Transportation (2013) 40:459–477
DOI 10.1007/s11116-012-9424-7

Managing a smart bicycle system when demand outstrips supply: the case of the university community in Seville

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Published online: 21 June 2012

Abstract Of the many public initiatives used to promote the use of bicycles in the urban environment, the one that has achieved the most spectacular results in a short period of time is the public bicycle hire system. The experience of Seville is one of the most successful internationally, where 6.6 % of mechanised trips were being made by bicycle within 30 months. This paper analyses this experience in the university community, which represents one-third of system users. We conclude that the people who are most satisfied with the system are those who use it for leisure and recreation activities, non-residents of the city, more environmentally aware people and those who have no alternative mode of transportation. Their satisfaction is also closely linked to their appreciation of the bicycles' level of comfort, the ease with which users can hire bicycles and return them and the small amount of paperwork involved required to sign up for the system. However, user appreciation has fallen over time because the system's rapid success has caused it to become overloaded. This experience therefore provides one main lesson: the system's success can result in eventual difficulties.

Keywords Bicycle commuting · Smart bikes · Sustainable urban transportation · Ordered probit/logit · Travel behaviour

Introduction

In recent years, public initiatives designed to promote bicycle use in cities have proliferated (Pucher et al. 2010; Vandenbulcke et al. 2009) as a component of the search for alternative solutions for a sustainable urban transportation system (Rose 2012; Cavill et al. 2008). These urban strategies and policies are usually justified to the public by touting the

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well-known and frequently studied advantages of bicycles over other modes of transportation, such as the automobile (Creutzig and He 2009). In short, references are usually made to the huge social and environmental benefits of bicycles (Chapman 2007), including reductions in fuel use, noise and air pollution and less traffic congestion (Martens 2007).

However, municipal governments also occasionally attempt to use these strategies to disguise their failure to develop a mode of public transportation that is a real alternative to the private automobile (Beirão and Cabral 2007; Gardner and Abraham 2007). Many Spanish municipalities are frustrated as urban public bus companies not only continue to be huge drains on their budgets but also constantly lose market share, and yet buses are the last resort for people who have a low opportunity cost for their time (Holmgren et al. 2008). The bicycle, meanwhile, is a cheap mode of transportation with low maintenance costs (Gatersleben and Appleton 2007; Horton 2006) that is also flexible and relatively quick, as it is able to circumvent urban traffic congestion. Bicycles are also easy to access and park. There is no need to get to stations or stops, which means that the problems with parking and having to follow timetables and schedules are avoided (Hopkinson and Wardman 1996).

Amongst the most common public initiatives traditionally used to promote bicycle use (Pucher et al. 2010) are the construction of bicycle paths or lanes (Tilahun et al. 2007; Dill and Carr 2003), the creation of specific bicycle parking facilities (Pucher and Buehler 2006), measures to encourage the combined use or inter-modality of bicycles and public transportation, such as the bus or the train (Hegger 2007) and measures to provide end-of-journey facilities for cyclists, such as locker rooms and showers at their destinations (Hunt and Abraham 2007; Wardman et al. 2007).

Compared with these strategies, the development of public bicycle systems for short-term or by-journey hire is a measure that has quickly achieved spectacular results in encouraging bicycle usage as a mode of urban transportation. In short, these are free-lending or subsidised bicycle-hire systems in towns and cities, and they are generally promoted by public administrations. The goal is to provide a practical mobility service as a part of a public transportation system that is both quick and designed for daily usage (Bührmann 2007).

Although this measure has become more widespread and popular in recent years, the concept of public-use bicycles can be traced back to the "White Bike Plan", which was established in Amsterdam in 1965. Many years later, in 1995, a second-generation bicycle-sharing scheme was launched in Copenhagen with a number of improvements (DeMaio and Gifford 2004) that was based on a new public bicycle plan called "Bycyklen". However, theft continued to be a problem for this second generation of bicycles, and this led to a third generation of shared bicycles, the so-called "smart bikes", which use a magnetic card.

First appearing in 2001, this third generation is the most widely used at present, and it has been progressively rolled out in a large number of towns and cities in many different countries. Public bicycles have thus become established as an effective mode of individual public transportation.

An example of a successful program is the Velo'v hire system in Lyon (France), which has increased the number of bicycle users in the city considerably. According to Bouf and Hensher (2007), this program has also coincided with a strong growth in bicycle sales. Another example is the Call-a-Bike system in Germany, managed by the German National Railway, which has made hired cycles available at a large number of train stations throughout the country (Noland and Ishaque 2006). A similar project managed by

OV-Fiets was also implemented in Holland, where a fast cycle rental system is available at more than one hundred stations (Pucher and Buehler 2008).

In Spain, there has been rapid adoption of these systems in the main towns and cities in recent years. Seville (July 2007) is a case in point along with several other cities, including Cordoba (September 2003), Gijon (September 2004), Barcelona (March 2007) and Zaragoza (March 2008).

On occasion, the rapid rollout of these systems has been underpinned by collaboration agreements with specific public and/or private organisations to facilitate bicycle use by a specific target population. This is the case in Seville, where only a few months after the system had been opened to the public, a collaboration agreement was signed between the municipal government and the University of Seville with the objective of facilitating access to the public bicycle service (SEVICI) for university community members.

The aim of this paper is to analyse the public bicycle hire program in the city of Seville (SEVICI), as it has been one of the most rapid successes from an international perspective and, specifically, we sought to assess the way that the program has been applied to the university community, which comprises nearly a third of annual season ticket holders. The typical profile of the user within this community will also be examined. We will investigate the opinions that these users have of both the hire service as a whole and its various component parts. The ways in which these opinions may have changed over time as the first signs of system overload began to appear will also be examined. The overload of the hire service refers to the success of the system leading to demand for additional service as the number of ticket holders increases at a much higher rate than the supply, measured by the number of bicycles in the system and the number of stations and docks.

The paper is organised as follows. "The use of the bicycle and the bicycle hire system in Seville" section explains the characteristics of this policy in the city of Seville. "Data" section describes the data used. In "Level of satisfaction and reasons for use" and "Factors on which increased use of the bicycle hire system would depend" sections, we analyse the evolution of user satisfaction with the Seville public bicycle hire program, the reasons for its use and the factors that would increase use of the system. "Analysis of the factors that determine the satisfaction of SEVICI users" section describes the econometric methodology and presents our empirical outcomes and "Conclusions" section offers conclusions and recommendations.

The use of the bicycle and the bicycle hire system in Seville

The development of cycling in Seville

One of the most important features of Seville's urban transportation system in the past 5 years is undoubtedly the success of the bicycle. The increased use of this mode of transport arose from an alarming decline in the use of public transportation in the Seville metropolitan area. Public transportation's modal share in Seville and its metropolitan area fell at an average yearly rate of 1 % from 1983 to 2007, with its market share dropping from 48 to 23 % of all mechanised journeys (see Castillo-Manzano and López-Valpuesta 2009 for an analysis of public transport in Seville).

In just a few years, Seville and its surroundings, which previously were totally dependent on the private automobile, have seen the bicycle become an effective transportation option. The number of journeys made by bicycle in 2010 is five times larger than it was in 2007 and constitutes 6.6 % of all journeys made using mechanical means. This is

an effective modal shift away from other modes of transportation towards the bicycle and represents an unprecedented success for the bicycle in such a short time, not only in Spanish cities but also in Europe. However, the paradox is that the bicycle's success has accelerated the decline in the use of public transportation, as, according to mobility studies, the bicycle has taken 7.6 % of the city bus system's previous modal share. Additionally, the peak hours for bicycles on working days are from 7:30 to 9:00 a.m. and at $\sim$3 p.m., corresponding to the same periods as road traffic and the demand for public transport. It would therefore be logical to leverage the synergies between the bicycle and public transportation, encouraging intermodality and the joint use of the two modes, bearing in mind that the two are partners rather than competitors.

The change in mobility patterns in the city was initiated by the Master Plan for Fostering Bicycle Use in Seville 2007–2010. This plan implemented a number of actions to improve infrastructure and services that encouraged bicycle use as a means of urban transportation. The two most important actions were the construction of an extensive network of bicycle lanes and the rollout of a public hire cycle system.

Approximately 80 km (50 mi) of cycle lanes have been constructed over eight routes and another 30–40 km (18–25 mi) complementary network is under construction (a large part is completed). This means that Seville's cycle lane network is now almost 120 km (75 mi) long.

Second, Seville's municipal government released a public tender for a public bicycle system. A contract was signed with the JCDecaux urban advertising firm to establish a public bicycle system in the city similar to those that the company had already installed in cities such as Lyon (Vélo'v, from 2005) and Paris (Vélib', from early 2007), and in the Spanish cities of Cordoba, Gijon and Santander.

The SEVICI public bicycle hire system

Called SEVICI, the public bicycle system was formally opened on July 24, 2007, with an initial fleet of 300 bicycles and 30 parking facilities or stations that are available every day and at all hours. The service became fully operational in 2008, with 2,500 bicycles distributed across 250 stations or bicycle parks located in public places throughout the city and at a maximum distance of 300 m apart.

An interesting feature of the system that distinguishes it from conventional public transportation is that it is self-financed through an advertising license scheme. The municipality has licensed advertising spaces, generally near the bicycle parks, to JCDecaux for 20 years in exchange for this private firm's installation and management of the public bicycle system at a low cost for the public.

Evidently, this situation does not mean that the system is cost-free, as it represents an opportunity cost for the city. The city government could have leased advertising spaces in the absence of the agreement and used the revenue in other ways. However, many of these advertising spaces were created around the smart bike stations and never would have existed had it not been for the system. Additionally, other means of public transportation that also use this type of advertising at their stops do not manage to cover their costs and instead operate with considerable losses.

In short, the smart cycle hire system's financial situation contrasts with that of, for example, the public bus company, which costs the city of Seville 60 million Euros every year. This is despite the system's significant revenue stream from advertising at stops and on the sides of the buses and trams themselves, which act as mobile billboards in areas with

heavy pedestrian traffic, such as the historic old town where no other type of advertising is allowed.

Users can opt for either short-term (weekly) or long-term (yearly) tickets that in 2009 cost 5 and 10 Euros, respectively (plus a deposit of 150 Euros that is returned in full once the period is over as long as none of the bicycles used suffered any damage). The first half hour of bicycle use is free. The next hour costs 1 Euro or 0.50 Euro (depending on whether the season ticket is short- or long-term, respectively), and the second hour and any subsequent hours are charged at 2 or 1 Euro per hour (short- or long-term ticket, respectively).

The intention behind this price structure is to maximise bicycle rotation. To do so, it is essential to penalise users for failing to return bicycles to the stations and make them available for hire when they are not actually being ridden. Journeys longer than a half hour are not usual in a city the size of Seville. Therefore, it may be assumed that when anyone hires a bicycle for a longer period of time, it is because the bicycle has not been parked at a station awaiting the next rider. The price structure, in short, is designed to ensure that anyone who uses a bicycle will not only hire the bicycle, park it at the destination and then return to the point of origin; instead, it is desirable that the user hire a bicycle to travel from the point of origin to the cycle station that is nearest the person's destination and then hire a second bicycle for the return journey.

The public bicycle system's success has translated into a large volume of season ticket holders and cycle hire data. During the first year it was in operation, i.e., through 24 July, 2008, when only 65 % of the bicycles and 70 % of the stations that were planned were operational, SEVICI recorded 1.8 million uses at an average of 12,000 per day, and there were 23,250 long-term and 54,117 short-term registered ticket holders.

These figures rose rapidly over the following months as all of the bicycles were made available and all of the stations came into service. According to the latest overall figures available, by the end of November 2009 (28 months after the service opened), SEVICI had already exceeded ten million total hires at an average of nearly 25,000 hires per day, there were 62,700 long-term and over 125,000 short-term total ticket holders. This large number of short-term ticket holders—season tickets are especially convenient for occasional visitors and tourists—is proof of how well the system was received by visitors to the city. In fact, the city has suggested the possibility of linking the system to organised, bicycle sightseeing tours of the city for tourists to JCDecaux to promote tourism.

Furthermore, the latest data show that the number of long-term ticket holders surpassed 70,000 in 2010.

The bicycle and the university community

Meanwhile, under the above-mentioned Master Plan for Fostering Bicycle Use in Seville 2007–2010, a program called "En bici a la Universidad" (To University by Bike) was implemented through a collaboration agreement signed in June 2008 between the city and the University of Seville. The aim of the agreement was to increase the number of urban cyclists in the university community (students, teaching and research personnel and administrative and services personnel). This collaboration specifically entails the university's centralised management of the yearly season tickets, making the procedure for applying for these tickets simpler and faster and thus reducing processing time. University community members are also exempted from making the deposit, which is a considerable benefit for students.

During the first 9 months that the collaboration agreement was in place, from July 2008 to March 2009, the university community's Help Desk processed 13,315 yearly tickets,

with 11,662 applications coming from the student sector, 911 from teaching and research personnel and 742 from administrative and services personnel. From June to October 2009, the majority of the aforementioned tickets were renewed and 5,491 new ticket applications were processed (5,251 from students, 126 from teaching and research personnel and 114 from administrative and services personnel).

Therefore, 18,806, or 30 %, of the 62,700 registered long-term SEVICI ticket holders in November 2009, were members of the university community. Another detail that demonstrates the relationship between SEVICI and the university community is that October produced the largest number of new ticket holders in both 2008 and 2009, coinciding with the beginning of the new academic year during the last week of September. These data demonstrate the usefulness of the specific policies aimed at this segment of the market.

Data

Three waves of surveys were conducted between June 2008 and June 2009 at the various University of Seville campuses to analyse the profiles of university users and gauge their opinions of SEVICI. The total size of the sample was 601, including students, teaching and research personnel and administrative and services personnel. The specific data are presented in Table 1.

The surveys were conducted in three different waves to record SEVICI users' opinions and their levels of satisfaction and make it possible to understand the ways in which their opinions evolved as the system rapidly became established and clear signs of system overload appeared, especially at docking stations.

Consisting of 25 questions, the surveys were used to construct the variables for the analysis and are presented in Table 2 along with their main descriptive statistics.

Level of satisfaction and reasons for use

The levels of satisfaction reported by SEVICI system users were determined by an initial analysis and are presented in Table 3. The highest-scoring factors and the reasons that determine system use are presented in Table 4.

Until recently, little use was made of the bicycle as a means of urban transportation in Seville, and as such, the level of satisfaction with the system's comfort for this purpose received positive scores ($\sim$7). This is an indication of the success of this mode of

Table 1 Interview campaign and data

Field work	Place	Smart bicycle stations near University of Seville campus		
	Period	June 2008	Feb 2009	June 2009
How information was obtained	Interview with closed questionnaire	25 Questions		
	Universe	Students, teaching and research personnel and administrative and services personnel		
Sampling	Sample size	168	244	189
	Sampling method	Random selection of users returning bicycles at the above-mentioned smart bicycle stations		

Table 2 Variables and descriptive statistics

Name	Explanation	No. obs.	Mean	Stand. dev.
(a) Date of survey and personal characteristics				
a.1. Date	1 if survey is in June 2008	168		
	2 if survey is in Feb 2009	244		
	3 if survey is in June 2009	189		
a.2. Gender	1 if male	389	0.65	0.48
	0 if female	212		
a.3. Age	Age of person surveyed	601	24.17	9.56
a.4. Part-time	1 if works part-time	24	0.04	0.20
	0 otherwise	577		
a.5. Full-time	1 if works full-time	115	0.19	0.39
	0 otherwise	486		
a.6. Level of education	1 if no formal education or school leaving certificate	4		
	2 if high school diploma or professional training	418		
	3 if upper grade professional training	18		
	4 if shorter graduate degree	51		
	5 if longer licentiate degree	99		
	6 if PhD	11		
a.7. Resident	1 if resident in city of Seville	496	0.83	0.38
	0 otherwise	105		
a.8. Own bicycle	1 if owns own bicycle	257	0.43	0.50
	0 otherwise	344		
a.9. Total months	Time has been a user of SEVICI (in months)	601	6.48	4.25
(b) Data on use of bicycle as means of transportation				
b.1. Use commute	1 if has begun to use bicycle to commute to place of work or study since became SEVICI user	351	0.58	0.49
	0 otherwise	250		
b.2. Use shopping	1 if has begun to use bicycle to go shopping since became SEVICI user	121	0.20	0.40
	0 otherwise	480		
b.3. Use exercise	1 if has begun to use bicycle for exercise since became SEVICI user	69	0.12	0.32
	0 otherwise	532		
b.4. Use recreation	1 if has begun to use bicycle for recreation or leisure since became SEVICI user	116	0.19	0.40
	0 otherwise	485		
b.5. Week frequency	Frequency of bicycle use per week	601	5.95	3.98
b.6. Use whenever	1 if only uses bicycle whenever s/he wants and considers there to be no factors that would make him/her increase use	78	0.13	0.34
	0 otherwise	523		
b.7. All bike	1 if does not need to combine SEVICI with other means of transportation	366	0.61	0.49
	0 otherwise	235		

Table 2 continued

Name	Explanation	No. obs.	Mean	Stand. dev.
b.8. Rain other public	1 if replaces bicycle with other modes of public transportation when it rains	412	0.69	0.47
	0 otherwise	189		
b.9. Rain auto	1 if replaces bicycle with private automobile when it rains	141	0.24	0.42
	0 otherwise	460		
(c) Level of satisfaction: scoring of bicycle use and SEVICI hire system (from 0 to 10)				
c.1. Comfort	Level of comfort experienced when using the bicycle	601	7.00	1.52
c.2. Dock stations	Scoring of siting and load at hire cycle collection and return docking stations	601	5.86	2.25
c.3. Price	Scoring of cost of hire charge	601	7.56	1.99
c.4. Processing	Scoring of administrative process for applying for season ticket	601	5.45	2.44
c.5. Website	Scoring of SEVICI website usefulness	601	6.31	2.03
c.6. Maps	Scoring of cycle-lane map usefulness	601	7.13	1.52
c.7. Satisfaction	General satisfaction with the SEVICI bicycle hire system	601	6.87	1.68
(d) Reasons for using SEVICI: scoring of reasons for choosing the SEVICI bicycle hire system as mode of transportation in Seville (from 0 to 10)				
d.1. Healthy	To do exercise and for health reasons	601	7.11	2.28
d.2. Environment	Benefits to the environment.	601	7.59	2.23
d.3. Avoid traffic congestion	To avoid urban traffic congestion	601	7.82	1.96
d.4. Cheap	Is a cheap mode of transportation	601	8.29	1.74
d.5. Lifestyle	Is a lifestyle choice	601	5.44	2.71
d.6. Ease of use	Easy to take out and return bicycles	601	6.36	2.64
(e) Factors which would increase surveyee's use of SEVICI: scoring of factors which would make surveyee increase his/her use of the SEVICI bicycle hire system (from 0 to 10)				
e.1. Weather	Better weather	601	6.75	2.64
e.2. More traffic congestion	Increased urban traffic congestion	601	6.81	2.31
e.3. More time	Having more time	601	6.52	2.47
e.4. Expand net	Expansion of bicycle lane network	601	7.46	2.19
e.5. End trip facilities	Opportunity of locker rooms and showers at destination	601	4.19	3.22

transportation and would justify the steep increase in the use of bicycles described in "The use of the bicycle and the bicycle hire system in Seville" section.

In broad terms, the general level of satisfaction with the SEVICI hire system is positive ($\sim$6.9). This score is similar to the score given to the above-described general use of the bicycle as a mode of transportation.

Price is the best-scored variable and is related to the cost of SEVICI tickets; the system's prices were among the lowest for hire systems (both in Spain and internationally), at 10 Euros for the yearly ticket at the time of the survey. Conversely, the score given to the

Table 3 Average scoring of level of satisfaction by date

Variable	June 2008	Feb 2009	June 2009
c.1. Comfort	7.39	7.04	6.61
c.2. Dock stations	6.71	5.93	5.03
c.3. Price	7.94	7.75	6.98
c.4. Processing	5.48	5.40	5.48
c.5. Website	6.66	6.28	5.98
c.6. Maps	7.28	7.17	6.90
c.7. Satisfaction	7.49	6.88	6.29

Table 4 Average scoring of the reasons for use by date

Variable	June 2008	Feb 2009	June 2009
d.1. Healthy	7.26	7.02	7.10
d.2. Environment	7.61	7.62	7.52
d.3. Avoid traffic congestion	7.92	7.90	7.62
d.4. Cheap	8.23	8.39	8.20
d.5. Lifestyle	5.96	5.42	5.00
d.6. Ease of use	7.34	6.45	5.37

hire stations is less than the average general satisfaction score. The score for the application process for season tickets is also especially low compared with the other variables, although this is explained by the system being overwhelmed by applications in a short period of time, a situation that was progressively aggravated by further increases in applications over the following months.

What is striking is that the level of satisfaction with each of the components falls over the three waves with the sole exception of application processing. This is the only variable that remains stable. This is not a positive detail, however, as its initial score was low (5.5), simply indicating that it did not improve over time.

In principle, this decline in the level of satisfaction can be attributed to the progressive overloading of the system. The way that the data evolve over the year during which the three survey campaigns were conducted—June 2008 to June 2009—is quite revealing in this respect.

The station system's benefits clearly increased as, according to information provided by the organisation managing the service, the total number of stations rose by 50 % and the number of bicycles by almost 80 %. The number of docks at stations where there were clear signs of overloading was increased, and user services at the stations were also improved. For example, information on the availability of empty docks at other stations began to be provided to users at stations with no free docks.

No changes were observed in other relevant components over the year apart from these improvements. For example, there was no change in the decoration of the docking stations or to their cutting-edge style, and no advertising was included during the period under study. The only variable that may, a priori, have had a significant impact on the decline in user scores is the number of ticket-holders/applicants.

The number of long-term ticket-holders rose from 18,865 at the beginning of June 2008 to 56,229 at the beginning of June 2009, i.e., an increase of nearly 300 % in a single year (this excludes short-term ticket holders, for whom we have no data). Increased demand therefore outstripped increased supply by four times in the case of the docking stations and by 2½ times in the case of the bicycles. This would logically result in signs of overloading.

However, the difference between supply and demand was much greater than these figures show. On the one hand, bicycles that broke down for one reason or another and could not be used until they were repaired by the concessionary have to be taken into account. On the other hand, this period coincided with a surge in vandalism targeting the hire system; some 1,400 bicycles were impacted in some way and of these $\sim$200 were stolen and never recovered (see Castillo-Manzano and Sánchez-Braza 2011 for other examples of vandalism in the city of Seville). The combination these factors contributed to the system becoming overloaded.

Furthermore, this type of system is especially susceptible to system overload, as the docking stations near the university campuses are prone to high concentrations of traffic. Early in the morning, demand for empty docks where students can drop off bicycles when they arrive on campus is high. This means that SEVICI has to remove bicycles to free up these docks beforehand. Meanwhile, between 1–2 p.m. demand for bicycles at the docking stations is high.

As it has been impossible to satisfy both requirements, users have had to go to stations further and further from the campus to hire or return bicycles, which increases their travelling time, both by bicycle and on foot. It should therefore come as no surprise that the greatest relative decrease was seen in the scores given to the SEVICI bicycle stations, which fell from 6.7 in the first wave, to a barely passing mark of 5 in the last wave. The potential significance of this variable (dock stations) in the econometric analysis will provide us with an indirect indicator of whether bottlenecks at the stations may influence the general level of satisfaction with the system.

The changes in the scores given to the price variable are also conspicuous. While remaining positive, there is a significant decline in the average score despite the price of the ticket remaining constant from the time that the hire system was launched, which means that the real price has declined once inflation is subtracted. Therefore, the increased load on the system could have also impacted the quality/price ratio score, and, consequently, there is a greater perception that the system is more expensive.

Another factor that may need to be accounted for is the time that an individual has been a user of SEVICI (total months variable). It is possible that the system was an excellent match for the preferences of users who initially joined the programme, and hence they were the most enthusiastic about the system and gave the highest satisfaction scores. Users who signed up later were probably less enthusiastic about the system and therefore gave worse scores. The potential significance of this variable in the econometric analysis may also indicate whether the time that an individual has been a user is really a determinant of the general level of satisfaction.

Finally, people who are aware of the existence of the SEVICI website and the cycle-lane network maps score them positively; notably, only 30 % of people know of and use the cycle-lane maps, and only 70 % are aware of the SEVICI website.

Users' ratings of the factors that induce them to use bicycles and the SEVICI bicycle hire system (Table 4) are in keeping with factors reported in earlier studies. The highest rated factor is that it is an inexpensive mode of transportation (as stated by Gatersleben and Appleton 2007; Hopkinson and Wardman 1996, low cost is one of the most commonly cited reasons for cycling), followed by the fact that, as a mode of urban transportation, bicycles do not get caught up in urban traffic congestion (in line with Vandenbulcke et al. 2009; Wardman et al. 2007) and produce environmental benefits (see Chapman 2007; Martens 2007 on the importance of this factor). Another well-rated factor is the use of the bicycle as a healthy mode of transportation that enables people to exercise (as in Coutts 2008). Additionally, the ease with which a bicycle can be hired and returned to docking

stations allows users to forget about parking needs, both at home and at their destination, and removes the security problems associated with having to leave a bicycle outside (see Hunt and Abraham 2007 on the importance of having parking facilities at the destination). However, the progressive overload of the hire system and the docking stations could, again, be the reason why the score given to "ease of use" plummeted from 7.3 in July 2008, to 5.4 in June 2009.

In other respects, compared with bicycle use in general terms, it is striking that smart bicycles are apparently not used for more philosophical reasons. To be precise, a much lower score is awarded to 'bicycle use as a lifestyle choice' (as stated by Horton 2006) than any other factor. There are two potential explanations for this: first is the short time that the bicycle has been an established and the habitual means of transportation in Seville, indicating that it had not been possible for a culture to develop around the bicycle as a lifestyle choice; second, because the majority of people who opt for the bicycle as a lifestyle choice usually use their own bicycles and are not frequent bicycle hire system users.

Factors on which increased use of the bicycle hire system would depend

It is also interesting to analyse the scores users award to the factors that would cause them to increase their usage of SEVICI. The results are presented in Table 5.

Extending the cycle-lane network is the most important factor with respect to encouraging greater use of the SEVICI bicycle hire system (according to Tilahun et al. 2007; Dill and Carr 2003, there is a positive relationship between the number of facilities that are provided and the percentage of people that use bicycles for commuting purposes). Another determinant is increased urban traffic congestion. This is also a major factor for persuading users to swap private vehicles and public transportation for the bicycles as their means of urban transportation.

Two other factors follow: better weather (according to Parkin et al. 2008, who conclude that cycle commuting is affected by the climate) and having more time available. The score awarded to the former is unexpected, as low levels of rainfall throughout the year mean that Seville is a city where the climate is highly conducive to bicycle use. Two reasons might influence the score given to this factor, including the excessive heat at certain times of the year when peak temperatures can regularly exceed 40 °C (104 °F) and the fact that the citizens are not habituated to rain, which means that when bad weather is forecast (even though there may only be light rain), they immediately revert to private transportation. The 'more available time' variable relates to greater SEVICI use not as a habitual means of getting around the city, but rather for leisure and as a way to exercise (see Coutts 2008, regarding the use of the bicycle as a healthy mode of transport and one that allows people to participate in physical activity).

Table 5 Average scoring by date of factors that would increase usage of the bicycle hire system

Variable	June 2008	Feb 2009	June 2009
e.1. Weather	6.86	6.83	6.56
e.2. More traffic congestion	6.95	6.90	6.58
e.3. More time	6.69	6.56	6.31
e.4. Expand net	7.63	7.47	7.31
e.5. End trip facilities	4.09	3.95	4.59

Finally, one factor that received a low score is the availability of locker rooms and showers at the destination (which, nonetheless, scored highly in Hunt and Abraham 2007; Wardman et al. 2007). This factor may be more relevant to the use of the bicycle for long journeys, especially when the destination is the workplace.

Analysis of the factors that determine the satisfaction of SEVICI users

An initial descriptive analysis was followed by a micro-econometric analysis to assess the factors that influence the degree of user satisfaction with the SEVICI bicycle hire system.

Ordered logit and ordered probit models were used (see Castillo-Manzano et al. 2011, to see these models applied elsewhere). Both of these models belong to the family of discrete choice models. Specifically, they are regression models for ordinal dependent variables with more than two outputs (other models, such as the logit or the simple probit, would only be used when there are two outputs).

The models are described as follows. According to Cameron and Trivedi (2005), let the underlying response model be:

$$y_i^* = \mathbf{x}_i'\beta + u_i,$$

where the subscript i denotes the ith of the N individuals interviewed, y^* is the ordinal dependent variable (satisfaction with the bicycle hire system), $\mathbf{x}$ is the vector of explanatory variables, β is the vector of the regression coefficients that we wish to estimate and u is the error term.

In this case, the dependent variable will be variable c.7. satisfaction, which denotes SEVICI users' general levels of satisfaction and can have a score ranging from 0 to 10. The number of categories of the ordinal dependent variable is denoted as m (there are eleven in our case: 0, 1, 2, …, 10).

The vector of explanatory variables employed in this analysis comprises the variables in Table 2, except for c.7. satisfaction, which is taken as an endogenous variable, c.5. website and c.6. maps, given the low numbers of users who responded that they were aware of the website and the network maps and the variables in category e, which correspond to factors that increase SEVICI use and that are, therefore, not related to the current level of satisfaction.

In general, for an m-alternative ordered model, we define:

$$y_i = j \text{ if } \alpha_{j-1} < y_i^* \leq \alpha_j,$$

where $\alpha_0 = -\infty$ and $\alpha_m = \infty$ and $\alpha_1 < \ldots < \alpha_{m-1}$ are defined as $m-1$ thresholds between which the categorical responses are estimated and j denotes the jth of the m alternatives.

In this context, we are concerned with how changes in the explanatory variables translate into the likelihood of observing a particular ordinal outcome. We can express the likelihoods of each ordinal outcome as:

$$\begin{aligned} Pr[y_i = j] &= Pr\left[\alpha_{j-1} < y_i^* \leq \alpha_j\right] \\ &= Pr\left[\alpha_{j-1} < \mathbf{x}'_i\beta + u_i \leq \alpha_j\right] \\ &= Pr\left[\alpha_{j-1} - \mathbf{x}'_i\beta < u_i \leq \alpha_j - \mathbf{x}'_i\beta\right] \\ &= F_j\left(\alpha_j - \mathbf{x}'_i\beta\right) - F_{j-1}\left(\alpha_{j-1} - \mathbf{x}'_i\beta\right), \end{aligned}$$

where F is the cumulative distribution function of u_i. For the ordered logit model, u is logistic distributed:

$$F_j = \left.\frac{e^{(\alpha_j - \mathbf{x}_i'\beta)}}{1 + e^{(\alpha_j - \mathbf{x}_i'\beta)}}\right|_{logit}.$$

And for the ordered probit model, u is standard normal distributed.

$$F_j = \left.\int_{-\infty}^{\alpha_j - \mathbf{x}_i'\beta} \left(\frac{1}{\sqrt{2\pi}}\right)^{\frac{-z^2}{2}} dz\right|_{probit} \quad -\infty < z < \infty.$$

The regression parameters β and the $m-1$ ($\alpha_1,\ldots,\ \alpha_{m-1}$) threshold parameters can be obtained with an maximum likelihood estimator (MLE) and maximising the log-likelihood function:

$$L^* = \ln\ L_N = \sum_{i=1}^{N}\sum_{j=1}^{m} y_{ij}\ \ln\left[(\alpha_j - \mathbf{x}_i'\beta) - F_{j-1}(\alpha_{j-1} - \mathbf{x}_i'\beta)\right].$$

This is performed by defining an indicator variable y_{ij}, that equals 1 if $y_i = j$ and 0 otherwise. As in all other discrete choice models, the sign of the regression parameters β can be immediately interpreted as determining whether the dependent variable y^* increases with the regressor.

Table 6 shows estimates of the ordered logit and ordered probit coefficients to determine possible causality and/or correlations between the explanatory variables and the level of general satisfaction with the SEVICI bicycle hire system.

The above results are fairly robust irrespective of the estimation model used, and they identify ten relevant variables that help to explain SEVICI users' levels of satisfaction. Five of these are significant at the 1 % confidence level, and the other five are significant at 5 %, although two fall to 10 % in the ordered probit estimation.

To be precise, the following positive links are found: first, as expected, there is a positive correlation between general satisfaction with the service and a number of its component parts, such as how comfortable the bicycles are, the ease with which they can be hired and returned and the ease of the sign-up process. However, it is striking that the price is not significant. This finding may be the case because the fixed cost of the yearly season ticket is so low, and the variable cost of each journey is generally nil; the first half hour of each journey is cost-free and this is sufficient time to make journeys in a medium-sized city such as Seville.

As anticipated in "Level of satisfaction and reasons for use" section, overloaded stations may be a key component of dissatisfaction. On the one hand, the ease with which bicycles can be hired and returned is one of the three service elements with positive scores. It therefore appears that the lower the load at the station and, consequently, the greater the ease with which a user can hire or return a bicycle (higher scores for the docking station variable), the greater the user's stated satisfaction. On the other hand, the ease with which bicycles can be hired and returned is one of the two reasons users have given for using the system, and this variable is significant in explaining satisfaction. Therefore, bottlenecks at stations disincentivise the use of the system and, consequently, reduce the level of satisfaction with the stations.

The other reason given for using the system, and the other statistically significant motive, albeit at 5 %, is the environmental aspect, i.e., users who have a heightened awareness of environmental concerns (see Horton 2006) experience a greater level of satisfaction with the smart bicycle system.

Table 6 Ordered probit and ordered logit coefficients for the estimation of the satisfaction level

Variable	Ordered logit	Ordered probit
a.1. Date	−0.27 (0.13)**	−0.15 (0.07)**
a.2. Gender	−0.03 (0.18)	−0.02 (0.10)
a.3. Age	−0.02 (0.02)	−0.01 (0.01)
a.4. Part-time	0.35 (0.39)	0.30 (0.24)
a.5. Full-time	0.28 (0.37)	0.10 (0.20)
a.6. Level of education	−0.03 (0.09)	−0.01 (0.05)
a.7. Resident	−0.49 (0.24)**	−0.24 (0.13)*
a.8. Own bicycle	0.13 (0.17)	0.09 (0.09)
a.9. Total months	−0.02 (0.03)	−0.02 (0.01)
b.1. Use commute	0.18 (0.17)	0.10 (0.09)
b.2. Use shopping	−0.15 (0.23)	−0.10 (0.13)
b.3. Use exercise	−0.05 (0.30)	−0.04 (0.16)
b.4. Use recreation	0.63 (0.23)***	0.35 (0.12)***
b.5. Week frequency	−0.02 (0.02)	−0.01 (0.01)
b.6. Use whenever	0.21 (0.31)	0.14 (0.15)
b.7. All bike	0.00 (0.17)	0.01 (0.09)
b.8. Rain other public	−0.61 (0.28)**	−0.29 (0.16)*
b.9. Rain auto	−0.93 (0.29)***	−0.46 (0.17)***
c.1. Comfort	0.60 (0.07)***	0.33 (0.04)***
c.2. Dock stations	0.42 (0.05)***	0.23 (0.03)***
c.3. Price	0.03 (0.04)	0.02 (0.02)
c.4. Processing	0.09 (0.04)**	0.05 (0.02)**
d.1. Healthy	−0.05 (0.06)	−0.04 (0.03)
d.2. Environment	0.12 (0.05)**	0.07 (0.03)**
d.3. Avoid traffic congestion	0.01 (0.05)	0.01 (0.03)
d.4. Cheap	−0.03 (0.05)	−0.02 (0.03)
d.5. Lifestyle	0.02 (0.04)	0.01 (0.02)
d.6. Ease of use	0.12 (0.04)***	0.07 (0.02)***
No. obs.	578	578
Log. pseudo likelihood	−829.62	−829.01
Pseudo R^2	0.199	0.200
Wald χ^2 (p value)	331.57 (0.00)	382.56 (0.00)

Note Standard errors robust to heteroskedasticity in brackets. One, two, or three asterisks indicate coefficient significance at the 10, 5 and 1 % levels, respectively

Finally, it seems that people who have begun to use bicycles for leisure and recreation activities because of SEVICI value its services more (see Noland and Ishaque 2006), while there is no relationship between these and any other uses. In this respect, it should be remembered that people who only use bicycles for fun and enjoyment are less exposed to traffic congestion because they do not normally use bicycles at peak times (unlike commuting to work or school) and they are not forced to travel to the main commercial areas, generally in the downtown area, which are the most congested.

Regarding the negative relationships, the following stand out, including the date variable, confirming the conclusion in "Level of satisfaction and reasons for use" section that the simple passage of time, in this case, 1 year between the first and the last waves, has led to a significant decline in user satisfaction. Therefore, the station overloading that

accompanied the rapid success of the system could have quickly impacted the popularity of the system.

It is also interesting that residents are less satisfied with the system than non-residents, i.e., generally people who live in the towns and villages on the outskirts of Seville. This is an indirect indication that the system is especially useful for people who do not have a place in the city where they can park their own bicycles and that the system, therefore, greatly complements other modes of transportation for users coming into Seville.

Finally, less satisfaction is reported by users of other modes of transportation, including public transportation and private automobiles, when the weather is bad compared with the base category that continues to use bicycles. There may be different reasons that people continue to ride in the rain: first, there may be a group of people who are so satisfied with the bicycle in general terms, and with the smart bicycle system in particular, that they continue to use it even in bad weather. Second, there are people who do not own a car and/or are not well connected to public transport. Therefore, for this second group of people, the variables may indicate that satisfaction with the SEVICI system is greater amongst users who are more dependent on the system, as they have no alternative mode of transportation.

However, compared with previous studies that analysed the bicycle user's profile in general terms, no correlation is found with variables such as gender (as found by Dickinson et al. 2003, who find that gender is clearly a major factor in bicycle use), age (as in Bernhoft and Carstensen 2008, for whom the preferences and behaviours of older cyclists are clearly different from those of younger groups) or level of education or professional status (as in Rietveld and Daniel 2004, who consider level of income to be one of the factors that determine an individual's transportation choice, as income impacts the ownership of vehicles such as an automobile or bicycle). Although these studies focus on the factors that influence bicycle use levels in general terms and not on satisfaction levels with cycling in particular, they are good indicators in so far as they analyse the profile of the bicycle user in general terms.

Similarly, no correlation was found with users' own experiences, including the number of months that they have been using the SEVICI system (total months), how often they use the system each week (week frequency) or whether they their own bicycles (own bicycle). Therefore, despite the considerations that were taken into account in "Level of satisfaction and reasons for use" section, there is no apparent correlation between the time that an individual has been a SEVICI user (total months) and the level of satisfaction with the system.

Conclusions

This paper analyses one of the most successful experiences of a smart bicycle system in the world, that of the city of Seville. Just two and a half years after it was launched, 6.6 % of mechanised journeys are made by bicycle. These results were achieved by a combination of many different factors, some of which are endogenous to the system, the large bicycle lane network, almost 120 km (70 mi) of which was constructed in recent years, and other factors exogenous to the system. Some of the latter factors are positive, such as the city's mild climate and geographical features—flat terrain at sea level—while others are negative, such as a poor and declining public transportation system that is barely capable of capturing 20 % of the journeys made in the city.

The university community in Seville was chosen for an analysis of this experience because it represents almost one-third of the system's ticket holders. The findings demonstrate the reasons that users currently give for using the system and factors that would increase their use of the system. The former can be summarised, in order of importance, as the bicycle being an inexpensive mode of transport that avoids traffic congestion and has environmental benefits, as well as being a healthy means of transportation that encourages physical activity. Furthermore, our findings confirm that making the bicycles easy to hire and return is important for the success of the program. Among the factors that would increase the system's use are the expansion of the cycle-lane network, an increase in urban traffic congestion, better weather and the availability of more free time.

Broadly speaking, satisfaction with the system is high, both in general terms and with its different component parts (price, docking stations, processing, website and maps), although it is striking that the level of satisfaction declined over the three waves of the survey. This could be attributed to the progressive overloading of the bicycle hire system.

Among the determinants of this satisfaction are the following: the positive determinants include the way that the system has been welcomed by leisure and recreational users (not directly affected by system overload), the environmental aspects and the high positive scores given to various elements of the system (such as the comfort of the bicycles, the ease with which bicycles can be hired and returned to their docks and the ease of the sign-up process).

Conversely, the factor that stands out among the negative determinants of the level of satisfaction is, fundamentally, the passage of time between the three waves of surveys. This revealed a significant decline in user satisfaction, which can be attributed to the system's rapid success and the congestion in the system triggered by this success. Residents' lower levels of satisfaction with the system compared with those of non-residents should also be highlighted.

In short, there is greater satisfaction with the system among users who use the system for leisure and recreation activities, non-residents of the city, people with a greater awareness of the environment and those who have no alternative mode of transportation to the bicycle.

This experience therefore provides one main lesson: the success of a system can eventually result in significant difficulties. In this case, the main difficulty is an increase in demand that is far greater than the growth in supply, leading to a decline in satisfaction. Thus the Kraus and Yoshida (2002) maxim is fulfilled; in a service that is provided efficiently for a certain number of users, as the number of users increase, the service quality falls. As in other types of transportation infrastructure where the supply cannot be resized to match demand at peak times, there is no easy solution to this issue. Moreover, in certain areas, it would be impossible to continue to increase the number of bicycle docks, even if greater funding were available, because they would be located in the old part of the city, which UNESCO classified as part of the heritage of humankind in 1987. The docks would affect the aesthetics of the area, and it may be impossible to build more docks without having a negative impact on pedestrian mobility.

Therefore, in the future, it seems more logical to formulate demand management policies, such as changes in the tariffs. This would produce greater revenue that could be used to increase the number of human operators to reduce congestion at docking stations by taking extra bicycles to other stations where they are more needed. As is the case with other modes of transportation, an increase in tariffs of this type could penalise peak time users and cause users who use the bicycles for shopping, enjoyment and exercise to move to other time bands (see the impact of time-of-day pricing in different areas in Holguín-Veras et al. 2006, 2011; Proost and Dender 2008; Nakamura and Kockelman 2002).

A change in tariffs seems to be the solution that the concessionary, JCDecaux, and Seville's municipal government intend to pursue. However, the latter advocates a more gradual and limited change. The two sides have therefore negotiated an increase in charges to guarantee the system's economic viability in exchange for an increase in the number of stations and bicycles. This agreement makes Seville the Spanish city with the highest ratio of bicycles per inhabitant according to a recent report on public bicycle hire services published by the Spanish National Consumer Association.

SEVICI tariffs, which are among the lowest that have been implemented for hire systems to date (both in Spain and internationally), would thus become closer to those of the majority of similar systems set up in other European cities. The annual ticket would cost 25 Euros, compared, for example, with Vélib' in Paris (29 Euros), Bicloo in Nantes (29 Euros), Villo! in Brussels (30 Euros), Bicing in Barcelona (30 Euros) and BikeMi in Milan (36 Euros). It seems that while these other bike-sharing systems have been well-received, have met with great success and have had profound effects on creating a larger cycling population (DeMaio 2009), they have not fallen prey to such a generalised high level of overloading. In this case, the main difference, apart from all the differences that may exist between one city and another, lies in the speed and intensity with which success was achieved, driven by the low tariffs during the system launch period.

This low-tariff model is not unique to Seville; another example is the Vélo'v system in Lyon, which is managed by the same company, JCDecaux. The hire system there was launched in 2005 with a similar strategy to SEVICI. Low tariffs were established during the system launch period, although they have increased gradually since. The charges have not reached the same levels as they have in the other cities mentioned previously, however, and the cost of the yearly ticket stands at 15 Euros.

Finally, the University of Seville has arrived at the same conclusion, that new solutions are needed to prevent the overloading that the system is currently experiencing. Having provided incentives for the use of SEVICI in recent years, the university is now redefining its strategy. First, major investments have been made in bicycle parking facilities, with the construction of racks for over 2,400 bicycles, 75 % of which are in enclosed areas on campus that are under surveillance. An aggressive bicycle-lending scheme for students and teaching and service personnel was initiated in the fall of 2010. In the first phase, 200 people were randomly chosen by lot to be lent folding bicycles in exchange for only a €50 deposit and a promise to use the bicycles daily. In short, after stretching the smart bicycle system to its limits, the university community is now being encouraged to use its own bicycles.

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