PEDRO PIMENTEL DE VASSIMON

PERFORMANCE EVALUATION FOR BIKE-SHARING SYSTEMS:

A BENCHMARKING AMONG 50 CITIES

Trabalho de Formatura apresentado à Escola Politécnica da Universidade de São Paulo para obtenção do Diploma de Engenheiro de Produção.

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Para Vitor, Eduardo e Mônica.

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I find the great thing in this world is not so much where we stand,
as in what direction we are moving.

(Oliver Wendell Holmes, Sr.)

ABSTRACT

The purpose of this work is the evaluation of the performance and service quality of bicycle-sharing systems through a benchmarking analysis that relies on key performance indicators and customer satisfaction. It also investigates the relationship between the business models for bike-sharing systems and its efficiency. To achieve this goal, 50 bike-sharing schemes were selected and assessed according to performance metrics defined based on the literature. Additionally, the three case studies of Turin, Washington and São Paulo were analysed with a more thorough approach, in order to compare customer satisfaction with the results previously obtained by these metrics. The study concludes that bike-sharing schemes operating in a public-private partnership business model present a higher performance for most of the indicators evaluated. Moreover, it reveals that city size is not a determining factor to system efficiency according to the analysed metrics. Finally, the study gathers a significant amount of bike-sharing data and may be used as future reference for any research to come in this subject.

Key words: Bike sharing. Performance indicators. Business models. Database.

RESUMO

Este trabalho tem como objetivo avaliar a performance e a qualidade do serviço de sistemas de compartilhamento de bicicletas (*bike sharing*), através de uma análise de benchmarking baseada em indicadores de desempenho (KPIs) e satisfação do usuário. O estudo investiga também a relação entre os modelos de negócio empregados para a operação e implementação de tais sistemas e a eficiência dos mesmos. Para atingir este objetivo, o autor levantou dados referentes a 50 sistemas de compartilhamento de bicicletas ao redor do mundo e os avaliou de acordo com métricas de desempenho definidas com base na literatura. Além disso, três casos de estudo nas cidades de Turim, Washington e São Paulo foram analisados de modo mais aprofundado, visando comparar a satisfação do usuário com os resultados obtidos previamente. O trabalho conclui que sistemas de compartilhamento de bicicletas que operam a partir de um modelo de negócio do tipo parceria público-privada apresentam um desempenho superior para a maioria dos indicadores avaliados. Ademais, o estudo revela que a população de uma cidade não é um fator determinante para a eficiência do sistema, de acordo com as métricas analisadas. Finalmente, o estudo concentra uma base significativa de dados relativos a sistemas de compartilhamento de bicicletas, podendo servir como referência futura para eventuais pesquisas sobre o tema.

Palavras-chave: Compartilhamento de bicicletas. Indicadores de desempenho. Modelos de negócio. Base de dados.

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LIST OF ABBREVIATIONS AND ACRONYMS

BSS	Bike-sharing system or bike-sharing scheme
CO_2	Carbon dioxide
CSV	Comma-separated values
DB	*Deutsche Bahn*
DC	District of Columbia
GDP	Gross domestic product
GPS	Global Positioning System
IDAE	*Instituto para la Diversificación y Ahorro de la Energía*
ITDP	Institute for Transportation and Development Policy
KPI	Key performance indicator
OBIS	Optimising Bike Sharing in European Cities
PPP	Public-private partnership
PUB	Public-use bicycles
SD	Standard deviation

CONTENTS

1 INTRODUCTION

This chapter aims at presenting the motivation and context under which this work was developed, as well as introducing the objectives of the research. Finally, the chapter structure arrangement is presented in order to allow for a more clear reading of this study.

1.1 Context and relevance

With the increase in greenhouse gas emissions and urban population growth, the development of new efficient and sustainable transport modes is a pressing need in cities throughout the world. When it comes to greenhouse gases, around 30% of all carbon dioxide emissions in developed countries result from the transport sector. In Europe, for instance, this sector is responsible for one third of final energy consumption and total emissions amount to an equivalent of 5 billion tonnes of CO_2 per year. Moreover, it is one of the few sectors where emissions continue to rise, as a result of the increasing transport demand (ANABLE; SHAW, 2007; VEIGA SIMÃO, 2014).

Today, there are around 4 billion people living in urban areas, up from 746 million in 1950, a figure that is projected to increase in 2.5 billion by 2050 (UNITED NATIONS, 2014). The high accessibility of jobs and services is what attracts individuals to live in cities. However, urban agglomerations of all sizes face big challenges in maintaining effective and agile public transport systems. In this context, bike share programmes are emerging as a cost effective and sustainable alternative to the existing urban transport options (KISNER, 2011).

The key concept of bike sharing is sustainable mobility. In fact, such schemes help achieving the reduction of pollutant emissions and traffic congestion by promoting the bicycle as a transport mode. This implies on the improvement of public health and renders the city a more a pleasant place to live in. Therefore, by providing the missing link between public transport stations and desired destinations, bike sharing offers a new form of transport capable of meeting the increasing mobility demand and reducing adverse environmental impacts (MIDGLEY, 2009). Nowadays, bicycle sharing is a growing trend that has spread across the globe. There are more than 600 cities around the world with their own bike-sharing scheme today, a figure that does not cease to increase (ITDP, 2013).

To date, limited research has been made focused on the performance evaluation and quality service management of bike-sharing systems, revealing a clear demand for more investigation in this area. Most existing studies on bike sharing focus solely on the implementation phase of new systems and cities are learning from one another in an informal way. Information is disperse and there is a shortage of updated manuals and guidelines (MIDGLEY, 2011). This is relevant as it shows there is a considerable gap concerning the assessment of bike sharing performance, aiming to improve the service quality of these systems.

1.2 Research motivation

This research was developed with the support of Banco Itaú, operator of the São Paulo bike-sharing scheme, Bike Sampa, and seven other schemes located in major Brazilian cities. The author was in contact with the team responsible for managing these systems and was able to extract valuable insights and information for the development of the study. Moreover, the most important results and findings were presented to the bank, aiming to improve Bike Sampa as an efficient and viable mobility alternative in the city of São Paulo.

1.3 Objectives

The scope of this research is the evaluation of the performance and service quality of bicycle-sharing systems through a benchmarking analysis that relies on key performance indicators and customer satisfaction. Moreover, this study aims at determining whether there is a relationship between the business model typology employed in the management of a bike-sharing system and the quality of the service provided. The outcome of this study is a bike-sharing database containing information and performance evaluation for 50 schemes around the world. In fact, system data and ridership and membership statistics are held individually by operators, with no open information available in most cases. Thus, another issue that is tackled with the development of this research is this lack of a central information repository on bike sharing. The creation of the benchmarking not only allows for the evaluation of the performance of bike-sharing systems but also is an important reference database for future studies on the subject.

1.4 Chapter structure

This work is structured in five chapters. After this introductory chapter, the literature review is presented to depict the state of the art of bike-sharing systems. The most relevant aspects concerning cycling and shared bicycle systems are detailed based on previous studies. Firstly, the importance of bicycles as a transport mode and the benefits associated with it are presented, followed by the basics of a bike-sharing system. Then, the most relevant aspects that influence bicycle use are highlighted, as well as success factors for bike sharing. Additionally, the different business models for bicycle-sharing schemes are analysed. Finally, an introduction to previous research on quality evaluation of these systems is exhibited, leading to the detection of the potential research gap.

Following the literature review, chapter two describes step by step the methodology adopted to achieve the objectives of the study, including sample definition and data collection.

Chapter three is devoted to expose all the results and findings of this research and is divided in four main sections. The first section presents the results of the data collection allowing for an overview of the variety of bike-sharing schemes around the world. Then, section two aims at proposing a series of key performance indicators that will serve as evaluation metrics for such schemes. Afterwards, the benchmarking analysis is performed, followed by the evaluation of system efficiency through the created key performance indicators. Finally, three case studies are presented and analysed with a more thorough approach, seeking to complete the performance evaluation in these cities, taking into account the quality perceived by their respective customers.

Chapter four discusses the results by comparing them with the relevant statements of the literature review. Through a critical analysis of the results a discussion is presented in order to draw the final conclusions.

The final chapter presents the conclusions drawn from the benchmarking analysis and the discussion. It summarises the most important findings of this study, shows its limitations and introduces possible future researches on the subject of bike sharing.

2 LITERATURE REVIEW

This chapter gathers previous research made on cycling and bike-sharing systems, as well as the planning, performance evaluation and service quality management of such schemes. The goal is to establish the theoretical foundations on the subject and understand the current worldwide situation of bicycle sharing. Initially, an overview of the benefits of cycling is presented, followed by the main aspects that can contribute to rendering cycling an efficient transport mode. The principles of bike-sharing systems and their evolution are then presented, together with its most important success factors. Finally, the last sections focus on the planning and quality management applied to bike sharing, in order to obtain insight on how to best implement and maintain such systems.

2.1 The importance of bicycles as a transport mode

There is a rather extensive literature on the benefits of cycling, not only to its users, but also to their surrounding environment. Cycling has many advantages in relation to motorised transport modes, especially for short-distance urban trips. For distances up to 5 kilometres in urban areas, cycling can compete with public transport and cars in terms of speed and time (TRANSPORT CANADA, 2009). It allows the user to go to underserved destinations, expanding the reach of trains and buses. Bicycles are relatively inexpensive to purchase and maintain and generally do not add to vehicular congestion, also requiring less infrastructure in the city. Moreover, it is increasingly recognised that pedalling is an effective way for people to cope with obesity and other associated health issues, significantly reducing their medical expenses in the process (CERVERO; DUNCAN, 2003; RIETVELD; DANIEL, 2004).

However, bicycles do have certain drawbacks when compared to other transport modes. Besides being more appropriated only for shorter distances, they require the user to have some riding skills and may be inaccessible to people with certain disabilities. In addition to that, uneven topography and weather conditions (i.e., wind, precipitation and temperature extremes) can further difficult pedalling. Safety can also be an issue for riders, as cyclists are rather exposed and vulnerable, especially to cars (RIETVELD; DANIEL, 2004).

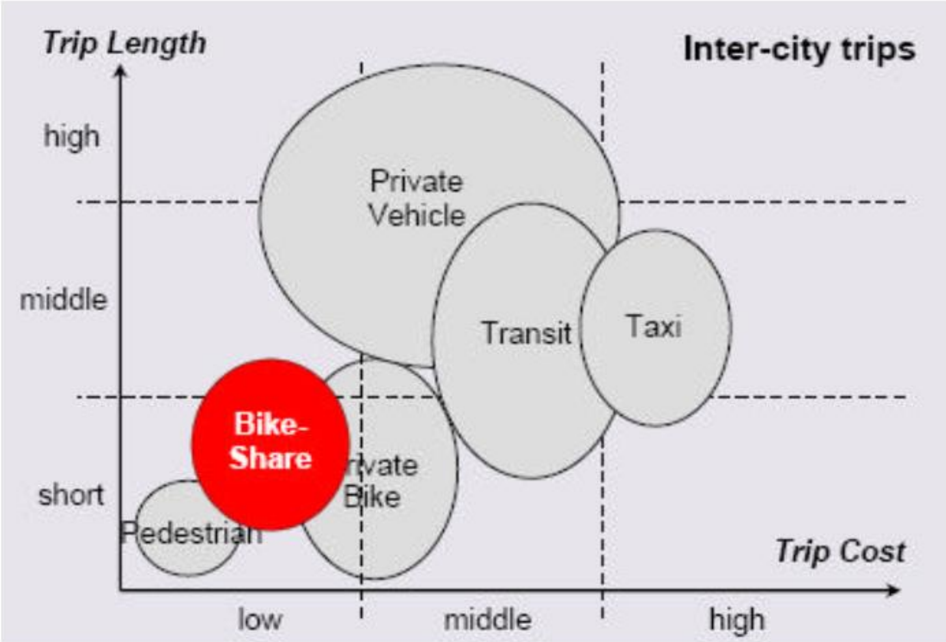
Nevertheless, bicycles are an important catalyst of change and development of sustainable mobility systems (OBIS, 2011). With very low emission of pollutants, noise and risk posed to others, they have a significant positive impact in the city. Cycling promotes social inclusion as it is an inexpensive and accessible mode of transport, which also stimulates local commerce and favours economic growth around its pathways. Thus, a high share of non-motorised transport modes contributes to a much more attractive urban environment for everyone (RIETVELD; DANIEL, 2004; SCHROEDER; ROSA, 2014).

In this sense, shared bicycle programmes play a major role in this process, as they can be an important “door opener” to greater levels of urban cycling. Such schemes are able to increase the acceptance of pedalling as an urban transport mode, especially in cities that still lack a good level of bicycle use and culture (BÜHRMANN, 2007).

2.2 Definition of bike-sharing systems

A bike-sharing system or bicycle-sharing system (BSS) offers a self-service, short-term, one-way urban bicycle rental in public spaces, for several target groups and with network characteristics (OBIS, 2011). This type of system, also called “Public-Use Bicycle” (PUB), “Bicycle Transit”, “Bike Sharing”, “Shared Bicycles” or “Smart Bikes”, enables bicycles to be picked up at any station and returned to any other station, being ideal for point-to-point trips. Individuals are able to use these bicycles on an “as-needed” basis, without having the responsibilities and extra costs of ownership, while benefiting from a transport mode with high flexibility (MIDGLEY, 2011; SHAHEEN; GUZMAN; ZHANG, 2010). Thus, bike-sharing schemes play an important role in the niche of short and low cost trips, as Midgley (2011) shows in Figure 1.

Figure 1 - Bike-sharing systems in urban mobility



Source: Midgley (2011)

Differently from traditional bicycle rental schemes designed only for leisure, shared bicycles are intended for shorter periods of use and a larger number of daily users per bicycle. This usually results in much lower or inexistent usage fees, with fixed fares for registration. Beyond these basic features though, bicycle-sharing schemes vary widely in nature (TRANSPORT CANADA, 2009).

Transport Canada (2009) divides bicycle-sharing initiatives in two broad categories: public and private. Private systems are operated by a certain organization and they are available only to its employees or clients to everyone, but within restricted premises. Some examples are students and staff of a university or bicycles available only inside a park. Public systems, on the other hand, are operated or regulated by a public local authority and are open to the public at large, being comparable to any other public transport mode.

According to the Spanish organization *Instituto para la Diversificación y Ahorro de la Energía* (IDAE) in its *Guía metodológica para la implementación de sistemas de bicicletas públicas en España* (2007), it is possible to distinguish two types of systems: manual and automated. In a manual bike-sharing scheme all the bicycle pick-ups and drop-offs are supervised by staff, while in the automated scheme the user is able to do so without assistance.

Moreover, for DeMaio and Gifford (2004) there are two distinct models of bicycle sharing: the community model allows the user to pick-up and drop-off bicycles in different stations, while the residential model requires the bicycle to be returned at the same location where it was checked out.

This study will focus on public, automated, community bicycle-sharing systems. Henceforth, in order to avoid any misunderstanding, only the terms “bike-sharing” and “bicycle-sharing” will be used when referring to the systems being studied, whereas the term “public” will be used for the business model typologies explained further in the literature review.

The concept of bicycle-sharing schemes emerged in Europe in the late 1960s. The first generation of bike-sharing programmes began in 1968 in Amsterdam, Netherlands. The so-called “White Bikes” were provided permanently unlocked for the public to use freely, which resulted in very high levels of theft and vandalism. In addition to that, police officers often confiscated unattended bicycles claiming they invited theft. A more recent attempt was made in 1993 in the city of Cambridge in England, but the outcome was similar. The city of La Rochelle in France is one of the few that has a free bike initiative of such kind that proved to be successful and continues to operate today since its creation in 1974 (SHAHEEN; GUZMAN; ZHANG, 2010).

Despite the lack of success of these earlier schemes, the bike-sharing concept grew and Denmark introduced the second generation in the early 1990s. The scheme implemented in Copenhagen in 1995 was the first large-scale one to charge a small deposit for the bicycle, which was returned to the user afterwards. The Danish bicycles could only be used in the city centre and were specially designed to withstand heavy usage and weather conditions. However, the system still had theft issues due to user anonymity (SHAHEEN; GUZMAN; ZHANG, 2010; WIERSMA, 2010).

Aiming to further reduce theft levels, the third generation of schemes was perhaps the most significant innovation for bike sharing. By incorporating advanced information technology for bicycle reservations, pick-up, drop-off and information tracking, users are not anonymous anymore. In order to retrieve bicycles they must undergo a registration process, which usually requires an upfront fee or deposit. In this way, the tracking allows to know the exact time interval of usage, as well as the identity of the customer who fails to return a bicycle.

These technological features represented a major improvement over the previous systems, which relied entirely on customer honesty (DEMAIO; GIFFORD, 2004; SHAHEEN; GUZMAN, 2011).

In recent years, a new generation of bicycle-sharing systems was defined. With similar characteristics in respect to the third one, the fourth generation of bike-sharing schemes is envisioned for improved efficiency, sustainability and flexibility to its users (WIERSMA, 2010). It includes potential design innovations such as movable docking stations, solar-powered docking stations and electric bicycles. Additionally, most systems already dispose of real time mobile applications and docking stations located near train and bus terminals, seeking greater integration with the public transport network (MIDGLEY, 2011; SHAHEEN; GUZMAN, 2011).

There are four main components in a fourth-generation system: bicycles, docking stations, kiosks-user interface and bicycle distribution system (SHAHEEN; GUZMAN; ZHANG, 2010). Bicycles are designed to be utilitarian and sturdy, usually built with solid rubber tires and strong steel frame. Components of uncommon dimensions that require special tools for disassembly discourage theft, while adjustable seats are necessary to allow for different people to use the same bicycles (DEMAIO, 2003).

Nowadays, bicycle sharing is a growing global trend. Growing concerns about climate change have led to increased levels of interest on sustainable transport alternatives such as bicycles, spreading bike-sharing systems across the globe in five different continents: Europe, North America, South America, Asia and Oceania (SHAHEEN; GUZMAN; ZHANG, 2010).

In 2011, there were over 375 schemes in 33 countries using 236,000 bicycles. While around 90 per cent of the systems were in Europe, more than half of the bicycle fleet was located in Asia and Pacific region. Together with the Americas, these continents represent the fastest growing bike-sharing markets (MIDGLEY, 2011; SHAHEEN; GUZMAN; ZHANG, 2010). Today, there are more than 600 cities around the world with their own bike-sharing scheme, a figure that continues to increase every year (ITDP, 2013).

Regarding the actual impact bicycle sharing has on reducing traffic congestion, results must be analysed carefully. While personal car usage may decrease after the implementation of a bike-sharing system (TRANSPORT CANADA, 2009), results show that such systems most commonly attracts those who would walk or use public transport (DEMAIO; GIFFORD, 2004; WIERSMA, 2010). This is because they offer a practical solution to the “last mile” problem, that is, the short distance between a public transport station and a destination, which may be too far for walking (SHAHEEN; GUZMAN; ZHANG, 2010). However, even though a higher level of car ownership is initially associated to a lower share of bicycles as a mode of transport (TRANSPORT CANADA, 2009), evidence suggests that it does not reduce the likelihood of bike-sharing systems to succeed (SHAHEEN; GUZMAN, 2011). The reason for this resides in the fact that bicycle sharing acts as a “door opener”, directly increasing cycling modal share (OBIS, 2011). Therefore, bike-sharing systems can also be regarded as a strategy to reduce pollutant emissions and fossil fuel consumption, given that shared bicycle trips contribute to decrease the share of motorised modals (TRANSPORT CANADA, 2009).

Although there are studies oriented to the implementation of bike-sharing systems, most cities are learning from one another in an informal and ad hoc way. There is a shortage of updated manuals and guidelines and there is no central information repository on bicycle sharing (MIDGLEY, 2011). Finally, there is little or no literature regarding the performance evaluation and quality service management of bike-sharing systems, which reveals a clear demand for more research in this area.

2.3 Determinants of cycling and bike sharing success

In order to build a successful bike-sharing scheme, a city must take into account several aspects. According to OBIS (2011), there are two main types of factors influencing the performance of these systems: exogenous factors, specific to a city and not easily changed; and endogenous factors, corresponding to the system design, adjustable according to the exogenous context. Endogenous factors can be further divided into physical design and institutional design, as shown in Table 1.

Table 1 - Factors influencing bike-sharing systems

Endogenous factors	Exogenous factors
Physical design	City size
Hardware and technology	Population density
Service design	Climate
Institutional design	Topography
Type of operator	Cycling infrastructure
Contracts and ownership	Mobility behaviour and culture
Financing sources	Demographic and economic factors
Employment opportunities	Financial and political situation

Source: adapted from OBIS (2011)

It is important to note that while endogenous factors are under the control of planning authorities, exogenous ones are conditions intrinsic to the city and often cannot be altered. Among the exogenous factors, elements such as city size and population density influence directly a bike-sharing system, while factors favouring the increase of cycling such as the presence of bicycle lanes also have major impact on a successful scheme.

The first exogenous factor to be considered is the city size. Although there is no clear lower boundary for a city to be able to sustain a bike-sharing scheme (TRANSPORT CANADA, 2009), a population range of at least 200,000 inhabitants is more suited to support an automated system (BÜHRMANN, 2007; MIDGLEY, 2011). The number of inhabitants of a city, if taken as a proxy for the quality and level of development of its public transport network, could result in less bicycle usage in larger cities (RIETVELD; DANIEL, 2004). However, as mentioned before, bicycle sharing is more likely to attract walkers and public transport commuters, that is, users looking to cycle the "first/last mile" between home and workplace (DEMAIO; GIFFORD, 2004; SHAHEEN; GUZMAN; ZHANG, 2010). Moreover, large cities have greater potential demand and number of destinations and traffic congestion is more intense, thus reducing the average speed of competing motorised modes (RIETVELD; DANIEL, 2004). Because of this, calculating the potential local cycling demand through discrete mathematical models can be of great assistance when planning an urban transport network and promoting non-motorised modes (SOUSA; KAWAMOTO, 2014).

Population density also plays an important role defining the levels of bicycle usage. Most studies show that a denser urban area is related to higher cycling rates and greater average trip lengths are likely to reduce bicycle usage (WIERSMA, 2010). In Europe, bike-sharing schemes are traditionally implemented in denser core areas of towns and cities, where population density is high. In some countries however, city centres and downtowns can be an exception to this rule due to the existence of central business districts, as it is the case in Canada. Although separated from denser residential areas, these central districts still generate a large number of trips due to high employment density (TRANSPORT CANADA, 2009). This is explained by the fact that a city centre with mixed functions greatly contributes to the success of a bike-sharing system, as displacements take place in many different directions in areas of mixed development (WIERSMA, 2010).

Still regarding the exogenous factors, there are two important geographical aspects to be considered: climate and topography. While it is true that local climate is a relevant factor influencing bicycle usage in different seasons (OBIS, 2011), bike-sharing systems have been successfully implemented in cities with very different latitudes and weather conditions (MIDGLEY, 2011; TRANSPORT CANADA, 2009). In addition to that, the knowledge of system usage data from previous years allows for the planning of seasonal availability of a bike-sharing scheme. When the usage is lower, it is possible to limit the number of bicycles available or even shut it down. For instance, in some northern cities such as Oslo, Stockholm and Montréal, the bike-sharing scheme does not operate during winter months (OBIS, 2011; TRANSPORT CANADA, 2009). Therefore, local climate characteristics are not necessarily a determinant factor to the success of a bike-sharing scheme.

It is important to mention that other meteorological aspects such as wind and precipitation also do not seem to influence the success of a bike-sharing scheme. Although they certainly diminish the comfort of riding, these factors can be mitigated, for example, by wearing waterproof clothing or simply postponing a trip until weather conditions are better (RIETVELD; DANIEL, 2004).

When it comes to topography instead, cyclists generally dislike going up inclines greater than 4% and avoid those over 8%. This means that depending on the geography of a city, this can be a meaningful restriction when planning the bike-sharing network. Docking stations at higher elevations will tend to be empty, whereas those with lower topography will be often full, as it is the case of Barcelona in Spain, whose city centre lies in a valley. This implies in a greater redistribution of the fleet and higher logistic costs, as vehicles must constantly bring bicycles uphill in order to meet the demand (MIDGLEY, 2011; TRANSPORT CANADA, 2009). Hence, when planning a bike-sharing network, municipalities must consider the terrain in order to avoid hilly areas when possible. Short distances between stations help diminish the problem and, in some cities such as Madrid and Copenhagen, this issue has been tackled by the implementation of electric bicycles (WIERSMA, 2010).

Cycling infrastructure comprises both the existing bicycle facilities as well as a maintenance plan for the city or region. These include the construction and repairs of cycle lanes or paths, direction signs for longer routes, safety measures for interaction with cars and pedestrians (i.e., junctions and zebra crossings) and bicycle parking spots (OBIS, 2011). The quality of these facilities also play an important role (WIERSMA, 2010) as cyclists must be able to travel easily and safely through the city (MIDGLEY, 2011). The perception of danger can be a key barrier to bicycle use (PUCHER; BUEHLER, 2006; TRANSPORT CANADA, 2009) and inexperienced cyclists consider the continuity of cycling infrastructure to be of great importance (WIERSMA, 2010). Additionally, when planning bicycle lanes and infrastructure it is important to consider the fact that cyclists not always prefer to take the shortest route to their destinations. Instead, they are prone to take a longer but more “cycling friendly” route, within a limited range of additional distance from the deviation (SEGADILHA; SANCHES, 2014). Finally, Bührmann (2007) states that “only cities with a minimum and safe cycling infrastructure and an integrated strategy to promote cycling provide good framework conditions for the implementation of a bicycle-sharing scheme”. This reinforces the fact that the advanced planning of bicycle facilities and infrastructure do contribute to the success of a bike-sharing system.

Cities that provide mobility plans that favour public transport over cars end up creating a more bicycle friendly environment (MIDGLEY, 2011). For instance, research shows that public policies that increase the number of bicycles on the street are an effective way of improving cycling safety (JACOBSEN, 2003). Another example is the presence of high gasoline taxes, which can further increase the costs associated to car ownership, thus encouraging the use of other transport modes. Such measures explain the great difference of cycling modal shares in countries with similar characteristics, as observed for Canada and United States (PUCHER; BUEHLER, 2006). Moreover, integration of bike sharing with the public transport network is essential for the success of a shared bicycle scheme. Public transport integration involves three different levels: integration of information, physical integration and technological access and charges (OBIS, 2011). The objective is to contribute to a more sustainable urban development through seamless integration with other modes of transport, making mobility across the city cheaper, more efficient and accessible to everyone (OBIS, 2011; SCHROEDER; ROSA, 2014; SHAHEEN; GUZMAN, 2011).

Another exogenous factor relevant to the success of a bike-sharing scheme is the travel behaviour. It can be the greatest barrier for the implementation of a successful scheme depending on the local cycling culture. Although empirical experience shows that such systems can thrive in cities that did not previously have high levels of cycling (TRANSPORT CANADA, 2009), there are several psychological factors involved. Car usage is generally perceived more positively than bicycle use, and cycling helps improve attitudes towards cycling (WIERSMA, 2010). This reinforces the importance of local policies that restrict car usage and stimulate bicycle culture. It is also important to keep in mind local jurisdiction and how it can affect a successful scheme. The obligation to wear a helmet is an example of legislation that could greatly reduce bicycle usage (MIDGLEY, 2011).

Finally, demographic aspects also play their part in defining the type of scheme. Bührmann (2007) points out that it is necessary to identify the potential main target groups of the bike-sharing system, and analysing their cycling habits is critical to plan the scheme accordingly. In countries with low cycling levels, men seem to be more likely to cycle than women, whereas in nations with greater bicycle culture cycling is equally popular among men and women. The typical bike-sharing user is in the 18-34 age range, with high level of education, awareness of environmental and social issues, and requiring high level of mobility. Because of this, students tend to represent a great part of users, as it is the case for Vélo'v in Lyon, where students correspond to 33% of all subscribers. Hence, marketing campaigns and strategies should be geared towards these demographic groups, in order to attract more customers (TRANSPORT CANADA, 2009; WIERSMA, 2010).

The second of group of factors are the endogenous ones, which are divided in physical and institutional design. As explained in the previous section, the physical design of fourth-generation bike sharing relies on modern hardware components and information technology to ensure quality performance and reliability of the system. It is not on the interests of this research to evaluate existing technologies that can be applied to bicycle sharing. Far more important are the business plans and decision-making models under which these systems will be implemented and operate, as defined by the institutional design.

2.4 Business models for bike-sharing systems

Regarding the institutional design of a bike-sharing system, OBIS (2011) states that bike-sharing schemes exist for many different purposes in different contexts, with various direct and indirect benefits. Therefore, when planning a bike-sharing scheme, it is important to bear in mind the different stakeholders that are involved in the process, in order to plan the business model accordingly.

Four major groups of stakeholders of a bike-sharing system can be identified: local authorities and urban planners, operators (e.g., transport companies, advertising companies and other associations), users and technology providers (BÜHRMANN, 2007; OBIS, 2011). The main notions of success for each of these distinct groups is summarised in Table 2.

Table 2 - Different stakeholders of a bike-sharing system

Stakeholder group	Notions of success
Local authorities and urban planners	Improve the city image and population well being Increase cycling modal share Reduce pollutant emissions Manage traffic congestion and transport demand
Operators	Good visibility/usage of the system Low service and administration costs
Users	High station density and coverage area in the city Reliable bicycle and parking spots availability Good bicycle speed, comfort and safety
Technology providers	User and operator satisfaction Low service and administration costs

Source: adapted from OBIS (2011)

Bicycle-sharing schemes are financially not self-sufficient in most cases (BÜHRMANN, 2007). While the only actual revenue streams are memberships and usage fees, operating costs can include maintenance, distribution, staff, insurance, office and warehouse space, storage facilities and associated costs, website hosting and maintenance, electricity charges for the docking stations and membership cards (MIDGLEY, 2011). Added to that, user fees are generally low with the objective of attracting more customers and often do not represent a significant source of revenue. This means that it is common for costs to surpass revenues and that operators must look to benefit themselves in other ways. Because of this, the majority of bike-sharing systems are operated as public-private partnerships with large companies paying for advertising space (TRANSPORT CANADA, 2009). Furthermore, this business arrangement requires little or no direct public funding from municipalities (MIDGLEY, 2011), who also benefit from system success in many ways, as shown in Table 2.

Over the past years, several models have been developed for implementing, operating and funding bicycle-sharing systems (MIDGLEY, 2011). These differ mainly in respect to the relationship between the local authorities and the operation of the system. Based on the existing literature, three main types of business models for the implementation and operation bicycle-sharing schemes can be identified: public, public-private partnerships, and private.

2.4.1 Public business model

The public business model for a bike-sharing system is the simplest of all three, based only on public funding. Usually, no advertising spaces are made available in exchange for private funds in the system itself (bicycles and docking stations) and the whole operation is typically government controlled. This means that the government must bear with practically all costs associated with the development and operation of the system. Local authorities are then the main stakeholders involved in this process, relying on maintenance and technology providers (public or private) to develop and operate the system.

Transport companies are the most common type of operator in this business model, as they help enhance integration with the public transport system. National railway companies in Germany (DB), Netherlands and China take part in some schemes, providing a bicycle-sharing network linked directly to their stations. Furthermore, non-profit organisations can also operate the system with the support of local authorities (MIDGLEY, 2011).

Although this type of business model ensures that the bike-sharing system is more closely aligned with the municipality and public interest, it is also a heavier burden on the state budget. Bicycle-sharing schemes require a substantial amount of initial investment and incur on great operating costs and need to be financially backed up in order to succeed (BÜHRMANN, 2007; TRANSPORT CANADA, 2009), suggesting that private funding might be a better alternative depending on local financial and political conditions. As of 2011, public operated systems comprised only around 27 per cent of total operating schemes in the world (MIDGLEY, 2011; SHAHEEN; GUZMAN; ZHANG, 2010).

2.4.2 Public-private partnership

A public-private partnership (or PPP) is a type of arrangement in which the local government is still a key player, but relies on private funding in order to develop the bike-sharing scheme. The advantage of this model is that little or no direct public funding is required and therefore it has little or no cost to the taxpayer. The city municipality is able to obtain sponsorship in exchange for advertising space on street furniture such as bus shelters and billboards or directly on docking stations and bicycles. Although there is no need for public spending, this still incurs in a cost for the state in the form of forgone advertising revenues. These arrangements comprise the great majority of bike-sharing systems, accounting for over 48 per cent of operating schemes in 2011 (MIDGLEY, 2011; SHAHEEN; GUZMAN; ZHANG, 2010).

It is important to note that the level of public involvement on the operation itself for these two first models can vary greatly. Local authorities can be completely “hands-on” or simply rely on a number of different private or public firms to design, implement, operate and maintain the system, regardless of its funding sources. Still, both these models are mainly a result of public interest, while the third model is the only exclusively privately initiated.

2.4.3 Private business model

The last and less common type of business model found in bike-sharing schemes is the private model. In this business setup, a private firm is completely responsible for all the phases associated with the planning and operation of the bicycle-sharing system. While local authorities can sometimes provide incentives and benefits such as space for docking stations, public transport data for integration or even small subsidies, all the major capital investment comes from the private operator.

From the municipality point of view, the government is not only free of all costs but also does not have to deal with any operational details. On the other hand, the municipality must always make sure that interests are aligned, in order to ascertain that the system is bringing benefits to the city and population. From the point of view of the private operator, it has more freedom to design the system and fees, while having the necessary public support and legal permissions.

This is the case of NextBike, a German based company operating 7 per cent of schemes around the world (MIDGLEY, 2011). Another example is one of the subjects of this study, the Brazilian bank Itaú, which provides privately operated bicycle-sharing schemes for many regional capitals around the country. These operators usually seek also to recover the investment through advertising either by selling their space to other companies, which is what NextBike does, or by promoting the company itself, as it is the case for Banco Itaú.

Table 3 summarises the different types of business models associated with the operation of bicycle-sharing schemes, together with their respective main advantages and disadvantages from the point of view of local authorities and urban planners.

Table 3 - Business models for bike sharing from the municipality point of view

Business model	Advantages	Disadvantages	Operator examples
Public	Complete autonomy to make decisions	Requires a more "hands-on" approach	OV-fiets (Netherlands)
	Revenue streams from fees and memberships	Requires public funding	DB Bahn: Call a Bike (Germany)
Public-Private	Requires little or no public funding	Forgone revenues due to advertising space lost	JCDecaux (multiple countries)
	Balance between autonomy and costs	Cannot take part in every decision	Clear Channel (multiple countries)
Private	No initial investment needed	Distant from system operation management	NextBike (multiple countries)
	No ongoing maintenance costs	Requires follow-up to align interests	Banco Itaú (Brazil)
	No need to plan or operate	Cannot take part in every decision	

Source: adapted from Midgley (2011); Shaheen, Guzman and Zang (2010)

There are many different manners in which a bicycle-sharing scheme can be planned, not only concerning the nature of the investments, but also related to public level of involvement in the project development and management. Hence, it is important to evaluate the performance and the perceived quality of bike-sharing systems for each of the models above, aiming to find out whether there is a direct relationship between the type of business model and the quality of the service provided. In this case, the type of business setup can be an important factor to be considered when planning a new scheme in order to develop and implement the best solution possible.

2.5 Performance evaluation of bike-sharing systems

In order to evaluate a bike-sharing system it is necessary to bear in mind that it is a type of service operation that is being analysed. As opposed to the production of industrial and consumer goods for example, services have their own particularities that must be taken into account when assessing quality and performance.

2.5.1 Bike-sharing systems as a service operation

No simple definition of service is able to encompass the great diversity of services that exist (MELLO, 2005), however some unique aspects can be identified. According to Gianesi and Corrêa (1994), three main characteristics can be highlighted when defining service operations: the intangible nature of services; the presence of the customer or a good of its property; and the fact that services are usually produced and consumed simultaneously.

First, because of the intangible nature of a service, it can be difficult for providers and sometimes even for customers to evaluate its quality. While products are physical goods that can be owned, services on the other hand are events which the customer experiences (GIANESI; CORRÊA, 1994). When considering bike-sharing systems, this point becomes evident, as the user does not own the bicycle, but instead makes use of the service to travel.

Secondly, regarding customer presence in the case of a bike-sharing system, it is also clear that the user must participate in order for the service to take place. The rider must be physically present at one of the docking stations to pick-up the bicycle and also to return it afterwards.

Lastly, the third point refers to the simultaneous creation and use of services. Concerning bike-sharing systems, this is no exception, as there is no intermediate step between the production and the use of the service being offered. Because of this, services cannot be stockpiled, that is, it is not possible e to produce a service and consume it afterwards. This also affects quality management, given that it eliminates the possibility of quality control inspections before the service delivery (GIANESI; CORRÊA, 1994).

Considering these three main points, the definition of service established by Gianesi and Corrêa (1994) serves well when considering bike-sharing systems and therefore will be used in this research. It is important to mention that it is not the only definition found in literature, as many authors define services and service operations with different emphases and particularities. Nevertheless, it suffices for the purpose of the study, which focus on bike-sharing systems specifically.

With this definition in mind, it is possible to present some indicators for evaluating the efficiency of service operations, aiming to evaluate the performance of bike-sharing systems.

2.5.2 Key performance indicators for bike sharing

Indicators or key performance indicators (KPIs) are used to assess the efficiency of a service or specific process, mostly through quantitative information. They are essential for planning, controlling and supporting decision making within a company. Additionally, KPIs are the basis for analysing and improving processes, as well as for benchmarking. Good KPIs should be easily measureable, unambiguous, understandable and comparable (MEIER et al., 2013).

When it comes to bike sharing, although numerous studies have been done regarding the planning and implementation of these systems, very little has been published concerning the service quality evaluation of such schemes. What was observed were reference numbers that aimed to serve mainly as planning guidelines for operators when sizing their systems. Nevertheless, for this initial analysis these metrics served as a basic starting point for the definition of the key indicators and satisfactory performance levels. However, even though most of these dimensions are ideally defined at the planning stage, a bike-sharing system is not unchangeable and should be adjusted aiming to improve operation and to offer a better quality service to its users.

The Institute for Transportation and Development Policy (ITDP) in its Bike-Share Planning Guide (2013) defines a few performance metrics that aim to serve as basic design guidelines for the planning of bicycle-sharing systems. According to ITDP (2013), adequacy to these numbers is essential for the maintenance of an efficient scheme. Moreover, factors taken into account are split in planning guidelines and performance metrics, as explained below.

Planning guidelines are recommendations referring to system sizing and characteristics, directly controlled by the design of the system. These include the number of bicycles, stations and docking stations, as well as the system area and population covered. By relating these numbers, it is possible to define the first KPIs for bicycle-sharing systems, such as station density, bikes per resident and docks per bike ratios. For this analysis, ITDP (2013) defines the coverage area as being the area comprised within a 500-meter radius around each borderline station. In addition, regarding the population inside this coverage area, it is enough to multiply the area by the city population density, as this is a good approximation. Furthermore, 14 stations per square kilometre is the equivalent to one station every 300 meters, which is an information more easily obtainable.

Performance metrics, the second group of bike-sharing KPIs, relate to system operating numbers and reflect directly the level of system usage. For instance, system efficiency can be measured by average daily trips per bike, while market penetration can be evaluated by comparing the same daily trips per resident in the coverage area. Table 4 summarises the initial performance metrics and the expected levels of efficiency defined by ITDP (2013).

Table 4 - Performance metrics and target efficiency levels for bike-sharing schemes

Performance metric	Target efficiency level
Coverage area	Minimum 10 km²
Station density	10-16 stations per km² [1]
Bicycles per resident	10-30 bicycles per 1000 residents within coverage area
Docks per bicycle	2-2.5 docking spaces per bicycle
System efficiency	4-8 average daily uses per bike
Market penetration	1 average daily trips for every 20-40 residents

Note: [1] 14 stations per km² is the equivalent to a 300 meters average station distance

Source: adapted from ITDP (2013)

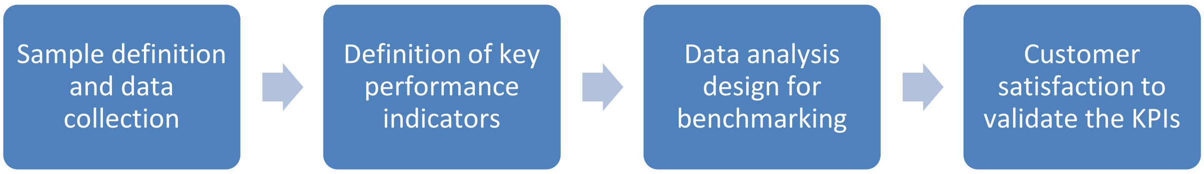
These metrics do not comprise all the aspects related to the quality of bike-sharing schemes, but will serve as a starting point for the development of this study. As mentioned before, there is no extensive literature concerning the aspects related to service quality management and the performance evaluation of such systems, which means there is a need for more research in this area. Because of this, the research gap identified concerns the assessment of the performance of bike-sharing systems.

3 METHODOLOGY

The main goal of this research is to carry out a benchmarking to evaluate the service quality of bicycle-sharing systems through key performance indicators and customer satisfaction. A secondary objective is to understand the role of the employed business model in determining system efficiency levels. In order to achieve these objectives, a methodology consisting of four main steps was followed (Figure 2):

1. Sample definition and data collection of bike-sharing systems:
    a. Criteria for universe and sample definition;
    b. Data collection;
    c. Classification of sample in city clusters.
2. Definition of key performance indicators:
    a. Literature review of the existent metrics for evaluating bike-sharing systems;
    b. Selection and creation of key performance indicators.
3. Data analysis design for benchmarking:
    a. Database overview of the current global scenario;
    b. Evaluation of average efficiency levels for each of the proposed metrics for the different clusters;
    c. Evaluation of average efficiency levels for each of the proposed metrics for the different business models.
4. Customer satisfaction to validate the key performance indicators: a cross-check analysis on three case studies
    a. Selection of the cities for case studies;
    b. Evaluation of customer satisfaction data;
    c. Comparison between customer satisfaction input and system performance data.

Figure 2 - Methodology main steps



Source: author

3.1 Sample definition and data collection

The first step aims at creating a database for bike-sharing systems around the world. Extensive research was made aiming to gather more information on current operating schemes. Data were collected for a sample of 50 urban agglomerations around the world, including demographic and economic indicators as well as relevant bicycle-sharing system parameters found in the literature. For the definition of the sample, cities were selected based on two main factors: relevance of the bicycle-sharing scheme according to existing literature and information availability. As described before, the studied universe consisted of third and fourth generation bike-sharing schemes in cities with more than 200.000 inhabitants, the lowest population in which an automated system can thrive (BÜHRMANN, 2007; MIDGLEY, 2011). Moreover, the focus of this research was on systems that operated exclusively inside a single urban area, explaining why some schemes in Germany (DB Bahn: Call a Bike) and Netherlands (OV-fiets) were not analysed, as these operate at national or regional level.

The parameters gathered were:

- City name, country and continent;
- Population;
- Urban area;
- GDP per capita;
- Kilometres of cycling lanes;
- Bike-sharing programme name and beginning of operation;
- Operator and business model;
- Initial capital cost, annual operating costs and cost of bicycle;

- System opening hours and months;
- Initial one-time deposit and/or annual membership price;
- Initial free time and fee structure;
- Number of registered users;
- Fleet size;
- Number of docking stations;
- Average distance between stations;
- Number of docks;
- Average daily trips;
- Average trip time.

Not every variable was available in each city, hampering a complete comparison as described in the results section. In addition, to make this comparison more accurate, some city clusters have been defined according to the city size. As shown by literature, city size is the first exogenous factor influencing bike sharing success. Furthermore, this factor also directly affects the planning of such schemes as it is the most important aspect determining the number of potential customers of a bicycle-sharing system, regardless of how population is spread on an urban area. Therefore, this analysis has taken into account only city population for the cluster individualisation.

3.2 Definition of key performance indicators

For the second stage of this methodology, a number of relevant key performance indicators (KPIs) were created for the performance evaluation of the studied schemes. Two main aspects were taken into account to define these KPIs: existent literature and data availability.

Firstly, a review of the literature analysis was made focusing on the existent metrics for the evaluation of bike-sharing systems. The metrics found were proposed by ITDP (2013) and were already presented in the previous chapter. These ITDP (2013) metrics greatly contributed for the creation of the KPIs to be used in the benchmarking analysis, as they showed how it is possible to correlate some basic system parameters to measure bike-sharing performance.

Secondly, data availability played an important role in defining the key performance indicators. In order to make the benchmarking feasible, all the KPIs considered only the bike-sharing parameters gathered for the database and that were introduced in the previous section. This means that no extra specific data had to be collected for the performance evaluation.

In addition, ITDP (2013) proposes target performance levels for the metrics it defined. This allowed for the establishment of a few satisfactory efficiency baselines for some of the defined KPIs that correlated directly to the original ITDP (2013) metrics. This allowed to comparatively evaluate the performance of the studied bike-sharing schemes by confronting some of the KPI results to the proposed reference values.

The objective of this step was the creation of adequate indicators for evaluating the performance of bike-sharing schemes. This enabled the actual benchmarking comparison by applying the defined KPIs to the cities with enough data, as explained in the next section.

3.3 Data analysis design for benchmarking

The analysis consists of two main sections. Firstly, the database conceived thanks to the data collected was analysed, in order to provide insight in the current global scenario on bike sharing. Then, the created key performance indicators were applied to the obtained data, completing the benchmarking analysis. This evaluation was done in two different settings: by city cluster and by business model.

Firstly, the KPIs were applied to all studied schemes and exposed by city cluster. This means that it was possible to observe which city fell into which category, as well as the average performance levels for the each of the clusters.

Secondly, a similar analysis was presented by bike-sharing business model. It was then possible to observe which bike-sharing scheme operated according to which model, as well as the average performance levels for each business model.

Consequently, the result of this stage was a quantitative analysis of the performance levels for all the studied bike-sharing schemes, divided in two sections. This allowed for the investigation of the relationship between city size and business model and the performance of bike-sharing schemes.

The database was created using Microsoft Excel and all graphical analysis were made using the Tableau Software and Google Fusion Tables, in addition to Excel. Most of the ridership information was provided in comma-separated values (CSV) files and analysed also using Microsoft Excel.

3.4 Customer satisfaction to validate the key performance indicators: a cross-check analysis on three case studies

Customer satisfaction data were used to complete the evaluation of the performance and of the service quality in the selected cities. Three case studies were analysed: the cities of Turin (Italy), Washington (United States) and São Paulo (Brazil). These cities were chosen because they represent all the different business models for bike-sharing systems, allowing for an investigation of the relationship between the different bike-sharing business models and the service quality perceived by the users. Moreover, as stated before, this work was developed with the support of the operator of the bike-sharing system in São Paulo.

The data related to the three cities were collected through the official websites and support of the service providers. For São Paulo, the Brazilian bank Itaú provided all the information on the schemes they operate in the country, whereas all the information for Washington was available at the official Capital Bikeshare website. Unfortunately for the [TO]Bike scheme in the city of Turin did not provide any information, thus data were collected from alternative sources, as it was the case for most of the other schemes in the studied sample. These sources included internet newspaper articles, blog news and previous academic publications on bike sharing.

Thanks to the customer satisfaction surveys, it was possible to obtain and evaluate the quality perceived by the user for different dimensions of the service. The outcome was the user satisfaction regarding the metrics defined in the previous step, thus enabling the comparison between the performance levels obtained in the data analysis and the quality perceived by the users for the three cities.

4 RESULTS

This chapter presents the results of this study in a logical sequence, as described in the methodology section. Initially, the process of database creation and sorting is detailed, followed by the creation of the key performance indicators. Then, an initial overview of current operating bike-sharing schemes is presented based on the data collected, succeeded by the performance evaluation with the created metrics. Subsequent to this, customer satisfaction levels are analysed and compared with the initial performance metrics. Finally, the comparison of all these results leads to final discussion and conclusion.

4.1 Sample definition and data collection

The database creation and sorting was divided in three main steps. Firstly, the criteria for sample and universe selection were defined, as detailed in the methodology section. Secondly, extensive research was conducted to gather specific information and various parameters regarding the selected cities and their bike-sharing schemes. Lastly, these cities were divided in clusters, allowing for a direct comparison of performance levels. The result is a collection of data that will later be used for the various performance analyses.

4.1.1 Data collection

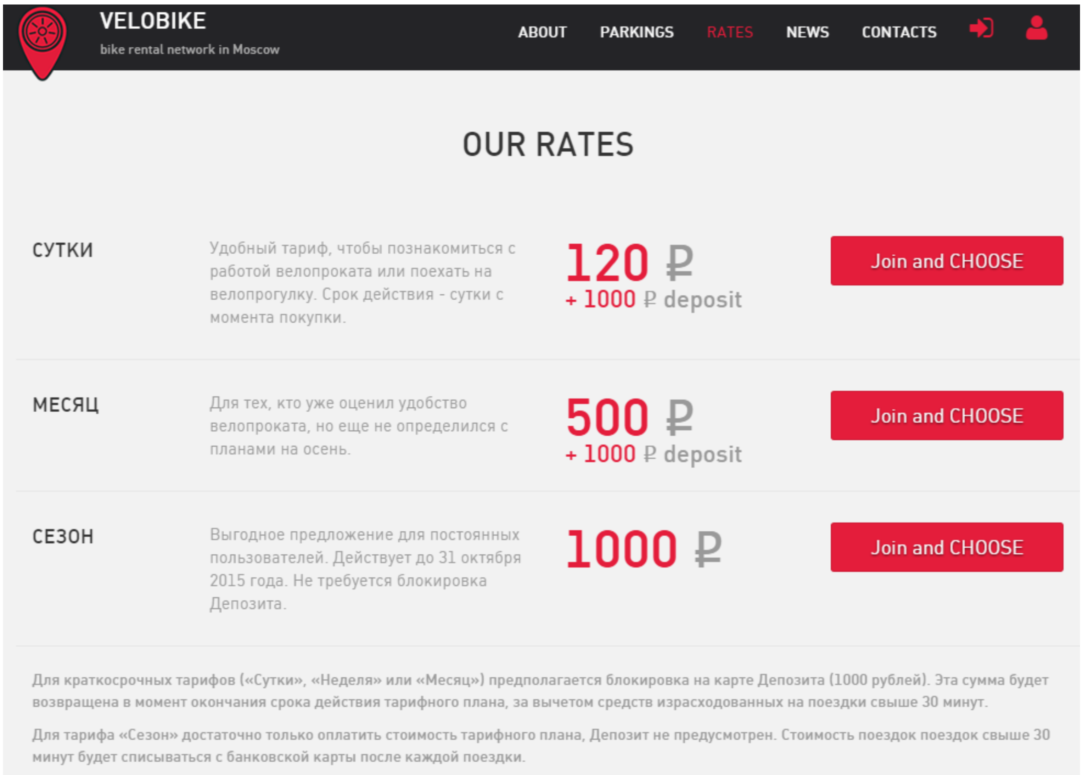
Initially, data were collected for each city concerning relevant demographic and economic factors. Hence, population and urban area for all agglomerations were gathered from a single source in order to have a uniform pattern for the calculation of population density. For some cities as New York and São Paulo, these figures had to be searched elsewhere as the selected source included neighbouring municipalities in the analysis, thus overestimating the population. Furthermore, the Gross Domestic Product per inhabitant was analysed for each city, as to have a comparable economic indicator. Although GDP per capita might not be the best measure to determine the economic development of a certain population, it is easy to obtain and it suits the need of an economic comparison. Finally, the number of kilometres of cycling paths or bicycle lanes was the last factor to be considered. Such figures were typically provided by municipalities or bicycle-sharing operators, but likewise they could not be found for every city.

The systems were segmented in public, private and public-private partnerships. Despite the lack of information regarding the financing of the systems, the business model often became evident once the operator was defined. Public schemes are typically managed and completely financed by municipalities or transport companies, having no private brands attached to their image. On the other hand, municipal systems that concede their space and naming rights to private enterprises in exchange for funding are an example of public-private business model. Lastly, private systems have no relationship with local governments or public authorities, usually run by an operator managing more than a single system, all carrying the company name.

Concerning the actual costs, the database sought initially to clarify how much approximately operators initially invest and spend annually to manage the system, as well as the value of one bicycle and docking station. However, this kind of information is hardly accessible and even when available it becomes difficult to assess the source reliability. Therefore, these figures were not included in the performance analysis, instead they were kept in the database and displayed as extra information. For the coin conversion the official European Central Bank reference table for the month of May 2015 was used. All currency data were converted to Euros, allowing for direct comparison analyses.

Regarding system data, because there is no central information repository on bike sharing, data gathering was a time consuming process that had to be done thoroughly in order to verify the reliability of sources. General system information such as membership costs and riding fees were found easily in the official websites of these schemes, while other specific operating numbers were sometimes more difficult to be gathered. These figures included registered users, fleet size, number of docking stations, number of docks, distance between stations, average trips per day and average trip time. Even though most of this information was also collected from official operator websites, some of them do not have open ridership and membership statistics, as mentioned before. In addition to that, in some cases language was a barrier due to the lack of complete English translation, as it was the case for Velobike, in Moscow (Figure 3). In such situations, automatic internet browser translation was used to assist in the research process. This illustrates one of the many obstacles faced during the long process of data gathering. Lastly, the start date of programmes was relevant so that the systems could be compared always taking into account for how long they have been operating.

Figure 3 - English page of rates for Velobike system in Moscow



Source: Velobike official website - http://velobike.ru/en/

In other cases, some websites such as Bicing in Barcelona are very clear and have available statistics updated monthly (Figure 4). For instance, the systems of Chicago, New York and Washington have all historic open data available for download, while Mexico City and Oslo have this information upon request. In these cases, historic open data were used to determine with certainty ridership and trip time.

Figure 4 - Monthly statistics for the Bicing system in Barcelona

Información del sistema

Abril 2015

Servicio Bicing	
95.581	Número de abonados
1.068.979	Número de usos mensuales
3.859.254	Número de usos acumulados año 2015
13,39	Tiempo medio de viaje (minutos)
Bicicletas	
6.000	Número de bicicletas
5,9	Media de usos por bicicleta y día
477,9	Km. recorridos por bici al mes
219	Media de bicicletas reparadas al día
Estaciones	
420	Número de estaciones
97,26	Porcentaje estaciones sin avería (%)
Internet	
54.980	Número de visitas mensuales a la web
6.046	Número de seguidores en Twitter
24.738	Número de fans en Facebook
1.185	Número de seguidores en Instagram
Top 3 estaciones más usadas del mes	
544 usos/día	79 - Pl. Universitat
499 usos/día	118 - C/ Pujades, 1
493 usos/día	80 - C/ Enric Granados, 35

Fecha de actualización: 08/05/2015

Source: Bicing official website - https://www.bicing.cat/es/

Finally, it is important to note that not every system has open data regarding ridership and membership, which means that for some analysis not all of these systems can be included. It is important to keep in mind that the absence of a central information repository on bike sharing made very difficult the collection of all the needed data. Because information is scattered, the reliability of sources can sometimes be questionable. Additionally, due to the multi-source nature of the collected data, some comparisons might have been not as accurate as it was expected. For instance, because of the different typologies of memberships, the number of registered users sometimes correspond to the total users registered in the system, while sometimes it reported the number of active subscriptions on a certain time period (yearly, monthly etc.). Nevertheless, this research allowed for an overview of current third and fourth generation bicycle-sharing systems of different business models. The next section clarifies the criteria definition for the classification of cities in clusters.

4.1.2 City cluster analysis

As said before, the analysed sample has been classified in clusters with similar characteristics for a more accurate comparative analysis. In order to group these cities, population was selected as the clustering factor.

Concerning city size, the United Nations (2015) report a few classes based on population. Firstly, urban agglomerations of more than 10 million inhabitants are mega-cities. Secondly, agglomerations with a population between 5 and 10 million are considered very large cities. Next, a population between 1 and 5 million inhabitants qualifies a large city. Finally, the fourth group is composed by cities with population between 500.000 and 1 million inhabitants. This last class was slightly modified to include cities with population ranging between 200.000 and 500.000, in order to better fit in the present analysis. These were defined as medium-sized cities with respect to the population. Table 5 reports the classification of the cities in clusters.

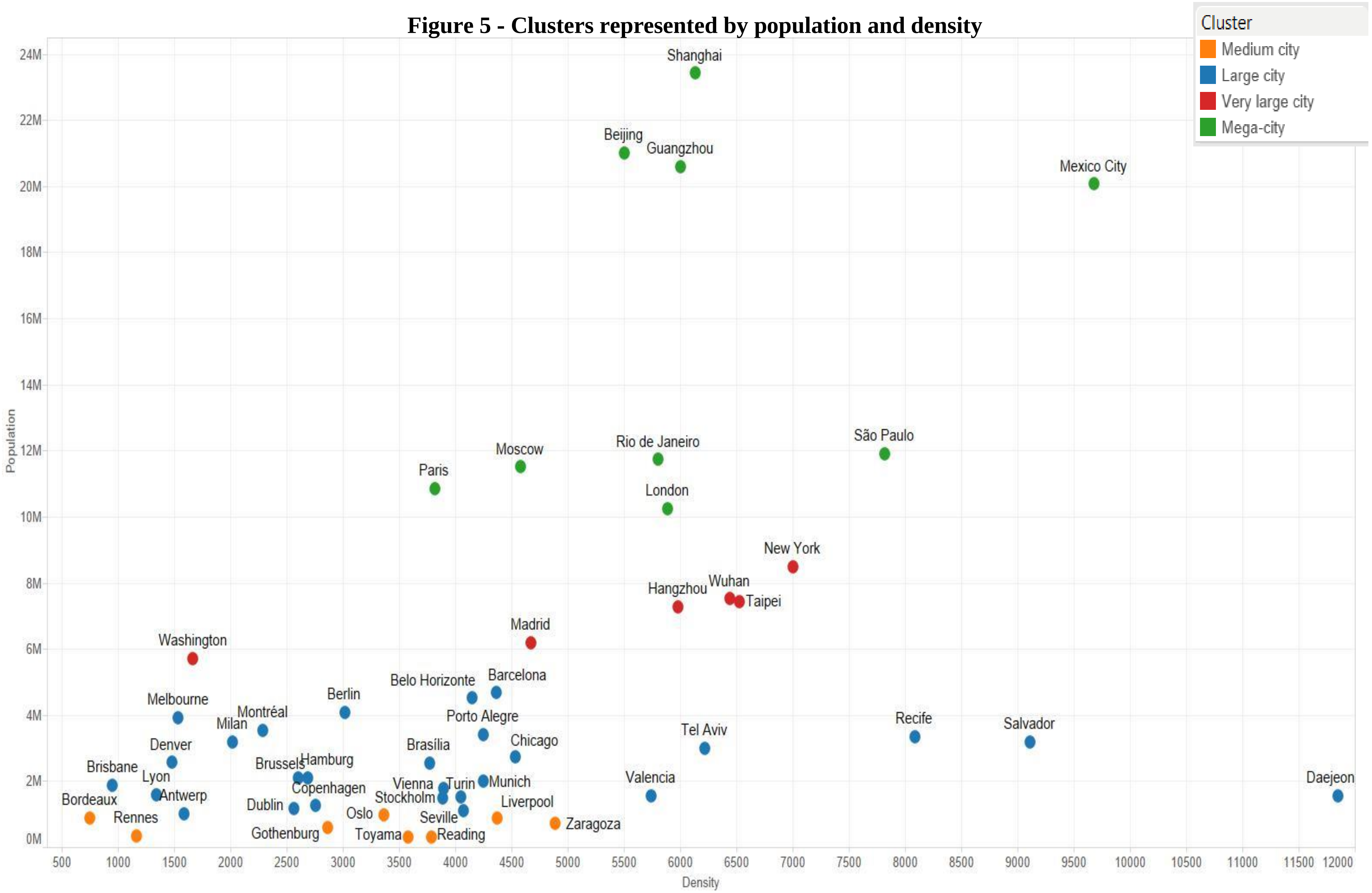
Table 5 - City classification by population

Population range	Classification
200.000 - 1.000.000 inhabitants	Medium
1.000.000 - 5.000.000 inhabitants	Large
5.000.000 - 10.000.000 inhabitants	Very large
> 10.000.000 inhabitants	Mega-city

Source: adapted from United Nations (2015)

Figure 5 shows the clustering represented according to population and density.

Figure 5 - Clusters represented by population and density



Source: author

It is important to note that, although cities in the same clusters may greatly differ when it comes to density, this is still a secondary aspect in respect to population, as described in the literature review. In the next section, the key performance indicators have been proposed to evaluate each city cluster and business model.

4.2 Definition of key performance indicators

The metrics proposed by ITDP (2013) were used as starting point for the definition of the key performance indicators used in the analysis (Table 6).

Table 6 - Performance metrics and target efficiency levels proposed by literature

Performance metric	Target efficiency level
Coverage area	Minimum 10 km²
Station density	10-16 stations per km² [1]
Bicycles per resident	10-30 bicycles per 1000 residents within coverage area
Docks per bicycle	2-2.5 docking spaces per bicycle
System efficiency	4-8 average daily uses per bike
Market penetration	1 average daily trips for every 20-40 residents

Note: [1] 14 stations per km² is the equivalent to a 300 meters average station distance

Source: adapted from ITDP (2013)

Although these metrics may be adequate for evaluating the level of the service provided, they require information difficult to obtain, such as coverage area. With that in mind, some were adapted and several other key performance indicators were also proposed based on the knowledge gathered during the literature review (Table 7).

Table 7 - Proposed key performance indicators

Key performance indicator	Metric
System station density	Average distance between stations
System fleet sizing	Number of bicycles per 100.000 inhabitants
System number of stations sizing	Number of stations per 100.000 inhabitants
System reach related to city infrastructure development	Registered users per kilometre of cycling lane
System fleet sizing related to city infrastructure development	Number of bicycles per kilometre of cycling lane
Parking space availability	Number of docks per bicycle
System network concentration	Average docks per station
Bicycle availability	Average number of bicycles per station
Fleet rotation	Average daily uses per bicycle
System usage	Average daily trips per registered user
System sizing adequacy	Number of bicycles per 100 registered users
System reach related to pricing	Registered users times register price
System pricing adequacy	Register price per GDP per capita
System market penetration	Registered users per total population

Source: author

The indicators proposed sought to analyse different parameters of success regarding the service quality for all the selected schemes. In this way, these KPIs could be applied to most of the analysed cities, while it was possible to draw a parallel between a few of the ITDP metrics and the selected KPIs.

The first indicator, system station density, is an approximate figure usually provided by operators on their official websites to attract users to their service. The average distance between stations reflects the network density as an alternative to the calculation of the number of stations per square kilometre. The ITDP station density metric correlates with this KPI, thus the average distance for the schemes analysed was observed in order to verify if they ranged within the target proposed values.

To determine whether the system has proper fleet sizing, planning authorities should divide the fleet size and the number of stations by the number of inhabitants. Additionally, the number of bicycles related to the number of registered users shows whether the planned sizing is adequate. This allows to evaluate if the dimensioning of the scheme is in line with city population and registered users.

The number of registered users and fleet size related to lane kilometres reflects the reach of the scheme taking into account the level of cycling infrastructure in the city. Similarly, the fleet size related to cycling lanes shows how the system is sized regarding cycling infrastructure.

The following indicators are important to evaluate how the planning of the scheme was made regarding bicycle and parking availability and sprawl. The number of docks per bicycle directly reflects the parking space availability, while the average number of bicycles shows bicycle availability. Thus, the number of docks per stations indicates the average size of stations, that is, the system network sprawl. The ITDP metric for docks per bicycle correlates with the KPI for parking space availability, meaning it was possible to verify if the analysed schemes were performing within the proposed range of 2,0 to 2,5 docks per bicycle.

System usage levels are calculated as the average daily trips taken by each registered user every day, while the average daily uses per bicycle reflect the system fleet rotation. The ITDP system efficiency metric correlates directly with fleet rotation, with a proposed target range of 4 to 8 daily uses per bicycle.

Furthermore, the number of registered users multiplied by price is a proxy of the system reach or grasp, that is, how the scheme attracts customers taking into account the price charged. Added to that, the pricing strategy adequacy is measured by the ratio between price and city GDP per capita.

Finally, the number of registered users per city population is an approximated indicator of system appeal or attractiveness, here defined as market penetration. Although perhaps not all inhabitants within the urban agglomeration are in fact potential users, this is an approximated measure that is much easily calculated in respect to the registered users per populations within the coverage area.

It is important to observe that these performance indicators are always correlated. This means that optimizing a certain parameter will most likely result in the changing of other indicators, not always positively. For instance, a system with high daily usage per bike may be undersized, that is, having few bicycles with respect to total population. Consequently, raising the number of available bicycles will directly affect these usage figures. This shows that it is important to seek a balance when aiming to improve performance levels, as this kind of tradeoff is always present. Hence, it is necessary to analyse each particular case in order to assess what metrics need improvement and, therefore, which will be affected by the actions taken.

4.3 Benchmarking analysis

This section aims at detailing all the findings obtained during the benchmarking, by exposing information through appropriate charts and tables. Initially an overall analysis is presented regarding the database, followed by the key performance indicator evaluation. Lastly, the three case studies are presented in order to complete the performance evaluation.

4.3.1 Current global scenario

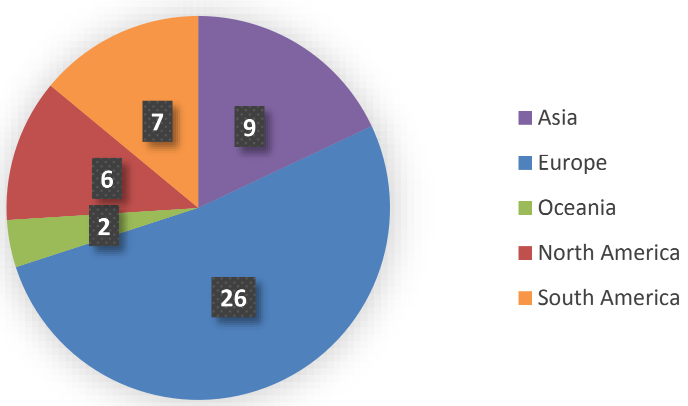
The database analysed contained bike-sharing schemes from all around the world. The 50 selected urban agglomerations come from 22 different countries throughout five continents, as shown in Figure 6.

Figure 6 - Selected bike-sharing systems around the world

Source: author

The majority of the analysed schemes was located in Europe, while a few were in Asia, Oceania and the Americas (Figure 7). This distribution shows that the sample is coherent with what was previously reported in the literature review regarding the current operating systems around the globe.

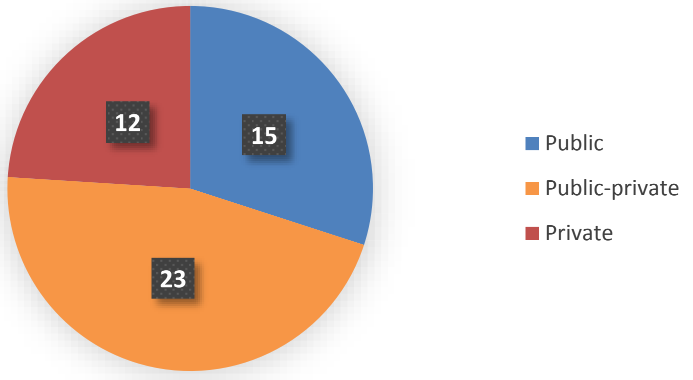
Figure 7 - Continent distribution of selected bike-sharing schemes



Source: author

As described before, bicycle-sharing systems are divided in public, public-private partnerships and private, depending on the nature of investment sources and operation management. In the studied sample, around half of the schemes were of the hybrid type, while there was a balance between public and private business models, with slightly less privately owned systems (Figure 8).

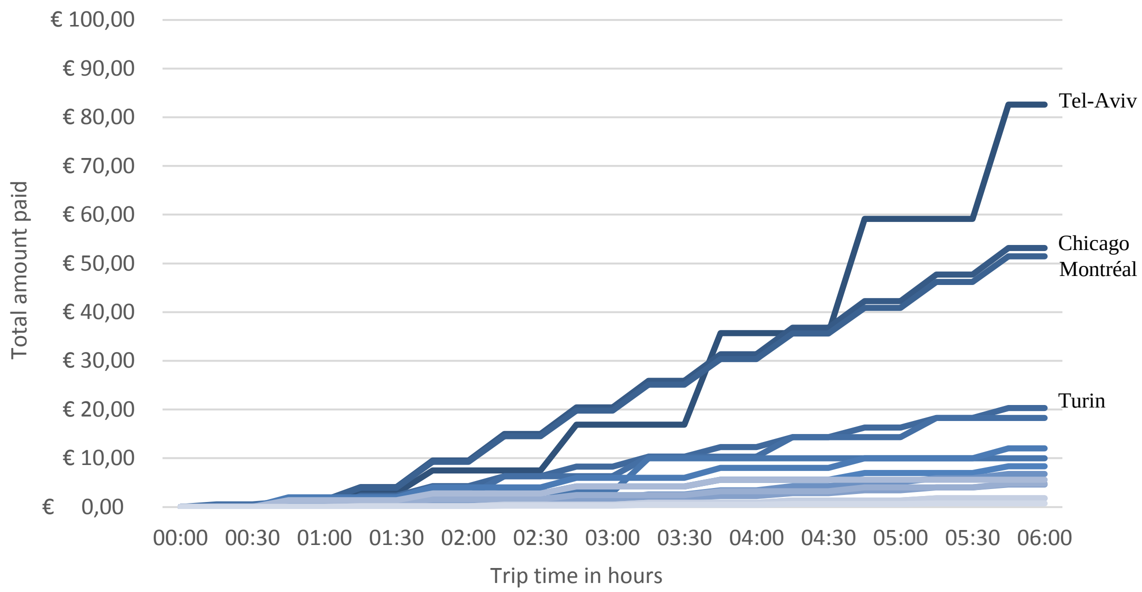
Figure 8 - Bike-sharing business models for the selected systems



Source: author

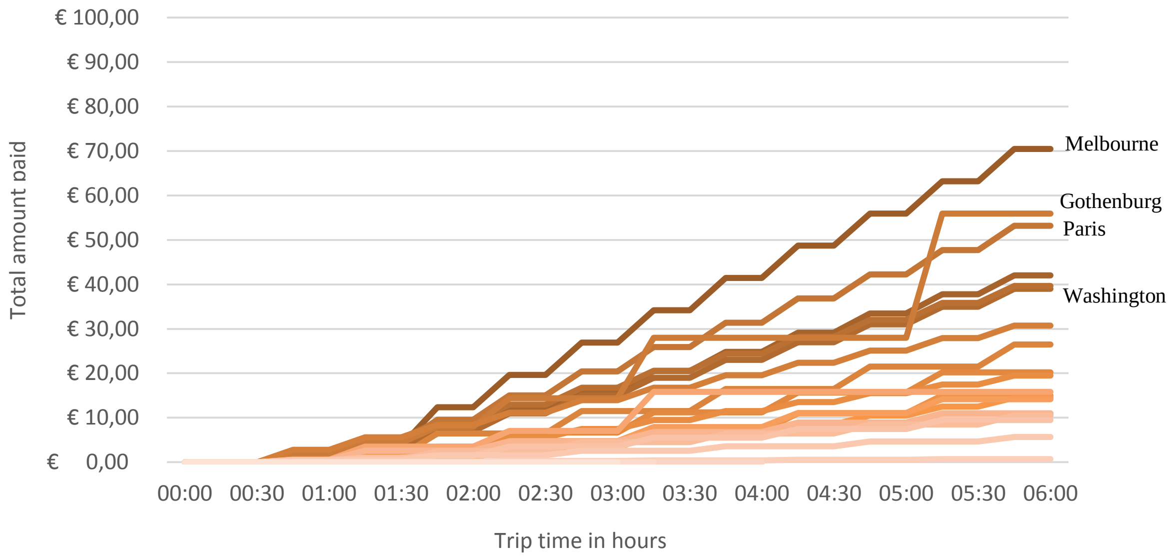
Fee structures were split in charts according to the business model, where each line represents one operating scheme (Figure 9, Figure 10 and Figure 11). The majority of systems offers to its users 30 minutes of free time, with only 4 of them offering 45 minutes and 12 offering 1 hour. A small portion of the schemes operate on honesty based systems, that is, systems that do not require additional payment and will block the user who fails to return a bicycle within the estipulated time interval. Only the schemes in Madrid and Taipei require the users to pay from the first minute. Moreover, only 29 schemes operate 24h non-stop, while the rest of them remain closed during the night. Some systems in colder countries operate seasonally, thus they remain closed during the winter months.

Figure 9 - Fee structure for public business model schemes



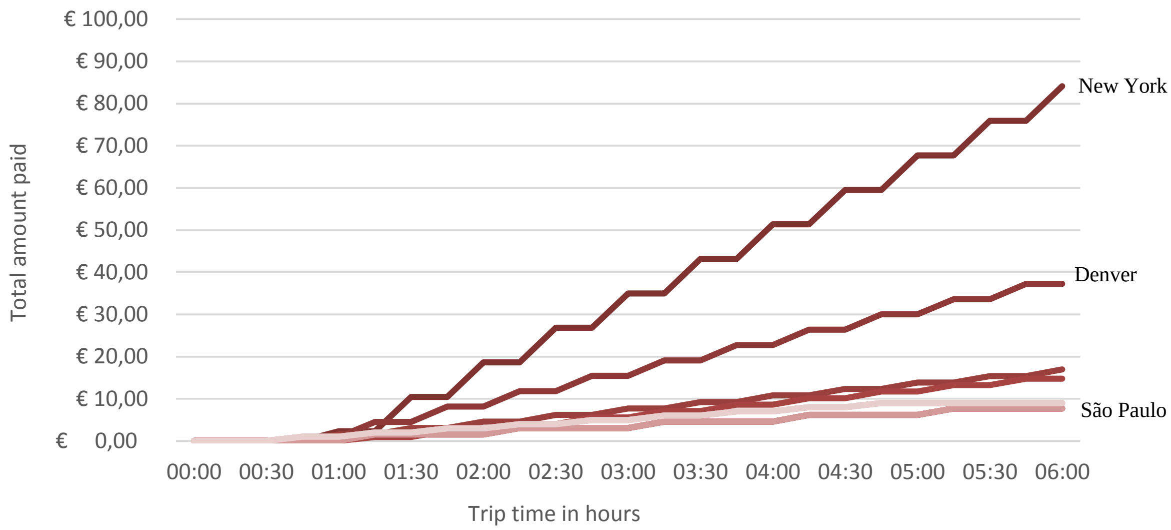
Source: author

Figure 10 - Fee structure for public-private partnership schemes



Source: author

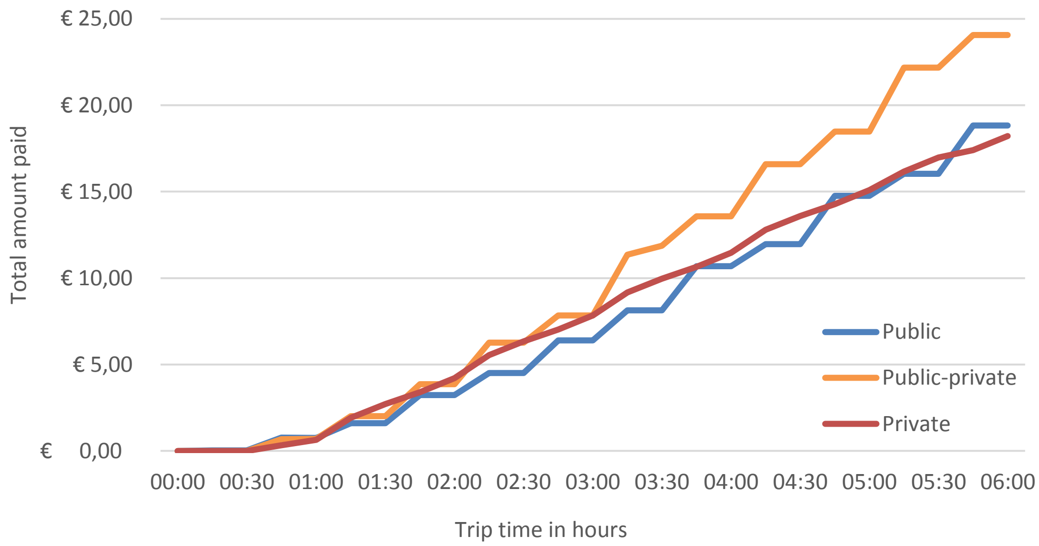
Figure 11 - Fee structure for private business model schemes



Source: author

Average fee structures differed little between the different business models, as shown in Figure 12.

Figure 12 - Average fee structure for each bike-sharing business model



Source: author

Additionally, Table 8 presents a comparison in terms of average trip times and initial free time in some cities (for which this type of information was available).

Table 8 - Average trip times and initial free time

City	Programme name	Initial free time	Average trip time
São Paulo	Bike Sampa	60min	60 min [1]
Dublin	Coca-Cola Zero Dublinbikes	30min	13 min [1]
Tel Aviv	Tel-O-Fun	30min	17 min [2]
Mexico City	EcoBici	45min	13 min [1]
Madrid	BiciMAD	-	18 min [1]
Chicago	Divvy Bikes	30min	17 min [1]
Washington	Capital Bikeshare	30min	17 min [1]

Source: [1] operators and official websites; [2] The Times of Israel.

Although average travel time was much higher for the Bike Sampa system in São Paulo, this is probably due to the fact that it is the only among these schemes that offers a full hour free of charge. On the other hand, Mexico City's EcoBici average trip time is among the lowest, even though it offers 45 minutes of free time. In addition, even though the BiciMAD in Madrid charges an extra fee from the initial minute used, average trip time was comparable to the other schemes, probably because this fee only increases further after half an hour.

Regarding expenditure for these systems, information was far more limited and was found mostly in newspaper articles. Thus, initial capital investment (Table 9) and operation costs (Table 10) were found only for a few of the selected cities.

Table 9 - Initial capital cost for bike-sharing schemes

City	Programme name	Business model	Initial capital cost
Montréal	BIXI Montréal	Public	€ 27.145.227 [1]
Guangzhou	Public Bike Initiative	Public	€ 4.104.910 [2]
Hangzhou	Hangzhou Public Bicycle	Public	€ 65.971.764 [2]
Paris	Vélib'	Public-private	€ 90.000.000 [3]
Mexico City	EcoBici	Public-private	€ 5.239.508 [2]
Moscow	Velobike	Public-private	€ 7.924.628 [4]
Barcelona	Bicing	Public-private	€ 2.200.000 [1]
Madrid	BiciMAD	Public	€ 5.000.000 [5]
Liverpool	Liverpool City Bike	Public	€ 2.094.680 [6]
London	Santander Cycles	Public-private	€ 125.680.771 [7]

Source: [1] New York City Department of City Planning; [2] PublicBike.net; [3] ITDP; [4] Russia Beyond the Headlines; [5] ciclivizzatevi; [6] BBC News; [7] Transport for London - Mayor Watch.

From Table 9 it is possible to observe that the most expensive systems appear to be located in the European metropolis of Paris and London, which are among the largest schemes in the world. Additionally, the Chinese city of Hangzhou also had a high initial cost, which can be explained by the fact that it has the largest fleet among all bike-sharing systems operating in the world today. It is important to note that this figure relates to the initial capital cost incurred for the implementation of the system, which means that systems that started at full size will naturally cost more, while systems that expanded over the years did not have its extra expansion costs included in this specific comparison. Table 10 presents the annual operation costs for a few schemes.

Table 10 - Annual operating costs for bike-sharing schemes

City	Programme name	Business model	Annual operating costs
Brisbane	CityCycle	Public-private	€ 1.700.334 [1]
Montréal	BIXI Montréal	Public	€ 4.524.204 [2]
Lyon	Vélo'v	Public-private	€ 4.000.000 [3]
Paris	Vélib'	Public-private	€ 30.000.000 [3]
Barcelona	Bicing	Public-private	€ 4.500.000 [2]
London	Santander Cycles	Public-private	€ 37.704.231 [4]
Denver	Denver B-cycle	Private	€ 140.883 [5]

Source: [1] Brisbane Times; [2] New York City Department of City Planning; [3] ITDP; [4] Transport for London - Mayor Watch; [5] ColoradoGives

Vélib' in Paris and Santander Cycles in London presented the highest operation costs, whereas the Chinese systems did not have any data available concerning this figure. Moreover, the city of Denver, which presents a smaller scheme in terms of fleet and number of stations, reported a much lower figure for the annual operation cost. Finally, in addition to those figures, it was also possible to compare the cost of the bicycle for a handful of schemes, as shown in Table 11.

Table 11 - Cost of bicycle for bike-sharing schemes

City	Programme name	Business model	Cost of bicycle
Montréal	BIXI Montréal	Public	€ 958 [1]
Guangzhou	Public Bike Initiative	Public	€ 62 [1]
Hangzhou	Hangzhou Public Bicycle	Public	€ 66 [1]
Wuhan	Public-Use Bicycle Programme	Public-private	€ 66 [1]
Copenhagen	Bycyklen	Public	€ 2.727 [2]
Lyon	Vélo'v	Public-private	€ 900 [1]
Paris	Vélib'	Public-private	€ 900 [1]
Mexico City	EcoBici	Public-private	€ 518 [1]
Barcelona	Bicing	Public-private	€ 300 [1]
London	Santander Cycles	Public-private	€ 727 [2]
Washington	Capital Bikeshare	Public-private	€ 909 [1]

Source: [1] PublicBike.net; [2] Copenhaguize

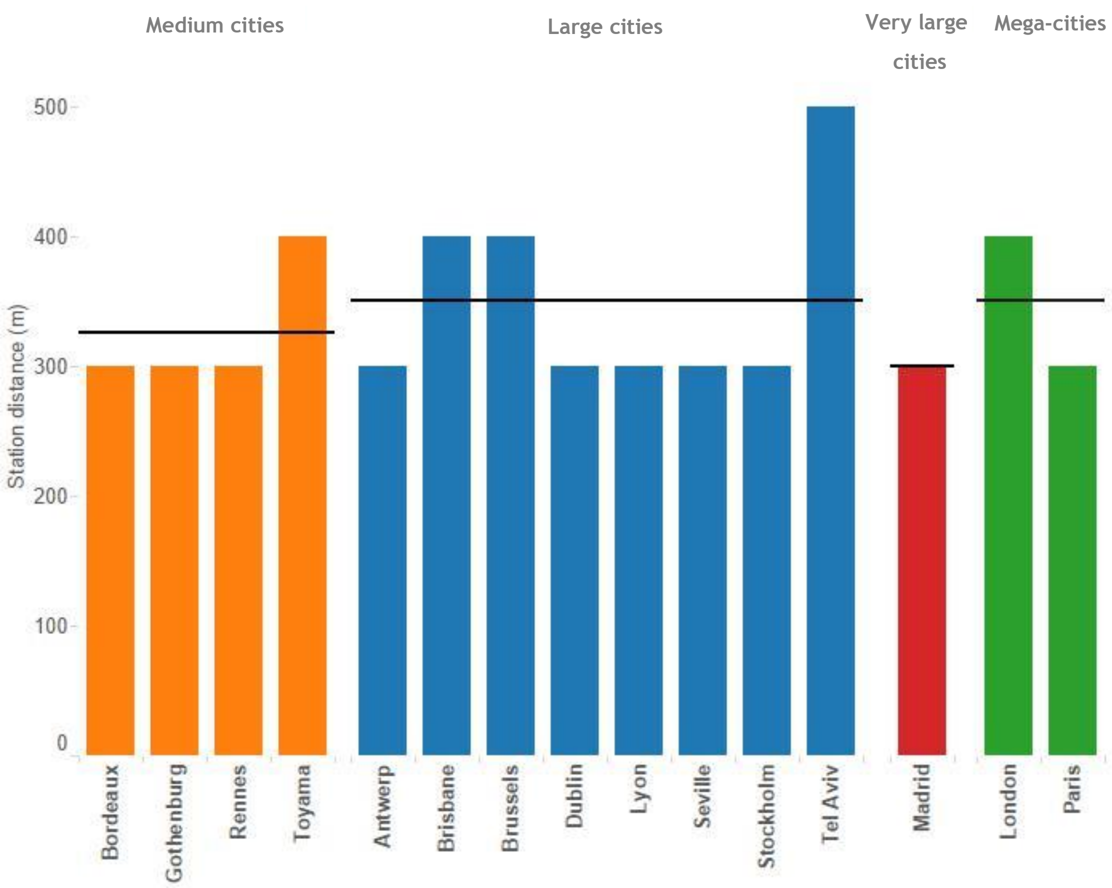
While the cost of bicycle in most European schemes ranged from €700 to €1.000, the cost of Bycyklen in Copenhagen was much higher, standing at €2.727. This can be explained by the fact that these new and modern bicycles are equipped with an electric motor and an integrated GPS on-board computer. Furthermore, the three Chinese cities of Guangzhou, Hangzhou and Wuhan presented an incredibly low cost for each bicycle, probably as a result of lower manufacturing costs and also reflecting less durable bicycles.

Subsequent to this current global overview on existing schemes, the next step was their performance evaluation through the selected key performance indicators. The KPIs were applied to the selected cities as long as data were available and presented by city cluster and by business model. This was made in order to investigate which of these two factors plays a bigger role in determining the system performance. For every indicator, performance levels were calculated and depicted through bar charts, with the cluster and business model averages represented by a horizontal line. Moreover, a translucent grey area marked the target performance levels for the metrics in which this was established by the literature. This will allow for a clearer observation of the actual performance of the analysed systems in respect to what was proposed by theory.

4.3.2 Average performance levels by city cluster

The first indicator which represents the average distance between stations is analysed at cluster level due to lack of data for many cities (Figure 13).

Figure 13 - Average distance in meters between stations by city cluster

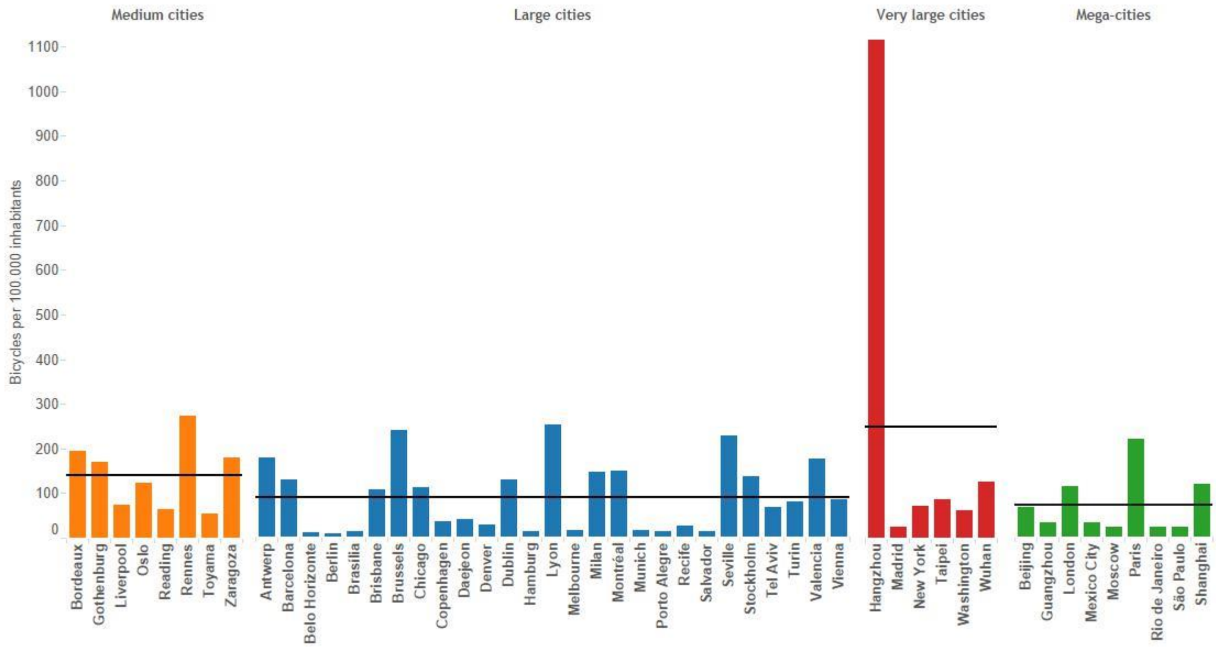


Source: author

Considering the very large cities, only the scheme in Madrid had available data, explaining why this average is at exactly 300m (SD = 0m). For all the analysed schemes, the average distance between stations ranges between 300 and 400 meters. Average distance for medium cities was 325m (SD = 50m), for large cities 350m (SD = 76m) and for mega-cities 350m (SD = 71m).

There was no clear trend relating the fleet per inhabitants with city size (Figure 14).

Figure 14 - Number of bicycles per 100.000 inhabitants by city cluster

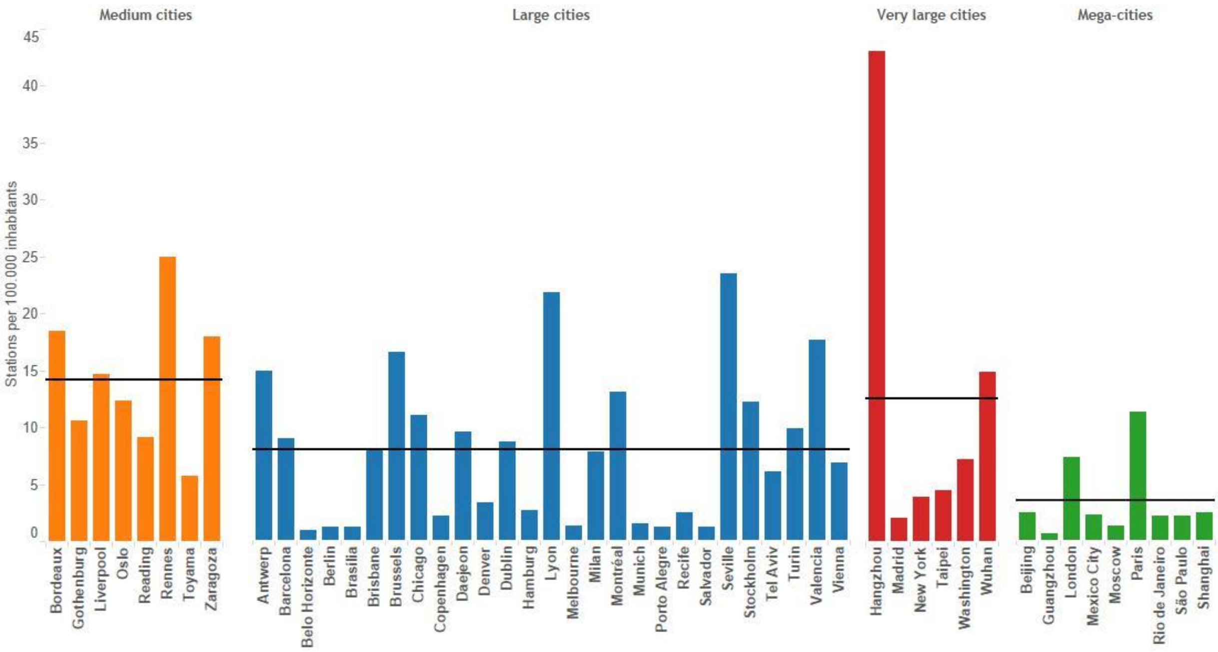


Source: author

The ratio was greatest for very large cities at 247 (SD = 426) and lowest for mega-cities, at 72 (SD = 68). The average number of bicycles for every 100.000 inhabitants for medium cities rated at 142 (SD = 77) and for large cities at 90 (SD = 78). The city of Hangzhou presented the highest value, 1.115 bicycles for every 100.000 inhabitants. This ratio is much greater than it is for every other city, as it is the scheme with the largest fleet, with over 81.000 bicycles. If the Chinese city was not to be considered in this analysis, cluster average for very large cities would drop to 74 (SD = 37) bicycles per 100.000 inhabitants, standing at level with mega-cities and below the other two classes.

Also for the number of stations per inhabitants no clear relationship with city population was identified (Figure 15).

Figure 15 - Number of stations per 100.000 inhabitants by city cluster

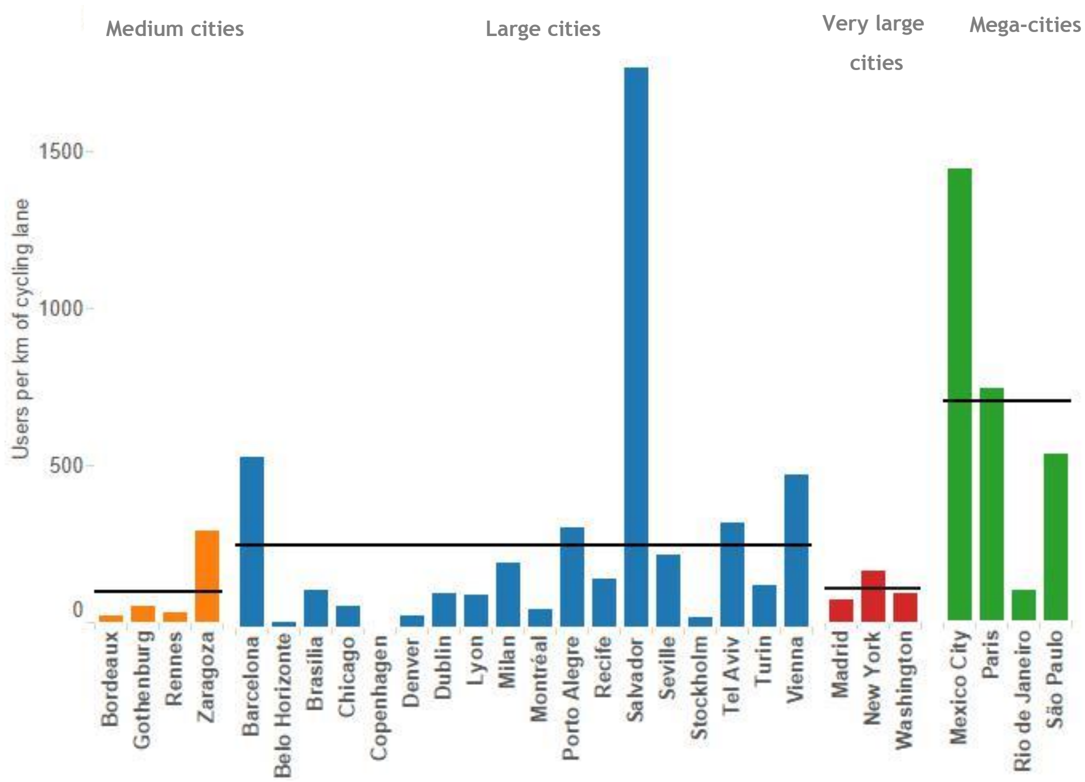


Source: author

However, for mega-cites the average ratio was the lowest at 3,5 (SD = 3,5) and for medium cities it was the highest, at 14,2 (SD = 6,1). Once again the city of Hangzhou has a much higher value than other cities, with 43,0 stations per 100.000 inhabitants. For large cities the average ratio was 8,0 (SD = 6,7) and for very large cities it was 12,6 (SD = 15,6).

At first glance, Figure 16 shows that mega-cities appeared to have more registered users per existing kilometres of cycling lanes when compared to other smaller cities, with an average of 702,1 (SD = 561,5).

Figure 16 - Registered users per kilometres of cycling lane by city cluster

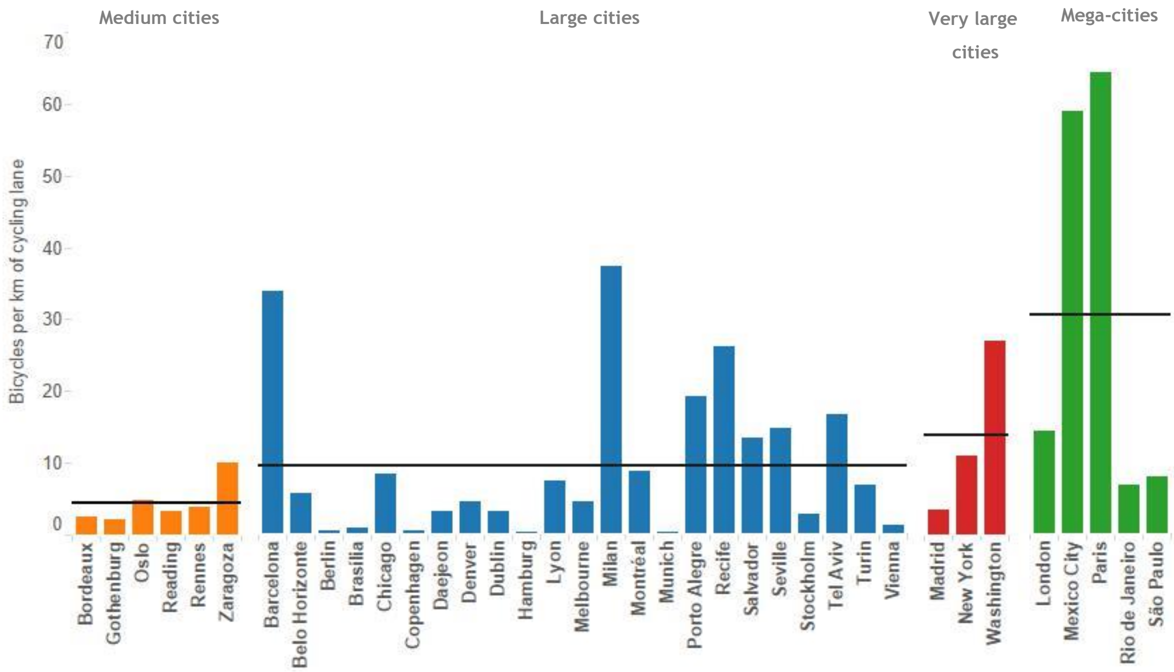


Source: author

Very large cities rated the lowest in average, with 107,4 (SD = 48,3) users per kilometre of cycling lane. Large cities rated at 261,1 (SD = 410,6) and medium cities at 98,9 (SD = 129,7). It is important to note that the scheme in the Brazilian city of Salvador, which performed best in this indicator did not present a great number of registered users. Instead, the city has only 27 kilometres of cycling lanes and paths in its metropolitan area, which is rather low for an agglomeration of over 3 million inhabitants with an operating bike-sharing scheme. If treated as an outlier and removed from this specific analysis, the average for large cities drops to 171,7 (SD = 161,7) registered users per kilometre of cycling lane. Although this is a considerable decrease, it does not affect the relative position of this cluster in respect to the others.

Figure 17 presents the number of bicycles also per kilometres of bicycle lanes.

Figure 17 - Number of bicycles per kilometres of cycling lane by city cluster

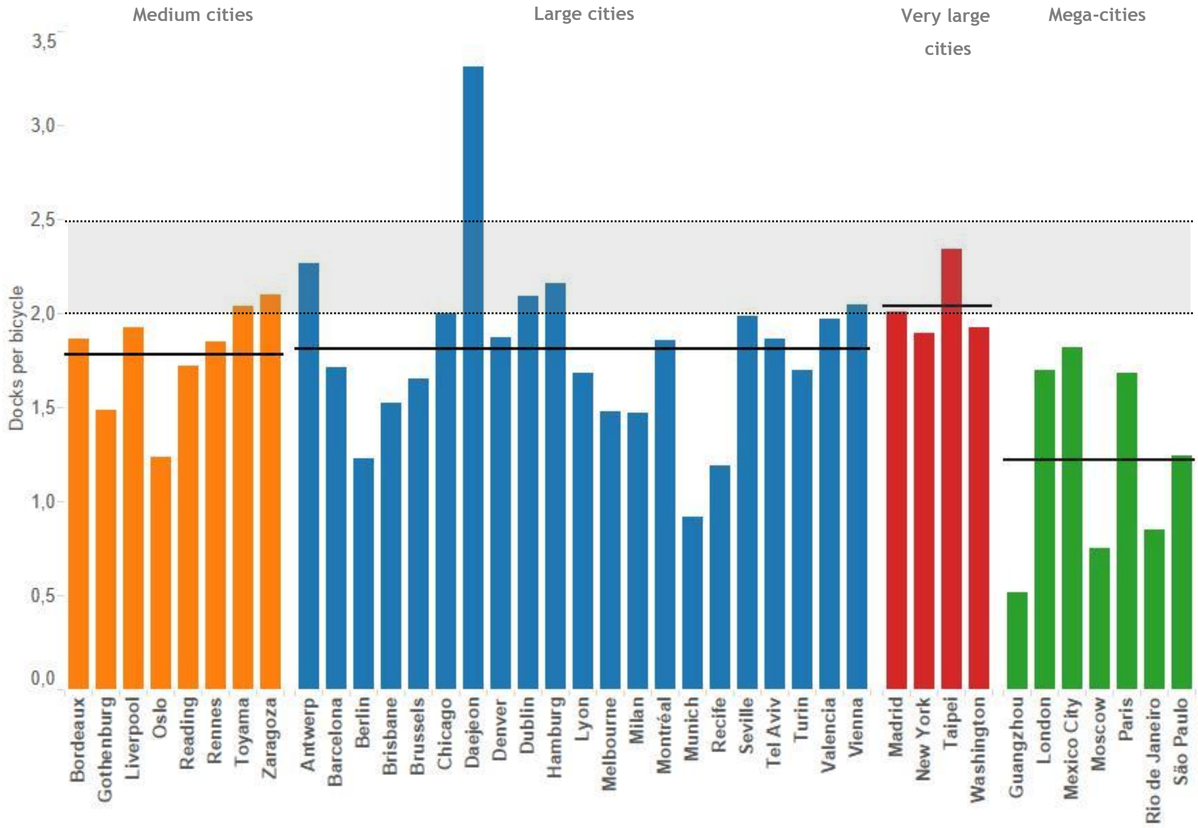


Source: author

An increasing trend was identified with respect to population. Medium cities presented an average ratio of 4,4 (SD = 2,9), large cities 9,5 (SD = 10,7), very large cities 13,8 (SD = 12,0) and mega-cities 30,5 (SD = 28,7). However, standard deviation was considerably high, with some less populated cities such as Barcelona and Milan presenting respectively 33,9 and 37,4 bicycles per kilometre of cycling lane. Moreover, Paris, which exhibited the highest ratio of 64,4 in this metric, has a considerable amount of cycling lanes with over 370 kilometres in its metropolitan region.

The ratio between docks and bicycles is presented in Figure 18.

Figure 18 - Number of docks per bicycle by city cluster

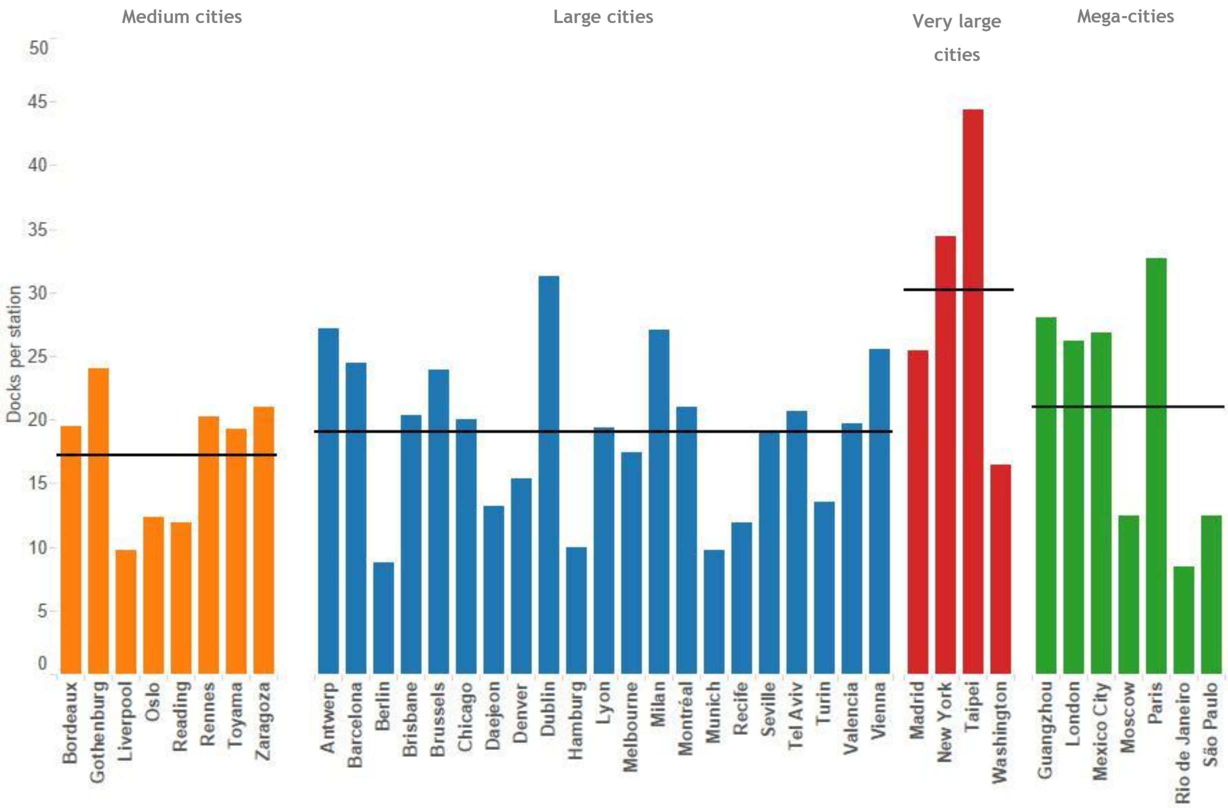


Source: author

No clear distinction could be observed among city clusters. However, only a handful of schemes presented a ratio between 2,0 and 2,5 docks per bicycle, the target range initially proposed by ITDP (2013), as represented by the grey area in the chart. Only eight schemes were inside this range: Toyama, Zaragoza, Chicago, Dublin, Hamburg, Vienna, Madrid and Taipei. Most schemes had a lower ratio, and the scheme in the city of Daejeon was the only one to perform above this range, with 3,31 docks for each bicycle. This can be very harmful to the scheme and the city, as not only it can represent a significant waste of physical space, but also an excessive number of docks per bicycle can further difficult fleet redistribution, as users are more free to return bikes wherever they want. Medium cities had 1,78 docks per bicycle in average (SD = 0,29), large cities 1,81 (SD = 0,49), very large cities 2,04 (SD = 0,21) and mega-cities 1,22 (SD = 0,52). Finally, it is crucial to mention that, sometimes, bike-sharing do not operate at full fleet capacity, in order to have a reserve for bicycles in maintenance. Because of this, a ratio of docks per total bicycles was actually under 1,0 in some cases, as it is impossible to gather statistics for the actual operational fleet. This detail will be taken into account in the discussion of the results.

Likewise, no tendency was identified for the average number of docks per station with respect to population (Figure 19).

Figure 19 - Average docks per station by city cluster

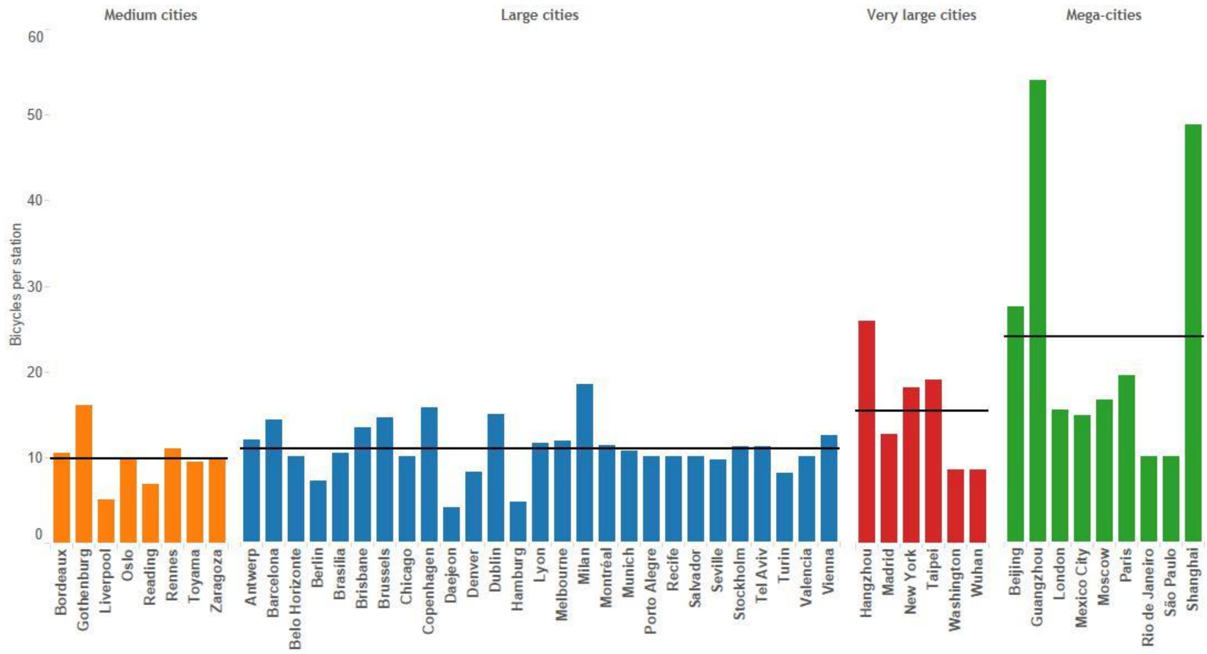


Source: author

The cities of Taipei and New York presented the highest figures, with 44,4 and 34,4 bicycles for every station respectively. Accordingly, the cluster of very large cities presented the highest average ratio of 30,2 (SD = 12,0), while medium cities presented an average of 17,2 (SD = 5,2), large cities 19,0 (SD = 6,3) and mega-cities 21,0 (SD = 9,6).

On the other hand, the average number of bicycles per docking stations was greater for highly populated agglomerations (Figure 20).

Figure 20 - Average number of bicycles per station by city cluster

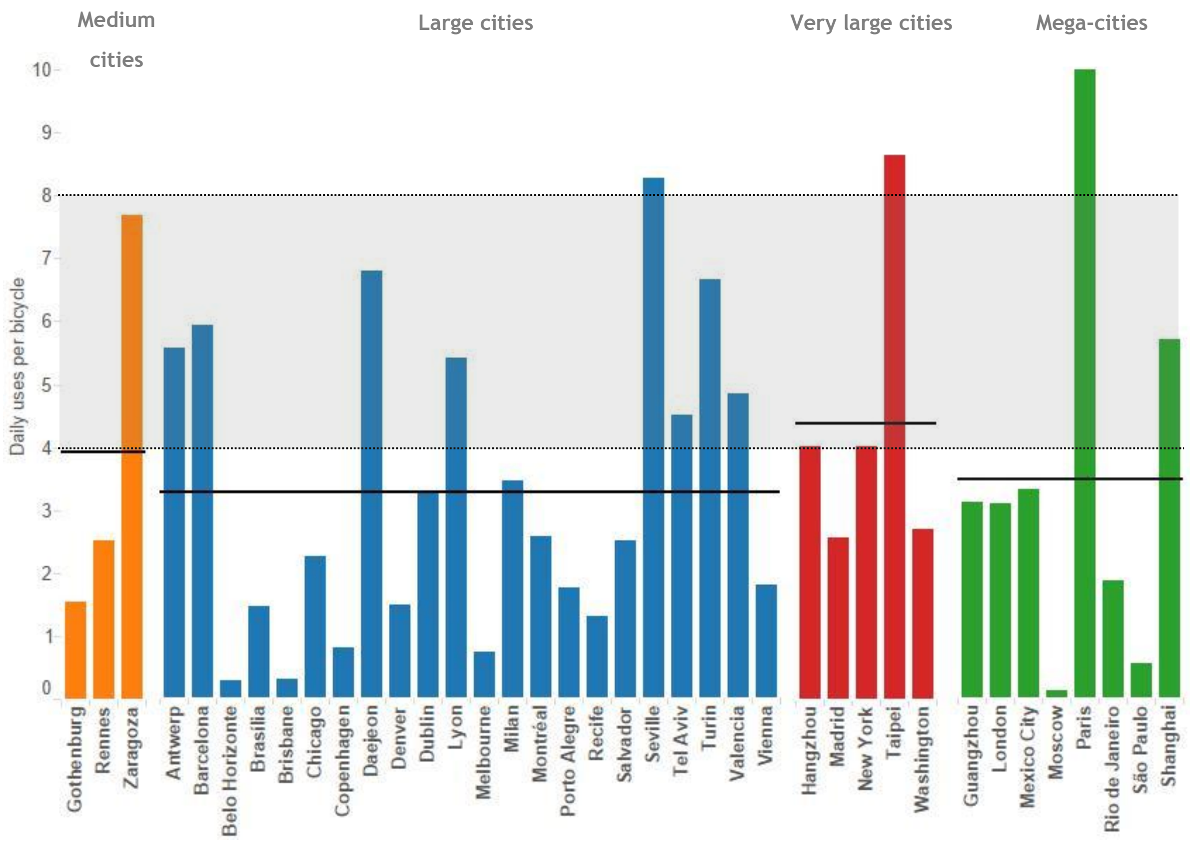


Source: author

This means that docking stations seemed to be larger with increasing population, as each station tend to serve a greater number of people. Mega cities exhibited 24,1 bicycles per station in average (SD = 16,4), very large cities 15,5 (SD = 6,8), large cities 10,9 (SD = 3,1) and medium cities 9,9 (SD = 3,2). Additionally, the largest stations were located in China, reflecting a more condensed station network with enormous docking stations located in important public transport commuting points.

When it comes to system usage, no clear trend was identified concerning average daily uses per bicycle in respect to population (Figure 21).

Figure 21 - Average daily uses per bicycle by city cluster

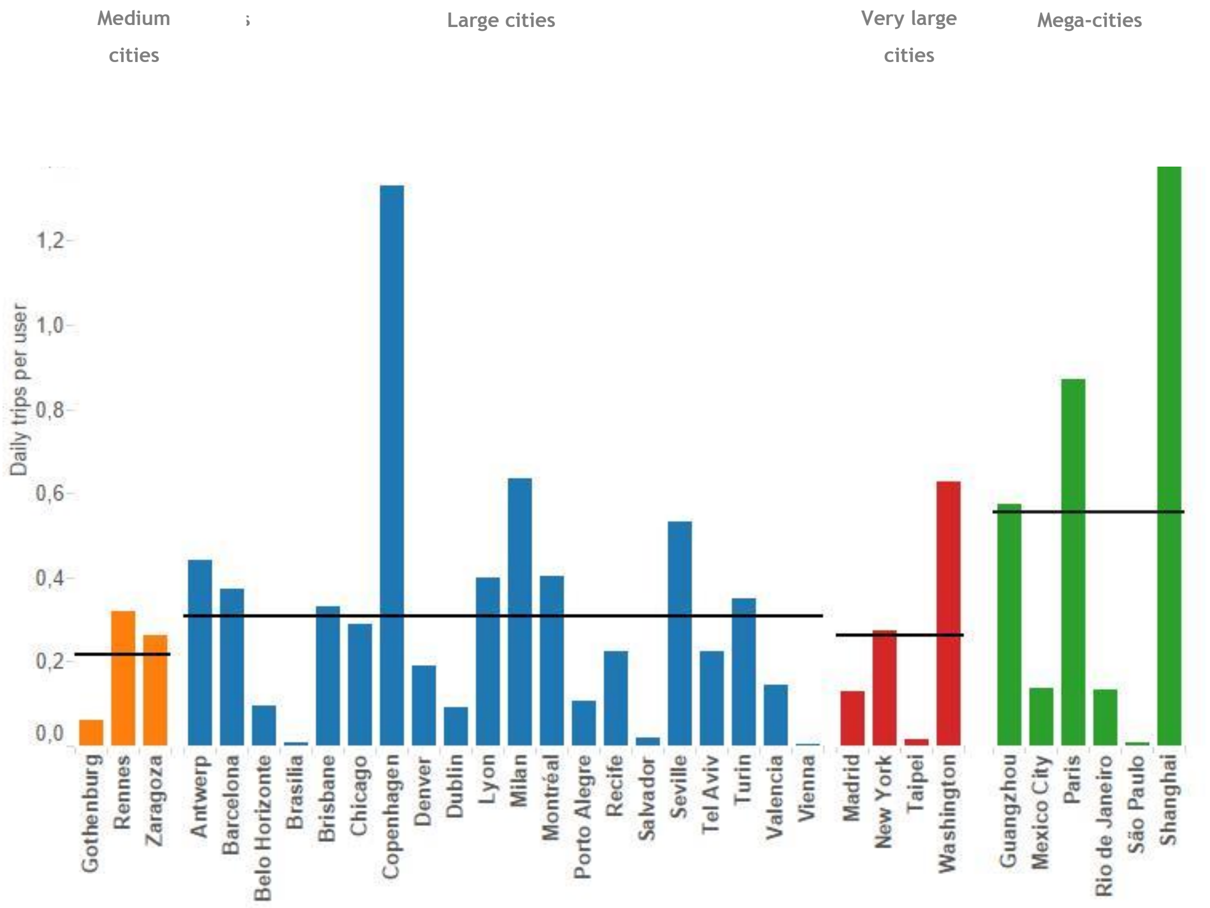


Source: author

Slightly higher levels were presented by very large cities and medium cities, with respectively 4,4 (SD = 2,5) and 3,9 (SD = 3,3) daily average uses per bicycle. Large cities rated at 3,3 (SD = 2,4) and mega-cities at 3,5 (SD = 3,2). Only a handful of schemes reached the target range of 4,0 to 8,0 daily uses per bicycle: Zaragoza, Antwerp, Barcelona, Daejeon, Lyon, Tel Aviv, Turin, Valencia, Hangzhou, New York and Shanghai. Moreover, three schemes located in the cities of Taipei, Paris and Seville surpassed the cap proposed by ITDP (2013), with each bicycle being used in average between 8 and 10 times daily. The Velobike scheme in Moscow presented the lowest ratio for this metric, as it has one of the lowest usages among all systems. With 305 daily trips, it is second only to the scheme in Belo Horizonte, Brazil, which has 105 daily displacements but with a much smaller fleet of 400 bicycles, compared to the 2.500 operating bicycles in the Russian capital.

Figure 22 demonstrated that, in average, mega-cities had higher usage levels regarding average daily trips per user at 0,55 (SD = 0,61), but no clear trend was distinguishable otherwise.

Figure 22 - Average daily trips per registered user by city cluster

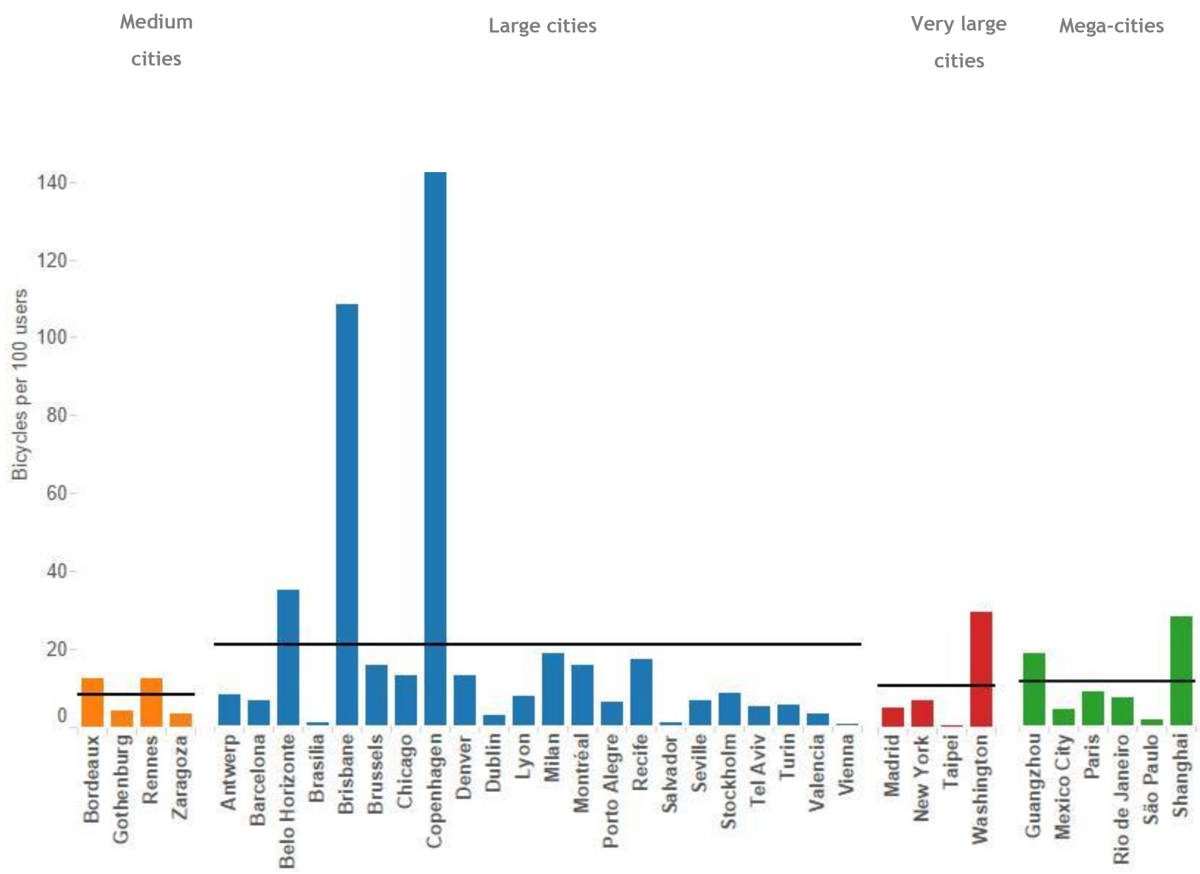


Source: author

Medium cities presented an average of 0,21 daily trips per registered user (SD = 0,14), large cities 0,31 (SD = 0,30) and very large cities 0,26 (SD = 0,27). It is necessary to point out the fact that the system which performed best, located in the city of Shanghai, presented an outstanding figure of 159.000 daily trips. On the other hand, the scheme in Copenhagen, which performed second best, has an extremely low amount of registered users. The new Bycyklen system which was inaugurated in the Danish capital little more than a year ago attracted no more than 256 annual subscribers, which helps explaining the high ratio for this metric. This is because a system with more registered users is more likely to have a higher share of inactive users, especially when registration is free or very cheap, which is definitely not the case in Copenhagen. Additionally, the low ratios in the cities of Vienna and Taipei are explained by the great amount of registered users in these schemes. On the other hand, the schemes in the Brazilian cities of São Paulo, Salvador and Brasília presented low daily usage, especially when compared to the amount of registered users.

Although Figure 23 presented a higher average for the number of bicycles per registered users for large cities at 21,0, the standard deviation was very high at 39,5, meaning it was not possible to affirm that it is significantly greater.

Figure 23 - Number of bicycles per 100 registered users by city cluster

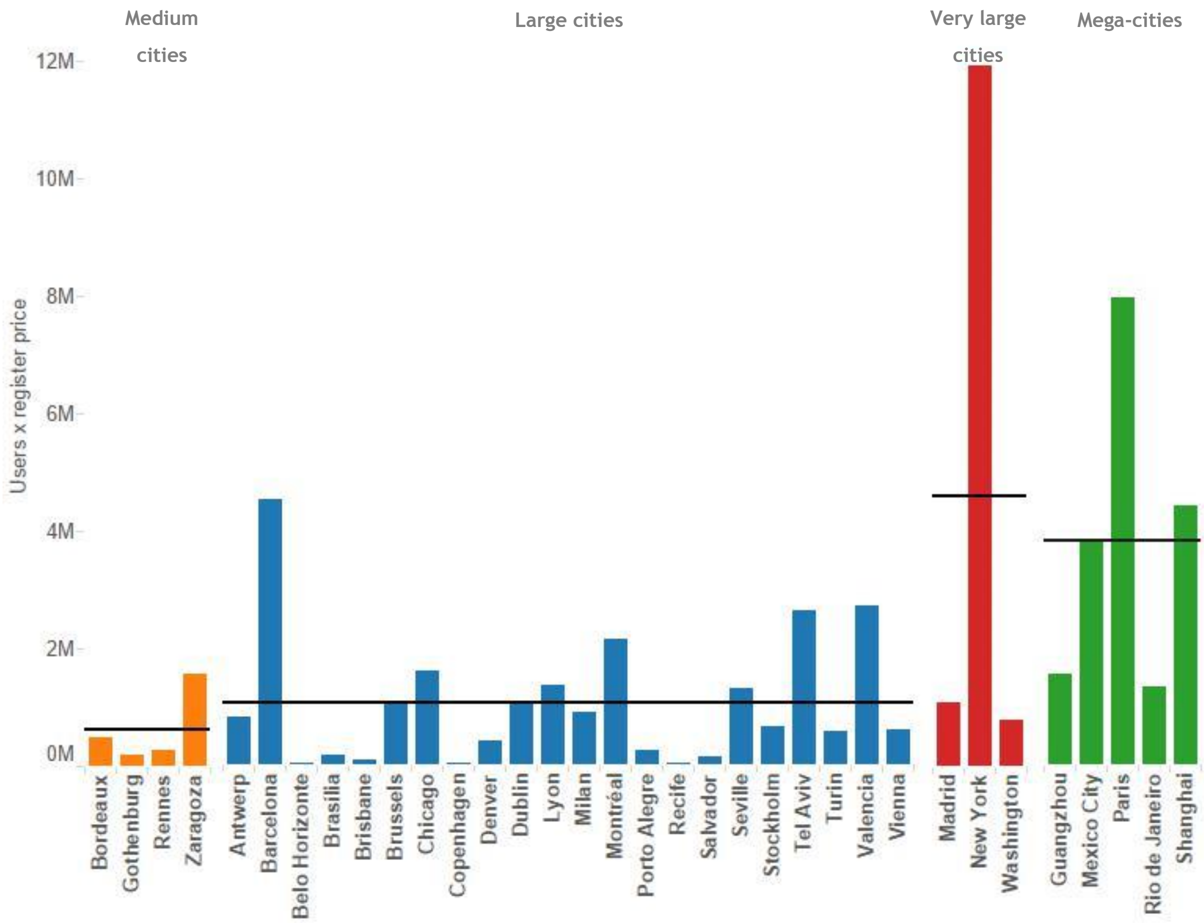


Source: author

Once more, the Bycyklen system in the city of Copenhagen presented an outstanding ratio, because of the extremely low number of registered users. Similarly, the scheme in the Australian city of Brisbane has only 1.845 registered users, leading to an increased ratio in this metric. Medium cities rated at 8,2 (SD =5,1), very large cities at 10,4 (SD = 13,1) and mega-cities at 11,3 (SD = 10,0). As reported in Figure 22, schemes in Taipei and Vienna have a large amount of registered users, while systems in São Paulo, Salvador and Belo Horizonte are undersized compared to their user pool.

Figure 24 presents the indicator referring to registered users considering the price charged.

Figure 24 - Users multiplied by price by city cluster

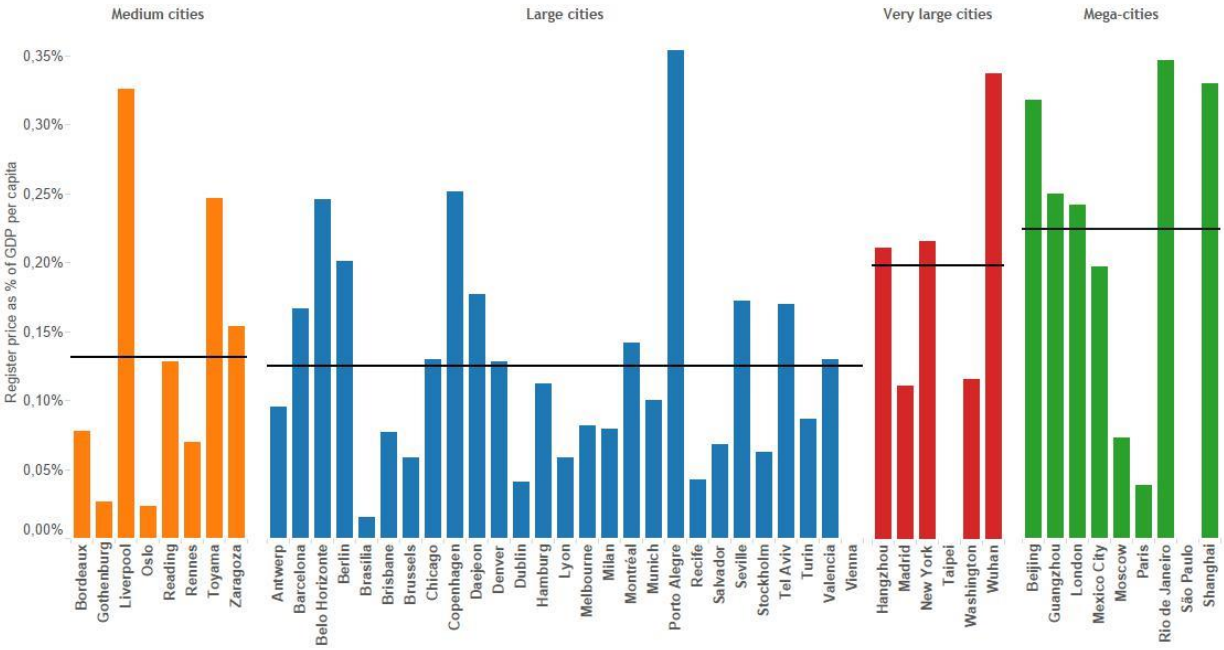


Source: author

Although this is not a perfectly comparable indicator, as more populated cities have a bigger target market to explore, it is a proxy system reach considering the price charged. As expected, medium and large cities presented much lower average figures with 627.276 (SD = 634.847) and 1.042.771 (SD = 1.118.997), however the highest average was exhibited by very large cities, which presented a number equal to 4.589.705 (SD = 6.337.502) for this metric. Mega-cities presented a lower number equal to 3.802.023 (SD = 2.683.652) users multiplied by price. This shows that, even with a smaller population related to mega-cities, this third cluster appears to have greater system grasp, either because it has attracted many more users, or it has a considerable amount of registered users while charging a high price. However, all standard deviations were very high, which means that it is difficult to affirm anything with certainty. Nevertheless, a high score on this indicator reflects an excellence service being offered. Important to note is the fact that Citi Bike in New York and Vélib' in Paris were the two schemes which thrived in this indicator, as that they are located in two highly populated agglomerations which are among the most important economic centres in the world. Once again, the schemes which fared poorly present a modest user pool, as prices do not differ greatly apart from the free registration schemes.

Additionally, the pricing adequacy measured by register price per GDP did presented higher averages for more populated clusters (Figure 25).

Figure 25 - Register price per GDP per capita by city cluster

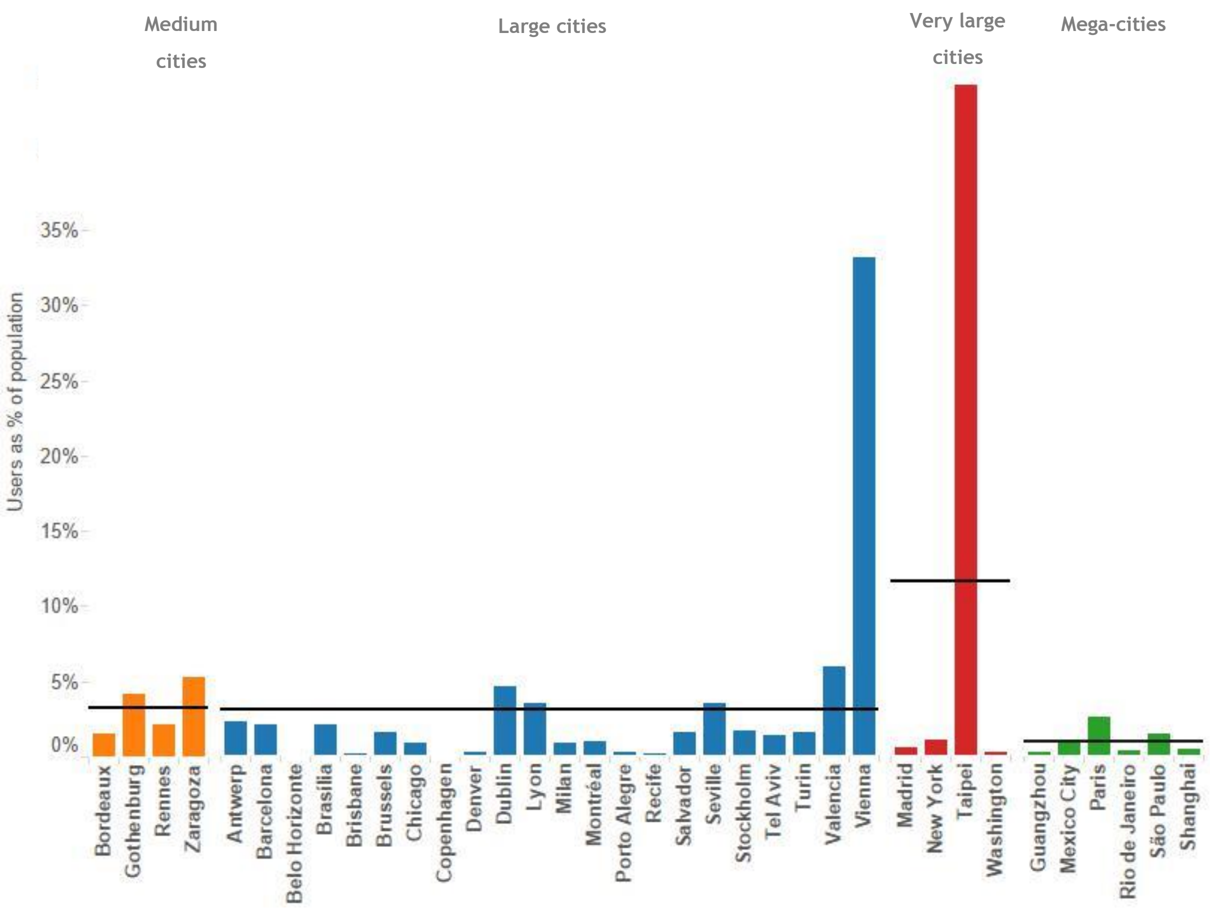


Source: author

While medium and large cities averages stood at respectively 0,13% (SD = 0,11%) and 0,12% (SD = 0,08%) of GDP per capita, very large cities exhibited 0,20% (SD = 0,09%) and mega-cites 0,22% (SD = 0,12%) for the same ratio. This means that systems located in more populated agglomerations appear to be charging more in average. Although, among the highest populated cities in this sample there are some of the most economically powerful cities in the world such as New York, Paris and London, which can explain partly why the average relative price is higher in these clusters. Still, standard deviation was high, as there were cities which presented high relative percentages in all city clusters. For instance, the medium sized city of Liverpool showed a registration price which is 0,33% of its GDP per capita, while Porto Alegre in Brazil is a large city which presented the highest percentage among all cities with 0,35%, explained by its low GDP per capita of €10.436. Furthermore, the schemes in the cities of Taipei and São Paulo do not charge for registration, explaining why these percentages stood at 0,00%. The same is valid for Vienna, which charges only €1 as registration fee. Finally, although Chinese cities present presented a high relative price for registration, these schemes charge very little for the extra time used, with at least 1 hour of free initial time in all of them.

Lastly, Figure 26 represents the registered users as a percentage of total city population. This is an approximation of the market penetration of the system related to all its potential customers, defined as all those living within the urban agglomeration.

Figure 26 - Registered users per total population by city clusters



Source: author

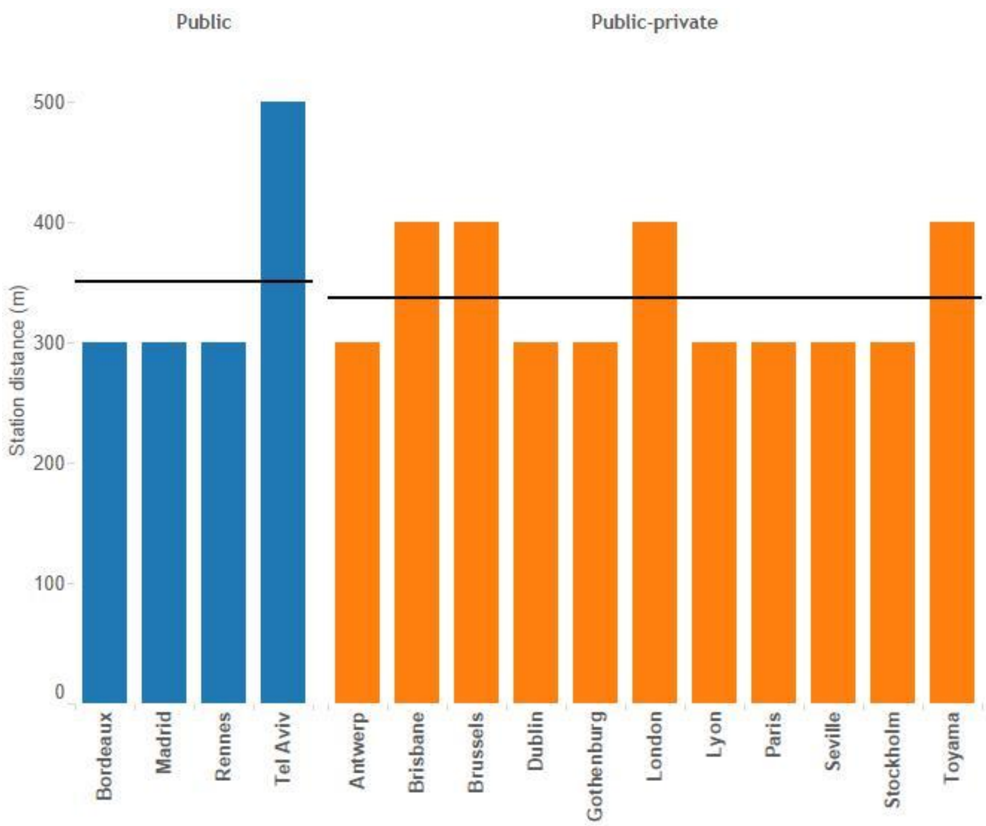
From Figure 26 it is possible to observe that very large cities appear to have a much higher performance with 11,60% (SD = 22,07%), while other city typologies trail far behind. Medium cities performed at 3,29% (SD = 1,73%) in average, large cities at 3,08% (SD = 6,90%) and mega-cities at 0,94% (SD = 0,90%). However, standard deviation figures were all considerably high, making it impossible to ascertain anything. This is related to the fact that some cities managed to attract a massive amount of users due to low registration prices. For instance, the Citybike in Vienna has a total of 585.000 users registered in the system, which corresponds to 33,18% of the city's population. Similarly, the YouBike scheme managed to attract an amount of 3.325.258 users, or 44,71% of the population of Taipei. However, in the Brazilian metropolis of São Paulo, despite charging nothing for registration, the Bike Sampa scheme has not yet reached a significant percentage of total population, partly because the city has more than 10 million inhabitants.

Although some trends were identified, this initial analysis showed that with the exception of a few performance indicators, the city clusters do not differ largely regarding most of the metrics evaluated. The next section presents the average performance levels for the same key performance indicators for the three existing business models.

4.3.3 Average performance levels by business model

Due to lack of data for many cities, the average station distance metric is better analysed for all cities together (Figure 27).

Figure 27 - Average distance in meters between in stations by business model



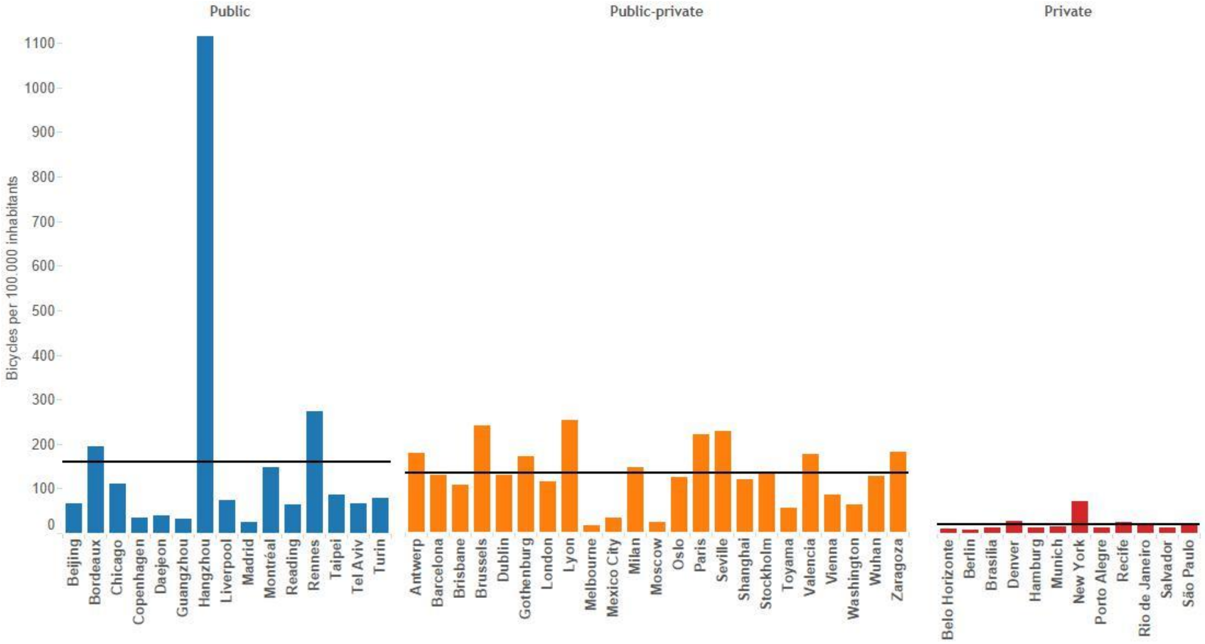
Source: author

As said before, the average distance between stations ranges between 300 and 500 meters for analysed schemes. For the public business model, the average distance was 350m

(SD = 100m), for public-private partnerships 336m (SD = 50m) and no data were available for any private business model scheme.

The number of bicycles per inhabitants seemed to have a strong relationship with the business model employed (Figure 28).

Figure 28 - Number of bicycles per 100.000 inhabitants by business model

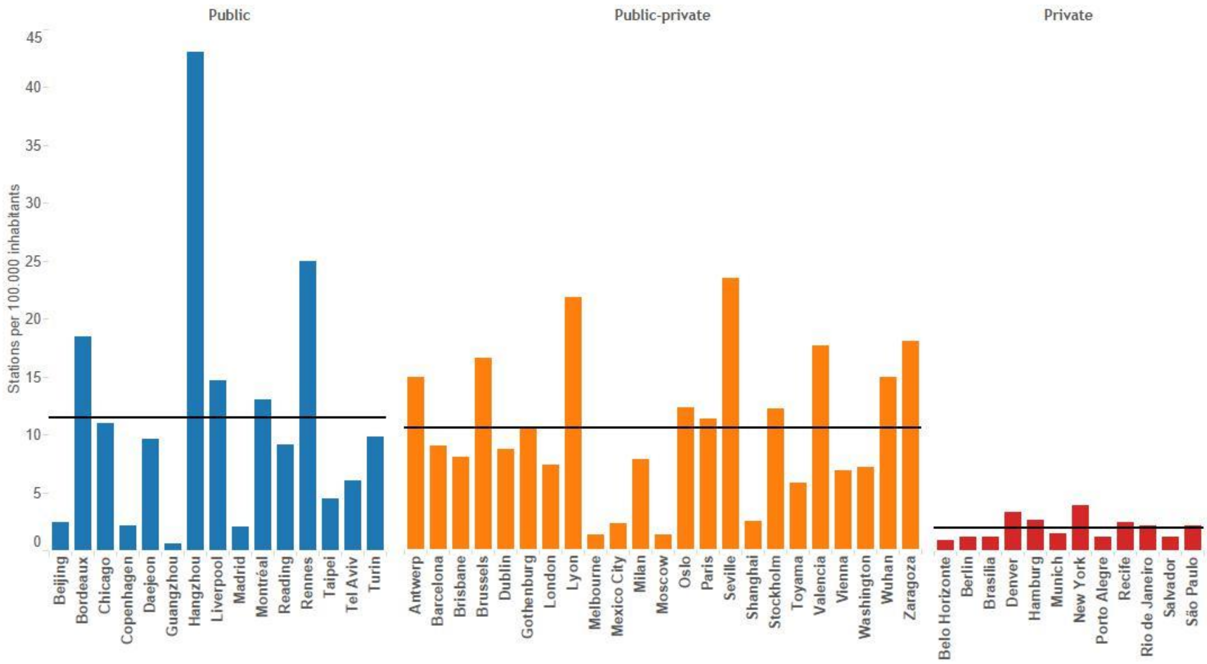


Source: author

While public and public-private settings showed average values of 160 (SD = 273) and 132 (SD = 68) bicycles per 100.000 inhabitants respectively, private systems trailed far behind, with only 20 bicycles (SD = 16). As mentioned before, the city of Hangzhou has by far the largest fleet among all schemes, thus explaining the outlying performance in indicators involving number of bicycles. If the Chinese city was not to be considered in this analysis, the public business model average would drop to 92 (SD = 70) bicycles per 100.000 inhabitants, which is considerably lower than the current public-private partnership average.

Also for the number of stations per inhabitants a similar trend was identified in Figure 29.

Figure 29 - Number of stations per 100.000 inhabitants by business model

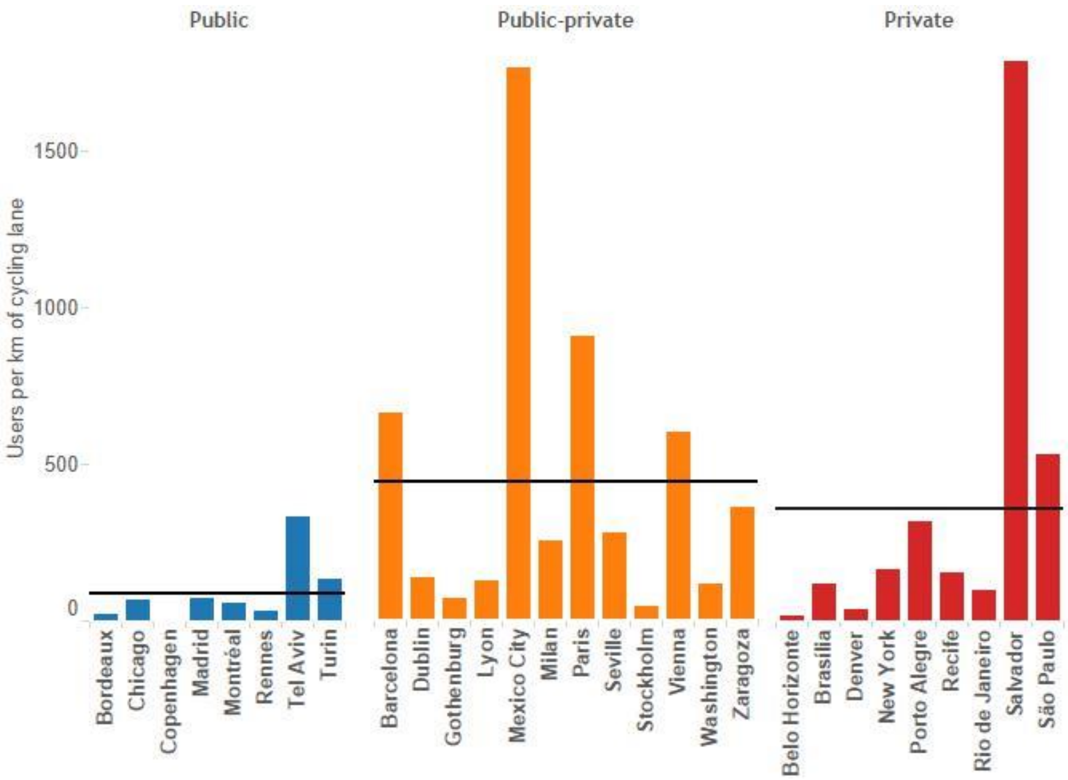


Source: author

Public and public-private again exhibited much higher averages, standing respectively at 11,4 (SD = 11,0) and 10,5 (SD = 6,3), while the private business model average stood at 2,0 stations per 100.000 inhabitants (SD = 0,9).

At first glance, Figure 30 showed an inverse trend with respect to what was previously seen.

Figure 30 - Registered users per kilometres of cycling lane by business model

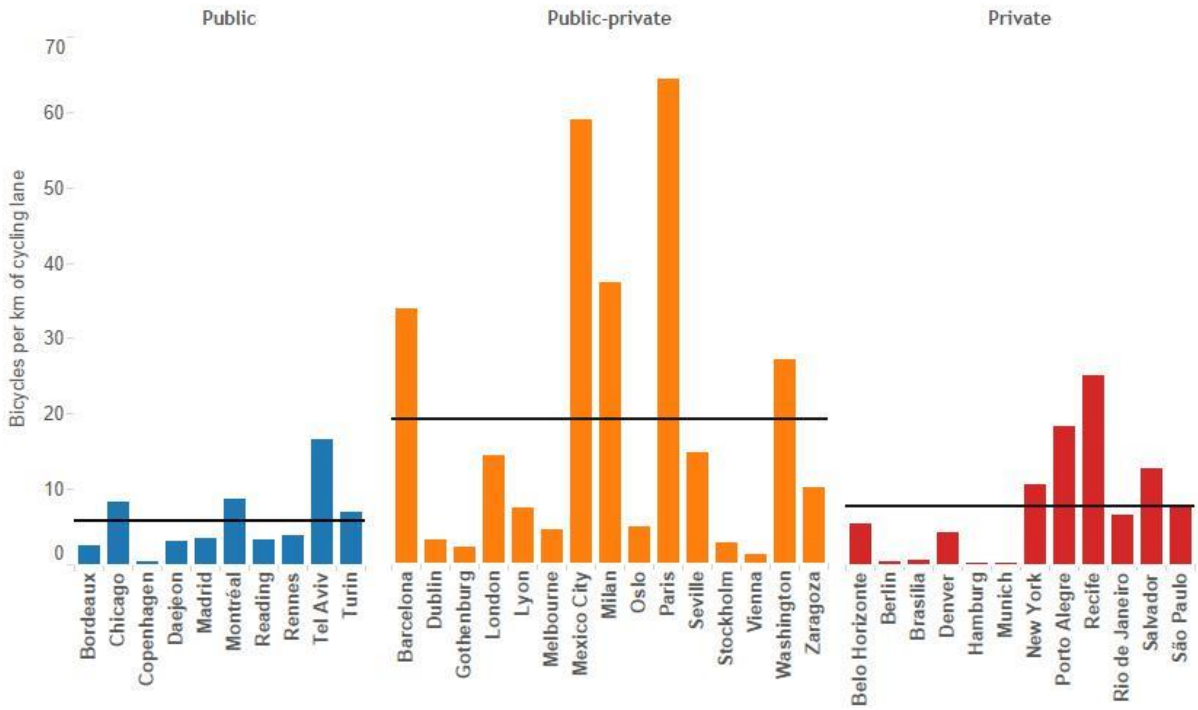


Source: author

Public systems presented the smallest ratio of 88,0 (SD = 106,7) relating registered users and kilometres of cycling lanes in the cities, while for private schemes it was 356,3 (SD = 525,8) and for public-private 359,6 (SD =406,3). However, it is important to note that for all three averages the standard deviation was significantly high, making it impossible to affirm any superiority. Moreover, as explained before, it was the city of Salvador in Brazil which currently possesses only 27 kilometres of cycling lanes that presented the highest ratio of 1.781,7. Because of this, if treated as an outlier and removed from this specific analysis, the private model average drops to 178,2 (SD = 159,3) registered users per kilometre of cycling lane. Although this figure is not as low as the ratio presented by public systems, it seems to confirm that for this indicator public-private partnerships exhibited the best performance among the three business models.

In addition, for the ratio relating fleet size and kilometres of cycling lanes, the results were similar (Figure 31).

Figure 31 - Number of bicycles per kilometres of cycling lane by business model

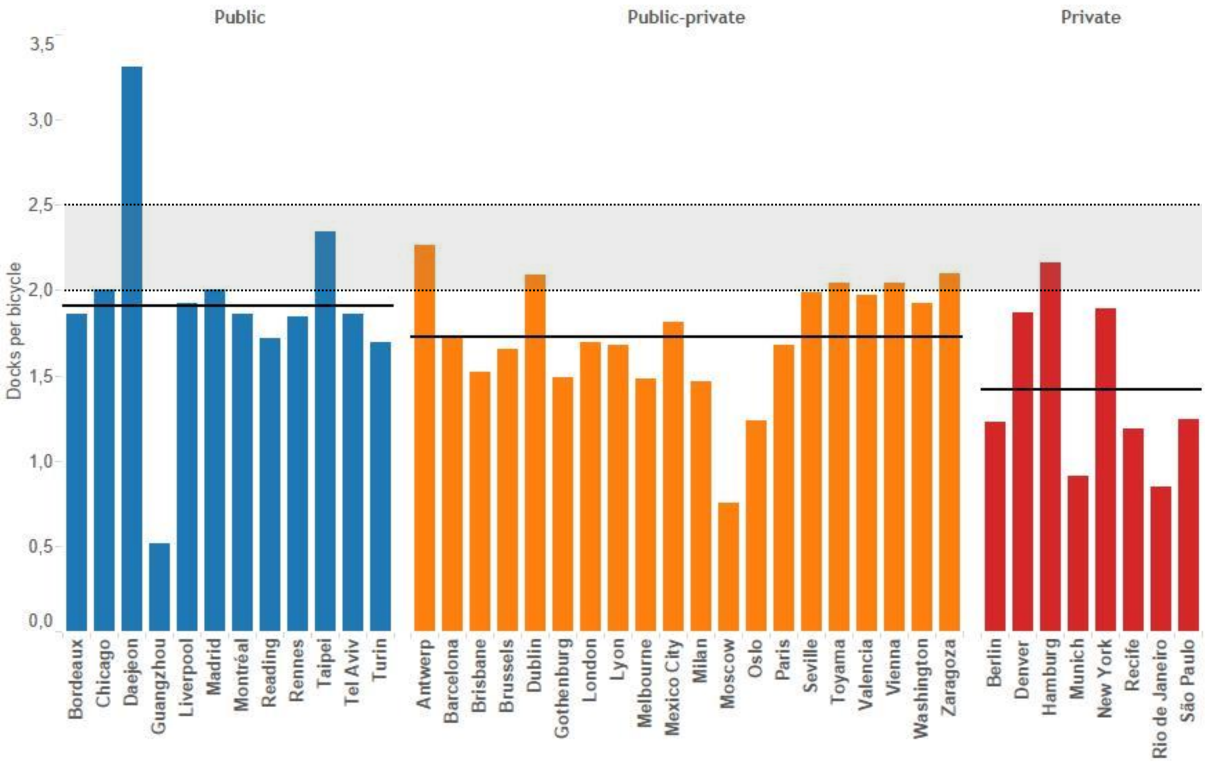


Source: author

The hybrid public-private model presented the highest average value of 19,1 (SD = 20,8), while public and private business models fared worse, with 5,7 (SD = 4,7) and 8,0 (SD = 7,9) respectively. Still, once more standard deviation figures were very high, representing around 100% of the mean value for all three business models.

Regarding the number of docks per bicycle, the same trend was observed (Figure 32).

Figure 32 - Number of docks per bicycle by business model

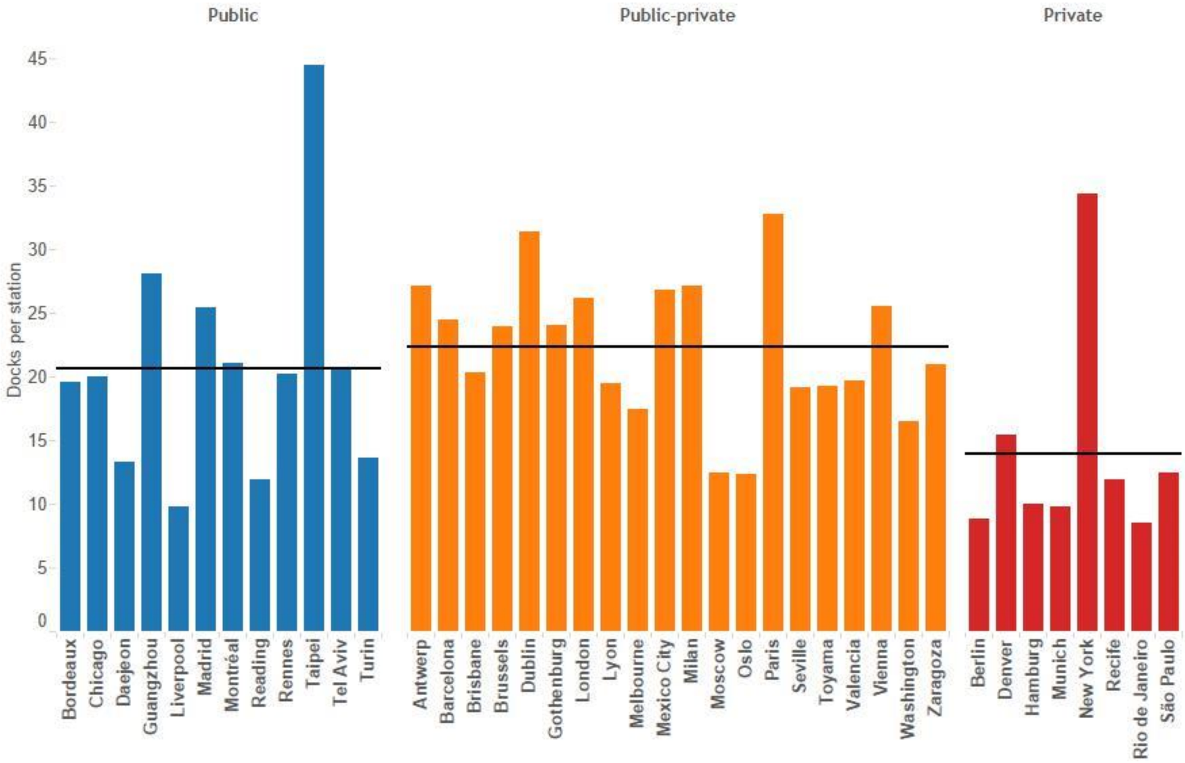


Source: author

Public model schemes displayed the highest value of 1,91 (SD = 0,62) in average, while public-private and private models showed respectively 1,73 (SD = 0,35) and 1,47 (SD = 0,46) docks per bicycle. Again, these values fell short of the initial target range of 2,0 to 2,5 suggested by ITDP (2013), as stated before. Once more it is important to remember that ratios of less than 1,0 are not unrealistic, because bike-sharing schemes not always operate at full fleet capacity, having sometimes a larger number of bicycles in respect to the existing docks.

The ratio between docks and stations is show in Figure 33.

Figure 33 - Average docks per station by business model

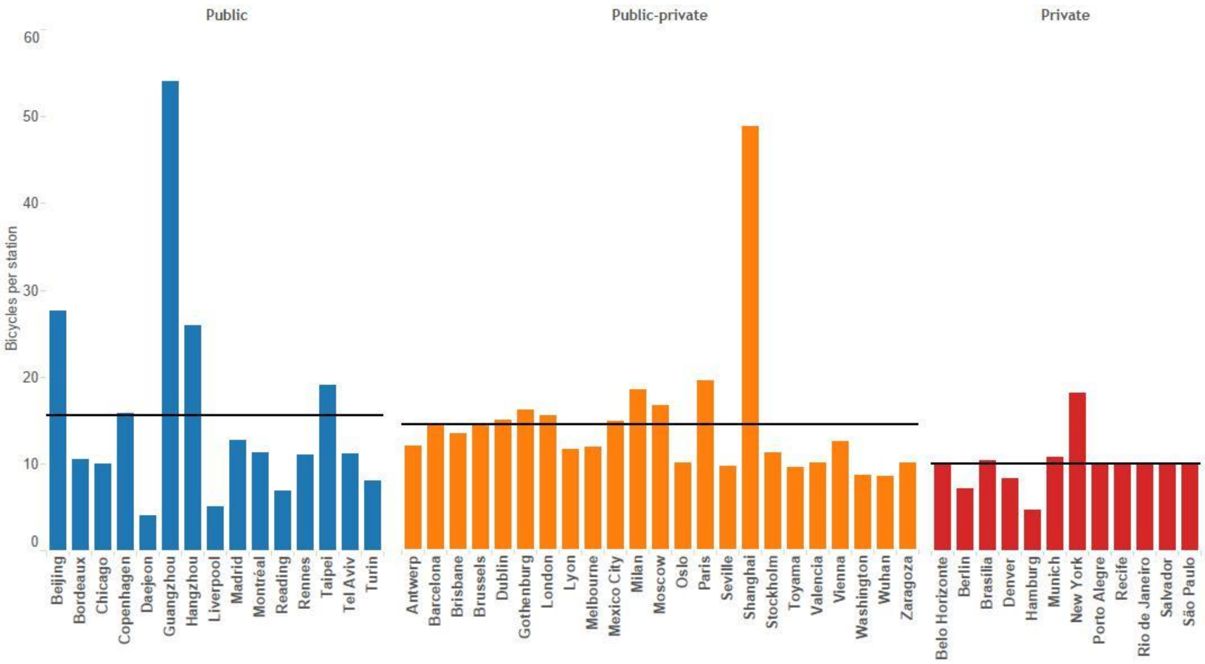


Source: author

Public-private partnerships showed the highest value of 22,3 (SD = 5,6), with public model business schemes presenting a slightly lower figure of 20,6 (SD = 9,3) and private schemes the lowest average of 13,9 (SD = 8,0). However, the percent standard deviation of the public business model mean was much higher than that of public-private partnerships, meaning that it is not possible to conclude with certainty which business model actually performed best in this metric.

Also for the average number of bicycles per docking stations a similar relationship was observed (Figure 34).

Figure 34 - Average number of bicycles per station by business model

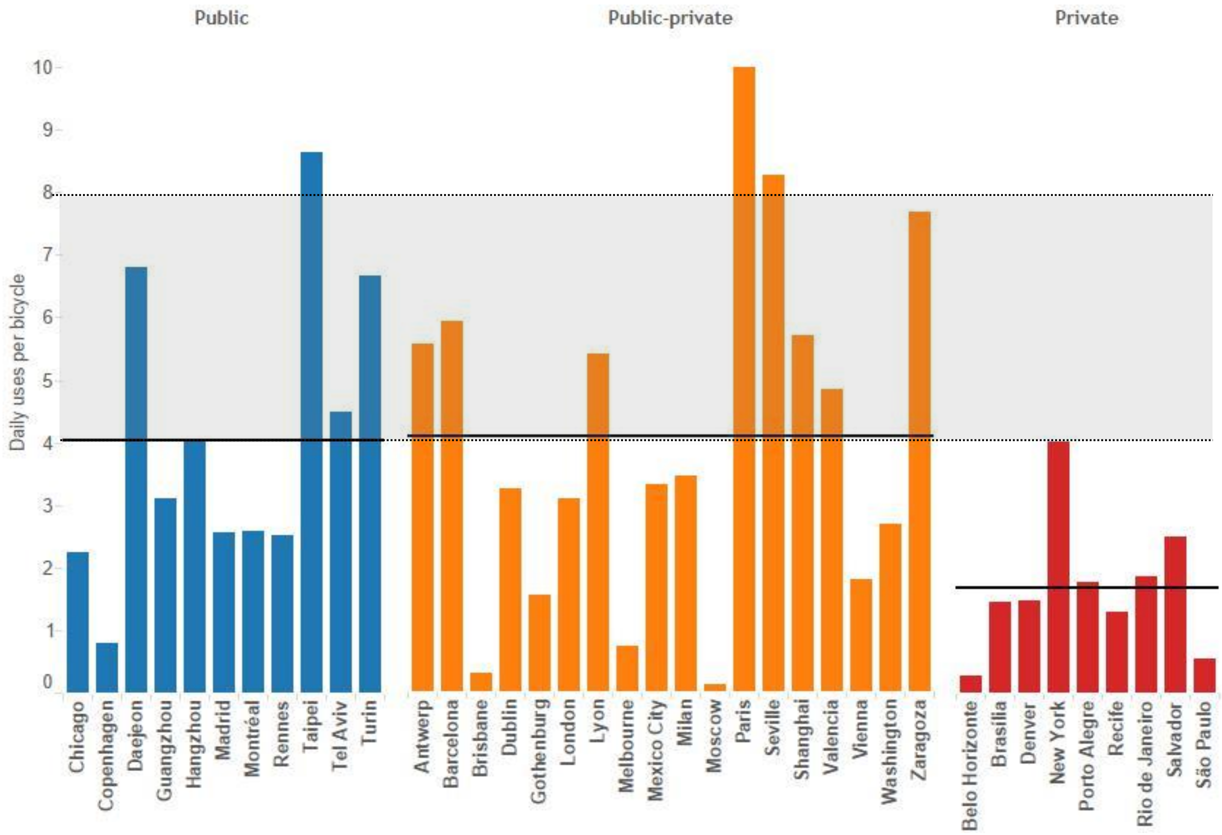


Source: author

Public model presented a ratio of 15,5 (SD = 12,7), public-partnerships rated at 14,4 (SD = 8,1) and private schemes at 9,9 (SD = 3,0). Still, high relative standard deviation values make it impossible to ascertain which business model actually performed better.

System usage is analysed in Figure 35.

Figure 35 - Average daily uses per bicycle by business model

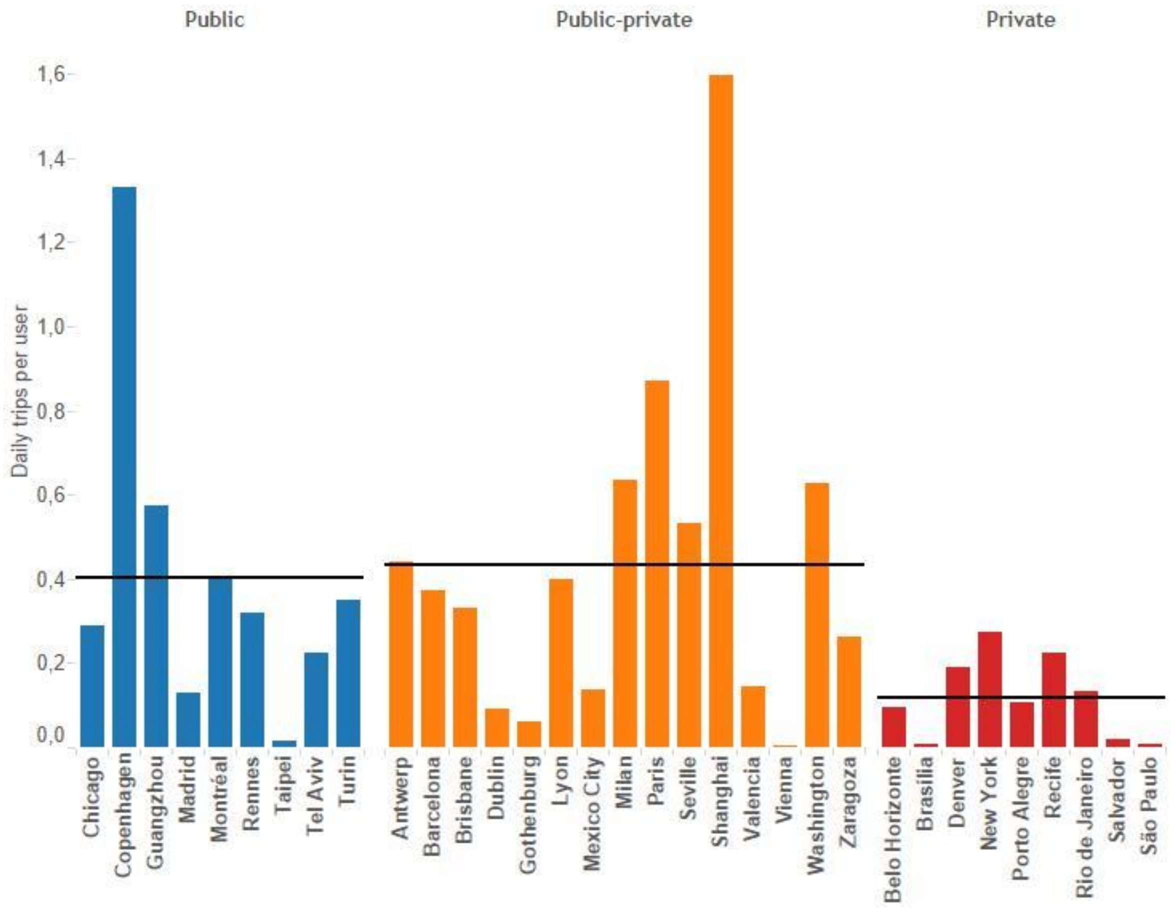


Source: author

Both public-private partnerships and public business model averages reached the desired target level of 4 to 8 daily uses proposed by ITDP (2013), with respectively 4,1 (SD = 2,8) and 4,0 (SD = 2,4) daily trips per bicycle. Once more private schemes trailed far behind, with an average 1,7 uses per bicycle per day (SD = 1,0).

Again a similar trend was observed regarding average daily trips per user, as shown in Figure 36.

Figure 36 - Average daily trips per registered user by business model

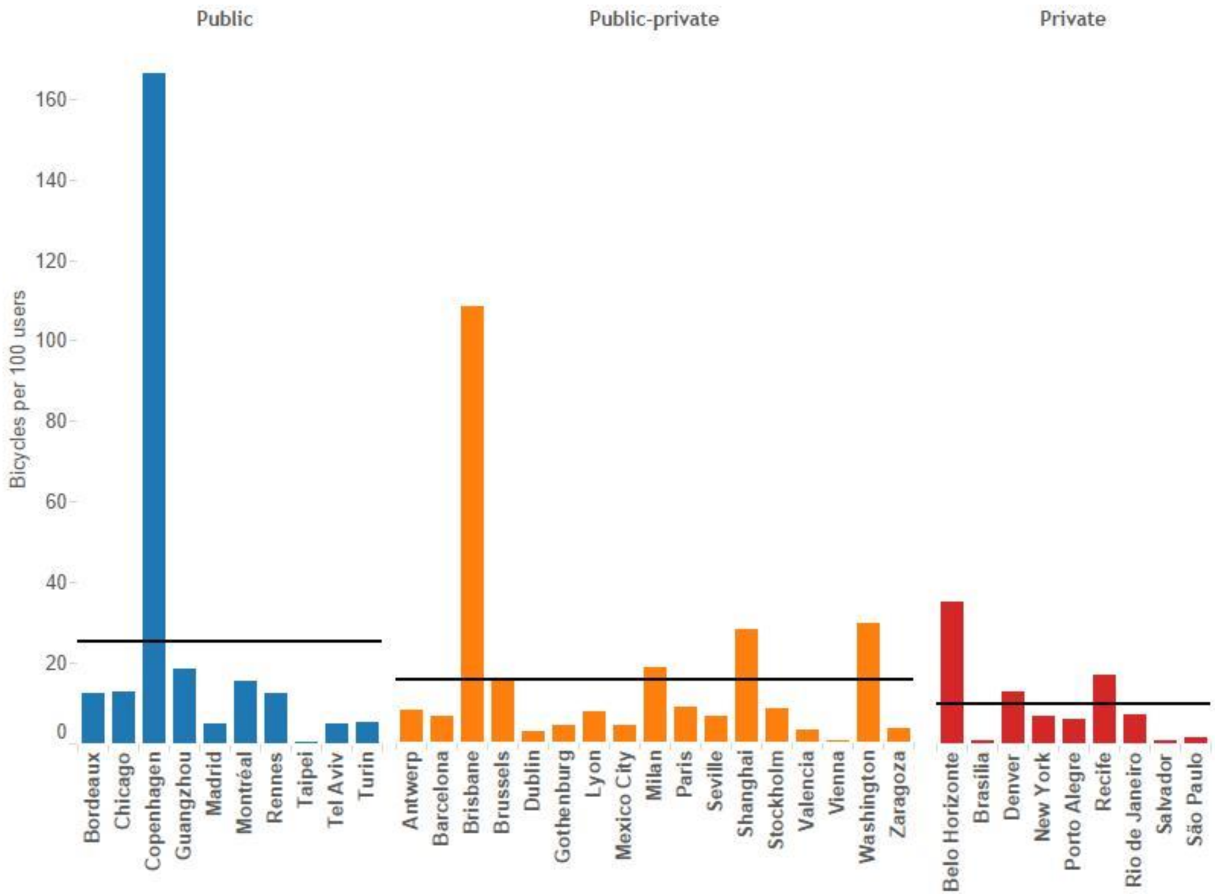


Source: author

Public-private partnerships presented 0,43 daily trips per user on average (SD = 0,40), public business model schemes 0,40 (SD = 0,38) and private systems 0,12 (SD = 0,09). Standard deviation was repeatedly high when compared to the average values. As described in the previous section, Shanghai has the top performing scheme due to the high amount of daily trips, whereas in Copenhagen there are not many registered users, thus increasing this ratio.

The ratio between fleet size and number of registered users is presented in Figure 37.

Figure 37 - Number of bicycles per 100 registered users by business model

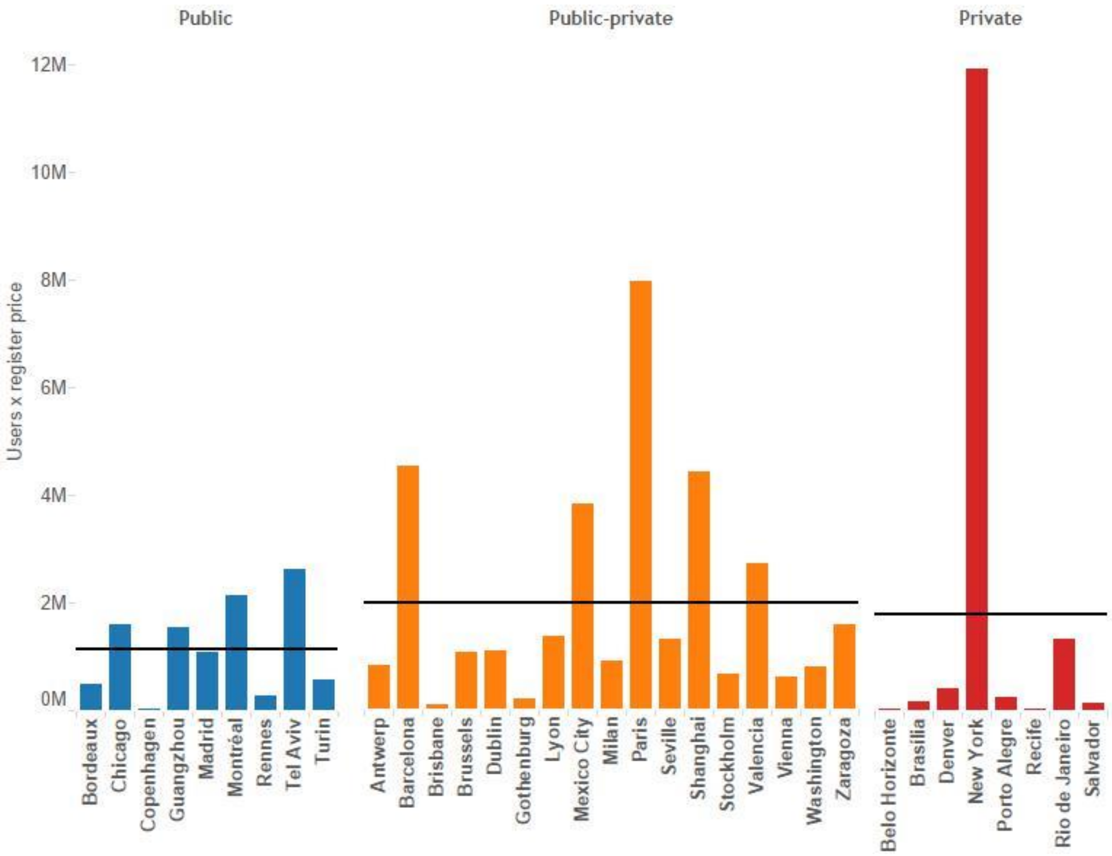


Source: author

Private business model schemes had the lowest value with 9,7 (SD = 10,3) while public ones presented the highest one, with 25,4 (SD = 49,9). Public-private partnerships presented an average of 15,5 bicycles per 100 registered users (SD =25,4). All the three standard deviations represented more than 100% of the relative average values.

Figure 38 presents the value for registered users multiplied by the price charged for each of the business models.

Figure 38 - Registered users times register price by business model

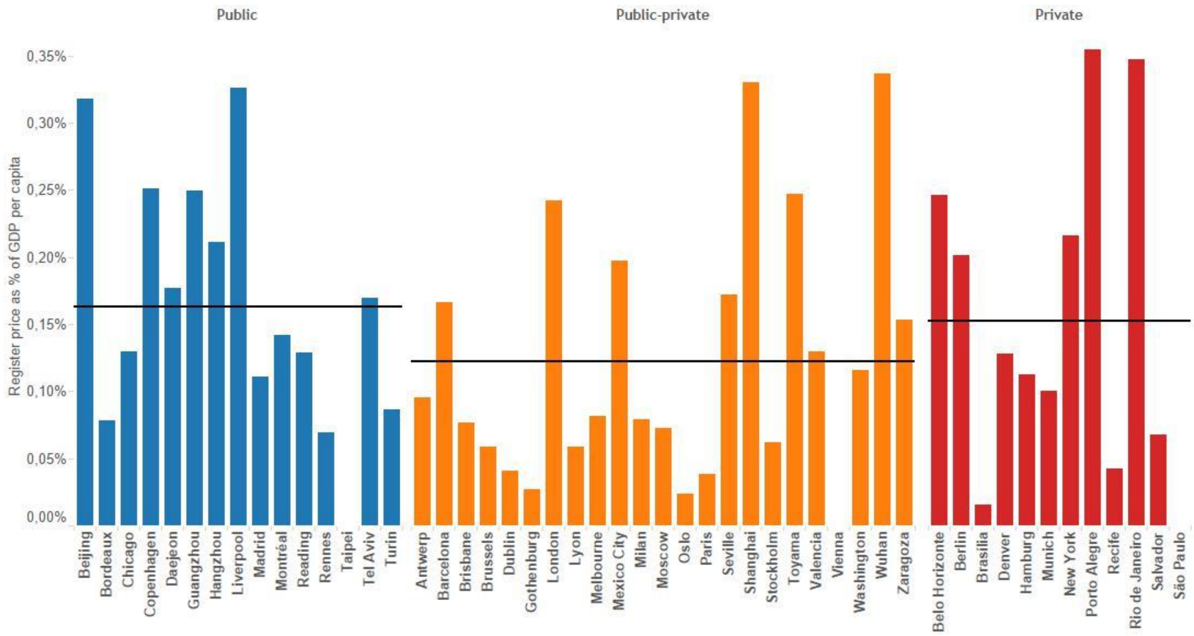


Source: author

Without considering price adequacy, public business model schemes had lower performance regarding the reach of the system taking into account total registration price with a figure of 1.146.337 (SD = 888.247). Moreover, once more public-private partnerships presented the greatest average value with 1.982.510 (SD = 888.247), slightly higher than private business model schemes, with 1.776.198 (SD = 3.849.037). As mentioned before, New York had the highest value due to large population and economical power, whereas Copenhagen, Belo Horizonte and Recife fail to achieve a significant number of registered users despite of the price charged, which is especially low in the two Brazilian cities.

Additionally, both public and private business model average prices stood at 0,17% of GDP per capita with standard deviation of respectively 0,08% and 0,09% (Figure 39).

Figure 39 - Register price per GDP per capita by business model

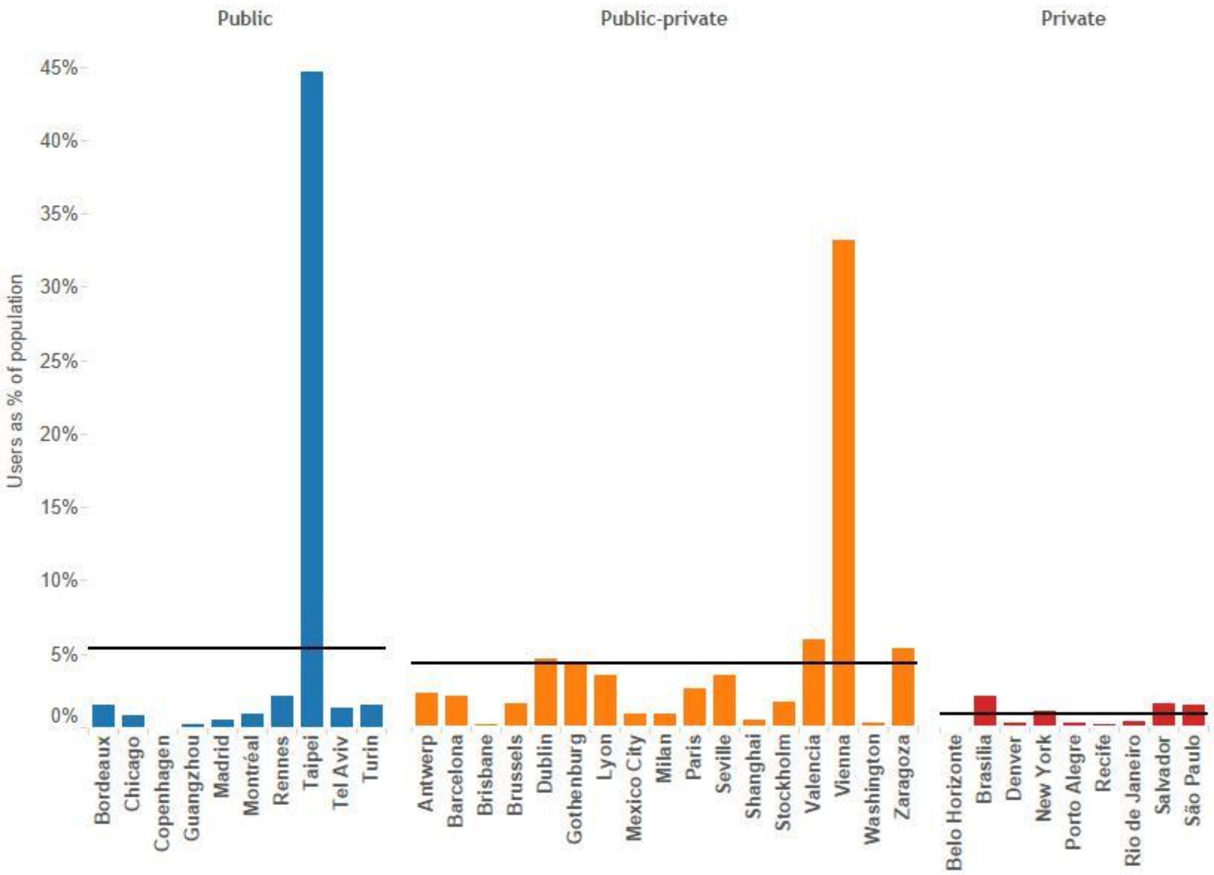


Source: author

Although public-private partnerships presented a lower value of 0,13% (SD = 0,11%), it is not necessarily a positive point, as the system could be undercharged, thus having decreased revenues. Likewise, a higher figure does not necessarily point out to a less efficient system. Again, Taipei and São Paulo do not charge for registration, explaining why the indicator stood at zero. The same applies to the scheme in Vienna, which charges only €1 for registration.

The last indicator is the system appeal or market penetration measured by registered users as a percentage of total population, as shown in Figure 40.

Figure 40 - Registered users per total population by business model



Source: author

For this metric public business model schemes demonstrated a better performance with 5,38% (SD = 13,84%), while public-private partnerships performed slightly worse having a percentage of 4,26% (SD = 7,67%) and private schemes of 0,76% (SD =0,70%). Once more the standard deviation is explained by the fact that some cities charge nothing or very little for registration, thus attracting many more individuals to register.

Differently from the analysis by city clusters, the evaluation for each business model suggests that public-private partnerships have higher average efficiency levels. While both public and private business models fared poorly in a few metrics, the hybrid model presented the highest performance values for most indicators, and did not trail behind in any of them.

The schemes operating according to a private business model fail to perform at the same level of other business model for most of the evaluated metrics. It is important to note that these systems can sometimes fail to keep interests aligned with public authorities, explaining the poor performance in terms of system efficiency. For the sample analysed, most private systems were located in Brazil, all managed by Banco Itaú.

Hence, while the cluster analysis may suggest that some city sizes are more adequate for large-scale bike-sharing systems, it appears that the typology of business model is a more determinant factor for the quality of the service provided. Because of this, the business model typology should be carefully analysed as it is a factor within the control of planning authorities, differently from the population. With this in mind, it was possible to proceed with the next phase, the evaluation of customer satisfaction through three case studies, one for each business model.

4.4 Customer satisfaction to validate the key performance indicators: a cross-check analysis on three case studies

With the objective of setting target values for each of the proposed key performance indicators, a more thorough research was conducted for three of the selected cities. Based on customer input data availability, the cities of Turin (Italy), Washington (United States) and São Paulo (Brazil) were analysed.

Due to time limitations, instead of conducting new customer satisfaction surveys, this information was collected from municipalities and operators, as some schemes do have periodic inquiries aiming to improve their service. Although these surveys were carried out by operators seeking to improve the quality of service provided, due to privacy issues it was impossible to access the raw data. In this way, it was necessary to rely on the aggregated results, which is a limitation for this part of the research.

4.4.1 Turin: public business model

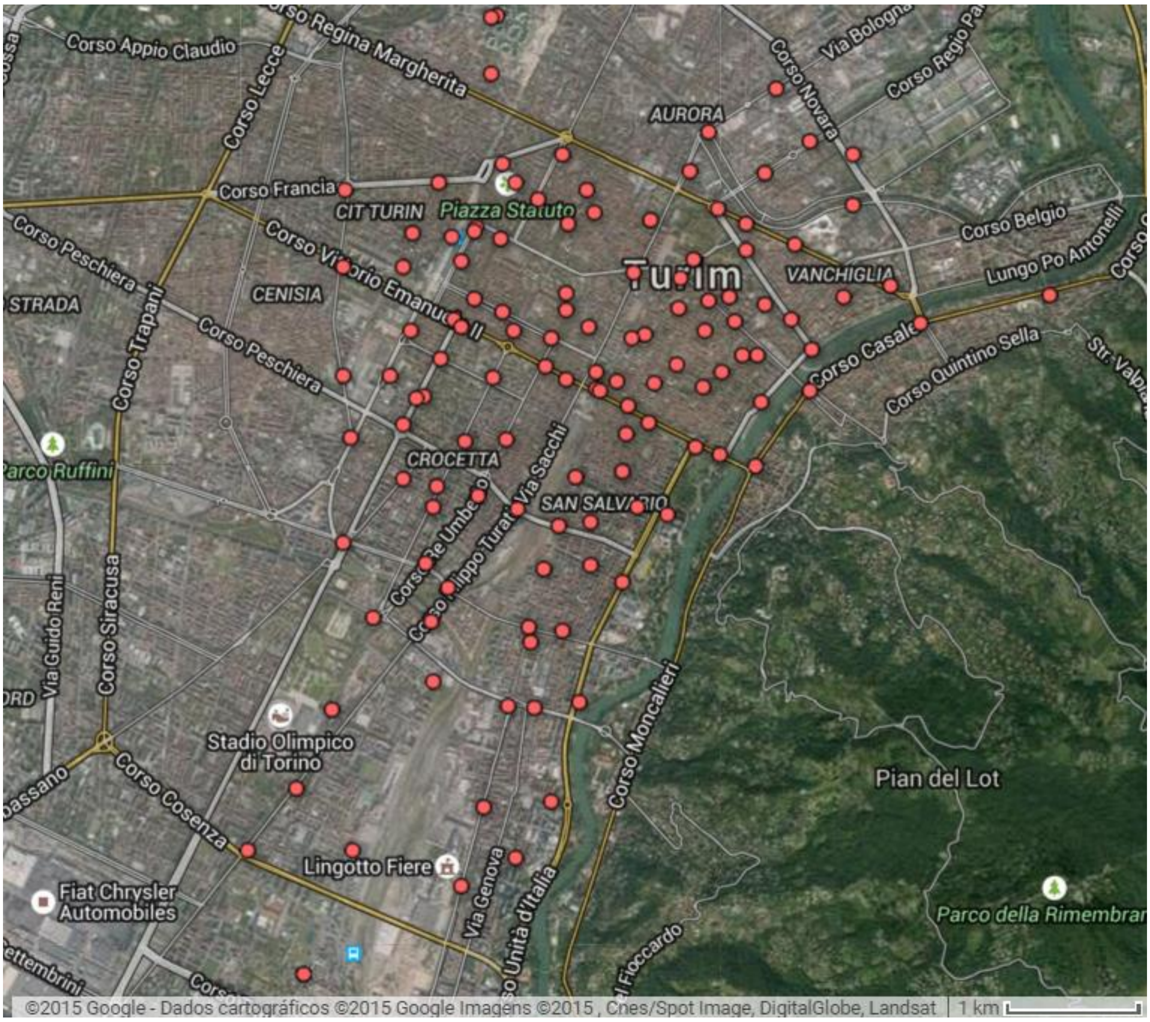
The city of Turin is located in the northwest of Italy. It is the 4th most populated agglomeration in the country, with over 1.5 million inhabitants within its metropolitan area. It is also one of the economic centres of Italy, with a GDP per capita of €28.900. Like most European cities, it has a fairly developed public transport network. Today, Turin has a total of

175 kilometres of cycling lanes.

4.4.1.1 System overview

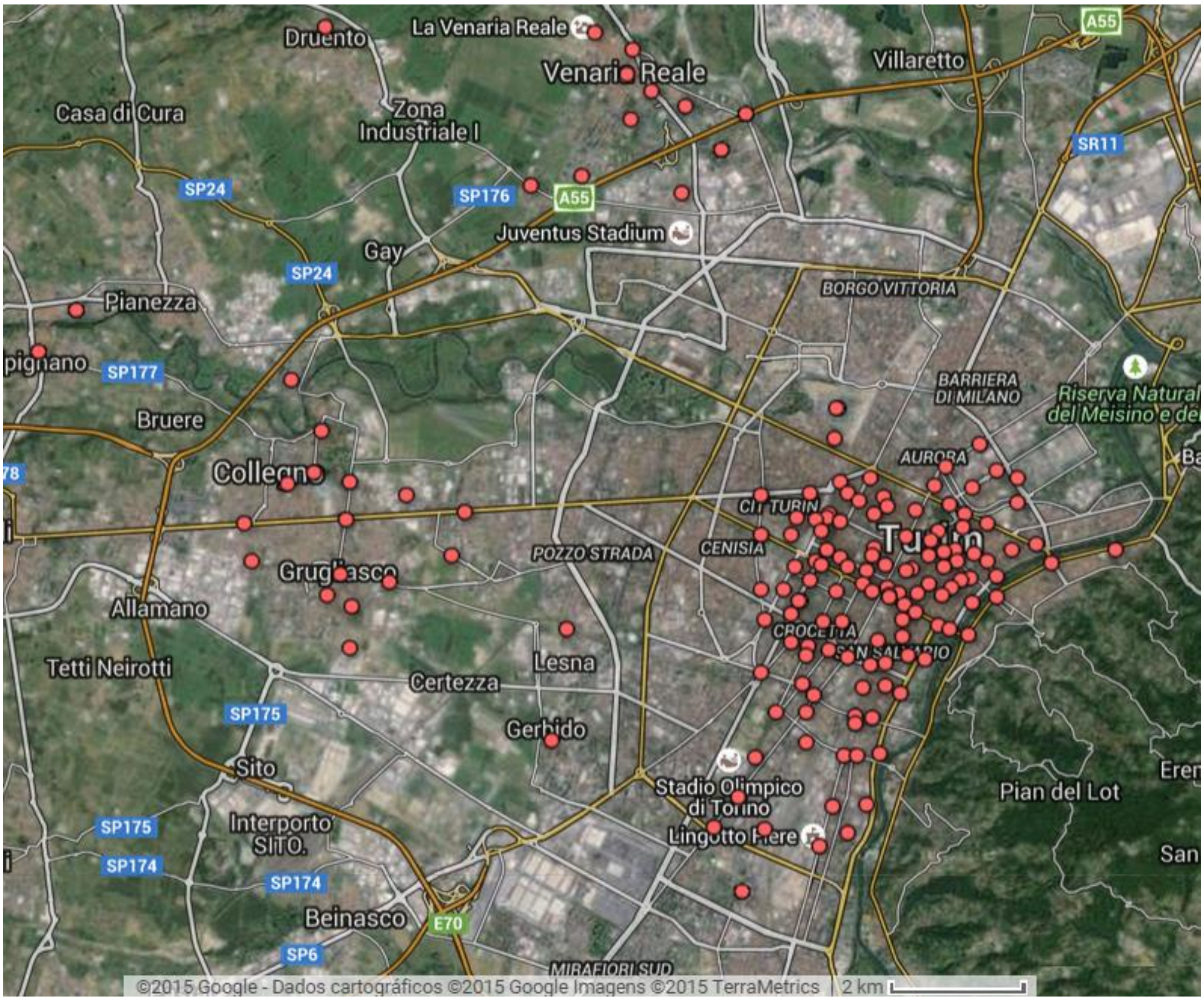
Turin's public bicycle scheme, [TO]Bike, was initiated on the 6th of June 2010. It is a public business model scheme, managed by the city of Turin. Today, it has 1.200 bicycles spread throughout 150 docking stations, with more than 2.000 docks. Most of the stations are located in the central area of the city (Figure 41), with a few located in the municipalities of Collegno, Grugliasco and Venaria Reale, within its metropolitan area (Figure 42). Docking stations are open 24 hours a day, all year long.

Figure 41 - Map of [TO]Bike stations in the central area of Turin



Source: author, Google Fusion Tables

Figure 42 - Map of all [TO]Bike stations in the city of Turin and surroundings



Source: author, Google Fusion Tables

[TO]Bike annual membership costs €25, of which €5 are granted as credit. The system offers 30 minutes for free and after it charges €0,80 for the additional first half hour, €1,50 for the second and €2 for every additional 30 minutes after, for annual pass holders. The system also offers weekly passes for €8 and daily passes for €5, both with €3 credit included. For weekly and daily users hourly fees are slightly higher, starting at €1 for the second half hour, €2 for the third half hour and €3 for every additional 30 minutes after. Finally, the 4FORYOU pass grants a total of 4 hours of bicycle use within a day for €8, while the 8FORYOU pass grants 8 hours within 48 hours for €13.

As of August 2014, [TO]Bike had over 23.000 registered users riding an average of 8.000 daily trips. This is the equivalent to 6,7 uses per bicycles and 0,35 trips per user in average every day. Moreover, during public transport strikes, this figure can scale to 10.000 daily trips, which corresponds to 8,3 daily uses per bike, and 0,43 daily user trips.

4.4.1.2 System performance

Table 12 presents the performance levels for the selected metrics for the [TO]Bike system in comparison with its cluster, business model and global averages. The arrows represent how each of the average values is related to the system being analysed: if the comparable average is significantly higher than the [TO]Bike value, it is represented with an upward pointing arrow (↑); if the analysed average is significantly lower than the [TO]Bike value, it is represented with a downward pointing arrow (↓); finally, if the difference observed was no more than 10% of the [TO]Bike reference value, the averages were considered to be at level, represented by the ≈ symbol.

Table 12 - Performance levels for [TO]Bike

Key performance indicator	[TO]Bike	Large cities average	Public business model average	Global average
Average distance between stations (m)	-	350	350	340
N. of bicycles per 100.000 inhabitants	79	90 ↑	160 ↑	114 ↑
N. of stations per 100.000 inhabitants	9,9	8 ↓	11,4 ↑	8,7 ↓
Registered users per km of cycling lane	131,4	261,1 ↑	88 ↓	283,7 ↑
N. of bicycles per km of cycling lane	6,9	9,5 ↑	5,7 ↓	11,9 ↑
N. of docks per bicycle	1,70	1,81 ≈	1,91 ↑	1,72 ≈
Average docks per station	13,6	19 ↑	20,6 ↑	20,1 ↑
Average n. of bicycles per station	8,0	10,9 ↑	15,5 ↑	13,7 ↑
Average daily uses per bicycle	6,7	3,3 ↓	4 ↓	3,5 ↓
Average daily trips per registered user	0,35	0,31 ↓	0,4 ↑	0,34 ≈
N. of bicycles per 100 users	5,2	21 ↑	25,4 ↑	16,8 ↑
Registered users times register price	575.000	1.042.771 ↑	1.146.337 ↑	1.717.626 ↑
Register price per GDP per capita	0,09%	0,12% ↑	0,17% ↑	0,14% ↑
Registered users per city population	1,51%	3,08% ↑	5,38% ↑	3,69% ↑

Source: author

By analysing the different dimensions shown in Table 12, some points are worth of notice. First of all, despite the fact that there was no official [TO]Bike data available concerning the average distance between docking stations, it is safe to assume that this figure ranges between 300 and 500 meters. Not only this is the suggested distance for a bike-sharing scheme to operate, but also it was the case for every other scheme analysed.

Regarding system dimensioning, two different results were found regarding bicycles and stations. While the ratio of bicycles per total population was below the average, the number of stations seemed to be greater than comparable cities and global average, standing only slightly lower than the business model average. This means that the system could be operating with more stations than needed, with a possible shortage of bicycles. In fact, by observing the indicator referring to system sizing adequacy, it is clear that the number of bicycles for every 100 users is much lower than the comparable averages, thus confirming this last hypothesis. Because of this, bicycle availability can be compromised, as demonstrated by the low ratio between the average number of bicycles per station. Additionally, the fleet sizing in respect to city infrastructure was also low, as the number of bicycles per existing km of cycling lane was only higher than the public business model ratio, while standing well below the global average. However, it is important to note that the cycling network in Turin is not among the most developed, with only 175 kilometres in total.

When it comes to system reach and market penetration, the results are similar. The amount of registered users in [TO]Bike appears to be very low in comparison to other schemes. The ratio between riders and kilometres of cycling lane is half of the city cluster average and even less than the global average, standing only higher than public business model schemes. Likewise, system market penetration is quite low, as only 1,51% of the city’s total population have acquired a membership. Although this was not among the lowest percentages, it is well below all the three averages. Moreover, the product between users and price charged is also very low, meaning that the system could also be under-priced. Indeed, the pricing adequacy measured by the register price as a percentage of GDP per capita is among the lowest when compared to all the analysed schemes.

At first glance, it seems that concerning system usage and fleet rotation [TO]Bike operates efficiently. The number of daily trips per user is at the same level or only slightly different from the other averages and daily uses per bicycle are well above other figures, standing within the proposed range between 4 and 8 average daily pick-ups. However, it is necessary to keep in mind that both system fleet and pool of registered users are quite low, thus considerably increasing these ratios.

Finally, the parking space availability was slightly lower or at level with the other averages, all of which did not reach the initially proposed ratio of 2 to 2,5 docks per bicycle. In addition, the number of docks per station was much lower with only 13,6 in average. This does not necessarily reflect a negative aspect of [TO]Bike, instead it demonstrates a less concentrated system network.

In short, it appears that [TO]Bike is not performing very well when compared to other corresponding schemes. In order to assess this hypothesis, it is necessary to evaluate the customer satisfaction, as it is a more accurate measure of the excellence of the service provided from the user's point of view.

4.4.1.3 Customer satisfaction survey

In November 2014 the municipality of Turin conducted a survey regarding diverse quality aspects of the [TO]Bike service. This investigation aimed at measuring user satisfaction by identifying the best and worst features of the system. Additionally, it sought to collect suggestions on how to best improve the service and implement a performance measuring method that could be replicated over time. It was doing using the SERVQUAL theoretical model, which allows for the estimation of how much each single aspect of the service contributes to overall customer satisfaction.

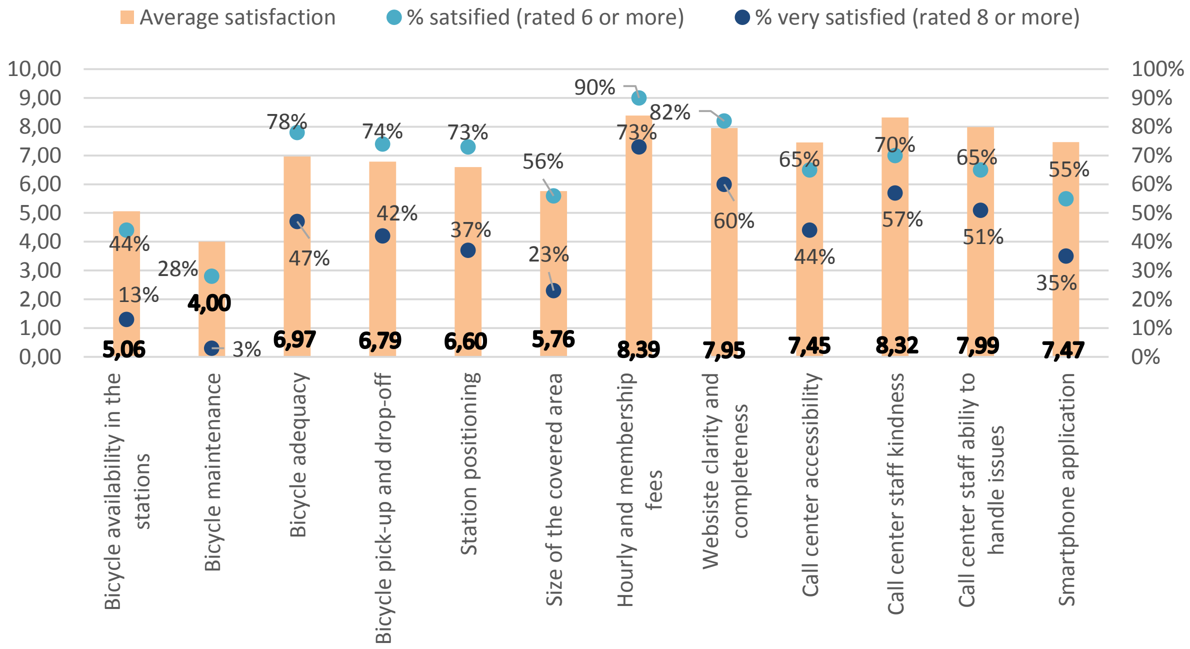
The considered population consisted of all registered users who had used the service at least 20 times in the last 12 months, which corresponded to 17.909 users. Then, sampling was made based on gender, age and home address. Finally, the survey link was sent by email to 7.367 users, a number three times higher than the statistical sample needed, in order to account for those who did not fill it in. The result was a respondent sample of 2.642 users consisting of 1.357 men and 1.285 women, of which 81% lived in the central area of Turin and 4% in its metropolitan area. Regarding age, 21% were between 16 and 28 years old, 25% between 29 and 39, 35% between 40 and 55 and the remaining 19% had more than 55 years of age. Concerning education, the sample did not seem to be very representative of the population: 67% had a university degree and the remaining 33% had a high school or comparable technical degree. Moreover, when asked about current occupation, 15% said that they were students and only 3%

said were unemployed and looking for work. Lastly, 64% of total respondents claimed they owned a bicycle.

In respect to system usage, 33% said they used [TO]Bike only a few times per month, 57% said they used it a few times per week and only 20% claimed to use the service daily. In addition, only 42% of the respondents declared to use the service for work or study related trips, while the remaining 58% uses [TO]Bike for leisure and other activities. Furthermore, 29% of respondents claimed their average trip time was under 15 minutes, 68% said their average time was under 30 minutes and only 3% said they spent more than 30 minutes on trips. Last of all, 92% of the consulted users do not use the stations on the neighbouring municipalities of Turin, and 36% do not use the official [TO]Bike smartphone application, of which one respondent out of four did not know its existence.

When it comes to the actual satisfaction survey, customers were asked to rank eleven quality factors on a scale from 1 to 10. From this information it was possible to infer for each factor the average customer satisfaction, the percentage of customers who were satisfied, which are those who graded 6 or more, and the percentage of customers who were very satisfied, that is, those who rated 8 or more (Figure 43).

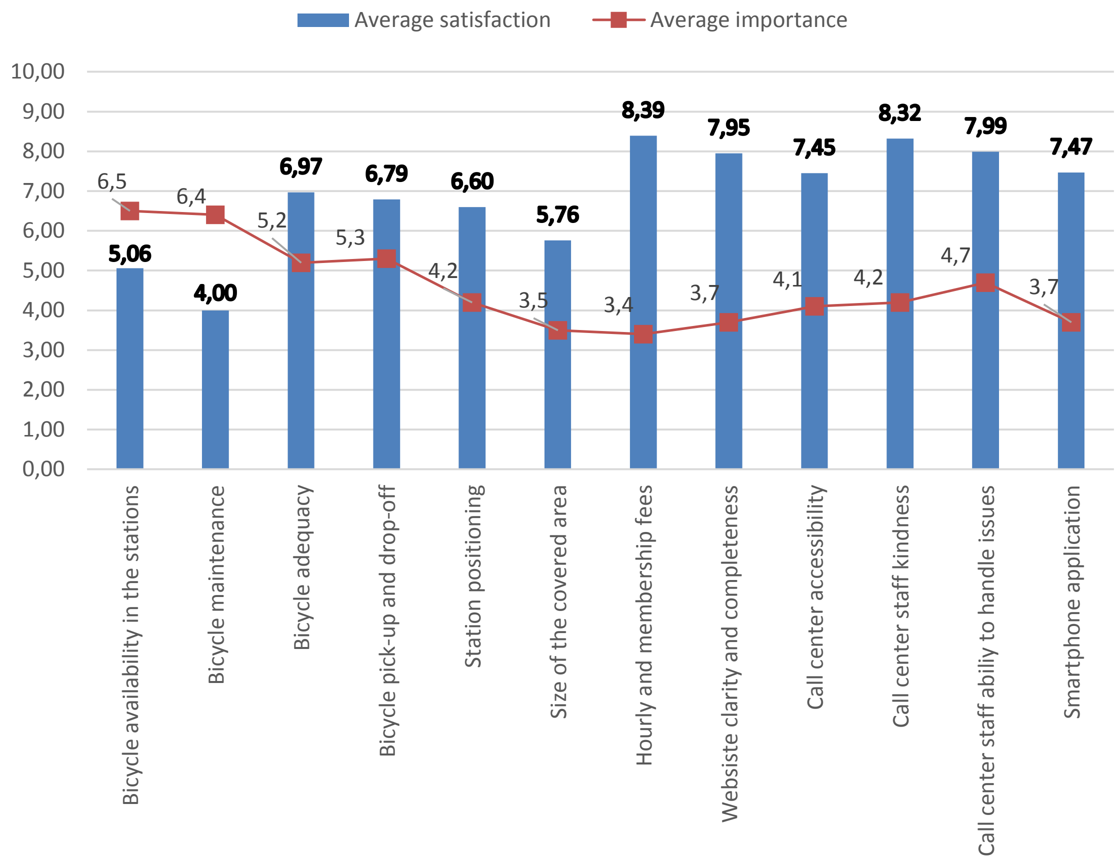
Figure 43 - [TO]Bike customer satisfaction



Source: adapted from [TO]Bike 2014 customer satisfaction survey

Additionally, the respondents were asked to rate the average important of each factor (Figure 44).

Figure 44 - [TO]Bike average customer satisfaction and importance



Source: adapted from [TO]Bike 2014 customer satisfaction survey

Although customer opinion appears to be of overall satisfaction regarding the [TO]Bike service, it is important to note that the two most important factors according to users are those which presented the lowest performance rating.

From the survey results it was possible to conclude some other important points regarding the [TO]Bike system. First of all, it appears that bicycle availability and bicycle maintenance are two urgent priority areas for improvement that the municipality of Turin must keep in mind. This is due to the fact that not only these were the two lowest rated aspects, but also the two with the greatest assigned importance. Additionally, the system rated quite high on most aspects that were rated with little importance from the users, which means that maybe some resources and staff can be better allocated in order to improve the score of most critical factors. Finally, it appears that most of the users do not use the stations in the surrounding areas of Turin. Investigation should be conducted in order to explore the cause of this, and expansion should be focused aiming further integration with the city centre.

4.4.1.4 Cross-check analysis

When comparing the survey results with the performance levels obtained in the key performance indicator analysis, some important insight is reached. It is important to keep in mind that not every metric has a correspondent customer input. This is due to the fact that this analysis was based on a customer satisfaction survey previously administered, which was not tailored to meet the exact dimensions evaluated by the key performance indicators. Because of this, the final comparative analysis will be limited to a few of the metrics, those that can be correlated with the feedback given by the respondents.

First of all, bicycle availability was evaluated as a critical issue as mentioned in the paragraph above, with an average satisfaction of 5,06 out of 10 and average importance of 6,5 in the same scale. Additionally, only 44% were satisfied with this aspect and 13% very satisfied. Not surprisingly, the [TO]Bike system rated the 6th worst in the bicycle availability key performance indicator, measured by the average number of bicycles per docking station. Moreover, fleet sizing ratio showed there were only 79 bicycles per every 100.000 inhabitants, as opposed to a global average of 114.

Secondly, it is possible to draw a parallel between two dimensions questioned and system station sizing. Users rated station positioning at 6,60 (73% satisfied, 37% very satisfied) and size of the covered area at 5,76 (56% satisfied, 23% very satisfied). Moreover, users rated the importance of these two aspects respectively at 4,2 and 3,5. Comparably, the ratio for the number of stations per 100.000 inhabitants was more or less the same of the other values, standing at 9,9, whereas global average was 8,7.

Finally, a clear relationship can be observed between user opinion on hourly and membership fees and system pricing adequacy. While customers rated an impressive 8,39 out of 10 for this aspect, the register price as a percentage of GDP per capita stood at 0,09%, which was considerably lower than all three averages. Although this figure is not among the lowest in all schemes, it is important to note that customer opinion rated 8,39 not only for register price, but also for hourly fees, which are not included in the key performance indicator. Because of this, it is natural that user opinion rated very high whereas the metric rated somewhat lower, as the hourly fees of the [TO]Bike system are also considerably low, as observed in previous sections.

Although [TO]Bike presents some issues related to system dimensioning and availability, customers appreciate the fact that it is a rather cheap scheme, thus lowering some expectations regarding the service quality. All in all, there was a consistency between the quality perceived by the users and the performance evaluated by the key metrics. Hence, it appears that that the designed indicators do reflect the performance of a bike-sharing system. However, further investigation has to be conducted regarding the other case studies before any major conclusions can be stated.

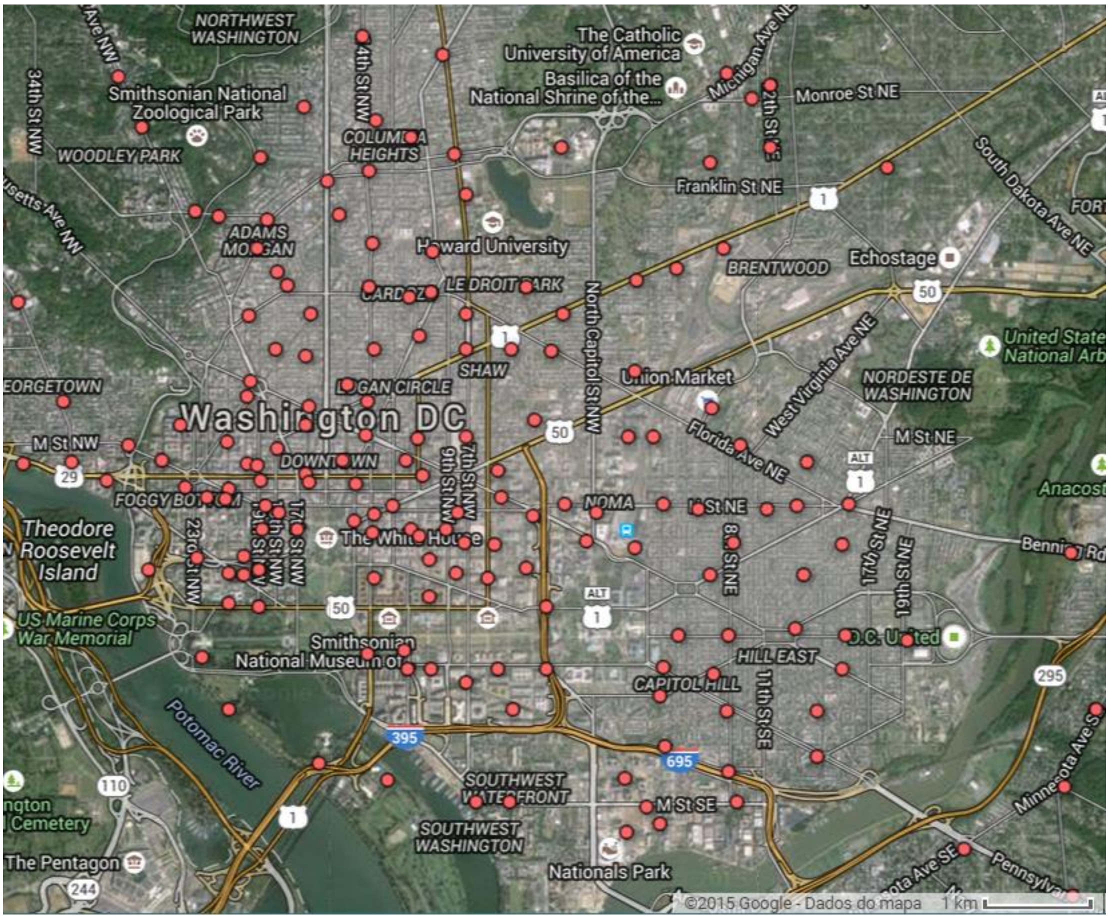
4.4.2 Washington: public-private partnership

Washington, the capital of the United States of America is located in the state of District of Columbia in north-eastern coast of the country. It has a population of more than 5 million inhabitants in the metropolitan area, with a GDP per capita of €66.700. Like many American cities, Washington is highly populated agglomeration spread in a large area, which favours car mobility. Although this mobility culture makes it difficult for bike-sharing systems to thrive in some of these cities, such programmes are likely to succeed in compact urban areas and dense neighbourhoods with younger people. Implementation of shared bicycles in the United States in fact are a manner of providing individuals with greater number of mobility options (DEMAIO; GIFFORD, 2004). The municipality of Washington is already trying to change this culture, as today there are around 111 kilometres of marked cycling lanes within the district.

4.4.2.1 System overview

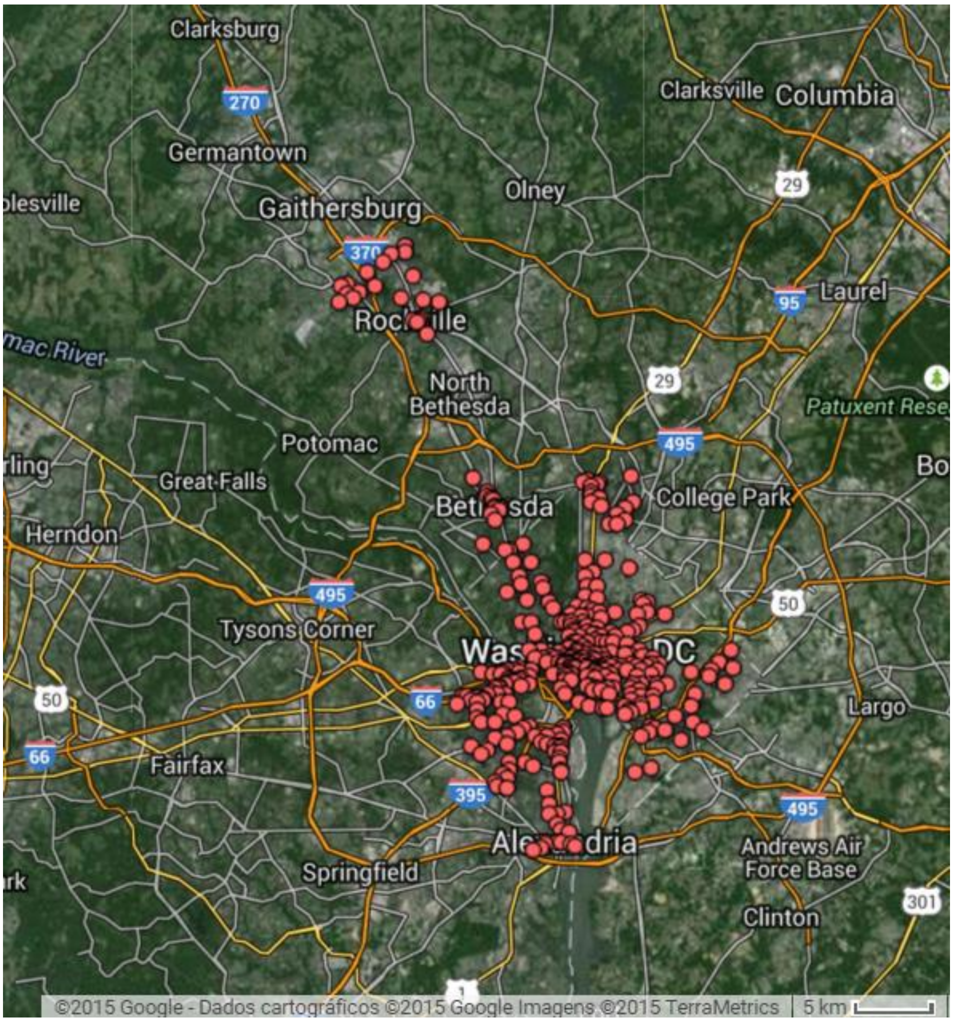
The Capital Bikeshare programme was inaugurated in September 2010 through a public-private partnership between the D.C. Department of Transportation and Alta Bike Share private operator. Today, a total of 3.000 bicycles are available in 350 docking stations in the central area of Washington (Figure 45) and neighbouring counties of Arlington and Alexandria in Virginia, and Montgomery in Maryland (Figure 46). All stations are available 24 hours a day throughout the whole year.

Figure 45 - Map of Capital Bikeshare stations in the central area of Washington



Source: author, Google Fusion Tables

Figure 46 - Map of all Capital Bikeshare stations in the city of Washington and surroundings



Source: author, Google Fusion Tables

Capital Bikeshare has several different membership typologies from which users can choose. Annual membership costs €77,26 ($85) or €87,26 ($96) if paid in monthly instalments. In addition, a 30-day pass is priced at € 25,45 ($28), while the 3-day pass costs € 15,45 ($17). Finally, a 24-hour pass costs € 7,27 ($8), or it is possible to purchase a day key for € 9,09 ($10), with which every additional day costs only € 6,36 ($7).

Concerning usage hourly fee structure, the first 30 minutes are free of charge for all users, regardless of membership type. For users possessing an annual membership, a 30-day pass or a day key, the second half hour of use costs €1,36 ($1,5) and the third half hour costs more €2,73 ($3). After that, an additional of €5,45 ($6) is charged for every subsequent half an hour, to a maximum of €64,08 ($70,5) for 24 hours. Fees are slightly higher for 24-hour pass and 3-day pass users: second half hour costs €1,82 ($2), third half hour costs an additional €3,64 ($4) and after that every 30 minutes adds €7,27 ($8) to the charge, up to a maximum of €85,44 ($94) for 24 hours.

Considering only annual memberships, 30-day passes and daily keys, Capital Bikeshare had accumulated in March 2015 a total of 60.066 registrations, of which 10.153 were annual passes made in the year of 2014. If added the number of 3-day and 24-hour passes, this figure scales to 698.731 total passes. Also during the year of 2014, there were 2.946.108 trips recorded for annual and 24-hour pass holders, which is the equivalent of 8.071 trips per day, or 2,7 daily uses per bicycle on average. When considering only annual pass holders, total trips were 6.374, corresponding to 0,63 trips per registered user. In addition, average trip time was 16 minutes for weekdays, 19 minutes for weekends, and 17 minutes the overall average.

4.4.2.2 System performance

Table 13 presents the performance levels for the evaluated metrics for the Capital Bikeshare system in comparison with its cluster, business model and global averages. The arrows represent how each of the average values is related to the system being analysed: if the comparable average is significantly higher than the Capital Bikeshare value, it is represented with an upward pointing arrow (↑); if the analysed average is significantly lower than the Capital Bikeshare value, it is represented with a downward pointing arrow (↓); finally, if the difference observed was no more than 10% of the Capital Bikeshare reference value, the averages were considered to be at level, represented by the ≈ symbol.

Table 13 - Performance levels for Capital Bikeshare

Key performance indicator	Capital Bikeshare	Very large cities average	PPP average	Global average
Average distance between stations (m)	-	300	336	340
N. of bicycles per 100.000 inhabitants	61	247 ↑	132 ↑	114 ↑
N. of stations per 100.000 inhabitants	7,2	12,6 ↑	10,5 ↑	8,7 ↑
Registered users per km of cycling lane	162,2	107,4 ↓	359,6 ↑	283,7 ↑
N. of bicycles per km of cycling lane	27	13,8 ↓	19,1 ↓	11,9 ↓
N. of docks per bicycle	1,92	2,04 ≈	1,73 ≈	1,72 ↓
Average docks per station	16,5	30,2 ↑	22,3 ↑	20,1 ↑
Average n. of bicycles per station	8,6	15,5 ↑	14,4 ↑	13,7 ↑
Average daily uses per bicycle	2,7	4,4 ↑	4,1 ↑	3,5 ↑
Average daily trips per registered user	0,63	0,26 ↓	0,43 ↓	0,34 ↓
N. of bicycles per 100 users	16,7	10,4 ↓	15,5 ≈	16,8 ≈
Registered users times register price	1.390.656	4.589.705 ↑	1.982.510 ↑	1.717.626 ↑
Register price per GDP per capita	0,12%	0,20% ↑	0,13% ≈	0,14% ↑
Registered users per city population	0,18%	11,60% ↑	4,26% ↑	3,69% ↑

Source: author

As it was the case for the city of Turin, no explicit data were available for the average distance between stations. Nevertheless, this figure demonstrated to be similar for all schemes in which data were available, always between 300 and 500 meters.

As opposed to [TO]Bike, Capital Bikeshare seemed to present an under dimensioning of the station network, reflected by the low ratio between docking stations and inhabitants in the metropolitan area. Additionally, the Washington scheme also appears to have a shortage of bicycles in respect to city population, as it presented a lower figure than the studied averages for bicycles per 100.000 inhabitants. On the other hand, its sizing adequacy ratio measured by the number of bicycles per 100 users is quite high, standing higher or at level with the other averages. This means that the system most likely does not appeal to a significant pool of users, thus raising this ratio. As a matter of fact, the market penetration indicator demonstrates that Capital Bikeshare manage to attract no more than 0,18% of the total population in the metropolitan area of Washington, a figure which is one of the lowest among all systems. Because of this, both the remaining indicators related to the number of registered users must be analysed carefully. Firstly, the multiplication of registered users times price charged results in a lower product when compared to averages as expected, reflecting a poor system reach related to pricing. Secondly, although average daily trips per user presented one of the highest ratios between all systems, this is actually caused by the low amount of registered users, as Capital

Bikeshare actually exhibited a low value for daily displacements when compared to other schemes. Because of this, the ratio between average daily uses per bicycle reflected a poor fleet rotation for the Washington scheme, well below other averages.

Moreover, with 111 kilometres of cycling lanes and marked paths, the cycling network of Washington features among the smallest. Because of this, the fleet sizing in respect to city pedalling infrastructure is very high, as shown by the ratio between bicycles divided by the total length. Nevertheless, the ratio between registered users and total kilometres of cycling lanes is rather low when compared to global and PPP averages because of the small user pool the system owns, as detailed above.

Continuing with the analysis, results showed that parking space availability is comparable to cluster and business model averages, but still stand slightly below the target range of 2,0 to 2,5 docks per bicycle. In addition, bicycle availability measured by the ratio between bicycles and stations is almost as low as in Turin, well below all three other averages. Still concerning system planning, the average number of bicycles per station ratio was low in comparison to other schemes. This reflects a less concentrated system network, as bicycles presented a greater spread across docking stations.

Finally, the price adequacy determined by the register price as a percentage of GDP per capita demonstrated that Capital Bikeshare has rather low price in comparison to other averages. At 0,12% of the GDP, its relative price was at level with the PPP average and lower than cluster and global average. Moreover, it was slightly higher than the ratio of 0,09% presented by [TO]Bike.

To summarise, it seems that Capital Bikeshare did not perform as poorly as the scheme in Turin. However, some of its most positive indicators were boosted by small dividing factors represented by the very low amount of registered users and daily displacements. Thus, it is fundamental to evaluate the quality perceived by the customer in order to assess the actual system service quality.

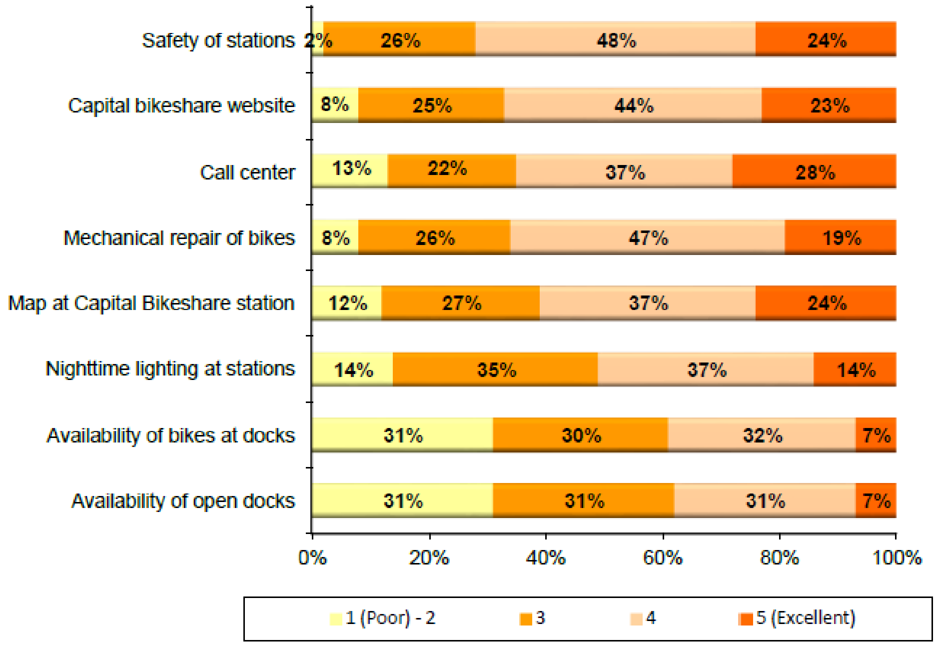
4.4.2.3 Customer satisfaction survey

In November 2014 Capital Bikeshare conducted a customer use and satisfaction survey with the purpose of investigating some aspects regarding system usage: demographic characteristics of users, characteristics of trips, travel changes made in response to service availability and user satisfaction with the features of the service provided. The last item is the most important for this research, as it helps assessing the performance levels of this bike-sharing scheme through the quality perceived by the user.

The respondent sample consisted of 4.314 active members who completed the survey after having received an email with the link containing the questions. Capital Bikeshare staff sent the survey to approximately 27.600 annual and 30-day pass holders, meaning the survey had a total response rate of 16%. Among the consulted users, 91% said they were employed full-time and 5% were employed part time, while 11% of all respondents were students, being 5% full-time and 6% part-time students. Gender wise, 59% of the sample was composed by male users and 41% female users. When it comes to age distribution, 59% of respondents had less than 35 years of age, 21% between 35 and 44, 12% between 44 and 54, and the remaining 8% were between 55 and 64 years old. Lastly, 16% of users reported having an annual income of less than €45.446 ($50.000) and 34% between €45.446 and €90.893 ($100.000) annually, while the remaining 50% reported having an income greater than €90.893 per year. It is important to note that this sample of bike-share users did not mirror the adult population of the metropolitan area of Washington.

With respect to customer satisfaction, respondents were asked to rate certain aspects of the Capital Bikeshare service from 1 (Poor) to 5 (Excellent), as show in Figure 47. Concerning availability, 31% of respondents rated satisfaction as 1 or 2, 30% rated 3, 32% rated 4 and only 7% rated this aspect as excellent. Almost identical results were observed for the availability of open docks, with 31% rating 1 and 2, 31% rating 3, 32% rating 4 and the same 7% rating 5.

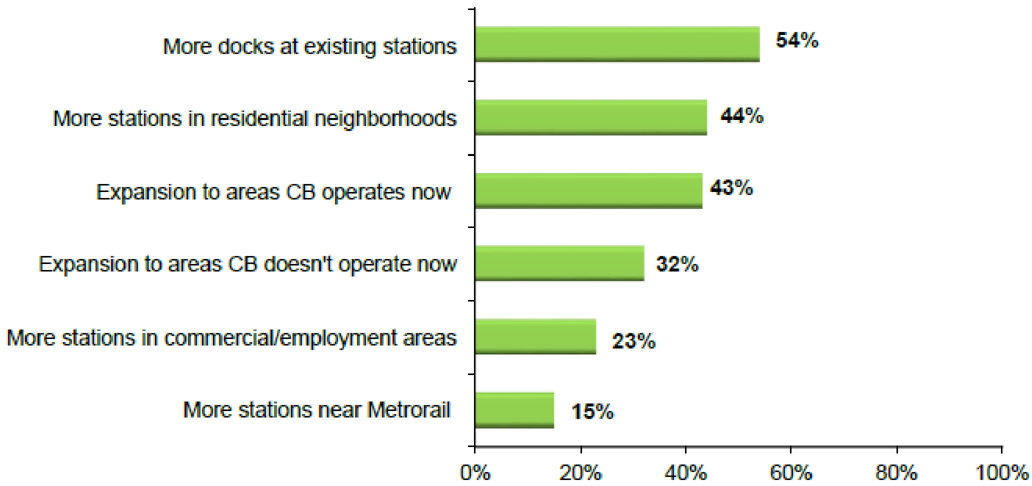
Figure 47 - Capital Bikeshare customer satisfaction rating



Source: Capital Bikeshare 2014 Member Survey Report

Moreover, users were asked how Capital Bikeshare could improve focusing on system expansion. Six options were given, from which users could select as many as they thought relevant (Figure 48).

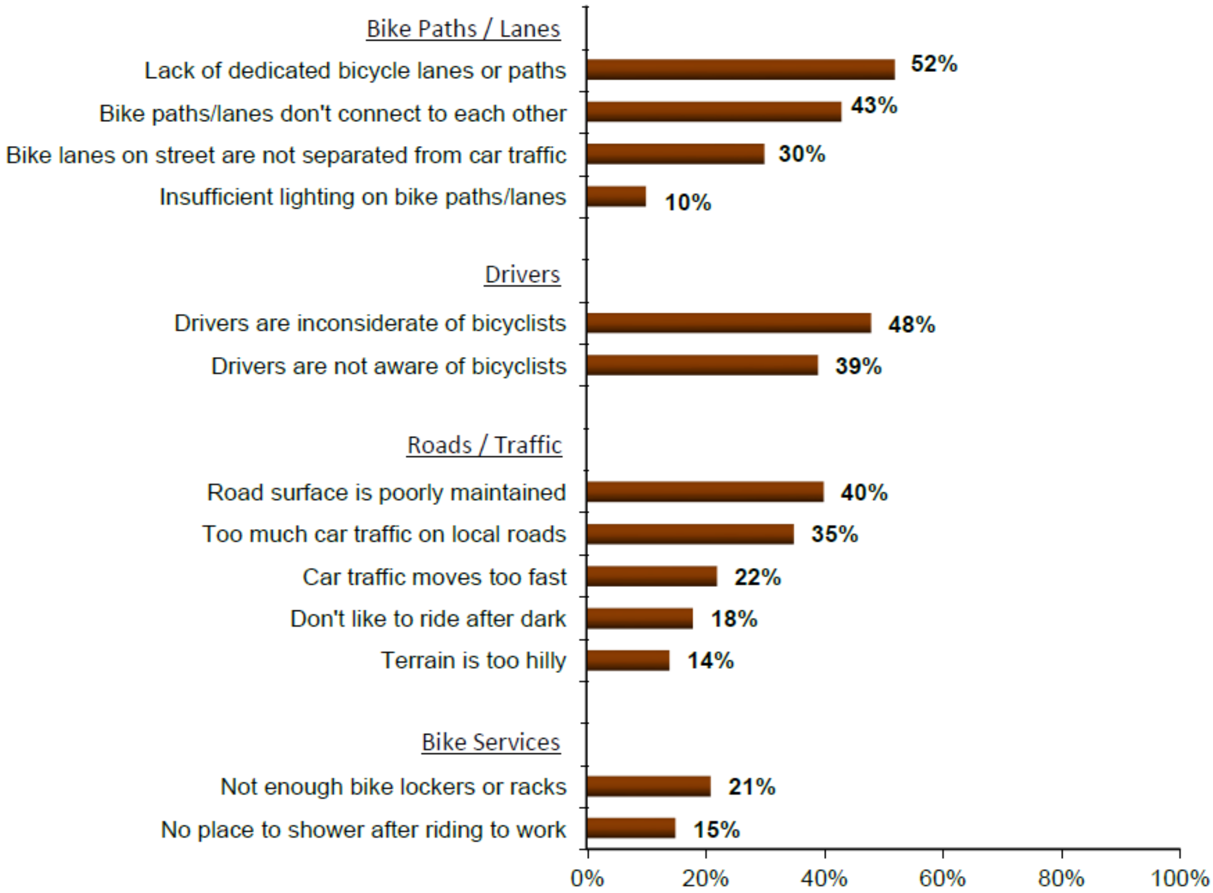
Figure 48 - Most needed Capital Bikeshare expansion alternatives



Source: Capital Bikeshare 2014 Member Survey Report

Finally, when asked what were the main obstacles for cycling in Washington, users gave the feedback depicted in Figure 49.

Figure 49 - Barriers to cycling in the metropolitan area of Washington



Source: Capital Bikeshare 2014 Member Survey Report

Some important conclusions can be drawn from the survey. First of all, it is clear that cycling infrastructure plays a determinant role as a cycling barrier. Also, the cyclists still perceive the behaviour of car drivers as a major obstacle to cycling in the metropolitan area of Washington. When it comes to Capital Bikeshare growth, users expressed greater desire of system expansion in areas it already operates. This means that station density can be improved, and average station distance reduced. Finally, although general satisfaction levels do not seem to reflect any major issues, the availability of bicycles and docking spaces is an important matter that should be worked on in order to improve the quality of the service provided.

4.4.2.4 Cross-check analysis

Again, by confronting the customer survey results to the evaluated performance metrics it is possible to draw a few relationships. Unfortunately, the dimensions analysed in the Capital Bikeshare member survey did not match well the metrics used in the performance analysis. This means that this comparison will be more limited when compared to the [TO]Bike system. Nevertheless, a direct link could be established for some of these aspects.

The first comparable dimension is bicycle availability. Capital Bikeshare users rated the availability of bicycles from 1 (Poor) to 5 (Excellent) as explained above. By weighting the average percentages relative to the mark assigned by customers, the average approximate grade as rated by the users was 2,995 out of 5, which is the exact middle of the 5 point scale. In comparison, the average number of bicycles per station was 8,6, which is a figure considerably lower than the global average of 13,7.

Likewise, while similar respondent percentages rated the availability of open docks at approximately 5,97 out of 10, the performance metric reflected there are 1,92 docks per bicycle in average in the Capital Bikeshare scheme, a ratio that is at level with the other comparable averages, but still lower than the reference value range of 2,0 to 2,5. Accordingly, 54% of the respondents claimed that for the expansion of Capital Bikeshare an increase in the number of docks per station is needed.

Lastly, when inquired on the barriers to cycling in the metropolitan area of Washington, 52% of users mentioned the lack of dedicated bicycle lanes or paths as a problem. Correspondingly, the benchmarking analysis revealed that the cycling network of Washington is among the smallest of all cities, as mentioned before.

Although the obtained average customer ratings were not as low as the relative performance in the evaluated metrics, bicycle availability and dock availability were the two most critical issues of Capital Bikeshare as rated by the users. Moreover, the transformation of user input percentages to a 5 point scale is a mere approximation, as it is not possible to distinguish between the percentage of users who responded 1 and 2 in the 5 point scale. Nonetheless, it seemed that once again the performance evaluation was consistent with customer satisfaction.

4.4.3 São Paulo: private business model

São Paulo is the largest metropolis in Brazil with around 12 million inhabitants, not considering its neighbouring municipalities. It is the capital of the south-eastern state of São Paulo and one of the most important economic centres in South America. Although its GDP is the greatest in the country and features among the largest in the world, GDP per capita stands well below sample average at €13.520. As it is the case for the majority of Brazilian capitals, the city traditionally has a very strong car-oriented mobility culture, with a massive vehicle fleet and daily traffic congestion. However, recent measures have been taken aiming to change this, and bicycles are playing a major role in the process. According to official town hall numbers, São Paulo currently has 323,6 km of cycling routes and paths, most of which was developed in recent years.

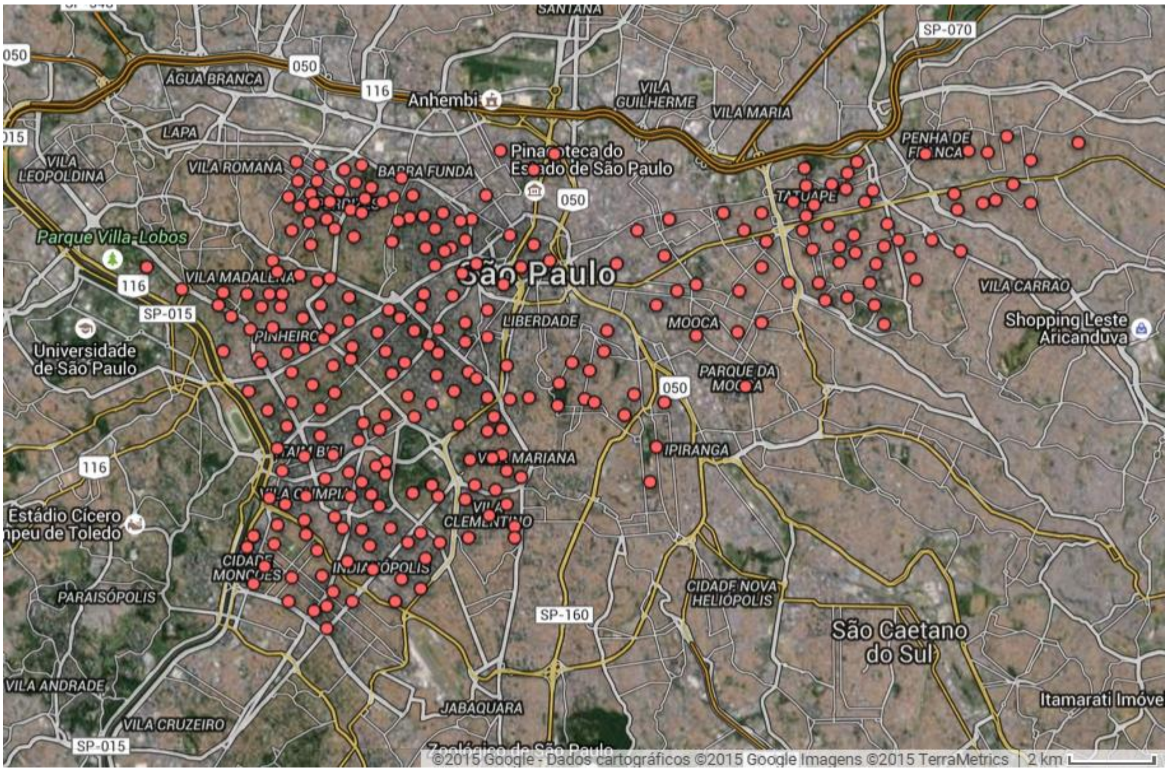
4.4.3.1 System overview

The privately owned bike-sharing scheme of São Paulo, Bike Sampa, was inaugurated in May 2012 following the success of Bike Rio, which inaugurated in November 2011 in Rio de Janeiro. The Brazilian bank Itaú is responsible for financing and managing the whole operation, defining the private business model for bike sharing. Today, five other schemes controlled by Itaú operate in the cities of Belo Horizonte, Brasília, Porto Alegre, Recife and Salvador. Together they have amounted to more than 7 million trips, with a total of 7.500 bicycles in 739 stations. The systems in São Paulo and Rio de Janeiro are the largest ones, both in terms of scheme sizing as well as system ridership. The technology provider for Bike Sampa and the other six schemes is the Brazilian company Serttel, responsible for all the system operation and maintenance.

It is important to note that, unlike Turin and Washington, the city of São Paulo does not have a single functional bike-sharing system. CicloSampa, operated by bank Bradesco, is also a privately owned scheme that currently exists in the city. However, today it is much smaller than Bike Sampa both in terms of fleet and station sprawl. Because of this, it should be made clear that all the analyses in this research regarding the city of São Paulo refer only to the scheme operated by bank Itaú.

Bike Sampa has currently a fleet of 2.590 bicycles spread in 259 stations concentrated in an area of approximately 10 square kilometres (Figure 50). Planning was made taking into account factors such as population and employment density, as well as public transport network and cycling infrastructure. Moreover, São Paulo has uneven topography, which is another important factor that had to be considered when planning station locations. Stations are open from 6:00 to 22:00, every day of the year.

Figure 50 - Map of all Bike Sampa stations in the city of São Paulo



Source: author, Google Fusion Tables

User registration is completely free, which appears to be very uncommon. In the sample analysed, only the city of Taipei in Taiwan presented a completely free of charge registration, and yet charges apply from the initial minute used. On the other hand, Bike Sampa offers a full hour of free time, which is more than the 30 minutes offered by the majority of schemes. In addition, Bike Sampa hourly fee is also quite inexpensive, the fee structure is flat as the system charges only €1,54 (R$5,00) per hour. The reason for this might be related to the fact that cycling is still largely perceived as a leisure activity in São Paulo and in Brazil. Therefore, a free bike-sharing system can be a good strategy for increasing awareness of cycling as a transport mode and changing travel behaviour.

As of 2015, Bike Sampa had a total of 215.966 registered users, of which 86.694 were registered in the year of 2014. In the same year, a total of 508.525 displacements were made, an average of 1.393 daily trips, which correspond to 0,5 daily uses per bike and 0,01 daily trips per registered user. These figures are significantly below averages, which can be explained both by low usage and the fact that registration is free, meaning that the number of registered members will be consequently higher. Additionally, average trip times were significantly higher than other studied cities, standing at 54 minutes for weekday trips and 73 minutes for weekend trips, for an average of 60 minutes for all trips taken in 2014. This can be explained by the fact that, unlike most schemes, Bike Sampa offers 1 hour free of charge, instead of the usual 30 minutes.

4.4.3.2 System performance

Table 14 presents the performance levels for the evaluated metrics for the Bike Sampa system in comparison with its cluster, business model and global averages. The arrows represent how each of the average values is related to the system being analysed: if the comparable average is significantly higher than the Bike Sampa value, it is represented with an upward pointing arrow (↑); if the analysed average is significantly lower than the Bike Sampa value, it is represented with a downward pointing arrow (↓); finally, if the difference observed was no more than 10% of the Bike Sampa reference value, the averages were considered to be at level, represented by the ≈ symbol.

Table 14 - Performance levels for Bike Sampa

Key performance indicator	Bike Sampa	Mega-cities average	Private business model average	Global average
Average distance between stations (m)	-	350	-	340
N. of bicycles per 100.000 inhabitants	22	72 ↑	20 ≈	114 ↑
N. of stations per 100.000 inhabitants	2,2	3,5 ↑	2,0 ≈	8,7 ↑
Registered users per km of cycling lane	531,7	702,1 ↑	356,3 ↓	283,7 ↓
N. of bicycles per km of cycling lane	8,0	30,5 ↑	8,0 ≈	11,9 ↑
N. of docks per bicycle	1,24	1,22 ≈	1,42 ↑	1,72 ↑
Average docks per station	12,4	21,0 ↑	13,9 ↑	20,1 ↑
Average n. of bicycles per station	10,0	24,1 ↑	9,9 ≈	13,7 ↑
Average daily uses per bicycle	0,5	3,5 ↑	1,7 ↑	3,5 ↑
Average daily trips per registered user	0,01	0,55 ↑	0,12 ↑	0,34 ↑
N of bicycles per 100 users	1,5	11,3 ↑	9,7 ↑	16,8 ↑
Registered users times register price	-	3.802.023	1.776.198	1.717.626
Register price per GDP per capita	0,00%	0,22% ↑	0,17% ↑	0,14% ↑
Registered users per city population	1,45%	0,94% ↓	0,76% ↓	3,69% ↑

Source: author

Once more there was no explicit data concerning the average station distance for the scheme being analysed. Nevertheless, this distance rested between 300 and 500 meters for all schemes in the database.

In parallel with the Capital Bikeshare system, Bike Sampa presented an under dimensioning of both fleet and station network. Although figures were at par with private business model average, both ratios were well below cluster and global means. In fact, the number of bicycles per 100 registered users is among the lowest in São Paulo, reflecting a poor system sizing adequacy. Finally, system sizing related to the development of city infrastructure is slightly lower when compared to the global average, and much inferior when compared to the mean value for mega-cities. São Paulo has a total of 323,6 kilometres of cycling lanes and marked paths, which is slightly below sample average.

Planning wise, the number of docks per bicycle is relatively low, standing at level with cluster average but below the other means and the minimum target value of 2,0. This could compromise parking space availability, as there are not enough docks for each bicycle. Likewise, bicycle availability rated low at 10,0 bicycles per station, whereas global average rated 13,7 and cluster average 24,1. Finally, the average docks per station reflected a system network even less concentrated than the schemes in Turin and Washington.

When it comes to system reach and market penetration, Bike Sampa seems to appeal to a significant pool of users. With 531,7 registered users per kilometre of cycling lane, its reach with respect to city infrastructure is above business model and global average. Because the scheme charges nothing for registration, its relative price to GDP per capita stands at 0,00%, making it impossible to assess system reach related to price. Furthermore, although the relative percentage between registered users and total city population was below global average, it is important to remember that São Paulo is a mega-city with around 12 million inhabitants, thus lowering this ratio considerably. Nonetheless, due to lack of registration fees the system should be able to exhibit a greater market penetration.

Last of all, system usage indicators exhibited a very low number of daily trips per registered user. This is due to the fact that, despite not managing to attract a big portion of the total population of São Paulo, Bike Sampa still presented a total of 172.059 registered users. In absolute terms this is a significant figure, which decreases this performance ratio. Even so, the average number of daily trips is quite low when compared to other systems, thus resulting in a low fleet rotation, measured by the average daily uses per bicycle.

To conclude, it appears that Bike Sampa trailed slightly behind Capital Bikeshare and [TO]Bike with respect to some important aspects. Although the relative amount of registered users was at level with the city of Turin and much higher than in Washington, system usage numbers in São Paulo were well below the two other schemes. However, it is important to point out that the Bike Sampa scheme not only is considerably younger than the other two, but also is located in a much larger metropolis with a very strong car culture. Because of this, a customer satisfaction analysis is decisive in complementing the performance evaluation of this system.

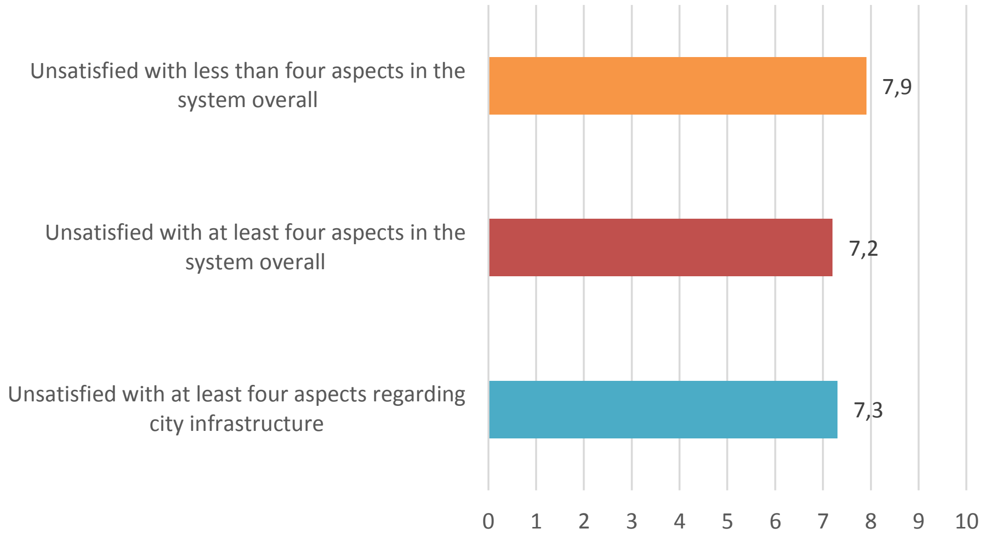
4.4.3.3 Customer satisfaction survey

Concerning customer input, Itaú conducted in 2013 a field survey for the seven Brazilian aforementioned systems. For the city of São Paulo, riders were approached between November 22 and December 11 in the moment of bicycle drop-off. Among the interviewed Bike Sampa users, the great majority ranged between 20 and 39 years of age, comprising 75% of riders, while 13% were 40 or older and 12% were younger than 20. Regarding education, only 6% of the sample did not attend high school, whereas 41% completed it and 53% owned a university diploma. Moreover, 6% earned less than €462 (R$1.500) per month, 21% earned between €462 and €924 (R$3.000), 36% earned between €924 and €1848 (R$6.000), and the remaining 37% earned more than €1848 in average. Therefore, the sample group in question shows a greater share of young and high income educated users, which appears to reflect the profile of the average bike-sharing user in São Paulo.

Concerning system usage, users were asked to what end Bike Sampa most served for them. While cycling is still a developing mode of transport in Brazilian cities, only 43% of respondents claimed that they used the system for leisure trips. The remaining 67% reported work trips (34%), study travels (10%) and personal affairs, shopping and health (13%). However, intermodality is still low, with only 32% of total respondent users commuting bike-sharing with bus (19%), subway (12%), train (4%) and car (3%).

The survey provided important insight regarding the perceived quality of the service provided. When considering all the interviewed users for the Bike Sampa scheme, overall system average satisfaction ranked 7,9 out of 10 (Figure 51). For those who were unsatisfied with at least four items in the system, the figure dropped to 7,2 out of 10, while for those who were unsatisfied with at least four items in the city cycling infrastructure average satisfaction graded 7,3 out of 10.

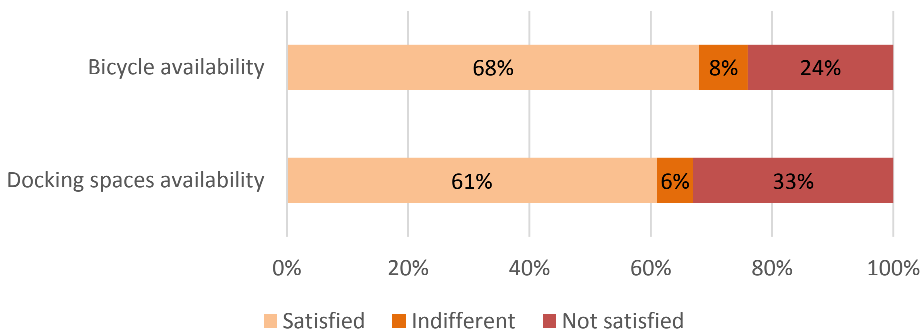
Figure 51 - Bike Sampa overall average customer satisfaction



Source: adapted from Bike Sampa 2013 customer satisfaction survey

Two of the most important aspects regarding customer satisfaction are bicycle and docking space availability. With respect to the first, the survey showed that 68% of respondents were satisfied with bicycle availability, whereas only 24% were not satisfied and 8% were indifferent (Figure 52). For docking spaces availability, 61% of users were satisfied, while 33% were unhappy and 6% indifferent. Moreover, 59% of users are pleased with maintenance, 28% are not satisfied and 13% are indifferent.

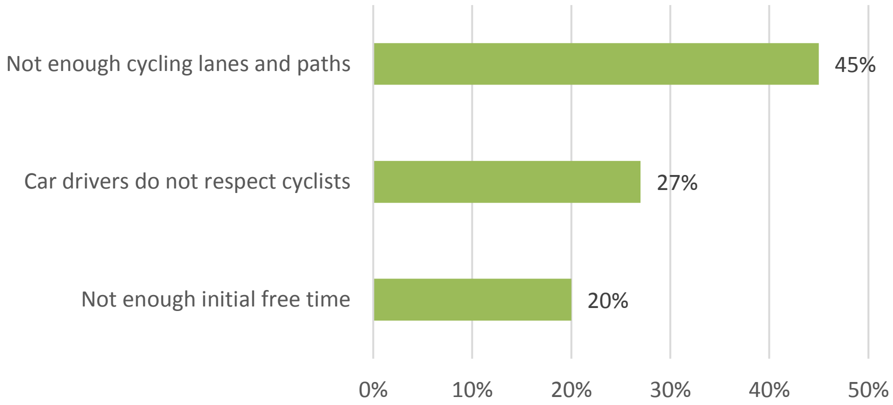
Figure 52 - Bike Sampa customer satisfaction rating



Source: adapted from Bike Sampa 2013 customer satisfaction survey

Furthermore, 45% of Bike Sampa respondents said that there are not enough cycling lanes and paths in the city of São Paulo, while 27% claimed that car drivers do not respect cyclists (Figure 53). Finally, only 20% of Bike Sampa users complained that the initial free time was an important issue, compared to 36% in Rio de Janeiro and 51% in Salvador.

. **Figure 53 - Bike Sampa most relevant user complaints**



Source: adapted from Bike Sampa 2013 customer satisfaction survey

From the survey results it was possible to draw a few conclusions. Firstly, the level of development of the cycling infrastructure seems to greatly affect the system usage. Because of this, expanding cycling lane network can be a determinant factor for the success of bike sharing. Additionally, intermodality levels are still considerably low, especially for a city with the size of São Paulo, where bike sharing should cover the "last mile". Nevertheless, the share for non-leisure trips is satisfying considering cycling is still developing in Brazil as a mode of transport.

4.4.3.4 Cross-check analysis

This part of the case study consists once more in comparing customer satisfaction results to the evaluated performance through the key performance indicators. Because the Bike Sampa survey did not rely on a numerical scale to assess user satisfaction concerning specific issues like the two other schemes did, this comparison will have a more qualitative approach.

Firstly, with more than half of the respondents satisfied, users did not regarded bicycle availability as an issue, as described previously. Intriguingly, although the average number of bicycles per docking station ratio revealed that Bike Sampa stood at level with the private business model mean, it stood well below cluster and global averages.

Likewise, while 61% of respondents were satisfied with respect to parking space availability, the ratio for number of docks per bicycle stood well beneath global average, which also did not reach the target value of 2,0.

Only 20% of responding users complained that initial free time was a problem. Accordingly, Bike Sampa offers 1 hour of initial free time instead of the usual 30 minutes. The benchmarking analysis revealed that this is the maximum initial free time offered by a bike-sharing system, except for a few schemes that operate on an honesty base and do not charge additional hourly fees, as it is the case in Wuhan, Oslo and Stockholm. Additionally, although the cycling network in São Paulo did not feature among the smallest in length, nearly half of users complained there were not enough cycling lanes and paths in the city. This is probably due to the fact that the city has a very large urban area, suggesting that a larger cycling network is needed.

Despite the poor result of Bike Sampa in some metrics when compared to other systems, users appear to be quite satisfied with the system, reflected by the average overall satisfaction of 7,9. However, it is important to keep in mind that this customer satisfaction survey was very limited for the purposes of this research, with no quantitative scaling for none of the evaluated performance metrics. Because of this, the ideal would be to conduct a new satisfaction survey, with a questionnaire designed to match the selected key performance indicators. By doing this it is possible to better assess the consistency of the created metrics, and consequently better evaluate the system performance.

4.4.3.5 Operator validation and proposition of measures for system improvement

Because this work was developed with the support of Banco Itaú, additional information and feedback were obtained from a meeting with the team responsible for Bike Sampa, after these analysis were performed. Unlike the other two case studies, the results were validated and some measures aiming to improve the bike-sharing system were discussed and proposed.

Moreover, the Bike Sampa team provided some important insight regarding the future of bike-sharing in São Paulo, as well as some of their objectives for the next years.

The system is quite new, and so the operator recognizes that it is essential to study other bike-sharing systems around the world in order to identify best practices and replicate them in São Paulo as an approach to improve Bike Sampa. It should be pointed out is that Itaú acknowledges the weaknesses identified by the KPIs and regards them as improvement opportunities rather than flaws. That being said, their bike-sharing team believes that is necessary to keep in mind that the system is located in a city with more than 12 million inhabitants and may present some singularities when compared to smaller agglomerations.

Regarding the KPIs in which Bike Sampa performed worst, some metrics can be highlighted. The first important aspect that was discussed with Itaú was the supposed under dimensioning of the system. The bike-sharing team believes that in a city the size of São Paulo these metrics cannot be directly compared to smaller cities, as the target coverage area does not encompass the full urban agglomeration, thus lowering these indicators. That being said, the planning responsible affirmed that in São Paulo the average distance between stations is actually greater than 500m, as to adapt the bike-sharing system to the environment in which it operates and obtain larger coverage area within the huge metropolis. A clearer definition of the coverage area the system plans to reach is a simple measure that can help Bike Sampa adjust better system dimensioning by considering only the population within its defined boundaries.

When presented with the different results between business models employed, the Bike Sampa team mentioned that there other aspects to be taken into account when planning a public-private partnership. For instance, a local law in São Paulo forbids that large advertising boards are placed in the city, making it impossible for companies such as JCDecaux or Clear Channel to operate in exchange for advertising space under this setup. This is just one example to show that local singularities should also be kept in mind when planning the business model for a bike-sharing system.

Furthermore, it appears that today Bike Sampa has many problems with its technology provider, Serttel. As stated before, the company was created in Brazil and is responsible for the operation and maintenance of all seven bike-sharing schemes managed by Itaú. Today, Serttel is the only major technology provider capable of maintaining an operation as large as Bike Sampa. This may result in a lower quality of the service provided, as there is no competition available. On top of that, Bike Sampa has an exclusivity agreement with Serttel until 2017, making it impossible for the bank to look for alternatives today. Nonetheless, Itaú is already investing in other minor Brazilian companies capable of supplying the technology needed when the current contract with Serttel expires.

In addition, the bike-sharing team commented on some external factors that may change in the next years and can greatly affect the success of Bike Sampa. First of all, there is a certain concern with the upcoming mayor elections in 2016. As of now, the city municipality great encourages cycling and cycling friendly measures, which directly impacts the success of Bike Sampa. For instance, São Paulo has set a target to reach a total of 400 km of cycling lanes in the city, up from 323,6 km it currently has. Should the new mayor choose not to favour the development of cycling infrastructure or even further difficult the process of obtaining the necessary authorizations for Bike Sampa to operate, its usage could decrease significantly.

Last of all, the bike-sharing team in Itaú mentioned that the city municipality intended to unify the two major shared bicycle programmes in São Paulo, Bike Sampa and CicloSampa. In terms of mobility and public transport, the network gain would be enormous, as today the two systems are competitors and not compatible. However, the city proposition was to unify the network by standardising the bicycles and allowing advertising to be placed only in the docking stations. This would greatly impair the current operators (Itaú and Bradesco), as each one has its singular bicycle visually recognizable by its users and attached to the brand sponsoring them. Because of this, it is highly unlikely that this merge will happen in the near future, given the conditions in which it is being proposed.

In sum, Bike Sampa is aware of its current limitations and main issues and is working to fix the problems within its grasp. Some punctual measures to increase popularity such as introductory cycling sessions for children and the implementation of stations inside the São Paulo university campus (USP) are already being discussed. Nevertheless, Bike Sampa plans to expand further in the years to come, provided that it continues to obtain the required authorizations and incentives from the local government to operate.

5 DISCUSSION

This chapter is devoted to comparing the results and findings of the previous section with the initial relevant statements of the literature review.

First of all, the benchmarking revealed that most of the target values set for the performance metrics do not reflect well the current operating bike-sharing systems. As an example, ITDP (2013) had defined the ideal ratio between docks and bicycles between 2,0 and 2,5. However, only eight schemes out of fifty presented a ratio within this range, the rest fell short of it while the scheme in Daejeon was the only placed above 2,5 docks per bicycle. For instance, if the minimal cut value was to be reduced to 1,5 considering that a system fleet is never fully operational, a total of 28 schemes would be placed inside the satisfactory target range. Once more, it is important to remember that, for the same reason, this ratio can be less than 1,0, as the systems sometimes have a total fleet larger than the number of available docks, in order to have a reserve for bicycles in maintenance. This can also help explaining the fact that the initial proposed target range seemed to be too high for the actual system numbers, as it might have not considered this extra non-operating fleet that sometimes exists.

Additionally, the system efficiency target range from 4 to 8 average daily bicycle uses placed only a handful of schemes within its satisfactory range, whereas some were placed above 8 daily uses and most were placed below 4 daily uses.

On the other hand, one target value that seemed to be more aligned with bike-sharing reality was the station density. Although it was not possible to measure the actual number of stations to verify the target range from 10 to 16 per square kilometre, ITDP (2013) provided an approximation of 14 stations per square kilometre as being the equivalent of one station every 300 meters. In fact, as mentioned in the literature review and proven by the benchmarking analysis, the average distance between stations was always between 300 and 500 meters for the schemes with available data. Hence, this metric was the only one in concordance with the situation of current operating schemes.

Table 15 presents the summary of the average numbers found in the results for each of these metrics. Unfortunately, the remaining target values could not be assessed as they involved data concerning coverage area and residents within the coverage area.

Table 15 - Target satisfactory levels proposed by literature and actual results found

Performance metric	Target efficiency level	Global performance average
Coverage area	Minimum 10 km²	-
Station density	10-16 stations per km²	300 to 500 meters for all schemes [1]
Bicycles per resident	10-30 bicycles for every 1.000 residents [2]	-
Docks per bicycle	2-2,5 docking spaces per bicycle	1,72 docking spaces per bicycle
System efficiency	4-8 average daily uses per bicycle	3,5 average daily uses per bicycle
Market penetration	1 average daily trip for every 20-40 residents [2]	-

Note: [1] 300 meters is the equivalent to 14 stations per km²; [2] within the coverage area

Source: adapted from ITDP (2013)

Altogether, this comparison reveals that the target values do not represent the actual situation of currently operating bike-sharing systems. While it would be normal for some schemes to not meet stipulated satisfactory performance baselines, if almost every scheme fails to reach the minimum values it means that these values are not completely adequate. It appears highly unlikely for almost every analysed bike-sharing scheme to be performing at unsatisfactory levels, thus these figures must be adjusted. Future research should take this into account, as it was not in the scope nor within the grasp of this study to propose new target values for the evaluated metrics.

Furthermore, it is necessary to reflect on the efficiency and relevance of the defined key performance indicators and how the results contrast with the initial statements taken set by the literature review. Although the proposed metrics were mainly based on the available data, they have provided important insight concerning different aspects of the current bike-sharing global scenario that will be detailed in this chapter.

By comparing the results obtained with the original factors suggested by the literature as determinants of bike sharing success, it is possible to highlight some relevant aspects. Starting from the exogenous factors, city size measured by its total population was initially regarded as a major influencing aspect. However, this hypothesis was proved inaccurate by empirical data in the benchmarking analysis. For some evaluated metrics, it was expected for the population to play a role in determining performance levels for bike-sharing because they considered parameters that should be naturally larger in highly populated cities, such as the amount of registered users or fleet size. However, even for these metrics, an increasing performance was not clearly related to a bigger city size. Hence, considering the key performance indicators created in this study, the premise that the city size is a major determinant of bike sharing success is not correct.

On the other hand, one exogenous factor that proved to play a significant role in determining the performance of bike-sharing systems was the city infrastructure. As it was stated in the literature review, a minimal and safe cycling infrastructure is needed for bike-sharing schemes to thrive (BÜHRMANN, 2007) and cyclists must be able to travel easily and safely through the city (MIDGLEY, 2011). As a matter of fact, customer satisfaction surveys revealed that users regard this as a major issue for cycling, as it not only reduces the comfort and commodity of pedalling but also increases the perception of danger, which can be a key barrier to bicycle use (PUCHER; BUEHLER, 2006; TRANSPORT CANADA, 2009). Moreover, although no hypothesis was tested to determine the statistical relevance of this aspect, cities with a very low amount of kilometres of cycling lanes and paths performed poorly in comparison to others in many metrics. For example, the Brazilian cities of Salvador and Porto Alegre presented the two shortest cycling networks in length among all studied systems. With 27 and 21 kilometres of cycling lane respectively, both cities ranked among the worst in many of the evaluated metrics. However, it is important to keep in mind that a larger cycling network does not necessarily reflect a more successful scheme. In fact, a highly developed cycling network can reflect a city with a high modal share of cycling, which can be harmful to the success of a sharing scheme, as individuals tend to own and use their private bicycles.

The last exogenous factor that could be assessed through the benchmarking analysis was the economic power of a city. The relative price metric sought to evaluate the pricing adequacy of the bike-sharing schemes, by relating the total registration price as a percentage of the GDP per capita of a city. Despite having not differed significantly for most schemes, the relative price ratio showed that in cities with lesser economic power such as Porto Alegre, Shanghai and Wuhan the price had a larger impact as a percentage of GDP per capita.

For the remaining exogenous factors such as topography, climate and travel behaviour it was not possible to perform any analysis due to lack of data. Moreover, city density was overlooked in this study as it was considered to be similar, but less important than city population.

Concerning the endogenous factors influencing bike sharing success, one aspect stood out in the empirical analysis. As opposed to city size, the type of operator according to the business model presented a strong relationship with the system performance. For the considered dimensions, public-private partnerships exhibited a higher overall performance while the other two models trailed behind, with the private business model performing slightly worse. This is a very relevant finding, as it suggests that cities can greatly improve the performance of a new bike-sharing scheme simply by adopting the best business model. The performance difference can be explained by the fact that a public-private partnership is able to benefit from private funding without facing the challenge of keeping the objectives of the system aligned with public interest, as it will still be managed by a local authority.

Private business model bike-sharing schemes, on the other hand, sometimes diverge from city objectives and end up bringing less benefits to the population in general. For instance, the schemes in Brazil, all managed and funded by the same operator, exhibited an average inferior performance when compared to the other business models for a significant portion of the evaluated metrics. This does not mean that these schemes are flawed, but only that they might not yet fully serve the purpose of a public transport mode, probably because there was little or no urban mobility planning involved in their implementation.

On the matter of bike-sharing purpose, some analysed schemes showed some divergence in respect to some of what was seen in the literature review. According to Transport Canada (2009), shared bicycles are intended for shorter periods of use and a larger number of daily users per bicycle. However, while average trip times were indeed relatively short (mostly due to limited initial free time), empirical evidence showed that these schemes do not have a large number of daily uses per bicycle. As detailed previously, most schemes did not reach 4,0 average daily uses per bicycle, with a global average of 3,5. In fact, some schemes did not even reach the figure of 1,0 daily average trip per bicycle, meaning that these are definitely not used as an exclusive transport mode. Instead, what is observed is that these schemes are serving the so called “last mile”. This shows that bike sharing tends to offer a solution to the short distance between a public transport station and a destination by attracting walkers and public transport commuters, as explained by DeMaio and Gifford (2004) and Shaheen; Guzman and Zhang (2010). Nevertheless, a more thorough analysis considering average trip distance would have to be conducted to sustain this hypothesis with greater certainty.

Moreover, concerning customer satisfaction, it was clear from the three case studies that the survey results corroborate the measured KPI values. For most of the points for which the users reflected dissatisfaction, the evaluated metrics reflected a relative inferior performance when compared to other schemes. For example, the most critical aspect of Capital Bikeshare, as defined by users, was bicycle availability. Accordingly, the average number of bicycles per stations in Washington rated at 8,6, a figure well below the global mean of 13,7. Likewise, a high level of satisfaction reflected a performance at least at par with schemes in other cities. For instance, customer satisfaction analysis in Turin revealed that users are highly satisfied with registration prices and hourly fees. Comparably, the relative price for [TO]Bike corresponds only to 0,09% of GDP per capita, a percentage which is fairly low in comparison to other schemes. However, it is important to bear in mind that the customer satisfaction analyses were limited to surveys not specifically designed for the comparison with the key performance indicators defined in this study.

Still concerning the case studies, it was not possible to infer any relationship among the three cities. With three customer satisfaction surveys very different from one another, the comparison with the key performance metrics was unique to each case. Hence, the analysis was limited to assess the performance of each of the schemes related to its perceived service quality.

Finally, it is true that in this work some important aspects of bike-sharing have been overlooked due to lack of data, such as maintenance and coverage area. Because of this, it is important for the official operators to make information more readily available for research. Only when a significant amount of statistics has been gathered and analysed for many systems around the world, research in this field will be able to draw additional conclusions and further improve the quality of bike-sharing schemes. Nonetheless, this study may be perceived as a starting point for future research in bike sharing in this sense, as it not only gathered a considerable amount of data but also designed key performance indicators for bike sharing that can be easily reapplied to any scheme.

6 CONCLUSIONS

This study aimed at evaluating the performance of bike-sharing systems and sought to determine whether the business model employed was determinant to the efficiency of the service provided.

The first finding of this research is that bike-sharing data are extremely disperse and unstandardised. The lack of a central information can be a significant obstacle for research in the subject of bike sharing. Nevertheless, this study succeeded in gathering a considerable amount of information on 50 relevant schemes around the world in order to evaluate their performance.

The most relevant result of this work shows that business model typology does affect the performance of a bike-sharing scheme. The benchmarking analysis revealed that public-private partnerships have higher average efficiency levels when compared to the other two business models. While the public business model relies exclusively on public funding to operate, private schemes might diverge from public objectives, thus reducing the benefit to the population. The hybrid model has the advantages of both plain models, while being able to cope with the disadvantages of each. Because of this, systems planned in this manner appear to be more efficient in average, according to the key performance indicators here proposed. It is important to add that private schemes were the ones that in average had the poorest performance according to the efficiency metrics, most likely due to this conflict of interest.

Additionally, while city typology determined by its population was considered to be a major determining factor for the efficiency of a bike-sharing scheme at first, results showed otherwise. Although some relationship tendencies were identified in a few metrics in the performance analysis by city clusters, the different classes did not differ largely regarding most of the evaluated dimensions. Nonetheless, the created key performance indicators were all defined as a relative ratio with respect to different factors including population, meaning that in the end it is not a surprise that no trend was established concerning city size. If this analysis had been performed in absolute terms probably a clearer trend would be evident.

When it comes to the key performance indicators employed in the analyses, results revealed to be optimistic. Not only it was possible to find a relationship between business typology and system efficiency, as mentioned above, but also the performance levels associated with these metrics were consistent with user input. As shown by the customer satisfaction surveys, users were more satisfied with high-scoring metrics and displeased with lower ratios. Hence, it is possible to acknowledge that the created indicators succeeded in evaluating the performance of bike-sharing systems.

Nevertheless, it is important to keep in mind that these metrics were specifically designed based on the parameters available. Because of this, the comparison between the evaluated performance and user satisfaction in the case studies was rather limited. This is due to the fact that all the three analysed customer satisfaction surveys were previously carried out by each operator, due to time constraints. A survey designed specifically based on the used KPIs would certainly contribute to a more precise cross-evaluation of customer satisfaction and system performance.

Moreover, it is important to bear in mind the fact that the designed key performance indicators fail to evaluate some important dimensions of bike-sharing systems. Relevant aspects such as bicycle maintenance and redistribution and cycling safety were already included in the customer satisfaction surveys but could not be measured by the created indicators due to lack of data.

Finally, the database created in this study should serve as starting point for the establishment of a bike-sharing data archive. As an emergent alternative form of transport that seeks to resolve traffic congestion and pollution issues, bike sharing deserves full attention from mobility researchers around the world. Future research should use the data collected in this work and focus on improving this database and, with the support of operators, create a reliable and consistent information source for bike sharing. It is only when knowledge is shared and best practices are replicated that bike-sharing systems will be able to act as an efficient and sustainable transport mode.

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