrowed and left anywhere in the city, to be borrowed again by the next individual. It was unsuccessful due to vandalism and theft. The second generation, born in Denmark in 1991, allowed bicycles to be picked up and returned to several central locations

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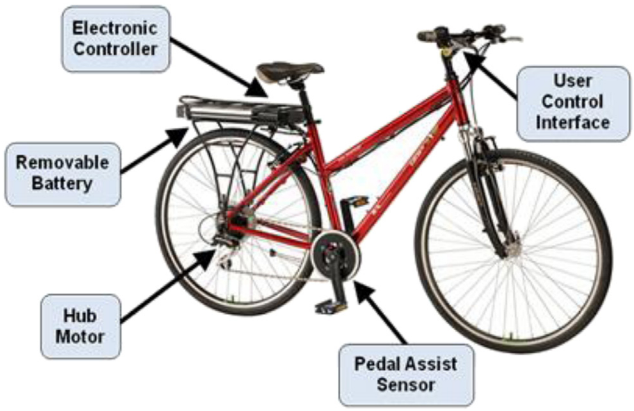

Fig. 1. Typical pedal e-bike.

with a coin deposit. Theft was also a problem largely due to the anonymity of the user. Third generation bike sharing was born in Portsmouth University in England and involved several technological improvements such as bike racks that locked automatically, on-board electronics, swipe cards, and telecommunication capabilities. In 2005 and 2007 respectively, Lyon and Paris, France launched highly successful third generation bike sharing programs that grew to over 15,000 and 20,000 bicycles respectively. Today, one bike sharing program per month is being created somewhere in the world (DeMaio, 2009; Shaheen et al., 2010). Beginning in 2008, cities outside of Europe began to launch third generation programs. Rio de Janeiro launched a pilot public bike sharing program in 2009. Several others followed in South America and Asia. Some of the largest bike sharing networks are in cities such as Hangzhou (40,000 bicycles and 1700 stations) and Wuhan, China (13,000 bicycles and 516 stations). In North America, Montreal, Denver, Minneapolis, Boston, and Washington D.C. have launched successful third generation bike sharing programs in recent years. Dozens of other North American cities are in planning stages for installing bike sharing systems (Krykewycz et al., 2010; Schroeder et al., 2009).

Simultaneously, e-bikes have gained popularity in many regions of the world. Some researchers suggest that shared e-bikes could provide an even higher level of service compared to existing bike sharing systems, while maintaining low environmental impacts. Based on recent research findings, benefits such as the ability to travel longer distances and over hills with less fatigue and sweat, compared to traditional bicycles, may help overcome some of the barriers to bicycling. In addition, surveys of e-bike riders reveal that most e-bike owners favor e-bikes over traditional bicycles or conventional motorized vehicles (Dill and Rose, 2012).

E-bikes are often regulated like bicycles in most jurisdictions. E-bikes, particularly pedal assist e-bikes, look and operate much like traditional bicycles (Fig. 1). Pedal assist e-bikes offer some of the health benefits of bicycling, requiring relatively modest amounts of physical activity (Gojanovic et al., 2011; Louis et al., 2012; Sperlich et al., 2012; Theurel et al., 2012). However, e-bikes are substantially more expensive than similar-quality non-electric bicycles. As such, the e-bike market has not grown as rapidly in the U.S. compared to other countries (Dill and Rose, 2012; Rose, 2012; Weinert et al., 2007a).

By spreading the higher cost of e-bikes over a community of many users and over time, e-bike sharing has the potential of overcoming the price barrier as well as the perceived expense of the technology. The provision of e-bikes in a shared environment also introduces electric vehicle technology to potential users without the pressure or commitment of capital purchase. E-bike sharing promotes electric mobility to users of other motorized modes of transport and introduces renewable energy, recharging infrastructure, and safety to the public (Silvester et al., 2013). By affecting mode shifts of users from other motorized modes and because of their light weight, e-bikes are considered a technology towards cleaner transportation (Tonn et al., 2003). E- bikes outperform other motorized transport modes, including bus transit, on energy efficiency and greenhouse gas emission (GHG) rates per passenger kilometer, considering the complete life cycle environmental impacts (Cherry et al., 2009). Moreover, e-bikes can move emissions from tailpipes to power plants that are often away from urban areas, further reducing human exposures to emissions (Ji et al., 2012).

Traditional bike sharing systems have been extensively researched in the past few years. Many studies aim to provide policy recommendations to encourage more bicycle trips (Bachand-Marleau et al., 2012; Gleason and Miskimins, 2012; Parkes and Marsden, 2012). Some studies try to employ geographic information system (GIS) to estimate the demand for

Fig. 2. System components of e-bike sharing system.