S. Shaheen, S. Guzman, and H. Zhang. 2010 Transportation Research Record

BIKESHARING IN EUROPE, THE AMERICAS, AND ASIA: PAST, PRESENT, AND FUTURE

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2010 Transportation Research Board Annual Meeting

March 15, 2010

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ABSTRACT

Growing concerns over global motorization and climate change have led to increasing interest in sustainable transportation alternatives, such as bikesharing (the shared use of a bicycle fleet). Since 1965, bikesharing has grown across the globe on four continents including: Europe, North America, South America, and Asia (including Australia). Today, there are approximately 100 bikesharing programs operating in an estimated 125 cities around the world with over 139,300 bicycles. Bikesharing's evolution is categorized into three generations: 1) White Bikes (or Free Bike Systems); 2) Coin-Deposit Systems; and 3) IT-Based Systems. In this paper, the authors propose a fourth-generation: "Demand-Responsive, Multi-Modal Systems." A range of existing bikesharing business models (e.g., advertising) and lessons learned are discussed including: 1) bicycle theft and vandalism; 2) bicycle redistribution; 3) information systems (e.g., real-time information); 4) insurance and liability concerns; and 5) pre-launch considerations. While limited in number, several studies have documented bikesharing's social and environmental benefits including reduced auto use, increased bicycle use, and a growing awareness of bikesharing as a daily mobility option. Despite bikesharing's ongoing growth, obstacles and uncertainty remain, including: future demand; safety; sustainability of business models; limited cycling infrastructure; challenges to integrating with public transportation systems; technology costs; and user convenience (e.g., limited height adjustment on bicycles, lack of cargo space, and exposure to weather conditions). In the future, more research is needed to better understand bikesharing's impacts, operations, and business models in light of its reported growth and benefits.

KEY WORDS: Bikesharing, Europe, Asia, North and South America, bicycle, technology

WORD COUNT: 7,479 words, including 2 Tables and 2 Figures

INTRODUCTION

Concerns about global climate change, energy security, and unstable fuel prices have caused many decision makers and policy experts worldwide to closely examine the need for more sustainable transportation strategies. Sustainable strategies include clean fuels, vehicle technologies, transportation demand management, and integrated land use and transportation strategies (1). Bikesharing—the shared use of a bicycle fleet—is one mobility strategy that could help address many of these concerns. In recent years, interest in this evolving concept has spread across the globe. At present, there are an estimated 100 programs in approximately 125 cities around the world with over 139,300 bicycles on four continents and another 45 planned in 22 nations in 2010.

Despite rapid global motorization, worldwide bicycle use has generally increased over the past 30 years. Indeed, bicycling in Dutch, German, and Danish cities increased between 20 to 43% between 1975 and 1995 (2). While cycling growth and trends vary worldwide, bikesharing offers a transportation alternative to increase bicycle use by integrating cycling into the transportation system and making it more convenient and attractive to users.

The principle of bikesharing is simple. Individuals use bicycles on an "as-needed" basis without the costs and responsibilities of bike ownership. Bikesharing is short-term bicycle access, which provides its users with an environmentally friendly form of public transportation. This flexible short-term usage scheme targets daily mobility and allows users to access public bicycles at unattended bike stations. Bicycle reservations, pick-up, and drop-off are self-service. Commonly concentrated in urban settings, bikesharing programs also provide multiple bike

station locations that enable users to pick up and return bicycles to different stations. Bikesharing programs typically cover bicycle purchase and maintenance costs, as well as storage and parking responsibilities (similar to carsharing or short-term auto use) (3).

Besides individual user perks, bikesharing also offers environmental, social, and transportation-related benefits. For instance, bikesharing provides a low-carbon solution to the "last mile" problem. The "last mile" refers to the short distance between home and public transit and/or transit stations and the workplace, which may be too far to walk. Thus, bikesharing has the potential to play an important role in bridging the gap in existing transportation networks, as well as encouraging individuals to use multiple transportation modes. Potential bikesharing benefits include: 1) increased mobility options; 2) cost savings from modal shifts; 3) lower implementation and operational costs (e.g., in contrast to shuttle services); 4) reduced traffic congestion; 5) reduced fuel use; 6) increased use of public transit and alternative modes (e.g., rail, buses, taxis, carsharing, ridesharing, etc.); 7) increased health benefits; and 8) greater environmental awareness. The ultimate goal of bikesharing is to expand and integrate cycling into transportation systems, so that it can more readily become a daily transportation mode.

In recent years, bikesharing also has expanded to college and work campuses throughout North America. Indeed, there are over 65 college/university bikesharing programs operating throughout North America and another 10 programs planned in 2010. Examples of college/university programs worldwide include "CibiUAM" at the Universidad Autonoma de Madrid (UAM) in Spain and "Velocampus Leeds" at the University of Leeds in the United Kingdom (UK). The focus of this paper, however, is on citywide systems that are open to residents and visitors, as opposed to closed systems that are only accessible to students and employees of a university or major employer. Furthermore, the authors do not address bike rental programs, which also have expanded worldwide. Unlike bikesharing, bike rental traditionally targets users interested in leisure-oriented mobility and are most prevalent in areas with a high tourist concentration. Bike rental systems generally consist of a single or limited number of bike stations that are operated by a service attendant. A majority of bike rental programs also require users to return rented bicycles to the original bike station and are generally operated on an hourly pricing basis.

Over the last 43 years, bikesharing's evolution has been categorized into three key phases (also known as bikesharing generations). These include the first generation, called "White Bikes" (or Free Bikes); the second generation: "Coin-Deposit Systems;" and the third generation or "Information Technology (IT)-Based Systems" (4). In this paper, the authors propose a fourth generation, called: "Demand-Responsive, Multi-Modal Systems," which builds upon the third.

This paper is organized into seven sections. First, the authors present a history of bikesharing in Europe, the Americas, and Asia, focused upon the first two generations. Next, current bikesharing activities (or IT-Based Systems) are discussed in Europe, the Americas, and Asia. Third, bikesharing business models and vendors are described. Next, the authors summarize the current understanding of the social and environmental benefits associated with bikesharing. Fifth, lessons learned are presented. Next, a fourth bikesharing generation is proposed with an eye toward future developments and innovation. Finally, the authors conclude with a summary and recommendations for future bikesharing research.

HISTORY OF BIKESHARING

In this section, the authors provide an overview of bikesharing's history. Asia and South America's experience with bikesharing does not begin until the third generation, IT-Based Systems. The authors categorize this as "the present." Thus, they are not included in this section, which focuses on the first two generations of bikesharing in Europe and North America.

Bikesharing in Europe

Early European bikesharing systems were small-scale, operated as non-profits, and focused on social and environmental issues. In July 1965, the Provos—an organization that was heavily involved with environmental issues—released their "White Bike Plan" in Amsterdam (5). This plan was seen as the solution to traffic problems in Amsterdam's inner city. Fifty bicycles were painted white, left permanently unlocked, and placed throughout the inner city for the public to use freely. These bikes were often stolen or damaged. In addition, police officers confiscated all bicycles that were found unattended or unlocked, claiming that they invited theft (5). As such, the "White Bike Plan" failed soon after its launch.

White Bikes (or Free Bike Systems): First Bikesharing Generation

Despite earlier experiences, the bikesharing concept caught on and led to the first generation of bikesharing known as "White Bikes" (or "Free Bike Systems") (6). In a free bikesharing system, the bicycle is the main program component. Other distinguishing characteristics of first-generation bikesharing include that bicycles were usually painted one bright color, unlocked, and placed haphazardly throughout an area for free use.

Other cities that implemented a free bike system were La Rochelle, France in 1974 and Cambridge in the UK in 1993, called "Green Bike Schemes." Soon after Green Bike Scheme's launch, the almost 300 shared bicycles in Cambridge were stolen, resulting in program failure (7). However, the La Rochelle initiative, called "Vélos Jaunes" or "Yellow Bikes," proved to be successful and continues to operate today. La Rochelle's Mayor, Michel Crépeau, created Vélos Jaunes. Similar to Amsterdam's White Bike Plan, Vélos Jaunes was launched as an environmentally progressive measure. Through the strong support of La Rochelle's Urban Community, Vélos Jaunes became the first successful bikesharing program in France.

Coin-Deposit Systems: Second Bikesharing Generation

Problems with Free Bike Systems (namely bike theft) led the city government and the City Bike Foundation of Copenhagen, Denmark to launch a bikesharing service that was different from any previous system. In January 1995, "Bycyken" (City Bike) was launched as the first large-scale urban bikesharing program in Europe. This initiative included 1,100 specially designed bicycles that were locked and placed throughout downtown Copenhagen at designated city bike racks (8). Bicycles were unlocked with a 20 DKK coin deposit ($3US) that was refunded upon bicycle return.

Bycyken of Copenhagen is famous not only because it continues to operate with more than 2,000 bicycles and 110 city bike racks today but also because it led to the second generation of bikesharing, known as "Coin-Deposit Systems." The main components of this generation are: 1) distinguishable bicycles (usually by color and special design); 2) designated docking stations in which bikes can be locked, borrowed, and returned; and 3) small deposits to unlock the bikes.

Soon after the implementation of coin-deposit systems, the Copenhagen model led to a series of European bikesharing programs including: "Bycykler" in Sandnes, Norway (1996); "City Bikes" in Helsinki, Finland (2000); and "Bycykel" in Arhus, Denmark (2005). The experience of these coin-deposit systems demonstrated that second-generation systems were more expensive to operate than early systems. Non-profit groups were frequently created to administer the bikesharing programs. In many cases, local governments also provided bikesharing organizations with funding.

The incorporation of designated bicycle stations and the use of coin-deposit locks in second-generation systems created a much more reliable bikesharing system that was both dependable and more theft resistant. While amounts vary by country, coin deposit fees are generally low (around $4US). Also, these systems do not issue a time limit for bicycle use, which

means that bikes are often used for long time periods or not returned at all. The major problem with coin-deposit systems is bicycle theft, which can be attributed to customer anonymity. Though bikesharing began as a way to reduce motor vehicle use, Bonnette (2007) indicates that "both the first and second generation bikesharing schemes provided welcome opportunities to cycle but did not provide adequate enough support nor reliable service to alter motorized transportation choices and influence people to make significant changes (9)." The shortcomings of second-generation systems later gave rise to the third generation of bikesharing.

Bikesharing in North America

While the history of bikesharing in North America is shorter than in Europe, North America has transitioned through three bikesharing generations. In 1994, the United Community Action Network (a small non-profit that works on environmental and livability issues) launched the first North American bikesharing program in Portland, Oregon, called: "Yellow Bike." Sixty bicycles were left unlocked at Pioneer Square in Portland and were available for anyone to use (10). This program, however, closed in 2001. Soon after, Yellow Bike evolved into "Create-A-Commuter" at the Community Cycling Center and focused on providing better cycling services. Since 2007, the City of Portland has tried to create a new bikesharing program.

Soon after Yellow Bike's introduction, Boulder, Colorado launched the "Green Bike Program" in 1995. The City Transportation Management department ran this program. At the time, 130 bicycles were provided for free use, and a group of high school students comprised the majority of volunteers who maintained the bicycles. This system was eventually cancelled as a result of bike theft. The City of Boulder, however, has issued a Request for Information and is considering a new bikesharing program that would consist of 250 bicycles and 10 stations and receive half its funds from President Obama's stimulus plan (11).

In 1996, the twin cities of Minneapolis and St. Paul launched the "Yellow Bike Project." Created by a local health club's law firm, it was the first Coin-Deposit System (or second-generation system) in North America. This program employed 150 bicycles that were placed at designated locations. To use this program, users made a one-time, refundable $10US deposit, signed a waiver, and received a Yellow Bike Card that facilitated bike use. In 1996, the Minnesota Office of Environmental Assistance provided the program with short-term funding. This program was eventually cancelled. At present, the City of Minneapolis has selected the Public Bike System Company (PBSC), maker of Montreal's "BIXI," to provide 1,000 bicycles and 80 stations by June 2010 (12).

The launch of St. Paul's Yellow Bikes was soon followed by multiple North American bikesharing systems that employed the "Coin Deposit" model. Programs included "Olympia Bike Library" in Olympia, Washington (1996); "Yellow Bike" in Austin, Texas (1997); "Red Bikes" in Madison, Wisconsin (launched as a free bikesharing system in 1995 and evolved into a coin-deposit model a few years later); "Freewheels" in Princeton, New Jersey (1998); and "Decatur Yellow Bikes" (DYB) in Decatur, Georgia (2002).

BIKESHARING: THE PRESENT

Since 1965, bikesharing activity has expanded to include four continents. These include Europe, Asia (including Australia), North America, and South America. Not surprisingly, Europe remains the leading hub for bikesharing growth, development, and success.

At present, there are approximately 101 bikesharing programs operating in an estimated 125 cities around the world, with over 139,000 shared bicycles. As the leader in bikesharing activity today, 19 European nations currently support it. The Americas operate programs in Canada, Mexico, the U.S., Brazil, and Chile. Asia, which represents the fastest growing bikesharing market, operates programs in China, South Korea, and Taiwan. Table 1 (below)

provides an overview of available bikesharing data worldwide.

This section includes a discussion of the evolution from second- to third-generation bikesharing and current bikesharing activities from Europe, the Americas, and Asia.

TABLE 1 Worldwide Bikesharing Programs[1]

Country	Programs	Bicycles	Stations
Austria	3	1,500	82
Belgium	1	1,000	100
Brazil	2	232	26
Canada	1	5,000	400
Chile	1	50	10
China	3	61,400	2,518
Czech Republic	3	51	16
Denmark	3	2,513	277
Finland	1	300	26
France	22	36,443	2,936
Germany [2]	3	6,069	128
India	1	100	6
Italy	16	3,392	361
Ireland	1	450	40
Luxembourg	2	370	40
Mexico	1	1,100	82
Monaco	1	10	2
Netherlands	1	—[3]	200
Norway	1	1,660	154
New Zealand	1	175	11
Poland	1	100	13
Romania	1	100	10
Spain	21	11,080	842
South Korea	1	430	20
Sweden	3	2,125	171
Switzerland	1	120	11
Taiwan	2	2,000	31
United States	1	120	10
United Kingdom	2	1,410	809
Total	101	139,300	9,332

[1] The authors count one program for each system that spans multiple cities in one country.
[2] Bikesharing in Germany has fixed stations and flex stations. In all, there are 128 fixed stations in Germany, and five cities employ flex stations for bikesharing. Flex stations are not designated; a user can leave their bicycle at a major intersection and inform the program where the bicycle is locked.
[3] Number of bicycles could not be confirmed.

Evolution from Second- to Third-Generation Bikesharing

While the first generation of bikesharing introduced an innovative mobility option, the notable failure of this approach demonstrated the need for a new model that deterred theft and incentivized bicycle return. Second-generation bikesharing programs introduced a more viable alternative by integrating the use of coin-deposit locks. Building upon this innovation, third-generation programs gained worldwide popularity by incorporating advanced technologies for bicycle reservations, pick-up, drop-off, and information tracking. See Figure 1 below for an overview of the generations of bikesharing. While a significant number of bikesharing programs currently operate as third-generation models, existing and developing bikesharing programs are exploring or exhibiting the potential for continuous improvements in what the authors call "fourth-generation" systems.

The four main components of third-generation bikesharing programs are: 1) distinguishable bicycles (either by color, special design, or advertisement); 2) docking stations; 3) kiosk or user interface technology for check-in and checkout; and 4) advanced technology (e.g., magnetic striped card, smartcards) (13). Third-generation bikesharing programs are distinct because the incorporation of information technology has allowed bikesharing programs to track bicycles and user information. The incorporation of third-generation information technology has helped to deter bike theft, which was a major concern of second-generation coin-deposit systems. The next sections summarize third-generation bikesharing in the three main regions of the world.

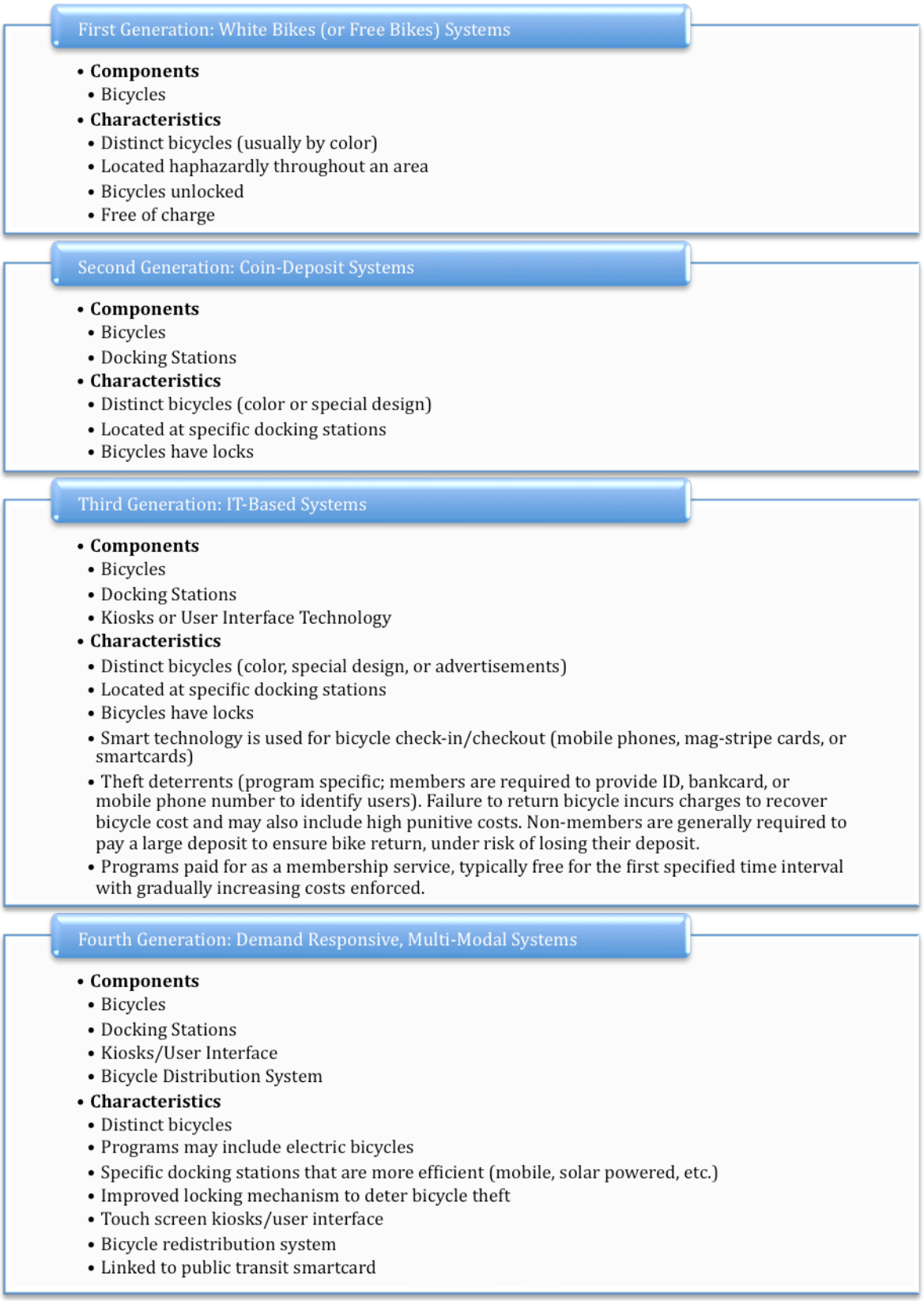

FIGURE 1 Bikesharing generations.

Europe

European experience provides a robust history of bikesharing planning, implementation, and operations. Furthermore, the more recent growth of third-generation bikesharing programs can be attributed to innovations tracing back to this understanding. Relative to other countries, third-generation bikesharing programs in Europe are large scale, operate through public-private partnerships, and feature advanced technologies.

In 1998, the first citywide IT-based system appeared when Clear Channel, a large outdoor advertising company, launched its first "SmartBike" program in Rennes, France. To access free bicycles for up to three hours, SmartBike required users to complete a smartcard application. After 11 years of service, the Rennes system, more commonly known as "Vélo à la Carte," came to an end in May 2009. This program has been replaced by "LE vélo STAR," which operates with 900 bicycles and 81 stations (14).

The program that popularized third-generation bikesharing is "Velo'v" in Lyon, France. JCDecaux launched Velo'v in 2005 with 1,500 bicycles. It operates with more than 3,000 bicycles in Lyon and Villeurbanne.

One early European bikesharing program—Vélos Jaunes, which launched in La Rochelle in 1974—continues to evolve, expand its geographic coverage, and adopt new technologies to support its growth. In 2006, the city extended the bikesharing system to include 120 bicycles available 24-hours per day, seven days per week at 12 different stations. In 2009, La Rochelle launched a second, fully automated system (i.e., bicycle pickup and drop off are self-service via smartcard), called: "Yélo," with 26 stations, 110 bicycles, and smartcards that enable full integration with the public transportation network. Yélo plans to operate a total of 50 stations and 300 bicycles (15).

As of Fall 2009, there were approximately 19 European nations operating bikesharing programs. These include Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, Ireland, Luxembourg, Monaco, the Netherlands, Norway, Poland, Romania, Spain, Sweden, Switzerland, and the UK. In addition, London partnered with BIXI and plans to launch its own bikesharing program with 6,000 bicycles and 400 stations by Summer 2010.

The most widely known third-generation bikesharing system today is "Vélib'" in Paris, France. To date, Vélib' operates with 20,600 bicycles and has plans of expanding to 23,900 bicycles by the end of 2009 (16, 17). Over two million Parisians have access to 1,451 bicycle stations, which are available every 300 meters, 24-hours a day, and seven days a week. Vélib' operates on a fee-based system where program users are encouraged to employ bicycles for short trips by offering the first thirty minutes of cycling free to users. After thirty minutes, increasing costs are scheduled. Users also have the option of purchasing a one-day pass for €1 ($1.42US), a one-week pass for €5 ($7.11US), or a one-year subscription for €29 ($41.21US).

Between 2007 and 2008, Vélib' reported that 20 million trips were made through their program. Averaging 78,000 trips per day, Vélib's usage rates require that the program operate as efficiently as possible to maintain and distribute bicycles.

The Americas

While North American bikesharing experience is more limited, Washington D.C.'s "SmartBike" pilot program demonstrated that bikesharing is feasible. Launched in 2008, SmartBike marked the beginning of North America's experience with IT-based systems. To date, this program operates with 120 bicycles at 10 different bicycle stations. In January 2009, the President of Clear Channel Adshel reported that the program was serving 1,050 subscribers (18). Users are required to pay a $40US annual subscription fee in contrast to a fee each time they access the service. At present, the program only allows users to access bicycles for up to three hours at a time.

The largest IT-based system in North America is BIXI in Montreal, Canada. BIXI stands for BIcycle-TaXI. Launched in May 2009, BIXI operates with 5,000 bicycles, 400 stations, and 11,000 program members (Gian-Carlo Crivello, unpublished data). BIXI's system has also been chosen as the provider for Boston's planned bikesharing program, which aims to launch with 2,500 bicycles and 290 stations by Summer 2010. It is equally important to note that technological advances in the BIXI program mark a shift towards the fourth-generation of bikesharing described below.

While the implementation of bikesharing programs in North America is limited, bikesharing activity in South America only recently started in 2008. At present, Brazil and Chile are the only two nations with fully operating programs. Argentina and Colombia are in the process of planning their own bikesharing systems.

In 2008, Brazil launched two bikesharing programs—"UseBike" in São Paulo and "Samba" in Rio de Janiero. UseBike operates with 202 bicycles and 23 bike stations. This program offers users one free hour and costs two Brazilian reais ($0.85US) for each additional hour.

Samba was launched with 80 bicycles and eight bike stations. It is in the process of expanding to neighboring cities and is expected to reach 500 bicycles with 50 bike stations by the end of 2009. To access bicycles, Samba requires mobile phone activation. Users are instructed to subscribe online, then they can walk up to any of the eight bike stations, call the designated number from their mobile phone, enter a security code, dial the station and spot number, and the bicycle is unlocked. Following the launch of Samba in Brazil, Chile launched its own bikesharing program with 50 bicycles and 10 bike stations.

Asia

Asia's bikesharing history is limited to third generation IT-Based Systems. Despite its more limited experience, Asia is the fastest growing market for bikesharing activity today. The first bikesharing program to launch in Asia was "TownBike" in Singapore in 1999 (known as "Smart Bike" from 1999 to 2004). This program ended in 2007.

The second bikesharing program in Asia was the "Taito Bicycle Sharing Experiment," which operated in Taito, Japan from November 2002 to January 2003. It was the first bikesharing pilot in Japan and was funded by the national government's Social Experiment grants. The program operated with 130 bicycles at 12 locations. Bicycles were accessed by magnetic striped membership cards, which helped prevent theft. Due to Taito's high population density, program users felt that more bicycle locations were necessary (despite access to 12 rental locations in one square mile) (19).

At present, bikesharing programs are operating in South Korea, Taiwan, and Mainland China. South Korea's city government launched its first bikesharing program, "Nubija," in Chongwan in 2008. The program has 430 bicycles and 20 terminals located at the city center. Similar to other programs, Nubija does not charge users a fee for the first hour of use.

"C-Bike" in Kaohsiung City launched in 2009, as the first bikesharing program in Taiwan. The entire system operates on a build-operate-transfer (or BOT) basis that costs NT$90 million ($2.58 million US). Following the launch of Kaohsiung's program, the Taipei government partnered with Giant to launch their bikesharing system, "YouBike," in 2009. This program is completely automated with an electronic management system that allows bicycles to be rented and returned to any location. There are 500 bicycles at 10 locations that provide 718 YouBike parking spaces in Taipei (20).

The largest and most famous bikesharing program in Asia is the "Public Bicycle" system in Hangzhou, China, which was launched by the Hangzhou Public Transport Corporation in 2008. This system was the first IT-Based system in Mainland China. With a population of 3.73

million, Hangzhou's high population density makes it a promising bikesharing location. Hangzhou's system operates with 40,000 bicycles and 1,600 stations and is expected to expand to 50,000 bicycles and 2,000 stations by the end of 2009 (21). Increasing the number of bicycle stations to 2,000 means that tourists and residents will have access to a bicycle station every 200 meters. According to a survey by the Hangzhou Public Transport Corporation, bicycles are used six times per day on average, and no bicycles have been lost during the first year implementation (21).

The Hangzhou Public Bicycle System has surpassed Vélib as the largest bikesharing program in the world. Not surprisingly, it has sparked great interest in bikesharing in Mainland China. Indeed, Beijing, Tianjin, Hainan, and Suzhou have already launched pilot programs in 2008 and 2009.

In February 2010, the City of Melbourne, Australia also announced plans for its first bikesharing program. The city has selected BIXI as the provider and plans to launch with 1,000 bicycles and 52 stations by Summer 2010.

BUSINESS MODELS AND VENDORS

The success of third-generation programs has made it the most prominent bikesharing model worldwide. Furthermore, third-generation successes have increased the number of bikesharing vendors, providers, service models, and technologies. Bikesharing providers, for instance, range from local governments to transport agencies, advertising companies, for-profit, and non-profit groups (22). Bikesharing is funded through advertising, self-funding, user fees, municipalities, and public-private partnerships (16). Table 2 below provides an overview of bikesharing business models and providers.

The most prominent funding sources for third-generation bikesharing are municipalities and advertising partnerships (i.e., adverstising companies provide bikesharing services in exchange for the right to advertise on city street furniture and billboards). According to Midgley (2009) local governments operate 27% of existing bikesharing systems. In addition, JCDecaux and Clear Channel— the two biggest outdoor advertising companies—operate 23% and 16% of worldwide bikesharing programs, respectively (7). Public agencies also are becoming an increasingly important provider of bikesharing programs. In China, for instance, public transport agencies operate the Hangzhou bikesharing system under local government guidance. Furthermore, non-profit bikesharing programs, which typically require public support at the start-up stage, are likely to remain a prominent model for the foreseeable future.

At present, major bikesharing vendors include Clear Channel Adshel, BIXI, Veoila Transportation, Cemusa, JCDecaux, and B-Cycle (16). Of these, the major bikesharing systems are: 1) SmartBike by Clear Channel Outdoor in the U.S., 2) Bicincittà by Comunicare in Italy, and 3) Cyclocity by JCDecaux in France (23). Increasing use of advanced technologies in third-generation bikesharing has led to a growing market for technology vendors. IT-based systems became popular after the largest outdoor advertising company, Clear Channel, launched their first SmartBike program in Rennes, France. Other companies that provide automated IT-based systems include: Biceberg (underground bicycle parking); BIXI Public Bike System (bicycles and bike station); Ebikeshare (bicycles and bike station); LeisureTec Bike Station (bicycle stations); Q I Systems CycleStation (Kiosks and smartcards); Sekura-Byk (bicycle racks and smart card systems); and Urban Racks (bicycle racks) (24).

TABLE 2 Bikesharing Providers and Business Models

Provider	Standard Operating Model	Revenue Sources	Program Example
Advertising Company	Provide bikesharing services in exchange for rights to advertise on city street furniture and billboards	• Advertising funding from city street furniture, billboards, bikes, and bikesharing stations • Member/non-member usage fee	• SmartBike (U.S.) • Cyclocity (France)
Public Transport Agencies	Provide bikesharing services under the guidance of a public authority to enhance the public transportation system	• Government subsidies • Member/non-member usage fee • Ads on bikes and bikesharing stations	• Hangzhou Public Bicycle (China) • Call a Bike (Germany)
Local Governments/Public Authority	Directly design and operate a bikesharing program for the well being of cities or a local government purchases bikesharing services that are provided by others	• Municipality funding • Member/non-member usage fees • Ads on bikes and bikesharing stations	• City Bikes (Denmark) • OV-fiets (Netherlands) • Nubija (South Korea) • YouBike (Taiwan) • Shanghai Public Bicycle (China)
For-Profit	Provide profitable bikesharing services with minimal government involvement	• Member/ non-member usage fee • Ads on bikes and bikesharing stations	• Next bike (Germany)
Non-Profit	Provide bikesharing services under the support of public agencies or councils	• Public-private partnership funding • Member/non-member usage fees • Bank loans • Local funding	• BIXI (Canada) • Hourbike (UK) • Bicincittà (Italy) • Wuhan Public Bicycle (China)

SOCIAL AND ENVIRONMENTAL IMPACTS

At present, there is limited research on the environmental and social benefits of bikesharing, particularly before-and-after behavioral trends. However, many bikesharing programs have conducted user-based surveys that document program experience.

One impact of bikesharing is its potential to provide emission-free transportation. SmartBike, for instance, estimates that over 50,000 SmartBike trips cover a total of 200,000 kilometers (km) per day. SmartBike calculates that a car covering this same distance would produce 37,000 kilograms of carbon dioxide (CO2) emissions per day (25). With an average of 78,000 trips per day and approximately 20 minutes per trip, Vélib users cover an estimated 312,000 km per day. A car covering this same distance would have produced approximately 57,720 kg of CO2 per day. As of August 2009, BIXI users covered an estimated 3,612,799 km, which translates into 909,053 kg of reduced greenhouse gas emissions (26). As of October 2009, the Hangzhou Public Bicycle Program generated 172,000 trips per day. With an average trip lasting approximately 30 minutes, Hangzhou program users covered an estimated 1,032,000 km per day. In contrast, an automobile covering this same distance would produce 190,920 kg of

emissions. If successful, these data suggests that increased bikesharing activity has the potential to yield notable greenhouse gas emission reductions.

The potential of bikesharing programs to reduce vehicle emissions is promising when one considers current data on modal shifts. For instance, in a recent survey of SmartBike (Washington, D.C.) members, researchers found that bikesharing drew nearly 16% of individuals who would otherwise have used personal vehicles for tripmaking (27). Velo'v in Lyon, France reports that bicycle use replaced 7% of trips that would otherwise have been made by private vehicles (28). In Paris, 20% of Vélib' users also reported using personal vehicles less frequently (29).

The growth and evolution of bikesharing programs worldwide has led to increased public awareness of bikesharing and its potential social, environmental, financial, and health-based benefits. Along with increased bikesharing awareness, public perception of bicycling as a transportation mode also has evolved. A 2008 Vélib' survey, for instance, found that 89% of program users agreed that Vélib' made it easier to travel through Paris. According to SmartBike, nearly 79% of respondents reported that bikesharing use in Washington, D.C. was faster or more convenient than other options. In Montreal, the initial public reaction to BIXI was skeptical. However, the heavy presence of BIXI bicycles has led Montreal residents to embrace the new system. In general, cities that have implemented successful bikesharing programs appear to have positively impacted the perception of bicycling as a viable transportation mode.

While very few studies evaluate behavioral shifts, available data suggest notable changes. For example, during the first year of Velo'v, the City of Lyon documented a 44% increase in bicycle riding (28). Ninety-six percent were new users who had not previously bicycled in the Lyon city center. In addition, bicycle riding in Paris also increased by 70% with the launch of Vélib'. Given the relatively limited impact data, more research is needed on the social and environmental benefits of bikesharing.

LESSONS LEARNED

The last 45 years of bikesharing planning, implementation, and operations have led to a range of lessons learned. Such developments have contributed to a growing body of bikesharing knowledge. The authors address five key lessons learned: 1) bicycle theft and vandalism; 2) bicycle redistribution; 3) information systems; 4) insurance and liability considerations; and 5) prelaunch considerations. Figure 2 below provides a summary of the lessons learned.

Bicycle Theft and Vandalism: Early on, bikesharing programs learned that user anonymity created a system that was prone to bicycle theft. Third-generation bikesharing introduced electronic smartcards to access bicycles from their racks. Smartcards record user identification information as well as bike usage (e.g., time, duration, location, kilometers). This improvement solved previous issues of user anonymity and facilitated bicycle tracking, which reduced bicycle theft and vandalism. Despite such innovations, a 2009 study of Vélib' reported that since its launch in 2007, 7,800 bicycles have disappeared, and another 11,600 bicycles have been vandalized (30). High rates of theft raise concerns because Vélib' bicycles are expensive. Indeed, it currently costs the program 400 Euros ($519US) to replace bicycles. While existing technologies, such as global positioning systems (GPS) and radio frequency identification tracking developments, have greatly decreased bicycle theft, such technology greatly increases implementations costs. Other methods that programs are now considering include a membership-based lending process (e.g., overnight) to reduce bicycle theft. In contrast to Vélib', Hangzhou's bikesharing system and BIXI in Montreal have experienced relatively low theft and vandalism rates. To curb theft and vandalism, Hangzhou's system employs inexpensive bikes (400 RMB). A high density of bicycles—free for the first hour—makes cycling more convenient, which can decrease the need to steal a bicycle. To curb the impact of vandalism, BIXI allocates 8 to 9% of their budget to address theft. To date, less than 3% of that budget has been used (Gian-Carlo Crivello, unpublished data). Overall, emerging fourth-generation models should consider more robust bicycles that require less maintenance and include more effective locking mechanisms that deter theft.
Bicycle Redistribution: Vélib's experience highlights the need for bicycle redistribution (i.e., bicycles must be redistributed to key demand locations frequently after use). To manage its 20,600 bicycles Vélib' uses 20 natural gas powered vehicles to transport bicycles from one station to another (31). As bikesharing programs grow and cover larger areas, emerging systems must find ways to address redistribution issues that have been raised in Vélib's experience. For instance, BIXI and Hangzhou are also employing trucks to redistribute bicycles. In addition, BIXI is redesigning redistribution trucks to include on-board computers that can provide drivers with real-time information on bicycle stations to facilitate a speedier and more efficient response to bicycle shortages and station overcrowding. As cities launch larger programs, it is important that emerging fourth-generation systems (described in the section below) incorporate technological improvements for bicycle redistribution.
Information Systems: One of the most revolutionary changes introduced by third-generation bikesharing programs is the use of real-time information systems. Today, the majority of third-generation programs provide users with real-time information on station parking and bicycle availability through the Internet (e.g. individual program website or websites such as Google Maps™), direct text messages to mobile phones, or by calling system hotlines. Such technologies should continue to be improved and included in current and future bikesharing programs to facilitate a more efficient and user-friendly system.
Insurance and Liability Considerations: The growth of bikesharing programs also has raised the question of insurance and liability. For instance, helmet use is not mandatory for most bikesharing programs, which may conflict with insurance liability laws. As of 2008, Vélib' reported three fatalities. In contrast, NextBike has encountered three accidents, while BIXI and Hangzhou have each encountered one each. One exception, however, is the Hangzhou bikesharing system, which currently covers any injury that occurs through their bikesharing system (Xuejun Tao, unpublished data). At present, the main obstacle for insurance is high cost.
Pre-launch Considerations: Bikesharing programs around the world agree that successful systems are those that address the specific needs of their users and market segments prior to and after deployment. Programs, such as BIXI, have found that bicycle availability is not easy to predict. BIXI addresses this issue by employing mobile bicycle stations, which can be relocated according to usage patterns. BIXI also has identified pre-launch marketing as a critical action for successful programs. Hourbike (UK) has noted pricing as key to establishing a successful business model. Furthermore, the implementation of incremental usage fees encourages bicycle users to plan short trips to avoid high fees.

FIGURE 2 Bikesharing lessons learned.

As third-generation bikesharing markets continue to expand worldwide, current models of implementation, operations, and technology provide key insights for future systems. In the next section, the authors propose a fourth bikesharing generation: "Demand Responsive, Multi-Modal Systems."

FOURTH-GENERATION BIKESHARING: DEMAND-RESPONSIVE, MULTI-MODAL SYSTEMS

The advances and shortcomings of previous and existing bikesharing models have contributed to a growing body of knowledge of this shared public transportation mode. Such experiences are making way for an emerging fourth-generation bikesharing model or Demand-Responsive, Multi-Modal Systems. These systems build upon the third generation and emphasize: 1) flexible, clean docking stations; 2) bicycle redistribution innovations; 3) smartcard integration with other transportation modes, such as public transit and carsharing; and 4) technological advances including GPS tracking, touchscreen kiosks, and electric bikes (32). See Figure 1 above for an overview of the four generations of bikesharing described in this paper.

"BIXI," which launched in Canada in May 2009, and is operating with 5,000 bicycles and 11,000 members, marks the beginning of bikesharing's fourth generation (Gian-Carlo Crivello, unpublished data). One of the major innovations of BIXI's bicycle docking stations is that they are mobile, which allows stations to be removed and transferred to different locations. This innovation enables bicycle stations to be relocated according to usage patterns and user demands. Another improvement that BIXI's system might offer to future bikesharing programs is the use of solar-powered stations. Not surprisingly, solar-powered stations would further reduce emissions and the need to secure access to an energy grid to support operations (33). Fourth-generation bikesharing also may consider omitting docking stations and opt for flex stations where users employ mobile phone technology and street furniture for bicycle pick up and drop off, as do five cities in Germany.

Another area of improvement for fourth-generation systems is bicycle redistribution innovations. Vélib's use of specially designed vehicles for bicycle relocation represents a first step towards addressing this issue. However, employing larger, designated vehicles for bicycle transport increases implementation costs and is not emission free, at present. In the future, bikesharing services will continue to deploy more efficient redistribution methods (e.g. automated technologies that facilitate demand-responsive bike relocation). Fourth-generation bikesharing models may also incentivize user based redistribution (i.e., where the rider performs bicycle redistribution) by employing demand-based pricing where users receive a price reduction or credit for docking bicycles at empty docking locations.

A third feature of fourth-generation systems is the seamless integration of bikesharing with public transportation and other alternative modes, such as taxis and carsharing (for more information on carsharing, see 3, 34, 35) via smartcards, which support numerous transportation modes on a single card. In 2009, the Yélo bikesharing system was launched in La Rochelle, France. This system includes a smartcard, which is fully integrated with the public transportation system. This facilitates multi-modal transportation linkages and user convenience, which could lead to greater auto ownership and usage reductions, as more daily trips are supported by alternative modes. However, creating a program that coordinates various forms of transportation on a single card is challenging, as this can be costly and often requires multi-agency involvement.

Another area for improvement is bicycle security, which can be supported by ongoing technological advancement, such as the design and integration of GPS units into more robust bicycle frames that further enhance existing locking mechanisms, deter bike theft, and facilitate

bike recovery. However, adding GPS units is costly and can potentially increase financial losses, if bikes with built-in GPS are vandalized or stolen. Finally, to target a larger scope of bikesharing users, fourth-generation systems may be more likely to incorporate electric bicycles, which enable longer-distance trips; encourage cycling on steeper hills and slopes; and lessen physical exertion requirements, particularly when users are commuting or making work trips in business attire.

CONCLUSION

Bikesharing emerged in Europe as a transportation mode 45 years ago. Since its inception, bikesharing systems have evolved to address geographic and technological demands. Bikesharing has expanded to include four continents—Europe, North America, South America, and Asia (including Australia). Bikesharing growth also has undergone three evolutionary stages including: 1) first generation white bikes (or free bike systems), which began in Amsterdam in 1965; 2) second generation coin-deposit systems, which started in Copenhagen, Denmark in 1995; and 3) third generation IT-based systems, which emerged in the Rennes, France city-based system in 1998.

Notable growth in third-generation bikesharing programs has led to a diversity of business models, ranging from advertising companies to non-profits. Despite the limited study of the social and environmental benefits of bikesharing, recent surveys document: 1) reduced auto use; 2) behavioral shifts towards increased bicycle use for daily mobility; and 3) a growing perception of the bicycle as a convenient transportation mode.

Building upon third-generation systems, the authors propose a fourth: "Demand Responsive, Multi-Modal Systems." This emerging bikesharing generation is characterized by: 1) flexible, clean docking stations; 2) bicycle redistribution innovations; 3) smartcard integration with other transportation modes, such as public transportation and carsharing; and 4) technological advances including GPS tracking, touchscreen kiosks, and electric bikes.

While bikesharing systems are growing worldwide and many have demonstrated the potential to reduce GHGs and fuel consumption by discouraging personal vehicle use for daily mobility, their future demand and long-term sustainability are uncertain. Many obstacles exist, such as: limited and supportive infrastructure (i.e., docking stations, bike lanes); theft; high technology costs; funding considerations; and safety issues. More in-depth understanding and research on bikesharing is needed. This includes bikesharing's social and environmental benefits; a better understanding of the conditions in which it thrives (e.g., cities in which biking is less popular as a daily mode and residential/business storage is limited); business models; operational understanding; advanced technology applications; and the potential role of public policy in maintaining this mode and supporting its expansion.

ACKNOWLEDGEMENTS

The California Department of Transportation and Honda Motor Company, through its endowment for new mobility studies at the University of California, Davis, generously funded this research. The authors would like to thank Melissa Chung for her assistance in gathering data for this paper. The authors would also like to acknowledge Gian-Carlo Crivello (BIXI), Xuejun Tao (Hangzhou Public Bike Share), Mareike Rauchhaus (Nextbike), and Tim Caswell (Hourbike) for their expert interviews. The contents of this paper reflect the views of the authors and do not necessarily indicate acceptance by the sponsors.

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