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Sustainable bike-sharing systems: characteristics and commonalities across cases in urban China

Lihong Zhang [a], Jun Zhang [b,*], Zheng-yu Duan [c], David Bryde [d]

[a] Liverpool Business School, Liverpool John Moores University, UK
[b] School of Design, Hunan University, China
[c] School of Transportation Engineering, Tongji University, China
[d] School of the Built Environment, Liverpool John Moores University, UK

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ABSTRACT

Bicycles are a desirable form of transportation for many reasons, including the fact that taking a bicycle is environmentally-friendly, economically cost-effective, a way to keep fit and healthy and, on occasions, an enjoyable social activity. This paper explores the characteristics and commonalities between particular bike-sharing systems in urban areas, with a view to deriving influences on the sustainability of such systems. The empirical study is China and the paper analyses bike-sharing systems in five Chinese cities. China is suffering from the severe negative consequences of high private vehicle usage in large and densely populated cities. Nevertheless a long history of bicycle usage in the country provides great potential for such a green form of travel to be part of public and private transportation. The findings show that bike-sharing systems have varying degrees of success. The configurations which seem the most sustainable consider and integrate elements relating to transport planning, system design and choice of business model. Key conclusions are that those responsible for developing policy and practices in relation to bike-sharing systems need to understand the diverse aspects of value for the stakeholders wishing to engage with such a system. Public bicycle sharing, as a Product Service System, needs to be carefully developed to appreciate the quality and timely interplay between the physical design of the system and the provision of services being offered.

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1. Introduction

In the move towards sustainable consumption and production patterns, mobility is one of the priority areas (together with food and energy). Sustainable mobility suggests seeking an effective way to integrate both product innovation and innovation on the level of the production & consumption system within which the product is placed and which satisfies a particular demand for transportation (Vezzoli and Ceschin, 2008). A move towards sustainable mobility necessitates a reduction in the inefficient use of private vehicles and an increase in access to environmentally sustainable transport, especially for communities with a high percentage of low-income households.

Recent years have seen a rapid development and implementation of public bicycle systems, or "bike-sharing" systems. Depending on the measures used it is estimated that there have been some 461 bike-sharing programmes set up in 28 countries (Beroud et al., 2010); or, alternatively, more than 500 programmes in 49 countries (Larsen, 2013). Technological advances, such as bike tracking, solar powering, telecommunicating and on-line shopping, have helped transform bike-sharing from an aspiration to reality. This aspiration dates back to the 1960's when people initially tried and failed to introduce bike-sharing schemes (DeMaio, 2009; Beroud et al., 2010). It is in this context that China has joined other wealthy countries in developing bike-sharing schemes. Part of the reason for this is that China is, like many other countries, suffering greatly from the negative consequences of an over-reliance on motor vehicles as a primary mode of urban transportation i.e. congested roads causing journey times to be high and carbon emissions from vehicles contributing to high levels of pollution of the air, costly demand for fossil fuels and harmful greenhouse gas emissions.

There is a relatively long history of bicycle ownership and use in China which means it is a logical focus for policy makers seeking alternatives to motor car use in the congested urban conurbations. This history shows three distinct stages of bicycle use in China, as follows:

* Corresponding author. Tel.: +86 18607319812.
E-mail addresses: zhangjun@hnu.edu.cn, zhangjuncoco@gmail.com (J. Zhang).

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a. The early stage from the 1950's to the end of 1970's. The take up in bicycle use was initially very slow but it gradually started to become part of people's daily life as a means of transportation.
b. From the 1980's to the end of the last century saw rapid growth in usage. By the end of this stage there were some 400 million bicycles in use throughout China.
c. From the start of the 21st century to the present day saw a period of relative decline, with motorised vehicles taking the place of bicycles. Despite this trend the serious concerns relating to transportation, energy consumption and environmental pollution saw concerted efforts to encourage Chinese citizens to opt to ravel by bicycle as a green and sustainable form of transportation (Zhao, 2013).

The fact that a bicycle is a cheap and green form of transport, with the attendant sense of freedom that having access to a bicycle brings to its rider, is at the heart of the marketing of the bike-sharing philosophy. As highlighted in recent reports on bike-sharing (see, for example: Fong, 2009; Weber, 2010; Hickman, 2010) the concept of community bike-sharing involves an individual checking out a bicycle from one of several public locations, usually called a docked station and returning it at another location. The principle is to provide an alternative or complementary form of public transport to cover short journeys within city limits.

The interest in bike-sharing has come at a time when issues such as environment conservation, cultural continuity and social and health return on investment all challenge policy-makers to rethink ways of creating shared value (see, for example, Grous, 2011; Porter and Kramer, 2011; Davies et al., 2006). Hence value can be defined in terms of reducing carbon-dioxide emissions, smoothing traffic flows and encouraging a healthier commute to and from work for human beings. This conception of value provides the background to the bike-sharing business: its advantages, benefits to the public, and its limitations (Beroud et al., 2010; Fong, 2009). Bike-sharing, then, is seen as a valuable approach to foster clean and energy-efficient modes of travel in urban areas. Though to make bike-sharing systems sustainable it has been highlighted that three fundamental interrelated factors need considering: the exogenous factors such as bike-ability and safety; the institutional ownership types; and the physical design factors (OBIS, 2011).

Whilst there has been an increase in the number of bike-sharing systems and attendant interest in the topic from an academic perspective (DeMaio, 2009; Lin and Yang, 2011; Shaheen et al., 2012; Fishman et al., 2013), there is still a need for further research in order to gain a full understanding of the contribution a bike-sharing system can make in reducing the reliance on the use of private vehicles in urban environments and in how the systems are configured to maximise the contribution. Such research needs to consider a number of different perspectives which are likely to encompass planning, design and business-related issues. The specific research question that this study seeks to answer is as follows: what are the characteristics of, and commonalities between, particular bike-sharing systems? Our analysis is undertaken in the context of establishing sustainable bike-sharing systems. Here we conceptualise such systems as being sustainable in the sense that they are well-established and making a contribution to the meeting of environmental and social sustainability goals. This does not imply that from an economic perspective they are self-funding, as part of the cost of meeting such goals may be met by the public purse in the form of subsidies.

2. Conceptual framework

In establishing a conceptual framework to guide the study it is useful to view a bike-sharing system through a number of lens: firstly, they are seeking to meet new conceptions of value from both public sector and private sector perspectives – for example a relatively new concept of public value is that such systems become an integral part of the fabric of a city and provide transportation with minimal visual pollution [i.e. see the proposed design for the Copenhagen Bike-sharing System by RAFAA Architecture & Design, which was a reddot design award winner 2010 http://www.rafaa.ch/rafaa/Copenhagn.html]; whilst, secondly, being a mode of transport that can be sustainable for not only bicycle users but also for suppliers, who, thirdly, have to consider financial and economic imperatives. As such, we argue, any analysis of bike-sharing systems cannot be fully complete by taking a single perspective. Hence in developing a conceptual framework for our study we consider bike-sharing systems from the following points of view: 1) transport planning 2) system design and 3) business models. In the next sections we consider each of these in turn.

2.1. Transport planning

Transport is one of the most challenging issues in sustainable urban development and in terms of transport planning a public transit-oriented mode has been officially recommended for most cities in China (Wang, 2002). This indicates that a top priority is given to developing mass public transit systems, such as urban rail (metro, light railway) and BRT (Bus Rapid Transit). The land resource of China has become increasingly scarce rendering a car-oriented transport mode unsustainable, at least in the urban areas where most cities in China have chosen high-density urban development models. Early in 2005, China's General Office of the State Council and the Ministry of Construction promulgated several notices for giving priority to developing public transit (General Office of the State Council, Ministry of Construction, 2005). "Transit Priority" and "Transit City" has become a shared view within all government levels in China. The ultimate purpose of "Transit Priority" and "Transit City" policy is to establish an open regional transit system and to build a transit oriented urban spatial structure (Yang and Zhang, 2011).

As bicycles can be used as a complementary means to public transit systems, a bike-sharing system provides an opportunity to be integrated into urban development. Bike-sharing is a convenient and "green" transport mode, and therefore plays an important and complementary role in the comprehensive transport system. Cycling has several advantages over other transport modes: it requires less facilities, can reach some under-served destinations, and a bicycle is relatively inexpensive to purchase and maintain. Research suggests that a bicycle is an ideal transport mode in 2 km–5 km travel distance range (Li et al., 2009). Using bicycles to connect with buses can solve the problem of the "last mile" in public transit modes. From a sustainable transportation planning perspective, though, the core issue of bike-sharing is: who would be served by such a system?

City dwellers who undertake a daily commute to and from their work and tourists are the two largest groups of transport demand in an urban area. To these groups a bike-sharing system can be an innovative and sustainable solution. In large cities of China, such as Beijing, Shanghai and Guangzhou, the average time of commute is 42 min, which is ranked as the longest in the world (Guan, 2011). Even in a mid-sized city like Zhuzhou the typical commute takes about 30 min. For tourists, riding a bicycle is an attractive activity. Bike-riding can help to protect scenic spots and historical conservation areas and it can also slow down citizens pace of life and improve their quality. For this and other reasons, local planning government departments in Shanghai, for example, are considering building "slow traffic facilities" (Wang et al., 2010). Here they are mirroring Barcelona in Spain and Hangzhou in China, which are

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quoted as the most successful examples of such initiatives (Hangzhou BSS Website, 2009).

2.2. System design

From a system design perspective bike-sharing can be seen as a Product Service System (PSS). According to Goedkoop et al. (1999) and Cook et al. (2006) a PSS requires companies to provide a mix of both products and services, so that sustainability in regard to both consumption and production is possible. Duygu (2006) supports this by arguing that PPS offers opportunities to dematerialise the economy and reduce the environmental impacts of industrial activity (Duygu, 2006). At the same time a recent surge of research on PSS has given us new opportunities and challenges in terms of understanding aspects of sustainable development. PSS has the potential to accelerate the transition to a sustainable society since PSS is not merely focused on selling material products but also on providing intangible services (Mont, 2002, 2004). Eco-efficient PSS innovations, then, represent a promising approach to addressing aspects of sustainable development (Ceschin, 2013).

From a PSS and innovative design perspective, a bike-sharing system should offer a "Use Orientated" approach to the ownership rights of the material artefact (Manzini and Vezzoli, 2003). The service provider retains the ownership in this PSS configuration and the customer purchases the use of the product/system over a given period of time or units of service. Bike-embedded eco-mobility schemes require fewer cars-per-kilometre travelled per person (Cook et al., 2006). If integrated with other forms of travel besides cars i.e. buses and trains, using a single smart card ticketing system such schemes have a great potential to increase the use of public transport and hence to decrease the environmental load of personal mobility activities (Midgley, 2009). The crucial role of designers is to define an effective and attractive PSS for bike-sharing. This involves working collaboratively with different stakeholders, such as institutional investors, system operators, and users in "Solution-Oriented Partnerships" (SOPs). In such partnerships there is no standard set of methods or tools for designers to use; rather they need to create a toolbox whereby different methods and tools can be used in different PSS contexts (Morelli, 2006). PSS also requires the focus being shifted from designing and selling only physical products to selling a system of products and services which are jointly capable of fulfilling specific clients' needs (Manzini and Vezzoli, 2003). PSS needs to consider consumer's behaviour and hence "need-feature-benefit" analysis is useful in designing a sustainable bike-sharing system (Mont, 2002; Vezzoli, 2007). Such analysis is predicated on the assumption that a lack of success in a new initiative is the result of a failure to follow a systematic approach involving the identification of needs followed by the implementation of a mechanism to deliver the planned benefits.

2.3. Business model

A number of business models have emerged for local, national and international stakeholders to manage bike-sharing service provisions (Shaheen et al., 2010; DeMaio, 2009). Stakeholders, among others, include city councils, advertising agencies, communities and private sector organisations such as bike providers. Recent studies suggest that for a bike-sharing system to be successful it is essential to run operations as a not-for-profit charity and to be subsidised by local government or other funding bodies whose ultimate multi-dimensional goal is to reduce environmental impact, lessen traffic congestion, enhance mobile connectivity, and finally improve public health (DeMaio, 2004, 2009). A counter-argument is that the existence of a suitable market for a profit-making business is a necessary precondition for a sustainable bike sharing system (Shaheen et al., 2010; Beroud et al., 2010). It is a moot point how each of these specific and sustainable business models are (co-) created to manage a complex and bespoke bike-sharing system. The process of creating a viable business model will take in the stages of design, development, implementation and operations. It iteratively relates to the issues of transport planning, infrastructure consideration and sustainable service design. (See Sections 2.1 and 2.2 above.)

A business model is a series of activities that are created to add value to the customers (Magretta and Stone, 2002; Demil and Lecocq, 2010). A bike-sharing system, by this definition, is developed to make something (such as a short-distance riding service, service guidance or advertising services) and then to sell them to a variety of customers, such as permanent residents who use the system as part of their daily commute to work, tourists who use it to help sight-seeing and companies who advertise their products and services at docking stations and on individual bicycles. As reported in many studies (see, for example, Shaheen et al., 2010, 2011; Beroud et al., 2010), there are many challenges that face bike-sharing operators. Logistics, for example, will need to consider the location and size of bike stations, the forecasting and scheduling of customer demands, route choice and development, bike maintenance and bike-redistribution systems. Bike-sharing operators will also need to deal with specific issues such as theft and vandalism and undertake relationship-based marketing to harmonise potential and even direct competition from local taxis, buses, and bike owners. A business model for a bike-sharing system will need to create value for stakeholders whilst comprising of a first-rate plan with an economic rationale that increases revenues and lowers costs (Magretta and Stone, 2002). The notion of shared value, as articulated by Porter and Kramer (2011), is where the system can generate commercial benefit for investors whilst at the same time being eco-friendly and enhancing social well-being; rather than being a system which relies on the traditional concept of trade-offs i.e. buying carbon credits to offset the adverse effects of a large carbon footprint on the environment or increasing donations to philanthropic causes to balance negative impacts of commercial activities on local communities.

In developing a business model and of value co-creation one must take into account the fact that a bike-sharing system is designed and implemented to be unique, bespoke and a one-off. In addition one must recognise that the stakeholder relationships are likely to be interdependent, multi-embedded and, sometimes, intangible (Mills et al., 2013; Frow and Payne, 2011). The complex system and performance requirements in bike-sharing have been described as interactions between infrastructural complexity (e.g. buildings, enabling facilities and hardware) and transactional complexity (e.g. performance involving high degrees of embedded knowledge) (Lewis and Roehrich, 2009).

Uncertainty, complexity and ambiguity tend to be commonplace in the management of a complex PSS (Zhang, 2013). Organisational learning provides the means for an enterprise to adapt to such a complex environment (Espinosa and Porter, 2011) and to reduce uncertainty in operating a PSS (Colen and Lambrecht, 2012). Some stakeholders are interested in the bottom-line figure while others seek non-finance performance. The nature of the complex bespoke system may mean that small business orientation and franchising are feasible management strategies in achieving complex performance targets in bike-sharing (Zhang and Zhang, 2011). Other issues concerning achieving satisfactory performance include managing the supply chain (Ashby et al., 2012), recycling bike materials, reverse logistics, maintenance, bicycle redistribution and customer problem-solving, such as quality assurance, service recovery and service guarantee.

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3. Methodology

Desk research was undertaken for the data collection. The empirical context was cities in China that had introduced bike-sharing systems. Four students of Year Three from a Chinese key university participated in this process of secondary research. Under a close guidance of the researchers, students worked as a group to present their findings in a module called 'sustainable design'. They spent eight weeks searching internal and external sources about bike-sharing systems in China, that is, five metropolitan cities – Beijing, Shanghai, Hangzhou, Wuhan and one mid-size city-Zhuzhou. Media reports, expertise opinion-based articles and academic papers were collected and issues and key elements were extracted.

During the desktop research process a working diagram, showing the meta-system for bike sharing was derived. The diagram facilitates the organisation of the data and an understanding of how key elements in the bike-sharing system interact, support or conflict with each other. It is a visualizing tool that articulates PSS concept design and implementation and supports the cross-analysis of the particular public bike-sharing systems. Fig. 1 shows the diagram generated for the Hangzhou bike-sharing system – which was one of 5 created.

MEPSS (Methodology for Product Service System) was adopted as a framework to guide this process. According to Van Halen et al. (2005) MEPSS helps designers to think 'How is today's value chain organised' and actively use visualisation tools and a modular method to analysis stakeholder management and service processes. It harnesses different methods from various fields of expertise that are needed to cover the various aspects so as to take into account key elements in developing, implementing and operating a PSS. This inductive data collection encompasses issues relating to the PSS concept design and implementation and success and failure factors in the development and implementation of PSS.

4. Findings and discussion

4.1. Description of the cases

Table 1 summarises the characteristics of the bike-sharing systems in the five case cities in China.

Sections 4.1.1–4.1.5 below contain a description of the singular cases for each of the cities included in the table, namely: Beijing, Hangzhou, Shanghai, Wuhan and Zhuzhou.

4.1.1. Beijing

Beijing is the capital city of China. It is the centre of economic, politics and culture and has high levels of tourism. Its population reached 22 million in 2010, with over 100 million tourists travelling to Beijing annually. Beijing suffers from the large number of private vehicles on its roads. There is heavy traffic congestion in the city centre and there is very poor air quality, in part due to the carbon dioxide emissions from car exhausts. In such a crowded city centre, where bike lanes do exist, they are constantly encroached onto by motor vehicles. The risk of accidents and injury to cyclists means it is not a very safe form of travel.

Public bike-sharing in Beijing was launched in 2007. The program was sponsored by the anti-theft arm of the Municipal Public Security Bureau and the Beijing Environment Protection Bureau, as the original intention was to focus on addressing the issue of theft of bicycles. Since then there have been 10 private companies and advertising agencies that have invested in and built bike-sharing systems in Beijing. By the end of 2010 most had terminated their

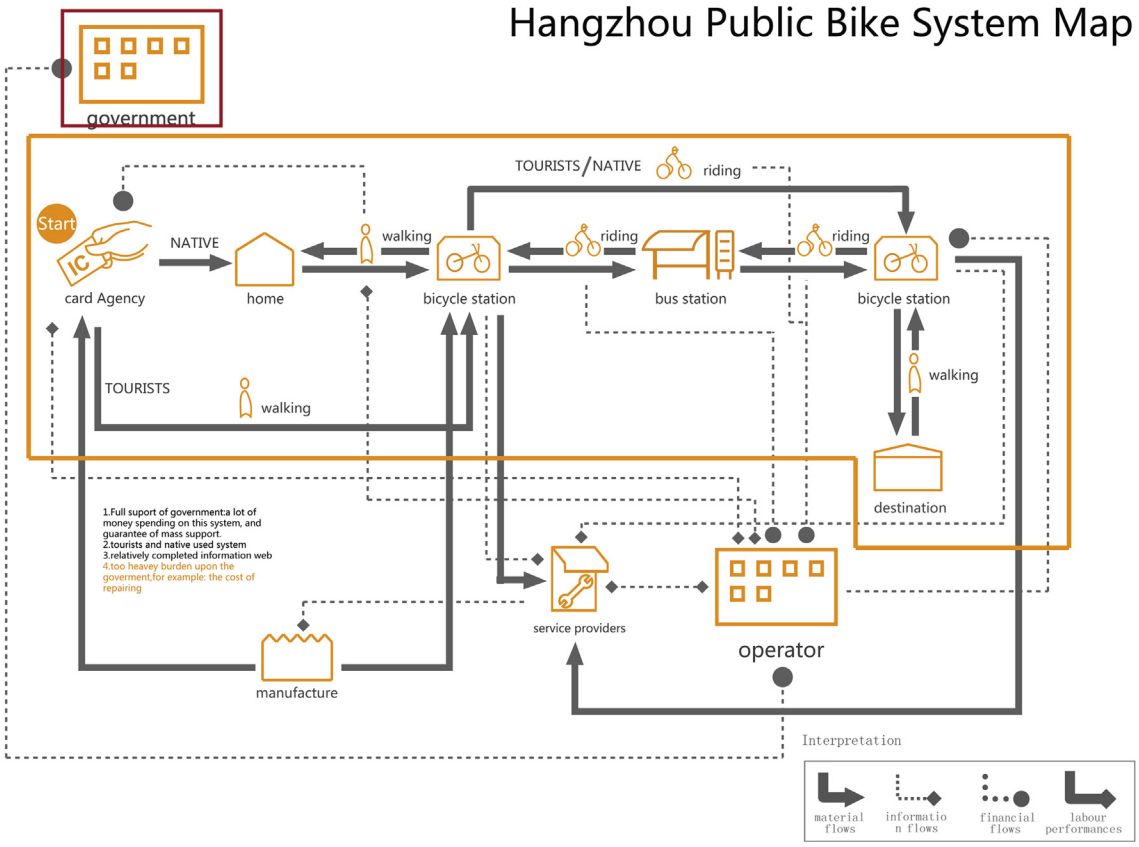


Fig. 1. Working diagram – meta-system map of Hangzhou bike-sharing system.

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Table 1
Bike-sharing systems in China – 5 city cases.

City	Beijing	Hangzhou	Shanghai	Wuhan	Zhuzhou
Population (m)	19.6	8.7	23	9.78	1.1
Territory (KM2)	16,410	3068	6340	8490	853
Bicycle ownership	66% (1970), 31% (2007)	61% (1997), 34% (2007)	67% (1981), 31% (2009)	59% (1982), 29% (2008)	60% (1981), 33% (2010)
Set up time and location	May 2007, eight private bike-sharing systems cover entire city centre	Jan 2008, one system cover West-Lake and entire city centre	Sep 2009, one bike-sharing system cover Min-Hang district	Oct 2008, two bike systems cover Qing-Shan and other districts	May 2011, one bike-sharing system cover entire city centre
Main users	Commuters, tourists	Tourists, commuters	Commuters, city dwellers	Commuters, city dwellers	City dwellers
Development	Set up to welcome Beijing Olympic 2008. Service provision virtually stopped.	Expanded after 4 phases from initially 2500 units and spread to other cities as a system solution	Expanded from initially 4000 units to welcome World Expo 2010. Struggled to operate	Expanded from initially 20,000 units. Struggled to operated	Expanded after 2 phase construction and spread to other city as a system solution
Business model	For-profit	Transport-agency	For-profit	Advertising	Government investment
Ways of revenue	Subsidy (v low) + fees mainly + ad	Subsidy (v high) + fees + ad	Subsidy (low) + fees	Subsidy (middle) + ad	Subsidy (v high) + fees
No of stations	1020	2670	567	1118	1015
No of bikes	10,500	65,000	20,000	50,500	20,000
Bike use (per day)	0.3	5.6	4.2	2	10.6
Maintenance repairing cost	High (¥2000/year)	Medium (¥1600/year)	Medium (¥1800/year)	High (¥2000/year)	Low (¥600/year)
Operations design	Service free: 30 min Ratio of bike to slot: 1:1 Ratio of bike to card: 1:0	Service free: 60 min Ratio of bike to slot: 1:2 Ratio of bike to card: 1:2	Service free: 30 min Ratio of bike to slot: 1:1.3 Ratio of bike to card: 1:11	Service free: 120 min Ratio of bike to slot: 1:1.2 Ratio of bike to card: 1:3	Service free: 180 min Ratio of bike to slot: 1:1.5 Ratio of bike to card: 1:5
Main issues in the system design	No information system. Links lack between these eight bike systems. Few bikes available and capable. Station squeezed with personal bikes.	Up-to-date info system. Upgrading bike hardware. Use of 'green corridor'. Co-running with other public transit systems.	Lack of info sharing and co-ordination. Stations far and between, mini-systems not interchangeable.	Poor design of the bike system, lack of user info stations easily broken, bikes wore and stolen, no tracking system.	High cost and quality bikes together with real-name savings deposit. Slots and bikes available, co-running with public transport system.

Sources include: He and Chen (2011), Yang, et al. (2011), Shen (2010), Li, et al. (2011), Huang and Wu (2010), Zhao (2013), Yao and Zhou (2009), Huang and Wu (2010), Shaheen, et al. (2011) and Liu et al. (2010)

involvement. For example the biggest contributor, Fangzhou, declared their intention to close down their operation in November 2010.

The Beijing bike-sharing system relies completely on a private-sector business investment & operation model. The government only provides policy support by approving advertising rights to the operators to enable them to recoup their investment. This model relies on adequate advertising revenue from on the chassis of individual bicycles and on the facilities where bicycles are docked between rentals. The intention is to allow for reduced rental costs and hence stimulate demand amongst price sensitive consumers.

The reality though is that the bicycle chassis advertising business model does not have enough support and guidelines at the policy level and lacks a strong legal foundation. So for the companies involved a lot of investment was made that was not recovered, leading to breaks in service – between providers – and in some cases files for bankruptcy. A typical experience was that of Fangzhou, which was established in 2008. Fangzhou was the biggest and oldest entirely private-equity company in China to operate a bike-sharing system. By 2009 it had built up a system consisting of over 10,000 bikes and 575 docking station sites. Yet by 2010 with the system beset by problems and service quality declining rapidly the company went into deficit and declared their intention to cease trading in 2010. Problems for Fangzhou, as well as for other providers, included a lack of clarity as to responsibilities at docking stations – some being in part-public ownership and a failure to carry out regular vehicle maintenance – mainly due to a lack of working capital.

4.1.2. Hangzhou

Along with Zhuzhou, see Section 4.1.5 below, the system in Hangzhou can be classed as a successful implementation. The bike sharing system of Hangzhou was built by the government in 2008, and the owner and operator is Hangzhou Public Bicycle Transportation Development Co, Ltd, which is a state-owned company affiliated to the Hangzhou Public Transportation Group Corporation. The urban area and population of Hangzhou is far less dense and smaller than cities like Beijing and Shanghai, which makes it more practical and operable to travel by bike. By 2010, the number of public bikes in Hangzhou was over 50,000, bicycle service points had reached more than 2,000, and you could find a service point every 100 m. Hangzhou is famous for its beautiful west lake and the human historical monuments in its southwest mountains. The first 20,000 public bicycles were mainly distributed in the west lake scenic area, where tourists were encouraged to ride bicycles to explore the natural surroundings.

In the early stage of the bike-sharing system, the government provided 150 million Yuan start-up fund and 270 million Yuan worth of subsidized loans in order to expedite the establishment of the system. Furthermore, advertising at service points and on the bicycles was granted to the operators, and this guaranteed them a stable source of funding. The management system developed included a monitoring system, scheduling system, information publishing system etc. This management system was very successful and was promoted to the cities of Dongguan, Foshan and Jiangyin, amongst others. It generates a business income of more than 60 million Yuan. In addition the city governors spent a great deal of effort on the details of the system, such as locating convenient service points, leasing modes, charge rules and fees, and the selection of vehicles. This detailing was done taking both the characteristics and geographical typology of Hangzhou and the Chinese living habits into consideration.

4.1.3. Shanghai

Shanghai has a huge transport demand and a relatively well developed public transit system. By the end of 2009 it had built an urban railway system with 11 lines and 355 km rail. Shanghai started a bike-sharing project in Minhang District in March 2009. The government invested 78.361 million Yuan to build 376 parking sites and provide 10,000 bicycles. After 2 years the system had only been implemented in one small area of the city and had not been rolled out to the whole of Shanghai.

There were many problems in the process of implementation. In terms of the business model the system is supported by both government investment and business operations, with the operating cost covered by public money and advertising revenue. There were two main operators in the early period of the system's implementation and this led to unclear lines of responsibility and other operational problems. This issue was subsequently addressed by the government. The system was beset by technical problems. The information system adopted was unstable in the early running period, which caused a great deal of frustration to the individuals attempting to either hire or return bikes at docking stations. The system was also prone to security breaches which made it susceptible to people seeking to steal bicycles. Shanghai's transport planning after 1990 did not pay enough attention to the bike-sharing system. There were no reserved spaces or public facilities for bicycles and in many areas no plans for bicycle lanes. Finally, there was no attempt to counter the negative effect of the rapid growth of motor vehicle usage. Most of Shanghai's empty urban spaces, including some pavements and bicycle lanes, where they exist, are typically occupied by motor vehicles. Motor lanes were broadened and in the city centre area the footways made very narrow.

4.1.4. Wuhan

The urban area of Wuhan is even bigger than that of Shanghai since it is made up of three large districts: Wuchang, Hankou and Hanyang. Each of these districts is the equivalent of a medium-sized city in China. By 2011 the number of public bicycles in Wuhan was over 50,000 and bicycle service points more than 1000. The Wuhan bike-sharing system, which adopted a mixed government-led/support and business investment/operation mechanism, was built in 2008 by two Investment and Media companies. It was billed as the first free-of-charge (free-deposits and free-rent mode) public bicycle system in China. The two companies, XINFEIDA and LONGQI, built their own systems in different city areas. This led to two systems running in parallel which do not talk to each other. A bicycle rented from a docking station which belonged to XINFEIDA could not be returned to a station belonging to LONGQI and vice versa. This incompatibility greatly reduced the efficiency of the bike rental.

The system relies on a mechanism of government support and business operations, which means a private company is the main stakeholder that invests in and operates the system. This includes investment in the infrastructure and the bicycles, system operation and day-to-day operations management. The government provides support by approving advertising management rights to the operators. Hence the operators can utilize the vehicles, rental and information points and other outdoor facilities in order to recoup investment and operational costs through advertising revenues. The free deposit and rent-free policy made it very accessible but was accompanied by problems, such as a lack of bicycles to rent, docking stations broken, bicycles worn, broken or stolen. Although the operator later changed the rental procedure to involve a deposit fee these deep-rooted problems were not easy to address, especially given the lack of vehicle tracking technology and robust

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information systems. The result was it became very difficult to find and rent a good quality bike in Wuhan.

4.1.5. Zhuzhou

With Hangzhou, the other notable success story is Zhuzhou. As a medium sized city with a large presence of heavy industry Zhuzhou has a lay-out which mixes newer and centrally planned districts with older areas that evolved more organically. In recent years the city has built up a low-carbon public bus system and it became the first electric bus city in China. In May of 2011, the Zhuzhou public bike-sharing system was officially launched. After more than one year and two phases of construction it is estimated that the Zhuzhou municipal government poured around 1.5 billion RMB into the project. The system has achieved a scale of more than 20,000 bikes, 1000 docking stations, supported by an infrastructure of 170 km special cycle lanes which cover nearly the whole of the city – new town and old. The distance between each docking station is no more than 500 m. The daily average usage rate of the bike-sharing system has reached approximately 150,000 people, with the peak rate rising up to 180,000. A participative planning process took place with citizens being invited to contribute to the decision-making on the positioning of docking points and on the system management and maintenance.

The system involved a government-led business model, with the initial investment being covered by the local municipal government as a public infrastructure project. Besides the construction budget the annual operation/running costs also comes from government funds. In the first year of operation this equated to 8.5 million RMB, with annual rises anticipated. There is an integrated managing system in place. Each bicycle has an on-board authentication and tracking system linked to an individual's personal identification card which ensures a smooth rent and return process. Police and city inspectors are involved in the daily maintenance and security processes and there are relatively low levels of cases of theft. There is a focus on high specifications in the design of the bicycles. All 20,000 bicycles have a no-chain design, aluminium frames, baskets-for-shopping and parent-child seats - all of which are well received by users. Such high product quality results in a high usage rate, 2 years more than systems in other Chinese cities, but relatively low maintenance costs. Whilst the cost of a bicycle exceeds 1000 RMB – compared with 500–600 RMB per bike for other systems, the maintenance fee is typically only 600 RMB per year – compared with average maintenance costs of 1350 RMB per year across the other 4 cities.

4.2. Comparison between cases

All the bike-sharing systems that were developed in Beijing, Shanghai, Hangzhou, Wuhan and Zhuzhou were designed to harmonise urban life and cope with huge populations. As shown in Table 1, whilst there has been a decline in bicycle ownership over the past 40 years, about 30% of the total population still own a bicycle. So the systems were being established on the basis of relatively high levels of bicycle ownership. All the bike programs started relatively recently, between from 2007 to 2011 with some being in response to specific events such as the 2008 Olympics in Beijing and the World Expo 2010 in Shanghai. Others were initiated as part of the government's urban development plans. Being seen to take a lead and invest in bike-sharing systems could also be used as a means of promoting a positive image of the government's commitment to green issues, both at home and abroad.

Most operators of the systems were (partly) privately-owned but government of varying levels provided administrative support in land use. For example, in Beijing new bike systems were proposed and co-ordinated by the city planner. The government also acted to some degree or other, as a source of venture capital. Operational designs of usage charges varied from 30 min free of charge to 3 h – which was often long enough to cycle through a whole city. Prolonged free service, though, did not seem to be linked to high usage of bikes – such relatively high free usage was present in the case of Wuhan, yet bike usage was the 2nd lowest of the 5 cities (2 bikes per day compared with 10.6 in Zhuzhou). Comparing ratios of bikes to slots suggest a minimum requirement of 1.2 (as was the case with Hangzhou and Zhuzhou). There were common problems in some cities in relation to technology integration, operations efficiency and effectiveness, abuse of the bikes and the upgrading of the software. The interfaces in design and operation between products, services, facilitating systems and urban infrastructures clearly posed challenges in the development of a PSS for sustainable bike-sharing.

The sustainability of particular systems seemed to rely, in part, on the strong and visible hand of government to provide co-ordination among departments and communities. All systems were initiated by city authorities, either the city administration or the city planning department. The systems were then design-built by a consortium of design institutes, original equipment manufacturers, universities and key suppliers. Entrepreneurship was typically evident (in this multidisciplinary approach) and managing the network of contributors as part of the process was a key to effective development of the bike-sharing system. These factors may explain why some bike-sharing systems like Hangzhou are prospering while some like in Beijing virtually stopped functioning.

The experience of the 5 cities reveals a multi-faceted role for bike-sharing systems, encompassing use by commuters, urban dwellers and tourists. Conventional understanding about the role of such systems is that they act as a supplement to travel on other forms of public transport (Shaheen et al., 2012; Beroud et al., 2010). This is the so-called first/last mile connection to the mainstream traffic system such as buses, railways and underground metros (DeMaio, 2009). The experience of China, particularly in the city of Zhuzhou suggests that a significant portion of people choose a public bicycle system to complete their entire urban journey i.e. not only travelling the first/last mile but also from door-to-door. To these city dwellers and the other types of user it could be that a bike-sharing system provides them with a highly convenient, reliable and cost effective way to commute, go shopping, tour, undertake recreation, visit families and friends, exercise and relax.

Having an effective bike-sharing system in place such as Hangzhou and Zhuzhou provides an opportunity for people to cycle more frequently and for longer distances without having to rely on using a bicycle that they own themselves. Many people live in residencies with small footprints and in high-rise buildings. So having a bicycle takes up precious space, as well as being difficult for some people to manoeuvre up and down stairs and along narrow corridors. There is also the cost of maintenance and repairs, especially if the bike is receiving frequent and heavy usage. Renting a bicycle then can be an attractive option, especially if the pricing mechanism makes it an increasingly cost effective option as a person's bike usage increases. Understanding this positive impact on usage patterns requires the government to reconsider and redefine bike-sharing systems as being an important part of public transport systems and as being an effective means of meeting environmental, economic, social and cultural sustainability goals. For example the introduction in Zhuzhou of a bicycle with a baby saddle was considered to be a solution to peak-parking problems at schools and a way of promoting sight-seeing within the city's public parks. It was also promoted as an efficient way of getting to and from local open markets and mini-supermarkets.

In urban areas with dense populations that have a need to reduce the over-reliance on motor vehicles a bike-sharing system

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may provide a complete solution to sustainable mass transportation. Though it is perhaps more easy to conceive bike-sharing systems in middle to small-sized cities which have cultural and historical attractions. In these urban environments narrow roads and other aspects of the built environment mean they are often unsuited to a high usage of motorised vehicles, be they cars or buses. Evidence further showed that in some instances up to 70% of cycle lanes in the Chinese cities are occupied by cars, commercial vans and buses. Even bike-stations are filled with privately-owned bikes. This can make bike-sharing an unpleasant experience. In some cities advertising is strictly restricted, which makes it difficult to reduce the level of public subsidy. Public attitudes towards green issues, such as pollution, traffic congestion and protection of the natural environment are complex, with the question of 'who's going to pay for the public value' of initiatives like bike-sharing often being on people's mind. So in order to establish bike sharing, or cycling, as a mainstream transportation, there may need to be decisions made at the public policy level that have physical, institutional and financial implications (Weber, 2010).

The case studies suggest that business and operations models of bike sharing systems are currently at their infancy stage and a value chain needs to be integrated at the operations level – for example, in an *inputs-processes-outputs* model of transformation (Slack et al., 2007) – so that the inputs to, processes of and outputs from a bike-sharing system are clearly defined and understood. Given that such systems are in their early stage of development, attention needs to be paid to designing a bike-sharing system that meets needs in order to provide the widest possible benefits for stakeholders. Creating such a business and operations model highlights a clear and crucial role for government. At the macro-level large-scale events such as the Beijing Olympics 2008 and Shanghai Expo 2010 can act as catalysts to the development of bike-sharing systems. Such momentum can be maintained where local governments participate and invest in and subsidise bike-sharing as part of initiatives to promote and coordinate urban green development. Program and project champions are most likely to be individual government officials who play an entrepreneur role in connecting business partners, facilitating the realisation of business ideas and strategies and acting upon the advice of expert advisers in the field. Developing a sustainable bike sharing program can be viewed as a crucial political achievement and a means of positive political branding and image making. In this respect the time, effort and resources spent on developing a bike-sharing system has pay-back from a political perspective.

It is important to recognise that the sharing of bicycles by members of the public involves a complex PSS that is constantly evolving (Neely et al., 2011). Citizens have a choice as to whether to own a bicycle/car or not to own one and instead to share one through a public sharing system. Unless a bicycle and a slot at a docking station is always available and functioning correctly when required they will still need to own a bike/car as a back-up, which will reduce the desire and need to use public bicycles. To solution providers, unless usage reaches a critical mass they will be reluctant to invest in such systems.

The experiences of the 5 cities in China shows that in becoming sustainable i.e. Hangzhou and Zhuzhou, they go through a number of phases in their development, from a few bikes to many thousands. This evolving nature requires providers to carefully consider the location and size of the operations, the application of product life-cycle management, process design and people management in the PSS of public bike-sharing. Inclusive design has recently started to address some of the multi-facets of this and other types of social and economic systems (BSI, 2005). As in Zhuzhou, where there was wide participation in the transport planning process, the involvement of key stakeholders, such as citizens, needs to extend into areas such as design in order to help inform the next stage of bike-sharing system development (Zhang et al., 2011).

5. Conclusions

This paper sought to explore the characteristics of and commonalities between particular bike-sharing systems in urban environments. This aim was addressed by analysing the bike-sharing systems set up in the Chinese cities of Beijing, Hangzhou, Shanghai, Wuhan and Zhuzhou. The analysis revealed a wide range of outcomes in terms of the sustainability of the particular systems. At one end of the spectrum is the experiences of Hangzhou and Zhuzhou which has seen bicycle sharing become established and expanded. At the other end of the spectrum is Beijing where service provision has virtually stopped. In between are the cases of Shanghai and Wuhan where the systems have been beset with problems and as a result are struggling to gain traction. Where the systems have become established they are making a contribution – albeit one which is not yet quantifiable, to reducing the reliance on private vehicle usage in cities.

In some cases, bike-sharing systems are used by urban dwellers for whole journeys in which not only a reliance on private vehicles is reduced but also on other, less sustainable, forms of public transport i.e. buses are more expensive, generally less green and don't provide the same health benefits that one gets from cycling. The city examples show multi-faceted uses of such systems; as just mentioned, urban dwellers using the system as their sole means of travel, commuters using them as a supplementary form of travel for the first/mile of their journey to and from work and tourists wishing to explore the natural and the built environment.

The cases show the different elements that make up a configuration of a sustainable bike-sharing system. From a transport planning perspective these include a proactive and supportive local government that puts in place the right infrastructure i.e. cycle lanes and, crucially, enforces their correct use. The more enlightened local authorities will engage potential users through a participatory process. They will also involve other agencies, such as the police, in ensuring the smooth operation of the system. Experiences to date suggest that the most effective business models involve government-led investment, with high levels of subsidy. Where they have been led by the private sector, with little subsidy and revenue mainly sourced through advertising, as in Beijing and Shanghai, they have been less effective.

The design of a bike-sharing system needs to recognise that it is a Product Service System (PSS). A sharp focus on the product in the best configured systems, such as Zhuzhou, sees initial capital investment in high specification equipment. This is justified in relation to the delivery of public values in general and the particular service desired by users; and, from a business model perspective, offset by lower operating costs i.e. in terms of maintenance repair. A sharp focus on the service requires a clear understanding of what value is attached to bike-sharing systems by potential users i.e. purely functional to get from one point to another, as a form of recreation or for keeping fit and healthy; and, through value chain analysis, designing a system to meet these requirement. The overall conclusion, though, is that any configuration has to consider all these disparate elements together. For example, a system that provides high specification bicycles with sophisticated tracking systems and high technology lend-and-return mechanisms is unlikely to be successful if the infrastructure, such as cycle lanes and docking stations, is not in place.

There is potential for further research in terms of exploring further the complex interplay in design between products, services and facilitating systems (i.e. infrastructure) that is needed to create complex bike-sharing systems which maximise the value of bike-

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sharing use in urban environments. In this regard, in-depth interviews with key informants may elicit rich datasets which allows the mapping of the value chain in relation to bike-sharing systems and, hence, the development of a sustainable business and operations model (as suggested by Boons and Lüdeke-Freund, 2013). The collection of quantitative data through simulation-based research also has the potential to inform bike-sharing system design and operation in such areas as: optimised design of the docking stations and operations improvement in terms of quality, capacity, supply chain and process technology. In terms of the influences on the sustainability of the bike-sharing systems, as shown in Table 1 the two cities that were most successful in this regard happened to be the two smallest cities in terms of populations: Hangzhou and Zhuzhou. An avenue for investigation is the influence of city size, as well as other potentially salient features, such as population density, on the development of the bike-sharing systems. Finally, bike-sharing represents a good example of green consumption in travel and an innovative solution to meeting the needs of people to be mobile in the urban environment of the future. Hence, survey-based research may provide useful insights into the link between consumers' eco-friendly attitudes/behaviour and the use of bike-sharing.

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