A Systems Perspective of Cycling and Bike-sharing Systems in Urban Mobility

Ashwani kumar
National University of Singapore
PhD Student, Singapore-MIT Alliance
Singapore 138602
ashwk@yahoo.com

Kwong Meng Teo
National University of Singapore
Assistant Professor
Department of Industrial and Systems Engineering
Singapore 119077
kwongmeng@nus.edu.sg

Amedeo R. Odoni
MIT
Professor of Aeronautics and Astronautics
MIT, Cambridge, MA, USA
arodoni@mit.edu

Abstract

Urban mobility is a prevalent problem in many cities around the world. Cycling offers a fast and cheap transportation option for short-distance trips, with smaller carbon and physical footprint than driving a car. Cycling can also encourage a modal shift from private car to public transport by providing efficient last mile connections. This has led to a renewed interest to promote cycling in cities, manifesting in a growing number of bike-sharing projects with larger bicycle fleets. However, the economic sustainability of these bike-sharing systems has not been demonstrated. Moreover, city governments may invest resources in bike-sharing projects at the expense of developing policies or infrastructure to improve cycling safety and convenience. We take a systems perspective to study how bike-sharing and other policies can influence cycling as a transport mode in the urban mobility problem. We observe that while bike-sharing projects may increase cycling level and generate public demand for better cycling infrastructure in the short run, loss-making bike-sharing projects can discourage the infrastructure investments over the long-run, thereby hampering cycle adoption. Public funds should not be invested in bike-sharing programs at the cost of cycling infrastructure. Instead, governments should facilitate economically viable bike-sharing systems by the private sector through adoption of appropriate policies. Investments in cycling infrastructure should come first.

Key words: Urban mobility, systems thinking, cycling, bicycle sharing

Introduction: Problem of Urban Mobility

Cities around the world are undergoing rapid urbanization, especially those in large developing countries like China, India and Indonesia. This development, coupled with increasing motorization, has directly led to deteriorating traffic conditions and indirectly to economic and social costs including time lost in traffic, extra fuel consumption, pollution, and lower quality of life. The cost[1] of such congestion in various cities in United States is estimated to increase from $20 billion[2] in 1982 to more than $100 billion in 2010, with more than 58% incurred in the largest 15 cities (Bureau of Transportation Statistics 2011). In Europe, congestion costs approximately 2% of GDP, or a total of €120 billion (UITP 2003).

In both Chinese and Indian megacities, traffic congestion has assumed alarming proportions (National Research Council 1996). The average speed of motor vehicles in Mumbai has plummeted from 38 km/h in 1962 to only 15-20 km/h in 1993 (Gakenheimer 2002). In Chennai, and Kolkata, average speeds dropped to less than 15 km/h (J. Pucher 2007). In central Beijing, overall average motor vehicle speed fell from 45 km/h in 1994 to only 12 km/h in 2003 while average bus speed dropped from 17 km/h in 1994 to only 9 km/h in 2003. In central Shanghai, average speeds range from 9 to 18 km/h. During peak hours, more than half of the roads in Shanghai's central area are severely congested, and 20% of Beijing's inner roads are completely gridlocked, with a traffic speed of less than 5 km/h (J. Pucher 2007). Such traffic congestion becomes an economic issue when it reduces productivity and consequently takes a toll on the developing nations' GDP. From the environmental point of view, it also increases automobile exhaust emissions and urban air pollution, which contributes to major health problems in most megacities (Gackenheimer 1994).

Concerns about how urban mobility affects the quality of life and environmental sustainability are gaining importance in the developed world (Mcclintock 2002, Krizek and Levinson 2005). This is especially true in many European cities which are not growing fast and already have in place good public transit systems (Pucher and Buehler 2008).

Apart from being a clean, cheap and equitable mode of transport for short-distance journeys, cycling can potentially reduce traffic congestion, parking space requirements and roadway costs (Mcclintock 2002). Consequently, it has a place in a policy maker's tool-kit of urban mobility solutions, especially for short distance trips. By providing efficient first / last mile connectivity, it can also play a vital role in increasing public transit ridership (Katia and Kagaya 2011). These considerations have led to renewed interest to promote cycling in urban areas, and result in city governments investing public funds in an estimated 135 bike-sharing programs with a total fleet size of more than 235,000 in cities around the world, as of March 2011 (Shaheen, Zhang, et al.

---

[1] Value of time lost and fuel costs only

[2] 2010 dollar value

2011). We take a systems perspective to understand the importance of such investments in promoting cycling as a preferred mode of transportation to solve the problem of urban mobility.

Problem Definition and Perspective

From literature reviews and discussion with counterparts, we observed that the framing of the urban mobility problem varies, leading to differing, or even contradictory, conclusions when given the same facts. This is unsurprising for complex issues, thus we advocate taking a systems perspective in analysing the problem.

This paper defines the problem of urban mobility from the perspective of policy makers whose concern is that traffic congestion and its associated costs may decrease a city's productivity and limit its growth and development through a multitude of urban dynamics including: (i) deterring companies from further investment in the city or, worse still, driving companies to move away, (ii) consuming too much of the residents' time, energy and resources to permanently restrict their ability to improve their lives through skill upgrades or entrepreneurial activities. The key measure we propose for this problem is the situation during the morning peak-hour traffic in the urban environment when commuters are going to work; an implied assumption is that if the morning peak-hour traffic can be alleviated, the urban mobility problem can be improved to a large extent. Furthermore, this paper shall only discuss and evaluate cycling under this context; it is only our first step to developing a systems perspective of all transportation modes in urban mobility.

For cycling to play a part in alleviating the urban mobility problem, it must attain significant modal share during the morning peak-hour. Commuters will compare it with other available modes of transport in terms of affordability, reliability, comfort, convenience, and other factors**.** Moreover, the relative importance of these factors can be influenced by a city's attribute.

Attributes of Cycling as a Transport Mode

Cycling offers many benefits to the problem of urban mobility. By consuming considerably less non-renewable natural resources than motorized transport modes, it is one of the most sustainable and efficient transportation modes for trips of distance up to 5 km (Katia and Kagaya 2011, Midgley 2011). Moreover, since the spatial efficiency of bicycles is close to that of buses in mixed traffic condition, cycling qualifies as a non-congesting mode (National Research Council 1996). Furthermore, cycling promises health benefits for individual commuters (J. Pucher 2007).

On the other hand, cycling becomes a challenge during adverse weather. Although commuters do cycle under different climatic conditions, extreme temperature and precipitation (Pucher, Buehler and Seinen 2011), data suggests a significant decline in cycle usage when cold (<5 ˚C) or when hot and humid (>28 ˚C and > 60% humidity) (Capital Bikeshare 2012).

While data also suggest that cycling decreases when gradient exceeds 4% (Midgley 2011) and may not be suitable for the elderly or the disabled, pedelecs[3] and e-bikes may change the situation (OBIS 2011) (Midgley 2011). Furthermore, there are surprising data from Netherlands and Germany that elderly people may not cycle less (Buehler 2010, Pucher and Buehler 2008).

Finally, safety concern is a deterrent since cyclists are more prone to accidents in mixed traffic conditions (Pucher and Dijkstra 2000). Counter-intuitively, as the number of cyclists goes up, fatality rate due to cyclists can go down (Pucher and Buehler 2008).

Cycling in Urban Mobility Today

Figure 2 shows that wide variations exist in the cycling modal share across global cities. The share of cycling has decreased substantially over the past three decades from a very high level in Chinese cities such as Beijing and Guangzhou. Such a decline is also observed in the Indian cities. This similarity in trend across both populous developing countries may be attributed to a combination of increased motorization, mass transport development, decline in cycling safety, and lengthening of trips due to city expansion (Tiwari 2011, J. Pucher 2007).

In the developed world, the level of cycling has been low and had declined further. However, cities such as Amsterdam and Tokyo are exceptions and have attained a fairly high cycling modal share (*Figure 1)* through a well-coordinated focus on cycling infrastructure and other cycle friendly policies.

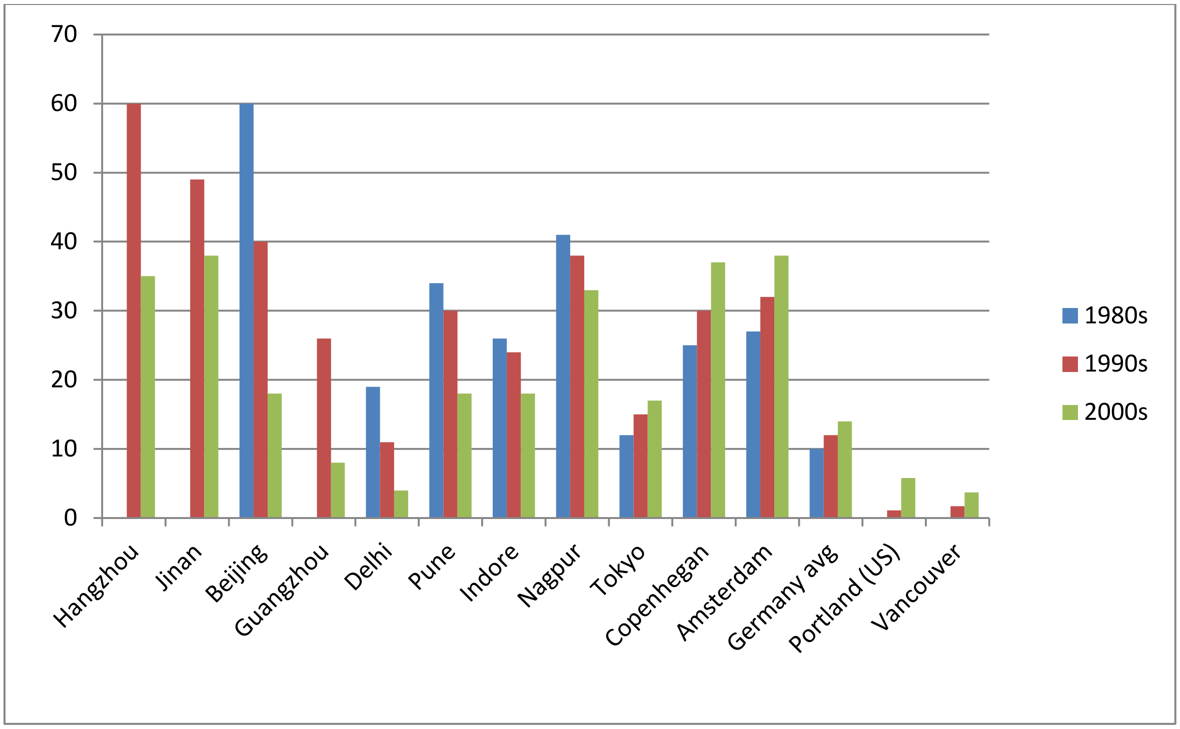
Cycling can encourage a modal shift from private car to public transport by providing efficient last mile connections, leading to a reduction in road congestion due to the volume of cars. Such high usage of cycles for last mile connectivity has been observed in Japanese and German cities; for example, around 20% of transit users use cycling as a last mile mode in Tokyo (Katia and Kagaya 2011), enabled by an extensive bicycle parking infrastructure at the transit stations (Pucher and Buehler 2008, Katia and Kagaya 2011).

Cycling can also be an efficient option for end-to-end short-distance trips. It can have a large modal share of total trips in small to medium sized cities with mixed land use (National Research Council 1996, Mcclintock 2002, Pucher and Buehler 2008). To reap these benefits, many cities have tried promoting cycling using different policies, particularly through the implementation of bike-sharing projects.

---

[3] Pedelec is a popular term for pedal assisted e-bike, as opposed to other types of e-bikes which do not require pedalling and are more similar to motorbikes. Regulations for these e-bikes are still evolving in most countries.

Figure 1 Cycle Modal Share across Selected World Cities over Past 2-3 Decades



Sources : (Tiwari and Jain 2008, Pucher and Buehler 2008, J. Pucher 2007, Pucher, Buehler and Seinen 2011, Pan 2011, Katia and Kagaya 2011, Pucher and Dijkstra 2000). *Note that: (i) values may not be comparable across cities due to differences in data collection methodologies and definitions, (ii) the 1980s data are not available for some cities.*

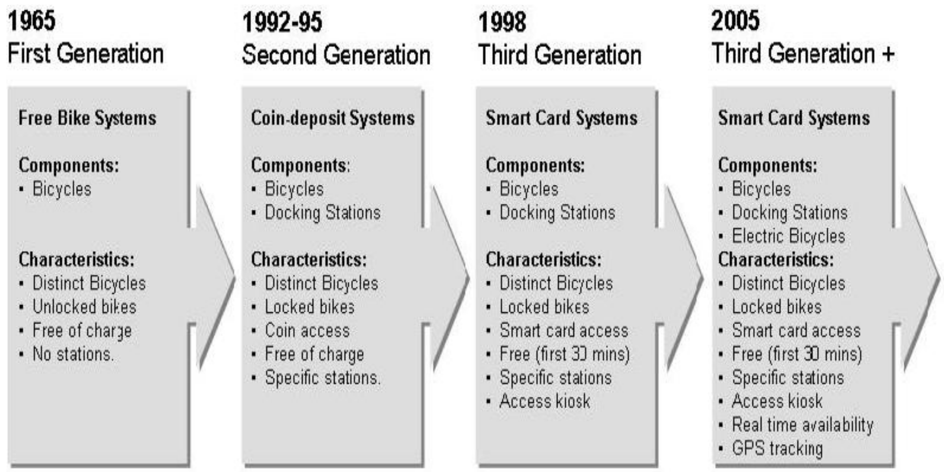
Bike-sharing: Evolution, Characteristics and Present Status

A bike-sharing system is a short-term rental scheme allowing bicycles to be collected and returned at any one of several self-serve stations. It enables commuters to flexibly use bicycles without incurring the cost and trouble of owning and maintaining them (Shaheen, Guzman and Zhang 2010).

Bike-sharing systems give cycling characteristics of public transport including (i) network of stations, (ii) pay as you use, and (iii) ease to incentivize by the city government (OBIS 2011). It shows 'Mobility on demand' features when station density and cycle availability are high. Bike-sharing may help in efficient use of resources by facilitating quick turn-around of cycles and parking spaces (Midgley 2011).

While bike-sharing systems have evolved over the past 45 years (DeMaio, 2003; DeMaio, 2004; Midgely, 2009) (*Figure 2)*, they came to prominence in 2007 with the launch of *Vélib*, a third generation bike-sharing program, in Paris. Starting with around 7,000 bikes, the program has expanded to more than 20,000 bikes to date. This massive program and its apparent operational success redefined the expectations of bike-sharing systems and led to enormous global interest.

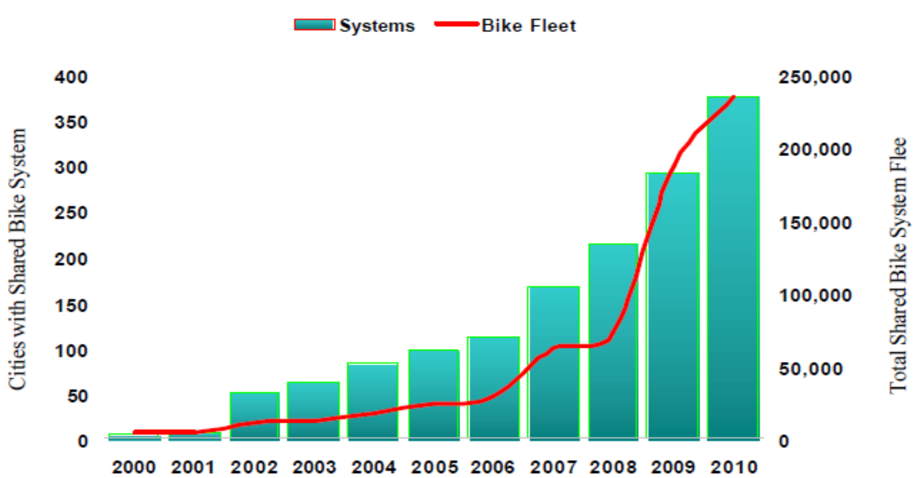
Figure 2 Evolution of Bike-sharing Systems (1965- 2010)



Source : Midgely, 2011

The number of bike-sharing schemes has grown significantly over the past decade, reaching a figure of 375[4] programs in 33 countries by May 2011, as shown in Figure 3 (Midgley 2011). This is accompanied by an impressive growth in bicycle fleet size - this phenomenal rate of growth in bicycle-sharing schemes and fleets has exceeded growth in every other form of urban transport (Midgley 2011).

Figure 3 Growth in Bike-sharing Schemes and Fleet (2000-2010)



(source : Midgley, 2011)

This apparent success of bike-sharing projects comes with its challenges. Because of uneven travel demands, re-distribution of bikes using trucks is often necessary. This is not just a problem

[4] Including smaller pilot studies

of cost, but may affect the availability in stations with high demand (Shaheen, Guzman, & Zhang, 2010; Midgley, 2011). Some projects have experimented with pricing and incentives to reduce re-distribution (Velib 2012), which has met moderate success.

Moreover, while reducing congestion through encouraging modal shift from cars to bikes is often one of the key objectives, most bike-share trips may substitute walking or public transport instead, resulting in limited impact on congestion (Midgley 2011).

Furthermore, while total cycle trips may have grown quickly after introduction of bike-sharing in many cities, the overall cycle modal share in these cities can still be low. Besides making cycling more acceptable and trendy (Midgely 2009), bike-sharing can bring in many new but occasional cyclists. While a larger number of cyclists may lead to better cycling infrastructure (OBIS, 2011), it is unclear whether bike-sharing will make cycling a significant mode in urban mobility in the long-term.

Finally, data shows that most of the big bike-share programs are, in whole or in part, supported financially by local authorities (Midgely, 2009; Midgley, 2011). Such support can either be direct or indirect through the sale of advertising rights, for example. To date, none of the programs can be considered a financial success (Midgley, 2011) although, given the recent implementations, it may be premature to assess the long-term viability of their business models. In Hangzhou, for instance, the local authority is promoting public transit ridership by financing explicitly an almost free bike-share service (Shaheen, Zhang, Martin, & Guzman, 2011).

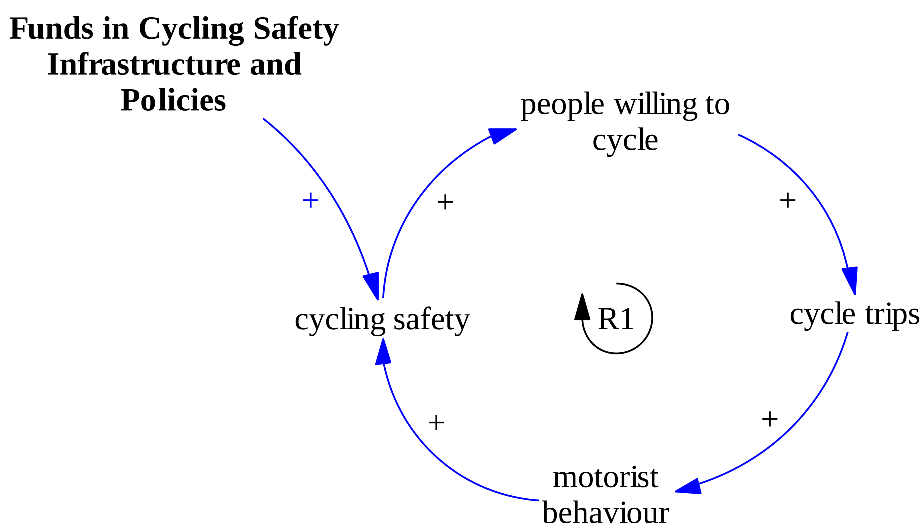
Given this backdrop, it is clear that the sustainability of bike-sharing systems is a concern; a better understanding of their long-term impact on cycling and the urban mobility problem is necessary.

Cycling and Bike-sharing: Taking the Systems Perspective

From a commuter's point of view, safety[5] plays a key role in making cycling a credible choice as a transport mode in an urban mixed-traffic environment. As the level of safety improves, more commuters will choose to cycle. Furthermore, motorists will develop better awareness of cyclists when there are more of the latter on the roads, leading to improved cycling safety, resulting in a reinforcing loop R1 as shown in *Figure 4*. Such a dynamic feedback loop has been observed in numerous research studies (Pucher, Dill and Handy 2010, Pucher and Buehler 2008, Mcclintock 2002); policies and infrastructure promoting cycling safety are found to be effective in promoting cycling. Such policies include (i) provision of cycle lanes along busy corridors, preferably separated from motorised vehicles, (ii) cycle-friendly intersections and (iii) wide-spread traffic calming.

[5] In this paper, cycling safety excludes compulsory use of helmets. There are research showing that compulsory helmet laws may be a hindrance in growth of cycling (Pucher, Dill and Handy 2010) due to a negative perception of cycling safety.

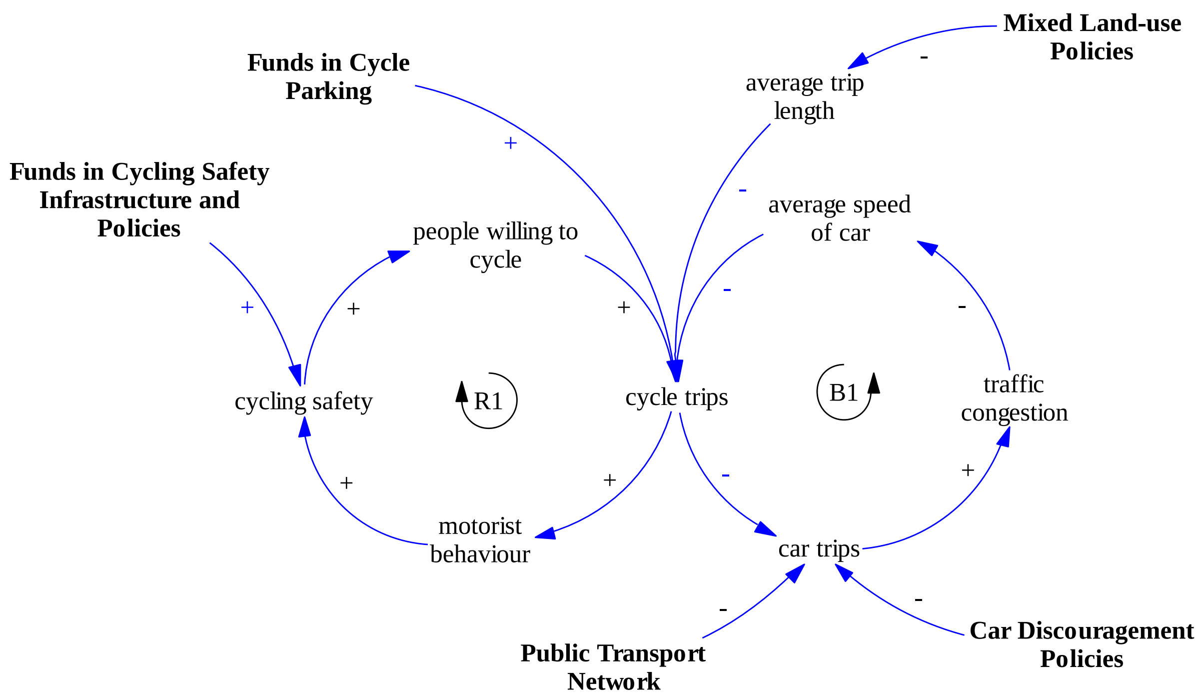
Figure 4 Cycling Safety Reinforcing Loop



Besides cycling safety, extensive cycle parking, especially at transit station, and mixed land-use can also increase cycling levels (Krizek and Levinson 2005) (Buehler 2010) (Mcclintock 2002) (Pucher and Buehler 2008) (Pucher, Dill and Handy 2010). Good bicycle parking at transit stations have been shown to encourage the usage of bike as a last mile transportation mode (Pucher and Buehler 2008, Katia and Kagaya 2011). Mixed land-use in urban planning policies put the workplace closer to the home, thereby decreases the average trip length and enhances the attractiveness of cycling as an option. The contribution of these measures to the reinforcing loop R1 is shown in *Figure 5*. The balancing loop B1 in *Figure 5* illustrates the dynamics when car are substituted by bicycles, and vice versa. Better public transport and car discouragement policies, such as a higher tax for car usage / ownership, would further encourage the switch from private car to bicycle usage.

On their own, bike-sharing systems are unlikely to have a big impact on cycling levels as the cost of owning and maintaining a bicycle is not the key issue preventing the choice of cycling in urban peak-hour commute. A majority of the commuters also follow the same origin-destination travel routine, thereby minimizing the need to rely on a large geographical coverage of bike-sharing network. Instead, cycling safety, comfort and trip length are the key determinants of cycling modal share, and bike-sharing does not change much of these attributes. Data from big bike-sharing projects, including *Velib*, *Bixi*, and *CaBi*, showed that while the number of cycling trips has increased in Paris, Montreal, and Washington DC respectively, the modal share remains low and accounts for less than 2% of all trips. On the other hand, cities in Netherlands, Denmark, Germany and Japan continue to have high levels of cycling modal share without any big bike-sharing system (Katia and Kagaya 2011, Buehler 2010, Warren 2010). Essentialy, if cycling is already an attractive commuting option due to safety, comfort and trip length considerations, there are few factors prohibiting an individual from owning using his/her own bike.

Figure 5 Causal Loop View of Cycling levels in Cities

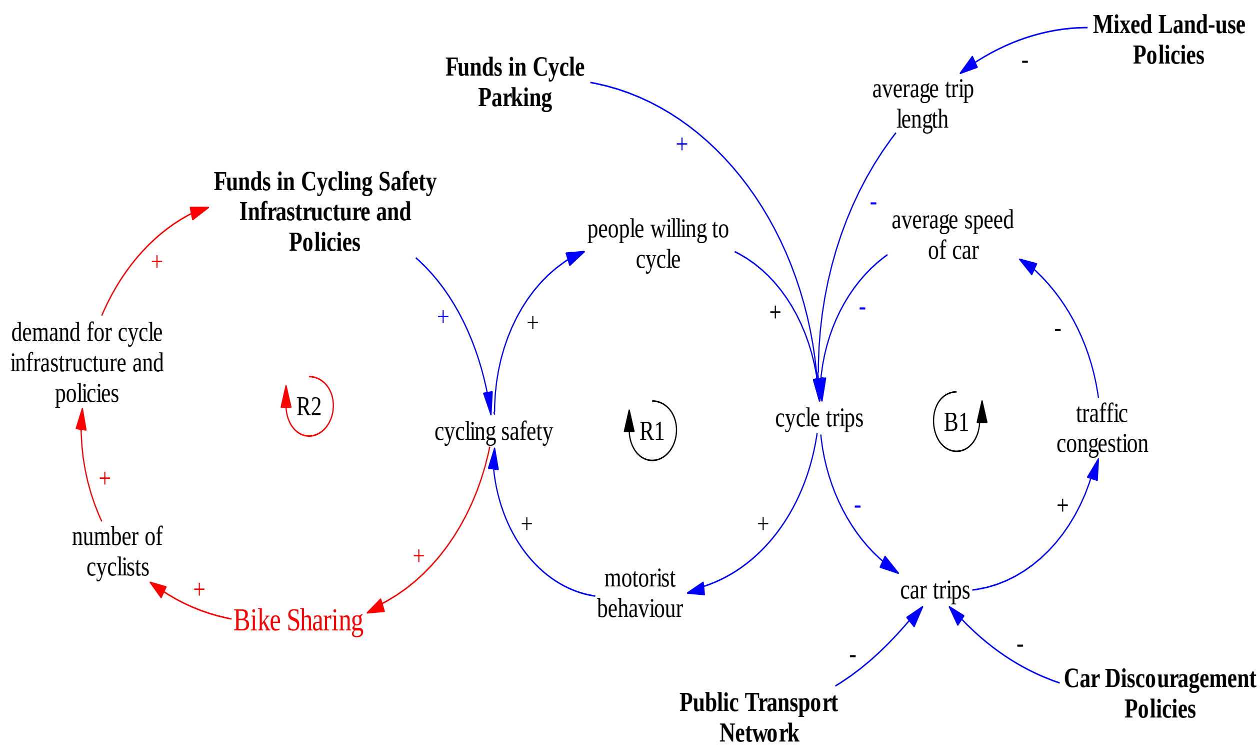


It is also important to ensure that bike-sharing systems are not implemented at the expense of private cyclists, since they are competing for the same parking spaces. If a significant portion of shared bike rides come from private commuter bike-rides (Midgley 2011), there would be little improvement in the cycling modal share.

Nevertheless, bike-sharing systems may increase the total number of cyclists on the road and a corresponding demand for better cycling infrastructure. This may in turn prompt governments to increase fund allocation for cycling (OBIS 2011). This dynamic is captured in the reinforcing loop R2 in *Figure 6*. Bike-sharing may also improve public transport ridership as some of the shared bike trips would be last-mile trips[6].

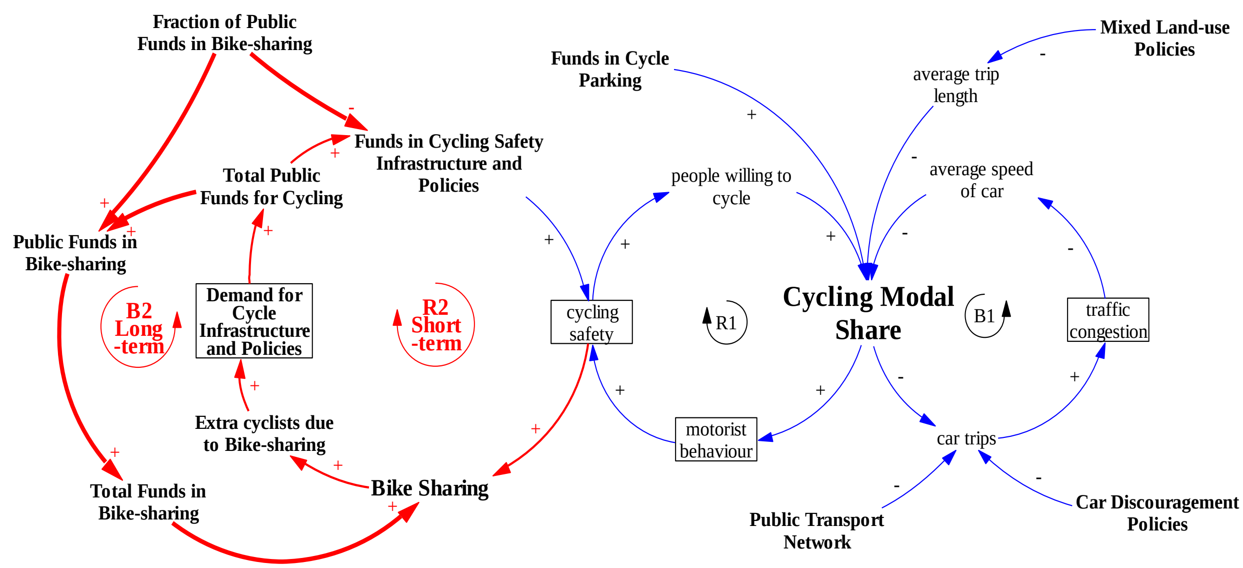
[6] Assuming that last-mile cycle trips exceed the transit trips substituted by cycling

Figure 6 Expected short-term Causal Loops for Bike-sharing



As highlighted earlier, most big bike-share programs have not shown to be economically sustainable (Midgely, 2009; Midgley, 2011). In the long-run, continued support of these bike-sharing projects using public funds may reduce the resources available to improve and maintain the cycling safety and parking infrastructure. This dynamics is shown by time delayed relationships in the balancing loop B2 in *Figure 7*. Conversely, if only private capital is invested in bike-sharing projects, city governments can deploy the funds saved to focus on cycling safety and parking infrastructure.

Figure 7 Causal Loops Depicting Long-term Implications of Bike-sharing Projects



Conclusion

Cycling is a clean, fast and non-congesting option for short-distance trips in cities, and can play an important role in alleviating urban mobility problems in different urban contexts. In cities with good transits, cycling can help to increase ridership of mass-transits by providing efficient last-mile connections. It can also satisfy most short distance end-to-end trips.

Policies available to promote cycling include provision of safe, preferably separate, cycling infrastructure along the busy commuter corridors, extensive bike parking at important locations such as transit stations, and wide-spread traffic calming on city roads. Active discouragement of car usage through speed, priority and parking controls can also play an important supplemental role. Moreover, land-use policies promoting compact, mixed-use developments can help shorten the trip lengths and make cycling more attractive. Implementing these policies in a well-coordinated manner over the long-term can help bring about higher cycling levels, introduce a cycling culture and make cycling a choice mode in addressing the urban mobility problem.

While bike-sharing systems may enlarge the reach of public transport and increase the number of cyclists and cycling trips, they are neither sufficient nor necessary in promoting cycling. Conversely, high cycle modal share can only be achieved and sustained with a safe, extensive and continually improving cycling infrastructure. Instead of spending public funds on bike-share, city governments should invest directly in cycling infrastructure to create an environment where cycling is an attractive commuting option. When that happens, individuals can buy and use their own bicycles, thus rendering bike-share systems non-essential.

Finally, much of cycling infrastructure is a public good which does not attract private investment. Governments can promote private investment in bike-sharing projects through offering appropriate incentives, while ensuring that cycling infrastructural developments will come first.

References

Acharya, Surya Raj. "Motorization and Urban Mobility in Developing Countries, Exploring Policy Options through Dynamic Simulation." *Journal of the Eastern Asia Society for Transportation Studies*, 2005: 4113-4128.

Buehler, R., Pucher,J. "Cycling to Sustainability in Amsterdam." *Sustain: A Journal of Environmental and Sustainability issues*, 2010: 35-40.

Bureau of Transportation Statistics. *National Transportation Statistics.* Washington DC: US Department of Transport, 2011.

Capital Bikeshare. *http://www.capitalbikeshare.com/system-data.* Feb 24, 2012. http://www.capitalbikeshare.com (accessed February 24, 2012).

DeMaio, Paul. "Bike-sharing: Its History, Models of Provision, and Future." *Velo-city2009 Conference.* Brussels, 2009.

DeMaio, Paul. "Smart bikes: Public transportation for the 21st century." *Transportation Quarterly*, 2003: 9-11.

DeMaio, Paul. "Will Smart Bikes Succeed as Public Transportation in the United States?" *Journal of Public Transportation*, 2004: 1-15.

Gackenheimer, R. "Six Startegic Decisions for Transportation in Mega-cities." In *Mega-city Growth and the Future*, by R. Gackenheimer, R.J. Fuchs and E. Brennan. New York: United Nations University Press, 1994.

Gakenheimer, R. *Planning Transportation and Land Use for Cities in India.* Cambridge, MA: Massachussetes Institute of Technology, 2002.

Katia, Andrade, and Seiichi Kagaya. *Cycling in Japan and Great Britain: A Preliminary Discussion.* Research Report, Louvain-la-Neuve , Belgium: European Regional Science Association, 2011.

Krizek, Kevin, and David Levinson. "Teaching Integrated Land Use-Transportation Planning." *Journal of Planning Education and Research* , 2005: 304-316.

Luoma, Juha, Michael Sivak, and Susan Zielinski. *The Future Of Personal Transportation.* Ann Arbor: University of Michigan Transport Research Institute, 2010.

Mcclintock, Hugh. "The Mainstreaming of Cycling Policy." In *Planning for Cycling: Principles, Practice and Solutions for Urban Planners*, by Hugh Mcclintock, 1-2. FL, USA: Woodhead Publishing and CRC Press, 2002.

Meyer, Michael, and Eric Miller. *Urban Transport Planning.* Atlanta: McGraw-Hill , 2000.

Midgely, Peter. "The Role of Smart Bike-sharing Systems in Urban Mobility." *Journeys*, May 2009: 23-31.

Midgley, Peter. "Bicycle-sharing Schemes: Enhancing Sustainable Mobility in Urban Areas." *Commission on Sustainable Development.* New York: UN Department of Economic and Social Affairs, 2011.

National Research Council. *Meeting the Challenges of Megacities in the Developing World.* Washington DC: National Academy Press, 1996.

National Research Council. "Transportation Options for Megacities in the Developing World." In *Meeting the Challenges of Megacities in the Developing World: A Collection of Working Papers*, by National Research Council, 65. Washington DC: The National Academies Press, 1996.

OBIS. *Optimizing Bikesharing in European Cities.* Handbook, Brussels: Intelligent Energy Europe, EU, 2011.

Pan, Haixiao. *Implementing Sustainable Urban Travel Policies in China.* Discussion Paper, Leipzig: International Transport Forum, 2011.

Pucher, J. "Urban Transport Trends and Policies in China and India." *Transport Reviews*, 2007: 379–410.

Pucher, John, and R Buehler. "Making Cycling Irresistible: Lessons from Europe." *Transport Reviews*, 2008.

Pucher, John, Jennifer Dill, and Susan Handy. "Infrastructure, programs, and policies to increase bicycling: An International Review." *Preventive Medicine*, 2010: 106-125.

Pucher, John, Ralph Buehler, and Mark Seinen. "Bicycling renaissance in North America? An update and re-appraisal of Cycling Trends and Policies." *Transportation Research Part A*, 2011: 451-475.

Shaheen, Susan, Hua Zhang, Elliot Martin, and S Guzman. "Hangzhou Public Bicycle: Understanding Early Adoption and Behavioral Response to Bikeshare in Hangzhou, China." *Transport Research Board TRR*, 2011.

Shaheen, Susan, S Guzman, and H Zhang. "Bikesharing in Europe, the Americas, and Asia: Past,." *Transportation Research Record: Journal of the Transportation*, 2010.

Sterman, John. *Business dynamics : systems thinking and modeling for a complex world* . Boston: Irwin/ Mcgraw Hill, 2004.

Tiwari, Geetam. "Key Mobility Challenges in Indian Cities." *International Transport Forum.* Leipzig: International Transport Forum, 2011.

Tiwari, Geetam, and Himani Jain. "Bicycles in Urban India." *Urban Transport Journal*, 2008: 52-58.

UITP. "Cycling and Economics." *The European Network of Cycling Expertise.* 2003. http://www.velo.info/Library/Cycling_Economics.pdf (accessed March 4, 2012).

UITP. *Millennium City Database for Sustainable Mobility.* Database, Brussels: UITP, 2001.

Velib. *Velib website.* Feb 15, 2012. http://en.velib.paris.fr/ (accessed Feb 15, 2012).

Warren, Jolin. *Civilising the Streets.* Edinburgh: Sustrans Scotland, 2010.