Title: How infrastructures can promote cycling in cities: Lessons from Sevilla.

Keywords: Bicycling. Cycling infrastructure. Active mobility. Sustainable transport. Sevilla (Seville). Spain. Europe.

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ABSTRACT

In this paper we analyze the development of a separated cycling infrastructure in Sevilla during the period 2006 – 2011, as well as its consequences for the city mobility. The development in such a short period of time of a fully segregated network of cycle paths has proven to be a valuable tool for the promotion of bicycle mobility in a city without previous tradition of utilitarian cycling. Besides segregation from motorized traffic, connectivity, continuity, visibility, uniformity, bi-directionality and comfort have proven to be good criteria for the design of such infrastructure. All these criteria are aimed to make cycling not just safe, but also easy and comfortable for everybody. Our analysis suggest that the fast building of such kind of infrastructure provides solid grounds for the development of utilitarian cycling with a high cost effectiveness, even in cities without previous tradition of cycling. However this strategy also has limits, that are also analyzed in our paper.

HIGHLIGHTS:

✓ Increase of urban cycling in Sevilla and other Spanish Cities.
✓ Segregated cycling infrastructure as a powerful tool to promote urban cycling
✓ Connectivity, homogeneity and quick building as key factors of success.
How infrastructures can promote cycling in cities: Lessons from Sevilla.

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I.- INTRODUCTION

Growing public awareness about the negative impacts of car-based urban mobility on ecological issues (local pollution, global warming, scarcity of resources... ), public health (obesity, cardiac diseases...), monetary economy (growing economic costs of traffic congestion and infrastructures), urban livability, and land use have pushed up for the search of urban mobility alternatives based on the promotion of walking, cycling and public transport all around the world. Bicycles may contribute to these policies as an independent mode of transport for trip distances up and around 5 km (Dekoster and Schollaert, 1999; ECMT, 2004), or for longer trips in combination with public transportation ((Dekoster and Schollaert, 1999; Martens, 2004).

Policies and investments for the promotion of cycling are usually made at the local level, and the impacts of these policies (as well as these policies themselves) vary from one country to another, and from one city to another. Mode share of cycling as high as 20-30% of all trips is common in many cities of central and northern Europe (Pucher and Bueheler, 2008) and, in spite of its growing motorization (Hook and Replogle, 1996), in many cities of China (de Boom et al, 2001), Japan (Pucher et al., 2012) and other eastern Asian Countries. However, in most cities in the rest of the world, percentages of cycling in urban mobility are usually very low, although efforts in order to amend this situation are ongoing in North America (Pucher et al., 2011), South America (Montezuma, 2005), Australia and other regions of the world (Pucher et al., 2010; Pucher et al, 2012; Pucher and Buehler, 2012).

Urban cycling in Mediterranean Countries has only reached meaningful levels in a few number of cities in France and the north and center of Italy (EPOMM, 2014). Most Italian, Greek, Spanish,
former Yugoslavian and Portuguese cities – not to mention cities of Magreb - did not seriously included cycling in their urban transportation plans until very recently, and with quite uneven success. Sevilla has probably been one of the most successful Mediterranean Cities to include cycling as an important part of its modal split in recent times (Marques, 2011; Morales, 2011, Marques et al., 2012). As in many other European Cities, utilitarian cycling was significant between 1930s and 50s of the last century although, as far as we know, there are no numerical evaluations of the number of bicycle trips. This cycling mobility, however, sharply declined in the following decades. By 1990 the participation of cycling in the city mobility was very small, less than 1%, and continued to decline with the growing motorization\(^1\). However, after 2006, in just five years (from 2007 to 2011) cycling in the Municipality of Sevilla increased from negligible values to more than 5% of the modal split (SIBUS, 2012; Marques et al., 2012). This change was closely related to the building of a cycling infrastructure, which also had a considerable impact on the landscape of the City, as well as on the mobility culture of the population. This cycling infrastructure mainly consisted of a highly connected cycle network which presently includes 164 km of mostly bi-directional segregated cycle-tracks (Ayuntamiento de Sevilla, 2013), and of a public bike sharing system with 2,650 bikes and 260 stations all around the City (Ayuntamiento de Sevilla, 2014). These developments followed similar initiatives in other Spanish cities, such as Barcelona and San Sebastián, and contributed to the present wave of interest in urban cycling mobility in many other Spanish cities, such as Valencia, Vitoria or Zaragoza (ConBici, 2007; OCU, 2013).

The success of Sevilla in the promotion of utilitarian cycling soon gained national and international recognition. Sevilla scored 76 points over 100 in the 2013 Copenhagenize index of bicycle friendly cities, being classified in fourth position (Copenhagenize, 2013). Also in 2013, the most influent consumers association of Spain declared Sevilla the most bicycle friendly city in the Country (OCU, 2013). However, there is a lack of information in the scientific literature available for a non-Spanish speaking audience about this experience, except some very valuable specific analyses of some particular aspects, such as the effect of political and ideological variables on the social perception of the impacts of the bicycle infrastructure (Castillo-Manzano and Sanchez-Braza, 2013) or the management of the public bike sharing system (Castillo-Manzano and Sanchez-Braza, 2013b).

The present article is aimed to offer a comprehensive description and analysis of this case study. It documents the policy and planning process leading to the building of the infrastructure, the role of stakeholders in such process, the style of infrastructure built, the pace and cost of building it, the implementation of the bike sharing system, complementary services such as parking and intermodal travel, and the social perceptions. The analysis includes numerical data on the evolution of bicycle trips, the participation of such trips in the modal split, the evolution of traffic road injuries, the impacts on public health and the contribution to savings of greenhouse gases emissions. The analysis ends with an evaluation of future trends and perspectives. Finally some conclusions are reached. We hope this analysis will be of interest for politicians, engineers, planners and stakeholders, mainly in cities with still low levels of cycling. Our work is based on the meta-analysis of the available sources (including our own research, mainly developed at SIBUS), as well as on our personal experience as active participants in the whole process.

II.- PLANNING AND DEVELOPMENT OF THE BIKE INFRASTRUCTURE

To begin with, let us properly place the process in its geographical context. Sevilla has a population of approximately 700,000 inhabitants for the City and 1,500,000 for the whole Metropolitan Region, with an urban density of around 5,000 hab./km\(^2\) in the City and 3,500 hab./km\(^2\) in the

\(^1\) The mobility survey of 1990 reported a participation of cycling in the modal split for the metropolitan area of 0.6%. Subsequent surveys did not considered bicycles until 2007.
Metropolitan Area. The per-capita gross domestic product is of 18,600 €/hab-year and the percent of car-free households is over 20% for the whole Metropolitan Region. The percent of university students is of over 15% in the city and 8% in the whole Metropolitan Area. Precipitations are very low, over 53 cm per year. There are no days with temperatures below 0 ºC but there are over 80 days per year with temperatures above 32 ºC, and the average maximum temperature is 29.9 ºC. It is, therefore, a typical medium sized Mediterranean City with not very high income and a relatively high level of motorization. Climate and orography (which is very flat) favors cycling, except in summer, when temperatures become very high.

The development of the present bike infrastructure in the city of Sevilla began in 2006, following the guidelines contained in three main planning documents. First of all is the Urban City Masterplan (Ayuntamiento de Sevilla, 2006) which was aimed to the general urban development of the City, and approved by the City Council in 2006. This document contained the concept of a segregated bike network as a part of the new city mobility system. In 2005 (Ayuntamiento de Sevilla, 2005) the municipality approved the Strategic Document for the Integration of the Bike in the Mobility System of Sevilla, which included a first approach to the design of the future bike network. And in 2007 (Ayuntamiento de Sevilla, 2007) the City Council approved the Bike Masterplan for the city. The main contents of these documents are shown in Table I. A survey made in 2006, before the cycle network was built, evaluated the potential number of utilitarian cyclists in 89,000, more than 10% of the city population (Ayuntamiento de Sevilla, 2007). This survey did also show a high level of interest on the project among the population, providing a strong political support for its realization.

The development of the bike network between 2006 and 2010 is shown in Fig. 1 and in Table II. Before 2006 there were some sparse and unconnected bike paths, which after 2006 were restored and included in the network. From the total length of 120 km shown in Figure 1, 77 correspond to the basic network defined in the Bike Masterplan (Ayuntamiento de Sevilla, 2007), and the remaining 43 km correspond to the first extension of the network. Further developments up to 164 km (not shown in Fig. 1) can be seen in (Ayuntamiento de Sevilla, 2013). They are mainly bike paths built in the periphery, with a small impact in the city mobility.

II.1.- The cycle network

The starting point for the design of the basic network (Ayuntamiento de Sevilla, 2005) was a “theoretical network” (Ayuntamiento de Sevilla, 2005, 2006) mainly based on the information collected during the elaboration of the City Masterplan. This theoretical network connected major trip attractors of the city, such as intermodal centers, main public service centers and main relational spaces (such as squares, commercial streets and green areas). This work was partially done during the elaboration of the City Masterplan, which included a parallel citizen participation process. During discussions, some specific trip attractors – such as university centers - were positively biased because of its previous cycling tradition. A first version of this theoretical network was included in the City Masterplan, as a part of its determinations for the city development.

The next step (Ayuntamiento de Sevilla, 2005, 2007) was adjusting this theoretical network by optimizing the distance to the specific trip attractors (educational centers, markets...) along the network, and taking into account the space constraints and opportunities in the different streets. This adjustment was made in a qualitative way, on the basis of extensive fieldworks and discussions with stakeholders, and resulted to a first detailed proposal for the bike network. This proposal also included proposals for bike paths typologies along the network (Ayuntamiento de Sevilla, 2005). It is worth noting that the aforementioned space constraints and opportunities usually favor the

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2 Data from Instituto Nacional de Estadística (Spain), Instituto de Estadístico de Andalucía y Asociación Española de Meteorología.
location of bike-paths along main streets and avenues. This location is also favored by the analysis of the main trip attractors, which use to be located along such roads. On the other hand, it is desirable to locate bike paths along main streets in order to provide visibility to the network (see below). Therefore, it can be concluded that, as a “rule of thumb”, bike paths should be located along main streets and avenues. Finally, after some final fine adjustments, more than 200 trip attractors were identified at a distance below 300 m from the cycle network (Ayuntamiento de Sevilla, 2006b).

The main characteristics of the resulting network (Ayuntamiento de Sevilla, 2005, 2006, 2007) are:

- Continuity and connectivity: the network is designed with the aim of connecting, through a continuum of bike paths, the main trip-attractors and the main residential areas of the city.
- Cohesion and homogeneity: the design of the bike paths is very similar throughout all the network, so that cyclists can easily follow it. This is achieved by using an uniformly colored (green) pavement throughout all the network, as well as a uniform morphology which will be described below.
- Directness and visibility: as we have already mentioned, the network follows the main streets of the city. Therefore it is quite visible. Moreover, as a general rule, detours and multiple street crossings were avoided.
- Comfort: The whole network should be comfortable for everyday cycling, with parking facilities and uniform pavement, without unexpected steps at intersections, etc...
- Quick building: The whole basic network (77 km) was built in less than two years, along 2006 and 2007.

Of course, not all these criteria are original. Many of them – such as connectivity, cohesion or directness - can be found in many manuals and are commonplace for many bike planning departments (CROW, 2007; Danish Cycling Embassy, 2012; German Federal Ministry of Transport, 2010). Other characteristics can be considered as specific of this case study. For instance, the quick building of the network or its extremely homogeneous design.

Continuity, connectivity and cohesion are important because utilitarian cyclists needs for transportation are similar to those of other citizens. Moreover, they need to move easily from one point to another in the city without leaving the cycle network except – perhaps – at the beginning and the end of their trips. Directness is important because bicycles are human powered vehicles, and it can not be expected that cyclist make big detours in their trips. Detour factors higher than 1.2 or 1.3 are considered excessive (CROW, 2007). Visibility and homogeneity, as well as comfort, are important on its own, but they are even more important in cities without a previous utilitarian cycling tradition, because potential cyclists will only be persuaded to cycle if the cycling infrastructure is visible and comfortable, and can be easily interpreted. Finally, quick building of the infrastructure is very helpful in cities without a previous cycling infrastructure, because what is useful and attractive for potential bicyclists is the whole network, not just one or two isolated and unconnected bike paths.

Regarding the constructive criteria for the bike paths, the planning determinations (Ayuntamiento de Sevilla, 2007) and our personal experience show that bike-paths design follows these criteria:

- Segregation: The whole cycle network is segregated from the motorized traffic.
- Bi-directionality: Most bike paths are bi-directionals, with a width of 2.5 m
- Uniform pavement and signposting: Bituminous pavement painted in green color, with clear and uniform signposting, including specific traffic lights
- Located between the motorized traffic zone (carriageway or parking lane) and the pedestrian
area, following these criteria:

- At the same level of the sidewalk, with a different pavement in color and texture\(^3\) or
- At the same level of the carriageway, but separated from it by bollards or other discontinuous physical barrier.
- In case a parking lane persisted in the street, the bike path is usually built at the same level of the sidewalk.
- Intersections parallel to crosswalks, but separated from them.
- Built mainly over previous parking lanes.

Once again some of them are well known concepts and other are more specific of Sevilla. Which is not so usual is the systematic application of these concepts, in order to ensure the aforementioned homogeneity of the network (Ayuntamiento de Sevilla, 2007), as well as the political decision of building up the whole network in such very short period of time. The 100% of the network was segregated from motorized traffic, and almost all bike paths are bi-directional, with the aforementioned characteristics. Segregation of motorized traffic, as well as continuity, are considered an essential characteristic of the network (Ayuntamiento de Sevilla, 2006, 2007), which was designed not to fulfill the needs of present cyclists, but to be attractive to potential bicyclists.

Bi-directionality might be controversial, because in many cities with long cycling tradition, like Amsterdam or Copenhagen, bike paths are usually mono-directional. It is beyond the scope of this paper to develop a complete discussion about the advantages and disadvantages of both designs. Bi-directional bike paths were preferred mainly because they save space (a mono-directional cycle path must be at least 1,50 m width, whereas a bi-directional cycle path can be 2,5 m width; Ayuntamiento de Sevilla, 2006, 2007; CROW, 2007). Moreover, in a city with low cycling tradition, it is expected that mono-directional bike paths were used at first as bi-directional ones, as actually happened in Sevilla with the few previously existing mono-directional bike paths, which will create conflicts once bicycle traffic increased.

Location of the bike-paths at the same level of the sidewalk has been controversial because of conflicts with pedestrians (Malpica, 2010; Castillo-Manzano and Sánchez-Braza, 2013). However, when a parking lane persisted in the street (the most common case), this design provides an easy access to the parked cars from the sidewalk.

Most bike paths were built on previous parking lanes (A Contramano, 2009). This design implies the loss of either parking places or traffic lanes. This loss of parking places and/or traffic lanes was also controversial (Malpica, 2010), but helped to reduce car traffic. Fig. 2 shows a photograph of a typical bike-path on a busy street at the center of the city. This photograph illustrates the main characteristics of the design, as well as the previous configuration of the street.

In the following years, the cycle network continued its expansion, with the same criteria and the same constructive characteristics, until it reached the present length of 164 km (including recreational and pedestrian-shared paths) which makes a 12% of the total road length in the city (Ayuntamiento de Sevilla, 2013 and personal communication). Nowadays, it makes a homogeneous and continuous network connecting the most important trip attractors and residential areas through the main streets and avenues, with a typical cell size of about 500 m. It is determined than new urban developments should be connected to this network by new bike-paths, built following the same criteria of design (Ayuntamiento de Sevilla, 2006, 2007). It is also determined that the network should be completed by other complementary actuations, such as parking infrastructure, at a smaller scale inside residential and industrial areas (Ayuntamiento de Sevilla, 2007), although this

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\(^3\) These design characteristics became afterwards enforced by law by the Regional Government (Junta de Andalucía) for any bike path built along pedestrian areas or sidewalks.
last determination is followed very unevenly in practice. In any case, it can be safely said that cycling from one point to another in the city can be done nowadays following the cycle network in a quite safe and comfortable way (Ride the city, 2013).

II.2. - The historical center

As many other Mediterranean Cities, Sevilla has a big historical center, of about 4 square km, with very narrow streets and a very old street map. In the case of Sevilla this street map comes basically (except a few modern developments) from the XIII century, when the city was the capital of a small muslim kingdom in Southern Spain. More than 56,000 people live in this area, and many of the most important relational spaces and commercial streets are located on it. Both, the City Masterplan (Ayuntamiento de Sevilla, 2006) and the Bike Masterplan (Ayuntamiento de Sevilla, 2007) determined that inside this area there should be strong traffic restrictions and priority for pedestrians and bicyclists. Therefore, as can be seen in Fig. 1, there were no planned bike paths inside the historical center, and bike promotion mainly relies on traffic calming policies, which included creation of pedestrian areas, restrictions to motorized traffic and speed limitations (Ayuntamiento de Sevilla, 2006).

These determinations, however, have been followed in a quite loose way by the different local governments, so that there is not presently any real enforcement to follow most of them. In practice, however, the narrow streets in the historical center make their job for speed limitation better than any regulation, providing some traffic calming and creating many areas with some kind of effective priority for pedestrians and bicyclists. Thus, in practice, and without too many specific policies, the historical center is well suited for bicycle traffic, and a lot of people can be seen cycling on it everyday.

II.3. - The public bike sharing system.

The public bike sharing system of Sevilla (Sevici: http://www.sevici.es/) is an important part of the cycling infrastructure, carrying a high percentage from the total bicycle daily trips (see Section III). It was introduced in a relatively late step of planning (Ayuntamiento de Sevilla, 2007), but the success was immediate, reaching a maximum of 59,455 associates in December 2009 (Ayuntamiento de Sevilla, 2012), two years and four months after the system started. At such time, the system became almost saturated (Castillo-Manzano and Sanchez-Braza, 2013b), with peaks of more than 10 uses per bike and day. At the end of 2013, the system has 2,650 bikes and 260 stations, 44,797 associates, and between 6 and 7 uses per bike in a typical business day (Ayuntamiento de Sevilla, 2014).

Public bike sharing systems evolved from the early free use “white bikes” of Amsterdam to the present third generation of modern automatic systems (de Maio, 2009). The bike sharing system Sevici is one of such third generation systems, conceived as an “individual public transport system” (Midgley, 2011) providing 24 hours almost door to door transportation every day of the week. Accordingly, the system has a high density of stations, similar to those of bus stops (average distance between stations is less than 300 m). The system is designed to have some level of auto-regulation, so that there is few need of re-arranging bikes between stations, which is favored by the flat orography. It is also designed with the aim of favoring connections with the traditional public transportation system: at least one bike sharing station is always located near any public transportation node (Ayuntamiento de Sevilla, 2007). As complementary actions, the Municipality promoted agreements between the main public institutions and Sevici, in order to promote the registration of their members, a fact which contributed to the early system saturation, specifically regarding the University (Castillo-Manzano and Sanchez-Braza, 2013b), which reacted creating its own (long term) bicycle sharing system (SIBUS, 2011; Castillo-Manzano and Sanchez-Braza,
At this point, it may be worth to say a few words about the role of smart public bike sharing systems in the mobility planning of modern cities. There is presently a big burst of smart bike sharing systems all around de world (Bike Sharing World Map, 2013). In Spain, many cities like Barcelona, Valencia, Zaragoza or Sevilla also have successfully implemented such kind of infrastructure. Spain was, in fact, the European country with more automatic bike sharing systems installed: 147 at the beginning of 2011 (Anaya and Castro, 2011). However, their success has been quite uneven. A few number of big systems installed in very populated cities which simultaneously developed other cycle infrastructure (Barcelona, Sevilla, Valencia and Zaragoza) have been quite successful. However, there also are a big number of systems with few bikes and/or a low density of stations, installed in cities without any other cycling infrastructure, which have been very unsuccessful (Anaya and Castro, 2011). It seems, therefore, that a high density of stations as well as some previous cycling infrastructure are necessary for the success of a smart bike sharing system (Midgley, 2011). These considerations reinforce the consideration of bike sharing systems as a new kind of public transportation (Midgley, 2011). They also suggest that bike sharing systems should be considered as a complementary infrastructure, useful once other infrastructures, such as cycle networks and/or traffic calming, have been implemented. The experience of Sevilla fully confirms this hypothesis.

II.4.- Parking, intermodality, and other complementary infrastructure

Parking is a very important part of cycling infrastructure (CROW, 2007). The Bike Masterplan (Ayuntamiento de Sevilla, 2007) included determinations about the location and design of bike parkings – up to 5,728 parking places at the end of 2010 (Muñoz, 2010) - along the cycle network, with emphasis in the main nodes of public transport, as well as the main trip attractors, such as schools, workplaces, commercial areas, public transport nodes, parks, etc. This infrastructure is very used, and our fieldwork shows that nowadays this parking infrastructure is almost saturated, mainly in central areas.

Providing indoor parking infrastructure at origin and destination (CROW, 2007), as well as in the main nodes of public transport (Martens, 2004, CROW, 2007) is also very important in order to attract potential bicyclists. The Bike Masterplan included some initiatives in order to promote indoor parking facilities inside residential and public buildings, schools, companies and shops, etc, which have had an uneven success. Probably, the most relevant initiative came from the University, which has built closed parking areas with automatic card access near its schools and administrative buildings (see Section V). Another interesting initiative came from the Metropolitan Public Transport Authority (Consorcio de Transporte Metropolitano del Área de Sevilla), which provided closed parking facilities and a manual system of public bikes inside the main metropolitan bus station (see Section V). Nevertheless, parking facilities in public transport stations, residential buildings, public buildings, companies and shops, etc... are still far from those currently available in countries with a longer tradition of urban cycling (Martens, 2004, CROW, 2007; Danish Cycling Embassy, 2012).

II.5.- Stakeholders engagement and participation.

To develop public works during two years along 77 km on the streets of any city can not be done without controversy. Therefore, if stakeholders engagement and participation is an essential part of any social or political process by its own, in the present case it was even more important. Urban bicyclists have a long associative tradition in Sevilla. The local cyclists union (“A Contramano”: www.acontramano.org) was created in 1987 and was very active in the local political context (A Contramano, 2011), providing a critical look on the mobility policy of the city (A Contramano,
A Contramano participated in the elaboration of the City Masterplan, making a first proposal for the network design (A Contramano, 2001), which was the seed for the final design contained in the City Masterplan (Ayuntamiento de Sevilla, 2006; A Contramano, 2011b).

During the design and implementation of the basic cycle network and the public bike sharing system, participation of stakeholders continued thanks to the creation of a Civic Committee (Spanish: Comisión Cívica de la Bicicleta). This Civic Committee participated in the design of the cycling infrastructure, and closely followed its implementation. The Committee met almost each fortnight at the Town Hall during the busiest time of the works, and regularly at any time during the whole design and development period. Representatives of the local cycling union, pedestrians, skaters (which are allowed to ride on the bike paths), bike shops and bike rentals; as well as consultants and other professionals linked to active mobility participated in the committee, which was open to all of them without restrictions. Network and bike path designs, as well as the public bike sharing system main characteristics were discussed in the Committee. These discussions helped to a better design of the infrastructure and played an important role for the communication between the Municipality and the Citizenship. The Committee actively participated in the design of the complementary promotion programs, which included bike demonstrations, participation in events such as the car-free day, ciclo-vías, and initiatives such as “bike to work”, bike to school”, “bike for health”...

II.6.- Management and costs

As it was already mentioned, the basic cycle network (77 km) was built in just two years. It was sub-divided into 8 independent but connected “itineraries”, which were built simultaneously. These “itineraries” had the sole functionality of allowing for a faster realization of the public works. This was the first phase of construction of the network, followed by other developments which are shown in Table II. Monetary costs, which can be estimated around 0.27 million euros per km, are also shown in the Table. All these developments were managed from a new ad-hoc department of the City Municipality, the Bike Office (Spanish: Oficina de la Bicicleta), and disseminated through a specific web page: http://www.sevilla.org/sevillaenbici/. This Bike Office was in charge of the redaction of the projects and the supervision of the public works. It was also in charge of the development of the Bike Masterplan in its different aspects, including the supervision of the public bike sharing system. Further developments of the cycle network reached the figure of 164 km, with an overall maintenance cost between 250,000 and 350,000 euros per year (Ayuntamiento de Sevilla, 2013 and personal communication).

It is illustrative to compare the aforementioned costs with other capital costs incurred by the city transportation system in the same period. The first line of the metropolitan subway (18 km) became operational in November 2009, with a final cost for the civil works of around 35.2 million euros per km. This mode carried around 53,000 daily trips in November 2011. The 21.5 km of metropolitan city highways presently in construction have a budget of 30.8 million euros per km, with an expected average traffic of 50,000 vehicles per day (Junta de Andalucía, personal communications). Although these capital costs are not directly comparable with the capital costs for the cycle network, because they respond to very different demands, the above figures illustrate the high cost effectiveness of the cycle network, which presently carries around 70,000 trips per day (see next Section).

The public bike sharing systems is operated as a public private partnership: The City Municipality provides the company (JC Decaux) with advertising space on street furniture in exchange for the company providing and operating the bicycle sharing system. This model also operates in many

4 After 2011 the Bike Office disappeared as a specific department of the Municipality, although the web page is still in operation.
other cities, such as Rome, Paris, Zaragoza or Valencia (Midgley, 2011), and has the obvious advantage of no cost for the City (except for the opportunity costs associated to the advertising spaces lent to the private company). Registration fees and tariffs follow the same schema as in the aforementioned cities (Midgley, 2012), with the particularity of a 24 hours operation. Although the costs of the system is not assumed by the City Municipality, an estimation of the operation cost per trip may be illustrative of the intrinsic cost effectiveness of the system. Our estimations give some figure around one euro per trip, which is in agreement with other estimations for similar systems (Midgley, 2012). This figure is similar to the operation costs of the city urban buses: 1.34 euros per trip in 2012 (TUSSAM, 2013) and is much lower that the cost for the single subway line in operation: 3.84 euros per trip in 2012 (Junta de Andalucía, personal communication). These data show the intrinsic high cost effectiveness of the public bike system.

III.- IMPACT ON CITY MOBILITY

III.1.- Evolution of bicycle trips

Data about the evolution of bicycle trips mainly come from the successive counts made along the cycle network in September 2006, July 2007, May 2008, November 2010, and November 2011 (Ayuntamiento de Sevilla 2006c, 2007b, 2008, 2010; SIBUS, 2012). They show a steady increase in the number of cyclist at each point of observation. Since these counts not always included the same number of observation points, we use the evolution of the average number of cyclist per observation point (or average bicycle daily traffic) as a first rough measure for the evolution of the bike use in Sevilla. These data are shown in the first row of Table III.

There is, however, a strong seasonality in the use of the bike, which can be clearly observed in the public bike sharing system statistics (Ayuntamiento de Sevilla, 2012, 2014). These statistics show a strong valley in August, between two strong peaks in May and in October - November. Therefore, in order to have a better picture of the evolution of the average bicycle daily traffic, it is convenient to adjust the aforementioned crude data to the same month of each year. These adjusted data are shown in the second row of Table III, where the data of 2006, 2007 and 2008 are adjusted to November of each year by using the simple formula \( Y = \frac{P}{Q} \cdot X \), where \( Y \) is the adjusted average bicycle daily traffic, \( X \) is the crude average bicycle daily traffic, and \( P/Q \) is the ratio between the average number of public bike rentals in a sunny business day of November 2011, and in a similar average day of the considered month of this year. Year 2011 is taken as a reference because in this year the total number of associates to the public bike sharing system was very stable (around 50,000).

Consecutive counts of cyclist on similar points along the cycle network can give a good picture of the evolution of the number of bicycle trips in the city, but they do not give any indication on the absolute number of bicycle trips. For this purpose we need some reliable data related to the absolute number of trips, which can be used as an starting point for the evaluation. Fortunately, the city bike sharing system provides records of the daily number of rentals of public bikes (Ayuntamiento de Sevilla, 2012, 2014). Between the days 7 to 10 of November 2011, we counted the number of public and private bikes at 22 observation points along the cycle network and in the historical center (SIBUS, 2012). Results were 33,237 private bikes and 13,423 public bikes. Then, the percentage of public bikes over the total number of bikes (46,660) was evaluated: 27.88% (there were no significant differences between points at the cycle network and points at the historical center). From such data and from the total number of trips made in public bikes during these days – 20,877 in average (Ayuntamiento de Sevilla, 2012) – the total number of bicycle trips was estimated as 20,877/0.2788=72,565 trips for a typical business day of November 2011 (SIBUS, 2012). The total

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5 This count was made before the cycle network was done, and it may be seen as the starting point of the process.
number of bicycle trips in the whole year 2011 can be estimated by using the same procedure, that is by dividing the total number of public bike rentals in 2011 by the measured percentage of use of public bikes (0.2877). The result is shown in the last column of Figure 3.

Starting from these results, it is possible to make an estimate of the number of bicycle trips in a typical business day along the period 2006-2009. This estimate is made by assuming that the absolute number of bicycle trips is proportional to the adjusted average bicycle daily traffic shown in Table III. The estimation for the remaining year, 2010, is obtained by a spline interpolation. The results of such estimate are shown in Fig. 3. It shows an almost linear increase between 2006 and 2009, which was smoothened between 2009 and 2011. Other estimates can be found in the 2007 mobility poll, which give an estimate of 41,744 bicycle trips in November 2007 (CTMAS, 2007; cited in SIBUS, 2012), a 50% larger than our estimate; and in (Ayuntamiento de Sevilla, 2010) which gives an estimate of 52,800 bicycle trips in November 2009, a 11% lower than our estimate. These discrepancies can be expected from the very different methodologies used for the evaluations. Therefore, the results in Fig. 3 for years different from 2011 must be taken as a rough, although consistent, estimation. In any case, whatever the correct estimates are, they show a high increase in urban cycling in parallel to the development of the cycle network, which clearly had a strong impact on city mobility.

III.2.- Modal split and profile of new cyclists.

Participation of bicycle trips in the modal split of a typical working day was evaluated in the last metropolitan mobility poll, made on November 2007 (CTMAS, 2007). From these data, and from the evolution of the trips made on the different modes of transport in the period 2007-2011, the modal split in 2009 and in 2011 was evaluated by the Municipality (Ayuntamiento de Sevilla, 2010) and by the authors (SIBUS, 2012), respectively. The results of these evaluations are shown in Table IV for all mechanical modes. If pedestrian trips are included in the analysis, the available estimates show an increase of bicycle trips from 3.2% in 2007 to 5.6% in 2011 (CTMAS, 2007, SIBUS, 2012). In order to properly interpret these results, it must be taken into account that the results for 2007 correspond to a period where the basic cycle network was almost finished and partially in operation (see Table II). The percentage of bicycle trips before the cycle network was built, was much less for sure, between 1% or 2%, as can be deduced from Fig. 3. Table III shows a 4% increase in the participation of public transport and a -11% fall in the participation of private cars in the City modal split (this last figure, however, is not true for the whole metropolitan region, which shows the opposite trend). This substantial decline of private car trips (-11%) can be partially motivated by the economical crisis, apart from specific traffic policies. The combined result of all these factors seem to have been a net transfer of trips from private cars to public transport and bicycle. However, without the described active policies for promoting bicycling, this last transfer would have not been possible, as the experience of the metropolitan region - where cycling remained stationary - shows.

The results of Fig. 3 and Table III show an impressive increase in cycling mobility. Which was the origin of the new bicycle trips? The available data from surveys made by the Municipality (Ayuntamiento de Sevilla, 2010) and by the authors (SIBUS, 2012) show that new bicycle trips came from previous pedestrian trips 26-28% respectively, public transport 37-40%, and private motor vehicles 37-32%. However, the results of Table IV show that, when all other transfers are taken into account, the result is a net increase in bicycle and public transport trips, and a net decline of car trips. Regarding the reasons for the modal shift, most new cyclists mention utilitarian reasons,

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6 During the preparation of this paper, some of the authors made a new evaluation of the number of bicycle trips following a methodology similar to our 2011 evaluation. Such evaluation (SIBUS, 2014) gives an estimation of 69,500 bicycle trips in November 2013 (previous value for November 2011 was inside the margin of error of this evaluation). This result confirms that the number of bicycle trips leveled off in recent years.
such as economy (25%) and saving time (21%) (SIBUS, 2012).

Regarding the characteristics of the cyclists, the different counts made at working days show an increase in female participation, from a 25% in 2006 (Ayuntamiento de Sevilla, 2006) to a 32% in 2011 (SIBUS, 2012). These figures are similar to other cities with similar percentages of bicycle trips (Garrard et al., 2012), but still far from cities with a longer tradition of utilitarian cycling, like Amsterdam or Copenhagen (Garrard et al., 2012). Our survey (SIBUS, 2012) show that cyclists are, in average, younger than city population: 39% of cyclists are below 29, whereas only 33% of city population is below 29. However, there is a high percentage of middle aged cyclists (34% of cyclists are between 30 and 44). Only for the elderly cycling sharply declines (only 4% of cyclist are above 64). Therefore, although there is some bias towards young people, cycling is present for all ages, except the elderly.

Most cyclists are commuters (workers 32%, students 32% and self-employed people 10%), which is consistent with the main reasons for trips (education 26%, work 26%), although there is also a significant number of trips made by leisure (21%). Interviewed people said to cycle very often (60% of people said to cycle everyday), which is consistent with the profile of the urban cyclist (young students and workers which cycle for utilitarian reasons). Finally, our survey shows that the average time per bicycle trip is 21.8 min (SIBUS, 2012). Considering an average speed of 14 km/h (WHO, 2011) for bicyclists, this implies an estimate for the average length of bicycle trips of 5 km approximately.

IV.- OTHER IMPACTS

IV.1.- Bicycle traffic safety

One of the most important targets of any policy of bicycle promotion is to reduce the number and the seriousness of bicycle road traffic injuries. In order to evaluate the impact of the analyzed policies on traffic safety, we used the data coming from the Spanish Traffic Authority (Dirección General de Tráfico, DGT). The DGT develops since 1993 a very complete database of all traffic injuries reported by the traffic police in Spain, with indication of the place of the accident, involved vehicles, injuries and material damages, etc. Table V shows the absolute number of car and bicycle crashes recorded by traffic agents in the city of Sevilla in the period 2002-2011, as well as the number of traffic injuries per 100,000 bicycle trips (the estimates of Fig.3 are used for the annual number of trips). The number of road traffic injuries per km cycled can be easily obtained from these data using the estimation of 5 km per bicycle trip (see Section III.2). The Table also shows the total length of the cycle network at each year.

Table V shows an increase in the absolute number of bicycle traffic injuries after 2006 (i.e. after the basic network of cycle paths became operative), probably as a consequence of the increase in the number of bicycle trips. However, as it is shown in the column for the number of traffic injuries per 100,000 bicycle trips, this ratio is non-linear and shows a negative slope, in agreement with the “safety in number” (Jacobsen, 2003; Elvik, 2009) theory. Table V also shows the evolution of the length of the cycle network. A dramatic reduction in the number of bicycle traffic injuries per trip is observed in 2007, wen the cycle network began to operate, and an overall inverse correlation between the length of the cycle network and the number of bicycle traffic injuries per trip can be observed in the period 2006-2011.

It is illustrative to compare the evolution of the risks of driving $R_d$ and the risk of cycling $R_c$ in the city during the first years of operation of the cycle network, that is, in the period 2006-2011. For a given year $Y$, risks, $R_d(Y)$ and $R_c(Y)$ can be evaluated as the ratio between the total number of road


traffic injuries and some measure of the volume of cars and bicycles in the streets (Jacobsen, 2003). As a measure of the volume of cars we used the annual average daily traffic (Elvik, 2009) which was extracted from the data provided by the Sevilla Traffic Center: http://www.traiano.com/. The risk of cycling was evaluated as the ratio between the total number of bicycle traffic accidents and the adjusted average bicycle daily traffic shown in the last row of Table III. The comparison of the absolute values of both figures $R_a(Y)$ and $R(Y)$ is not still meaningful, however, because the point counts used for traffic estimations are different. Moreover, the structures of car and bicycle traffics are very different. Nevertheless, the evolution of these figures can be compared using the relative risks with regard to 2006, $R_a(Y)/R_a(2006)$ and $R(Y)/R(2006)$. This comparison is done in Figure 4. The graphics in Fig. 4 show a very different evolution of both risks relative to 2006. Whereas the risk of driving shows a typical slow decline (with oscillations) between 2006 and 2011, the risk of cycling shows a sharp decline in the same period, consistently with the hypothesis of a strong negative correlation between the length of the cycle network (and well as the number of cyclists) and the risk of cycling.

The last column of Table V shows the number of cyclist killed or seriously injured (KSI) each year as a consequence of a traffic accident. In the period 2002-2005, a 10% of the cyclists involved in an accident were KSI, whereas in the period 2007-2010 this percent was a 5.4%. These data suggest that the cycle network also contributed to make cycling accidents less serious in average. More research will be necessary, however, before to reach a definite conclusion on this issue.

Let us now examine the evolution of the vehicles involved in bicycle traffic road injuries. Table VI shows the vehicles involved in bicycle traffic injuries between 2002 and 2011. Between 2002 and 2005, 94% of all cyclist's injuries were collisions with motor vehicles, whereas between 2007 and 2011, 81% of all cyclist's injuries were consequence of such kind of collisions. Therefore, in both periods most accidents were collisions with motor vehicles, which is also true for traffic crashes with KSI cyclists. Thus, even though the presence of the cycle network reduced the percentage of collisions with motor vehicles, this kind of accident is still by far the most common, and also the most dangerous.

In summary, the reported data show that the cycle network substantially reduced the risk of cycling, and that collisions with motor vehicles are, by far, the most common traffic accident. Taking into account that all cycle paths are fully segregated from motorized traffic, our analysis suggest that most accidents occur at the remaining friction points with ordinary traffic: intersections and streets without cycle paths. Therefore, intersection design and traffic calming strategies appear as the next steps towards safer cycling.

IV.2.- Health and environmental impacts

Cycling is an inherently healthy activity whose benefits for public health usually outweigh their risks (de Hartog et al., 2010; Pucher et al., 2010). In (SIBUS, 2012) we made an estimate of the health benefits of the increase of cycling in Sevilla. We used the Health Economic Assessment Tool (HEAT) for walking and cycling (WHO, 2011). With the percentages of substitution and the average distance per trip reported in Section III.2, this analysis provides an estimate of 24.17 deaths avoided per year as a result of the increase of physical activity (SIBUS, 2012). This result is in qualitative agreement with the available estimations for other Spanish cities in the same period (Rojas-Rueda et al., 2011, 2012).

Savings in greenhouse emissions were also estimated (SIBUS, 2012) using the methodology recently developed by the European Cycling Federation (ECF, 2011), and the aforementioned percentages of substitution and average distance for bicycle trips. The result is an overall saving of 8,633.9 tons of CO$_2$ equivalent, corresponding to a fuel savings of 27,151 oil barrels. These fuel
savings imply monetary savings associated to the reduction in fuel imports of around 2 million euros per year (SIBUS, 2012).

But probably the most important environmental impact was the change in the city landscape. The presence of a crowded continuous, and uniform network of cycle paths along the city changed the city landscape in an irreversible way. More research will be necessary on this topic in order to make a more precise evaluation of this impact, but it is clear that the impact of the cycle network in the city landscape has been enormous.

IV.3.- Social impacts

As a consequence of the increase in utilitarian cycling, cyclist evolved from a minority group to a emergent group, increasingly accepted and integrated in the city (Malpica, 2010). Regarding the impact of the cycle network itself, opinion polls show a sustained support from the population (Marques, 2011), who consider it necessary for the safety of cyclists (Ayuntamiento de Sevilla, 2007, Marques, 2011). However, some controversy arose about the elimination of thousands of parking places, as well as on the loss of space for pedestrians (Malpica, 2010, Marques, 2011). Loss of car parking places due to the construction of the cycle network can be evaluated around 8,000 places (Ayuntamiento de Sevilla, personal communication). On the other hand, in spite of the fact that most bike paths were built on previous spaces in the carriageway (A Contramano, 2009; see also Fig. 2), the building of many bike paths at the same level as the sidewalks created the perception that most space for bike paths was taken from pedestrian areas. And, in spite of the fact that the increase in city cycling had not a big impact on the safety of pedestrians (see Table VI), controversy about pedestrian's loss of safety due to the presence of bicyclist near the sidewalks has been constant since 2006 (Malpica, 2010; Marques, 2011; Castillo-Manzano and Sánchez-Braza, 2013). Citizen's political ideology seem to have strongly biased this controversy (Castillo-Manzano and Sánchez-Braza, 2013). More research on this issue will be necessary, but it is clear that a more unified and pedagogical approach to active mobility (pedestrians and bicyclists) would help to avoid these conflicts in the future (Castillo-Manzano and Sánchez-Braza, 2013).

The big increase in city cycling also had an impact on the local economy. Although more research is necessary to quantitatively evaluate this impact, it was apparent that many local industries, such as bike shops, retails, rentals and workshops, flourished surfing on this new wave of cycling. Tourism also take advantage of the city cycle network and the public bike sharing system, which changed the external image of the city (Lonely Planet, 2012; Reuters, 2012).

V.- SOME GOOD PRACTICES AND FUTURE TRENDS

In this section we will describe some good practices that were developed in parallel to the Bike Masterplan and helped to its success. These initiatives, developed in parallel to those of the Municipality, offer good examples of collaboration between different administrations in order to promote utilitarian cycling. Although they can be considered as exceptions in the present context, they could pioneer future initiatives aimed to overcome some of the present bottlenecks for bike promotion (see below, Section V.3), showing the way ahead to a more sustainable mobility.

V.1.- University of Sevilla

University of Sevilla has around 70,000 people, including students, professors and administrative staff, which makes around a 10% of the total population of the city. Therefore, the mobility policy of the University has a big impact on the city mobility. The University buildings are not concentrated in a single campus, but spread out along the city, many of them in the central areas.
Far before the cycle network was built (by the end of the 90's), the University was developing some initiatives aimed to promote cycling. Most important of them was providing parking facilities at all its buildings, including closed parking areas with restricted access, similar to those which are common in the main train stations in Denmark, Germany and the Netherlands (Martens, 2004; CROW, 2007). In 2011 there were closed parking areas at each university building, with 1,618 parking places, as well as 771 free bike parking places near the university buildings (SIBUS, 2011). When the public bike sharing system was operative, the University developed a program to promote the affiliation of its members to this system. The program was so successful that, in November 2009, 30% of the total associates of the public bike system came from the University, which contributed to the saturation of the system (Castillo-Manzano and Sanchez Braza, 2013b). The University reacted creating its own long term bike-lending system with 400 units (SIBUS, 2011), which are planned to increase in the near future. A specific research group (SIBUS) and a web page – http://bicicletas.us.es – were created in order to disseminate all these initiatives. These policies led to a participation between 11% and 14% of bicycle trips in the modal split for trips to and from the university buildings (Chávez de Diego et al., 2009; SIBUS, 2011), which more than doubled the participation of the bicycle in the city modal split.

V.2.- Bus+Bici.

Although intermodality with public transport was an important part of the Bike Masterplan (Ayuntamiento de Sevilla, 2007), this determination was followed in a very uneven way, so that presently there is almost no specific infrastructure on the main bus, metro and train stations, except a few outdoor parkings and some public bike stations near the public transport stations. An exception is the metropolitan buses main station “Plaza de Armas”, where indoor bike parking facilities and a manual public bike-lending system are offered for free to all users of the station. The bike-lending system had, in October 2010, 172 bikes which are lent for a whole day maximum, after the signature of a short contract. The system is mainly intended to commuters, and operates everyday from Monday to Friday, from 7:30 to 24:00 hours. Bikes had an average rotation rate of about 1.5 uses per day, which gives an estimate of around 3-4 trips per bike and per day. Estimated cost per trip is around 0.75 euros, including capital and operation costs. Demand is very high, with a 65% of lends during the first two and a half hours of operation each day (CTMAS, 2010 and personal communication).

V.3.- Future trends.

Our most recent research (SIBUS, 2014) shows that the number of bicycle trips leveled off after 2011, being now stabilized around 70,000 trips on a typical business day. This stabilization is accompanied by a decline in the number of trips in the public bike schema (Ayuntamiento de Sevilla, 2014). Thus, it seems that there is some transfer of bike users from public to private bikes, although more research will be necessary in order to verify this hypothesis. In any case, a slow decline in the use of the public bike schema and some stabilization in the total number of bicycle trips after 2011 are undeniable facts.

This stabilization of the bicycle mobility in the city suggest that the direct effect on bicycle promotion of the cycle network saturated, and that new initiatives are needed in order to achieve higher levels of participation of the bicycle in the city mobility. In fact, from the visual inspection of Figure 1, it can be realized that the basic cycle network presently covers reasonably well the most populated areas of the city. However, other facilities such as traffic calming and/or less segregated bikeways in secondary streets, indoor and/or closed parking facilities, links with public transport, and connections with the conurbation are not well developed. Therefore, present bottlenecks could be related with these other issues.
Regarding traffic calming, the partial pedestrianization of the historical center simultaneously promoted by the local government was repealed by the next one, a fact which also affected bike mobility. Recently, a new traffic regulation has been approved by the City Council. This new regulation includes “30-” and “20-streets”, a better definition of pedestrian areas and some new measures aimed to protect pedestrians and cyclists against motorized traffic. However, stakeholders have considered this regulation insufficient because 30 and 20 areas are not clearly defined and “wooners” as well as bike-streets, counter flow bike paths and other bicycle facilities are absent of this regulation (A Contramano, 2014).

Promotion of closed and/or indoor bike parking facilities is a crucial issue in a city like Sevilla, where people are very reluctant to park his bike at the street at night or during long periods of time, mainly due to fear to theft. There is not any policy to promote indoor bike parking in dwellings and residential areas, and even some neighbor communities forbid bike parking at courtyards. Therefore, this is a clear bottleneck for utilitarian cycling promotion. At workplaces, educational centers and malls, there are still very few initiatives of closed and/or indoor bike parkings. As mentioned before, only the University developed a consistent program to offer this service to its members (SIBUS, 2011). The success of this offer has been impressive, paving the way to other similar initiatives.

Closely related with this issue are links with public transport. Presently, only a very small percentage of trips in public transport show some kind of intermodality with bikes, mainly using a “bike on board” schema (Hernández-Herrador et al., 2014). There are very few infrastructures for bike and public transport intermodality. Indoor parking facilities at stations are not usual and, as mentioned above, just one metropolitan bus-station offers this kind of facility, connected with a bike-lending service similar to dutch OV-fiets. This experience has been, however, very successful (Hernández-Herrador et al, 2014), and could be the starting point for a more general policy.

Regarding connections with the conurbation, our research (SIBUS, 2012) detected a high demand of this kind of connections, with a relatively high usage of the few cycle-tracks presently available for these connections. As mentioned above, conurbation has a population similar to those of the municipality, but cycle-paths on that area are few an unconnected. The development in the conurbation of a cycle network similar to that developed in the central area is crucial. It is important not just because many trips in the conurbation and between the conurbation and the central area can be made by bike, but also because intermodality between bikes and public transport critically depends of this infrastructure (Hernández-Herrador et al., 2014). Recently, the Regional Government proposed a bike masterplan for the whole region, the “Plan Andaluz de la Bicicleta: http://www.aopandalucia.es/planandaluzdelabicicleta/” This masterplan addresses some of the above issues, mainly the development of a cycle network in the conurbation, and the intermodality between bike and public transport.

VI.- DISCUSSION AND CONCLUSIONS

“A simple and fundamental principle of economics is that consumption increases as goods become more attractive to the consumer. If transportation is viewed as consumable goods, then transportation infrastructure will partly determine its attractiveness to the potential user” (Pfleiderer and Dietrich, 1995). This effect of infrastructure-induced traffic is usually seen as a negative effect, due to the associated increase in air pollution, fuel consumption, traffic congestion, etc. However, this concept can be also applied to bicycle traffic: bicycle traffic infrastructure can make cycling attractive or even “irresistible” (Pucher and Buehler, 2008) and those negative consequences can be shifted to positive: reduced pollution, less fuel consumption, less traffic congestion, and so on... We
feel that the experience of Sevilla is a good example of how this effect may work in a medium-sized city with no previous culture of utilitarian cycling.

Although it is not necessarily the only effective model, the infrastructure model of Sevilla has some characteristics that, in our opinion, helped to its success. The main idea behind the model was to make cycling not just safe, but also easy and comfortable for everybody. The philosophy was that making cycling easy and comfortable also will make it safer (Jacobsen, 2003, Pucher, 2010). And indeed our analysis confirms this expectation. A key issue to be taken into account regarding the aforementioned philosophy is that the infrastructure must be designed to fulfill the needs of everybody, not just the needs of present bicyclist, which form at the beginning a minority group (Malpica, 2010). In order to make cycling easy and comfortable for everybody, the infrastructure has to be segregated (from motorized traffic), coherent, continuous, visible, uniform and easy of recognize and interpret. In the case of Sevilla, it looks like a green strip flowing uniformly along the city and connecting without discontinuities the most important residential areas and trip attractors.

A last consideration regarding the micro-design of the infrastructure: Mono-directional cycle ways may not be very appropriate at the first steps of a cycling infrastructure because, in a context of still low bicycle traffic, they will very probably be used as bi-directional, which will later cause conflicts. They also have the advantage of saving space in the street at the moment of the construction of the infrastructure, which is often a key political issue. Moreover, a bi-directional cycle path, if bicycle traffic makes it too narrow, can be transformed into two Copenhagen-style mono-directional cycle paths (Copenhagenize, 2013) by simply building its counterpart at the opposite side of the street.

Another key issue in order to help to the success of the infrastructure was quick building. Cities have “horror vacuum”, and unused infrastructures are almost immediately used for other unexpected purposes. This effect is even more present in compact cities, where there is a high demand of space in the streets. On the other hand, what is useful is the whole infrastructure, not just a small part of it. Therefore, if the infrastructure is built fearfully and slowly, very probably we will see how other activities, such as terraces or motorbike parking, flourish on the bike-paths, making them useless for cycling. However, if the whole infrastructure is fully operational few months after the civil works began, most probably many people will realize its usefulness and will use it.

Monetary costs is a factor that may act against quick building. However, as we already see in Section II.6, these costs are rather modest wit regard to other costs of the transportation system of any modern city, such as highways or subways. Investment in cycling infrastructure has big returns in terms of less capital and maintenance costs per trip. Moreover, smart public bike sharing systems imply similar or less operation costs that conventional public transport, provided they are properly integrated in the city cycling infrastructure (see Section II.6). Infrastructure for urban cycling also has big returns in terms of improved public health, improved traffic safety, reduced greenhouse gases emissions and reduced fuel imports (see Sections III and IV).

There are also social and political costs, although benefits largely exceed them. As it was already pointed out in Section II.1, building the cycle network of Sevilla was controversial in some aspects (Malpica, 2010; Castillo-Manzano and Sánchez-Braza, 2013). In spite of the high level of acceptance of the cycle network reflected in the opinion polls (Marques, 2011), integration and social acceptance of the cyclists in the city mobility system was not an easy process. Regarding these social aspects, we are probably faced to a much slower process, that will probably take much more time than building the infrastructure. Probably, only once this process will end the Town will achieve levels of cycling comparable to those of some Northern European Cities. However, it is undeniable that building the infrastructure played a crucial role as the starting point of this process.
Closely related to this process of social acceptance is another key aspect of the development of the cycling infrastructure: parking. Like any other vehicle, bicycles need of parking infrastructure. Developing indoor parking facilities at the origin (dwellings and residential areas) and at the destinations (educational centers, workplaces, shops...) is an essential part of this infrastructure (CROW, 2007, Pucher and Buehler 2008). These parking facilities, however, need for its effective development of the collaboration of many people and institutions, which will be only possible in an environment of public acceptance of bicycling as a part of “normal” everyday mobility. In spite of some interesting good practices (see Section V), this kind of infrastructure is far from being fully developed in Sevilla.

Also closely related with the social acceptance of cycling as a part of everyday city mobility is the integration of bicyclists in the city traffic beyond the cycle network. This integration, which has much to deal with traffic calming policies, is also far from being fully developed in Sevilla. Same thing happens with intermodal connections between bike and public transport, which in spite of some good practices (see Section V.2), are still far from the achievements of other cities in Northern and Central Europe (Martens, 2004). Moreover, the experience of Sevilla is still an isolated experience, with no similar experiences in other neighboring cities, nor even in its own conurbation. The Regional Government of Andalucía is now reacting to this situation by the elaboration of a regional bicycle masterplan (Plan Andaluz de la Bicicleta), which includes as a central issue intermodality between bicycles and public transportation.

In summary, the experience of Sevilla during the period 2006-2011 shows that the fast development of a segregated cycling infrastructure can be a powerful first step towards the integration of bicycling as an important part of urban mobility in cities with no previous culture of utilitarian cycling. Making cycling not just safe, but also easy and comfortable for everybody is a very appropriate guiding philosophy for the design of such infrastructure. But this first step should be followed by other measures aimed to the social and structural integration of cycling, including traffic calming in central and residential areas, indoor or closed parking areas et the origin and destination of bicycle trips, links with public transport, promotion campaigns, etc.

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FIGURES AND TABLES

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<tr>
<td>- Defines the bike parking policy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Defines the main criteria for the public bike sharing system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Defines other policies to promote cycling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Creates a Bicycle Planning Department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Makes a proposals of bicycle traffic regulation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I: Content of the main strategic planning documents. Source: Compiled by authors.
Figure 1: Evolution of the cycle network between 2006 and 2010. Solid lines show the basic network (77 km), while dashed lines show the complementary network - up to 120 km. Source: Compiled by authors from data of (Ayuntamiento de Sevilla, 2007) and (Muñoz, 2010). Further developments of the network can be found in (Ayuntamiento de Sevilla, 2013).
Figure 2: Before (left) and after (right) illustration of a typical bike path design. Source: (A Contramano, 2009)
<table>
<thead>
<tr>
<th>Period</th>
<th>Action</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-2006</td>
<td>Elaboration of the projects for basic the cycle network</td>
<td></td>
</tr>
<tr>
<td>Aug. 2006 – Dec. 2007</td>
<td>Public works for the basic cycle network (77 km)</td>
<td>18 Million €</td>
</tr>
<tr>
<td>July – Nov. 2008</td>
<td>Elaboration of the projects for the complementary cycle network</td>
<td></td>
</tr>
<tr>
<td>June 2009 – June 2010</td>
<td>Public works for the complementary cycle network (up to 120 km)</td>
<td>12 Million €</td>
</tr>
<tr>
<td>Oct. 2009 - Feb. 2010</td>
<td>Elaboration of a project for the improvement of the cycle network at some conflictive points</td>
<td></td>
</tr>
<tr>
<td>Sept. 2010 – June 2011</td>
<td>Public works for the improvement of the cycle network</td>
<td>2 Million €</td>
</tr>
</tbody>
</table>

Table II: Chronology and budget of the different phases of the development of the cycle network from 2006 to 2011. Source: (Muñoz, 2010)
Table III: *Average bicycle daily traffic* for the different counts of cyclists from 2006 to 2011. “Crude” row correspond to actual counts. *Adjusted row* show the data adjusted to the month of November of each year. Source: Compiled by authors from data of (Ayuntamiento de Sevilla 2006c, 2007b, 2008, 2010, 2012) and (SIBUS, 2012).

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude</td>
<td>330</td>
<td>532</td>
<td>1057</td>
<td>1587</td>
<td>1935</td>
</tr>
<tr>
<td>Adjusted</td>
<td>348</td>
<td>735</td>
<td>1054</td>
<td>1587</td>
<td>1935</td>
</tr>
</tbody>
</table>
Figure 3: Estimations for the total number of bicycle trips in a typical business day of November, and for the total number of bicycle trips per year. Source: Compiled by authors from data of (Ayuntamiento de Sevilla 2006c, 2007b, 2008, 2010) and (SIBUS, 2012).
<table>
<thead>
<tr>
<th>Mode</th>
<th>November 2007</th>
<th>November 2009</th>
<th>November 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>5.0%</td>
<td>6.6%</td>
<td>8.9%</td>
</tr>
<tr>
<td>Public transport</td>
<td>30.7%</td>
<td>32.5%</td>
<td>34.8%</td>
</tr>
<tr>
<td>Motorbike</td>
<td>7.1%</td>
<td>8.1%</td>
<td>8.0%</td>
</tr>
<tr>
<td>Car</td>
<td>57.1%</td>
<td>52.8%</td>
<td>48.3%</td>
</tr>
</tbody>
</table>

Table IV: Evolution of the modal split of mechanical trips in the city of Sevilla in a typical business day. Regarding trips by foot, see the text. Sources: (CTMAS, 2007), (Ayuntamiento de Sevilla, 2010), and (SIBUS, 2012).
<table>
<thead>
<tr>
<th>Year</th>
<th>Total number of car traffic accidents</th>
<th>Total number of bicycle traffic accidents</th>
<th>Bicycle traffic injuries per each 100,000 trips</th>
<th>Killed or seriously injured (KSI) cyclists</th>
<th>Length of bike paths (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>3179</td>
<td>53</td>
<td>--</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>2003</td>
<td>2573</td>
<td>59</td>
<td>--</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>2004</td>
<td>2276</td>
<td>57</td>
<td>--</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>2005</td>
<td>1743</td>
<td>42</td>
<td>--</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>2006</td>
<td>2178</td>
<td>56</td>
<td>1.824</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>2007</td>
<td>1254</td>
<td>56</td>
<td>0.846</td>
<td>3</td>
<td>77</td>
</tr>
<tr>
<td>2008</td>
<td>1345</td>
<td>83</td>
<td>0.894</td>
<td>10</td>
<td>92</td>
</tr>
<tr>
<td>2009</td>
<td>1958</td>
<td>139</td>
<td>0.956</td>
<td>11</td>
<td>--</td>
</tr>
<tr>
<td>2010</td>
<td>1696</td>
<td>134</td>
<td>0.840</td>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>2011</td>
<td>1172</td>
<td>93</td>
<td>0.545</td>
<td>1</td>
<td>--</td>
</tr>
</tbody>
</table>

Table V: Total number of car and bicycle traffic accidents, number of bicycle traffic injuries per each 100,000 bicycle trips from 2002 to 2011, and total number of killed or seriously injured (KSI) cyclists per year (serious injuries are defined as those resulting in a person being detained in hospital as an in-patient for more than 24 hours), as they were reported by traffic agents. Last column shows the total length of the cycle path network in km. Source: Compiled by authors using data from Dirección General de Tráfico (Spain) and other results in this paper.
Figure 4. Comparative evolution of the risks of driving and cycling relative to 2006, $R_d(Y)/R_d(2006)$ and $R_c(Y)/R_c(2006)$, in the period 2006-2011 (see the text for a detailed definition of the variables).
<table>
<thead>
<tr>
<th>Year</th>
<th>Motorized vehicle</th>
<th>Bicycle</th>
<th>Pedestrian</th>
<th>No vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>50</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2003</td>
<td>58</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>54</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2005</td>
<td>36</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2006</td>
<td>44</td>
<td>0</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>2007</td>
<td>41</td>
<td>0</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>2008</td>
<td>68</td>
<td>3</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>2009</td>
<td>116</td>
<td>6</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>2010</td>
<td>106</td>
<td>4</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>2011</td>
<td>78</td>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Table VI: Typology of bicycle traffic accidents from 2002 to 2010. Traffic accidents are classified as collisions with motorized vehicles, bicycles, pedestrians, and other traffic accidents with no other vehicles involved. Source: Compiled by authors from data of Dirección General de Tráfico (Spain).