Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 25 (2017) 5040–5058

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

The kingdom of the bicycle: what Wuhan can learn from Amsterdam

Gladys Frame[a], Arturo Ardila-Gomez[b], and Yang Chen[c]

[a] Consultant, [b] Lead Transport Economist, and [c] Transport Specialist, Transport & ICT Practice, The World Bank

Abstract

China used to be called "the Kingdom of the Bicycle," but this is no longer the case. Bicycle use in China has been marginalized over the past 30 years. In contrast, the Netherlands has seen bicycle use grow since the 1970s. This paper—through a comparative analysis of data from Wuhan and Amsterdam—explores the reasons why the two countries have gone in different directions. Although these cities have different socio-demographics they experienced similar issues. This paper suggests lessons that Wuhan can learn from Amsterdam. However, these are one-way as it is considered that Amsterdam has little to learn from the decline of bicycle use in Wuhan.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Transport; energy savings, bicycle; Wuhan; China; Amsterdam.; the Netherlands

1. Introduction

China used to be called "the Kingdom of the Bicycle," but this is no longer the case. Bicycle use has been marginalized since the late 1980s. In contrast, the Netherlands has seen bicycle use grow since the 1970s. This paper, by presenting a comparative analysis of data available for the cities of Wuhan and Amsterdam, explores the reasons why China and the Netherlands have gone in different directions. Although Wuhan and Amsterdam have contrasting socio-demographics, geographic forms, populations, and climate, they have experienced a similar journey in the evolution of the bicycle sector. This results in clear and positive lessons for Wuhan, in particular, and for Chinese cities in general. The lessons are, regrettably, one-way as it is considered that any lessons Amsterdam could learn from Wuhan in this sector are rather negative. For Wuhan, the "Bicycle Kingdom" has been forgone.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.
10.1016/j.trpro.2017.05.203

The difference between the two cities is stark and exemplifies the differences between the two countries. A key lesson is how the promotion of bicycle use and bicycle-friendly infrastructure can be an important element of a clean-air strategy to achieve energy savings in the transport sector.

Bicycle ownership and use in Chinese cities have gone through a cycle of restriction, encouragement, restriction again, marginalization, electrification, and then, finally, a patchy reinvigoration though bicycle-sharing schemes. The city of Wuhan is a vivid example of this sequence. Wuhan has seen bicycle use decline from over 35 percent in 1987 to 7 percent of trip modal split in 2008. WMEDRI (2014). This assumes that there were no E-bikes in 1987 and that 70 percent of figure in 2008 is E-bikes (from 2003 modal split data). On the other hand, bicycle use in Dutch cities has gone through a steady and strong growth for over a century with only a slight dip in the 1970s. Amsterdam showcases this trend and has seen bicycle use increase from 25 percent in the 1970s to 48 percent in 2013. Langenberg (2000), Iamsterdam.com (2015).

Initially, both Wuhan and Amsterdam went through a similar experience with bicycles, but 20 years apart. Wuhan saw an explosive increase in bicycle use in the 1980s followed by a rapid decline in the 1990s. There has been no resurgence to date in 2015. In Amsterdam, on the other hand, bicycle use increased in the 1960s, followed by a slight decline in the 1970s and then a huge and sustained resurgence.

This comparative data study uses freshly-sourced data from historic sources and ongoing projects. This study has a four-step approach. First, the national context for each country in terms of vehicle ownership is examined and compared. This showcases the dynamics between bicycle and car ownership. Second, transport policies and infrastructure investments employed by each city are examined to determine the extent to which they supported bicycle use. Third, the available measures of modal share in each city over time are plotted to illustrate why each city took a different path. Finally, insights are presented and it is concluded that potential energy savings provide the basis for a strong argument for Wuhan to follow Amsterdam's lead.

2. National context and the dynamics of bicycle and car ownership

2.1. *Preamble*

Bicycle and car ownership rates provide both the context for how transport modes have evolved in countries and cities, but also the basis for trip making. Furthermore, the data illustrate cultural norms and expectations. We see that households in the Netherlands have 1.5 times the bicycle ownership and six times the car ownership of China, yet the dynamics of bicycle use and the form of cityscapes mean that the Netherlands has a more sustainable, environmentally friendly, and efficient transport system than China.

2.2. *China bicycle and car ownership*

China was deemed to be "the Kingdom of the Bicycle" from the 1950s to the 1990s. Bicycle ownership increased slowly at first, then more rapidly in the 1970s, and finally explosively in the 1980s when ownership started to be registered. In 1985, bicycle ownership for the entire country was around 225 million, doubling to 440 million by 1992. Welleman (1995), Shen (1994). As recently as the year 2000, households owned 600 million bicycles, according to Chinese census data. NBSC (2001). Statistics for bicycle ownership ceased to be published in 2004 and bicycle registration was stopped the same year. As reported by *China Daily* at the time, it was a symbolic event and was viewed as the end of the "Bicycle Kingdom." *China Daily*, (2004).

Figure 1 shows the heyday of bicycle ownership in China and the start of its decline prior to statistics no longer being published. Bicycle registration ceased in 2004, but was not recorded in national statistics from 2003 onwards. In 2002, there were 143 bicycles/100 households. Figure 1 also shows the rise of motorcycle, car, and electric bike (E-bike) ownership. Motorcycles, which had been tolerated in some cities but restricted in most others, are now increasingly being replaced by E-bikes, many of which resemble motor scooters and small motorcycles. In 2013, E-bike ownership was recorded for the first time in the national statistics at 39.5/100 households, at least 170 million nationwide. NBSC (2014). However, E-bike policy remains opaque and as they are classified as non-motorized they continue to present safety problems in bicycle lanes due to speed differentials.

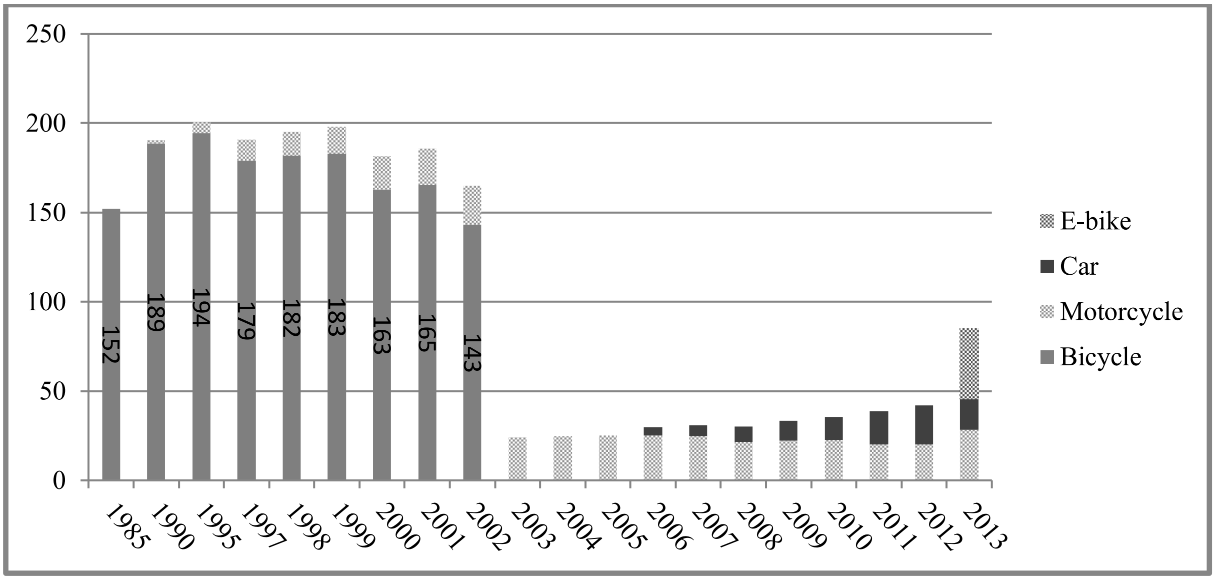

Figure 1: China vehicle ownership/100 households (1995-2013). NBSC (2014)

Private car ownership nationwide was only 19,300 in 1985, rising to 417,800 in 1992, and exploding to 92 million in 2013. NBSC (2014). In 2013, there were 16.9 cars/100 households and 68 cars/1,000 population. The growth rate was an average of 26 percent per year from 1990 to 2013. Despite the increase in private car ownership, the bicycle hung on as a mode of transport. In Beijing, for example, bicycle access and mobility were still seen as a symbol of the link between the government and its proletarian roots, and even today, in 2015, there is an obligation to have some bicycle facilities as is evident from Beijing's ill-fated Public Bicycle Scheme (PBS). In other cities, such as Wuhan, the political significance of bicycles has long been set aside in favor of car ownership. Bicycles are just barely tolerated, and cycling around Chinese cities is becoming less convenient, safe, and pleasurable.

2.3. *Wuhan bicycle and car ownership*

In Wuhan, bicycle ownership continued to grow until the 2000s from 1.65 million bicycles registered in 1998 to 3.77 million Non-Motorized Vehicles (NMVs) registered in 2000. It should be noted that the term "NMV" covers a range of motorized and electric vehicles that are termed such in order to restrict them to travelling in designated NMV lanes on the road network; they are not legally allowed to travel on motor vehicle (MV) lanes. NMVs comprise bicycles, motorized trishaws ("ma mu"), and mopeds. Of the NMV total, 99 percent of registrations are bicycles. Bicycle ownership in the city after 2000 is based on estimates as compulsory registration ceased and was estimated at 1.17 million with E-bikes at 0.7 million. WMEDRI (2014).

Figure 2 illustrates the evolution of the vehicle fleet from 1990 to 2012; it shows vehicle registrations for Wuhan with bicycle ownership extrapolated between 2001 and 2011 and E-bike registrations appearing in 2012. It also shows the rise of passenger vehicles (mainly cars, but also buses) at an annual average increase of 15 percent between 1993 and 2012.

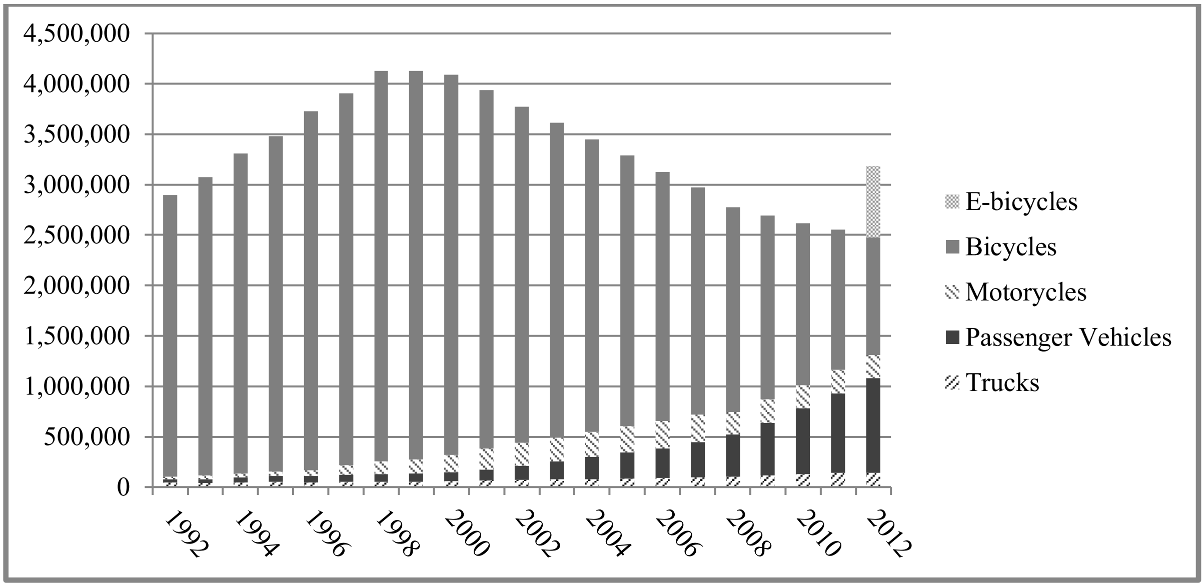

Figure 2: Wuhan vehicle registrations (1990-2012). WMEDRI (2014).

Passenger vehicles in Figure 2 comprise both public and private vehicles. Data on privately owned cars is sparse, but data shows private car registrations in 2007 were 246,000 comprising 70 percent of total passenger vehicle registrations. WMEDRI (2009). Private car ownership has risen rapidly with a 60 percent increase between 2002 and 2003, and a 22 percent increase between 2006 and 2007.

2.4. *The Netherlands bicycle and car ownership*

The Netherlands is the only European nation with more bicycles than people, yet it does not have a bicycle registration system because this was not considered useful or cost effective. As a result, data on bicycle ownership are estimated. In 1994, this was reckoned to be around one bicycle per person when the population was 15 million. Welleman (1995). In 2014, the national population was 16.6 million and it is estimated that there were 16.5 million bicycles in ownership. MvVW (2009). This has increased a little since then. Currently, in 2015, it is estimated that on average the Dutch own 1.11 bicycles per person. Figure 3 shows that in 2015 there were 215 bicycles/100 households; car ownership was 104 cars/100 households and 472 cars/1,000 population. So we see that every household has at least two bicycles and one car.

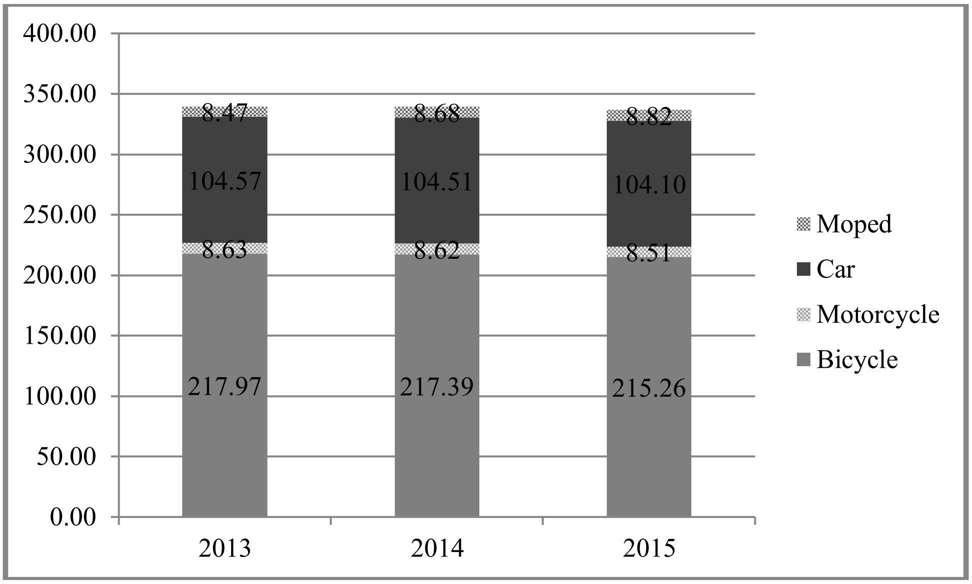

Figure 3: The Netherlands vehicle ownership/100 households (2013 -2015). Hilhorst (2014); Amsterdam (2015); Open Data Netherlands (2016).

2.5. *Amsterdam bicycle and car ownership*

Bicycle and car ownership in Amsterdam has remained relatively stable over recent years with little growth. This trend is showcased in the most recent data for 2015. Amsterdam, with a population of 811,000 in 2014, has bicycle ownership of 880,000 bicycles, an average of 1.1 bicycles/person. Hilhorst (2014). Car ownership was 264,170 and motorcycles 17,635.

2.6. *Conclusions*

In China and Wuhan, specifically, up to the 1990s, bicycle ownership was aspirational and reflected economic activity. The large number of bicycles in use was a sign of economic growth. Bicycle manufacturing thrived with the Flying Pigeon factory in Tianjin producing around 10,000 bicycles/day, around 3.6 million a year in the late 1970s, rising to 6.1 million bicycles in the late 1980s. Welleman (1995). China produced 83 million bicycles in 2011, 56 million of which were exported. Bicycles became so ubiquitous that Deng Xiaoping, the post-Mao leader who launched China's economic reforms in the 1970s, defined prosperity as "a Flying Pigeon in every household." Bicycles became desirable items to own and in the 1980s were one of three most sought after objects along with a sewing machine and a watch. The bicycle was initially expensive, costing around a month's salary, but soon affordable prices, combined with high prices for cars and motorcycles, led to a further growth in bicycle use. PADECO (1993).

Thereafter, car ownership was aspirational and reflected economic activity. The car manufacturing industry's rise was rapid. In 1995, China produced just over half a million cars; by 2014, this had risen to nearly 20 million at an annual average increase of 20 percent. Like the bicycle manufacturing industry in earlier years, the car industry was a key pillar of development and fostered by national government. The norm of door-to-door private individual modes of transport—whether this was a bicycle or a car—became established and resulted in future difficulties in kick-starting a change of mode to public transport.

Although car ownership in the Netherlands is high compared to China as shown in Table 1, in Amsterdam and other Dutch cities car use is lower than bicycle use as seen below when modal share is discussed.

Table 1: China and the Netherlands vehicle ownership comparison: recent years.

	Cars/100 Households	Cars/1,000 population	Bicycles/100 households	E-bikes/100 households	Mopeds/100 households
China	16.9	68	143	39.5	
The Netherlands	104.0	472	215		8.8

Finally, Figure 4 illustrates the stark reality of car ownership in various countries, including China and the Netherlands.

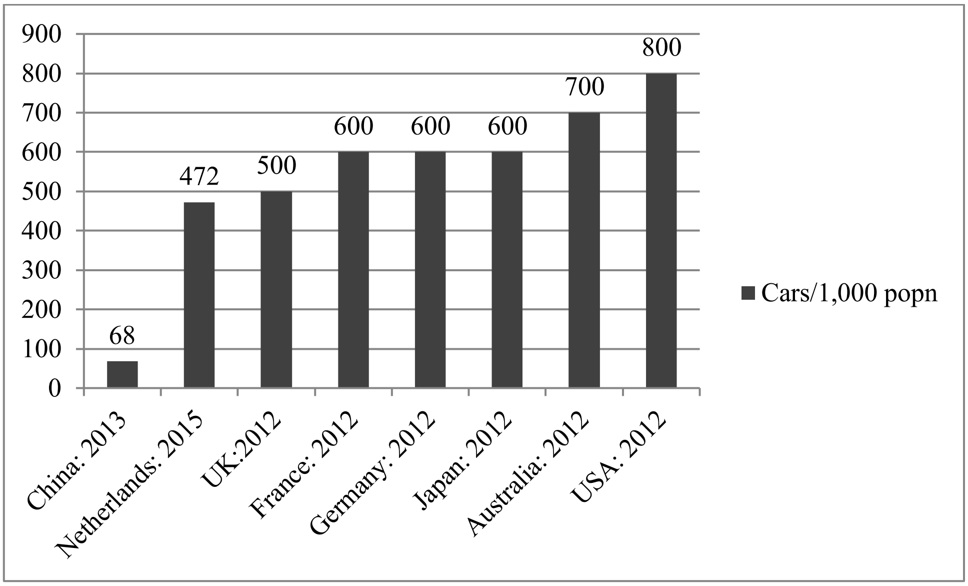

Figure 4: Car ownership/1,000 people, selected countries, Jorritsma (2014); NBSC (2014); Open Data Netherlands (2016).

Here we see that despite low car ownership in China compared to other countries, Chinese cities are becomingly increasing congested while many European cities such as Amsterdam are not. It is not merely a question of higher and denser populations; rather it is about how ownership is tackled in terms of policies and infrastructure. These questions are discussed below.

3. Government transport framework

3.1. *Preamble*

Government transport frameworks set the foundation for transport policy and how road infrastructure is developed, whether the emphasis is on providing for the private car, public transport or bicycles Here we examine how China's policies favored cars while the Netherlands quickly realized the pitfalls of car-oriented policies and adopted a more sustainable approach.

3.2. *China's transport policies*

From the 1970s onwards, government policies and actions favored bicycles. The national government aimed to make bicycle use attractive as an alternative to developing public transport and to relieve pressure on undeveloped urban road networks. Due to strict controls on car and motorcycle ownership, there were few alternatives and bicycles provided essential transport. Buses were often slow and crowded whereas bicycles provided individually tailored transport that was often faster and more reliable than public transport. Unwittingly, these policies and actions set the scene for favoring individual door-to-door transport over mass transit.

From the 1990s onwards, government policies and actions favored cars. Large volumes of bicycles on urban roads were perceived as causing ever-increasing congestion. Owning a bicycle was not considered to be necessary or desirable since other modes of transport—cars, public transport (PT), and electric bicycles—were developed. The focus, however, was on the private car with the development of PT lagging behind and focusing on metro construction often at the expense of bus networks.

Guiding Opinions from national government on bicycle provision. By 2012, it was clear that unrestrained development of private cars was unsustainable and something needed to be done to slow this trend. In 2012, three government agencies—the Ministry of Housing and Urban-Rural Development (MOHURD), the National Development and Reform Commission (NDRC), and the Ministry of Finance (MOF)—promulgated the *Guiding Opinions about Reinforcing the Construction of Urban Pedestrian and Bicycle Traffic Syste*m. WMEDRI (2014). The status of *Guiding Opinions* is unclear; they do not stipulate statutory, mandatory or legal provision, but provide some loose guidance to cities. Their key elements are presented in a negative manner; the objective was to solve the perceived problems caused by pedestrians and bicycles by focusing on improving interchange with PT and getting pedestrian and bicycle mode share to 45 percent in megacities with populations of over 10 million, such as Wuhan. However, for Wuhan this target did not make sense given that the mode split in 2008 for bicycles plus walking was already 45 percent (see below). Furthermore, it was not clear whether this target mode share included E-bikes.

Wuhan's "Two-Type Society" limps on with little to show for this initiative. In 2005, MOHURD put forward the concept of a "National Central City" whereby urbanization would be reformed and the sphere of influence of major cities would be expanded to include surrounding areas. The aim was to integrate services and infrastructure planning. Wuhan aims to qualify as one such city through developing a "Two-Type Society" that will focus on saving resources and being environmentally friendly. As such, the city aims to expand provision for pedestrians and cyclists, and reduce the volume of cars. However, measures taken so far have had little impact. Wuhan's Public Bicycle Scheme has been a failure (see below) and there have been no other bicycle initiatives. Transport Demand Management (TDM) measures for vehicles are piecemeal. While road tolling on the Third Ring Road has been implemented using Electronic Toll Collection (ETC), tolls on city bridges crossing the Yangtze and Han Rivers have been abolished. License plate restrictions have been ineffective. And a Congestion Charging Study remains just that, a research initiative with little prospect at present of being implemented.

No national or local cycling strategies. For a country that was "the Kingdom of the Bicycle" it is astonishing that China has no national or local cycling strategies. Even in the heyday of the bicycle, growth happened without a planned track. When bicycles became too many, there was still no stated national strategy; instead, nudge tactics, such as marginalization through motor vehicle takeovers of bicycle lanes and making cheap cars available to buy, were used.

3.3. *China's infrastructure and measures*

In the 1980s, city forms and road cross-sections favored bicycles. Land-use practices meant that residential areas and workplaces tended to be close together; the *danwei* or work unit and the *danwei dayuan* or work unit compound occupied vast areas of land and dominated Chinese cityscapes. Single work units often covered more than 50 ha of land and several work units abutting each other often resulted in block lengths of 2 km or more in some cities. Frame (1994). In transport terms, the advantage was that a lot of journeys to work were within the compound; the disadvantage was that the compound layout resulted in large superblocks making journeys around the city inefficient. In the 1980s, for a range of large cities, the average length of a bicycle trip was 3.8 km. Typical average bicycle trip lengths were around 5 km in Beijing, and 3.8 km in Guangzhou and Wuhan, as shown in Figure 5. MVA (1995), Frame (2008), Welleman (1995).

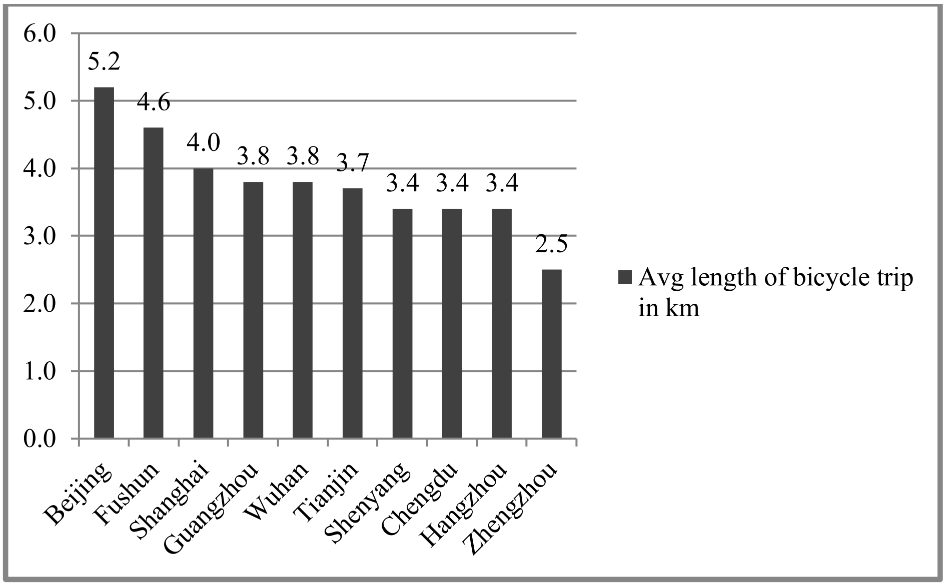

Figure 5: Average length of bicycle trip in select Chinese cities in the 1980s. Welleman (1995).

Road cross-sections favored bicycles with physically segregated bicycle lanes on major urban roads. Three section roads with wide bicycle lanes were enshrined in the National Standards (MOC, 1995) and are still implemented as standard practice. Bicycles could be ridden on almost every road and there were virtually no bans on bicycles.

From the 1990s onwards, city forms began to favor cars. City forms have increasingly marginalized bicycle infrastructure by focusing on providing for the private car. Bicycle bans and other restrictive measures began to be imposed on selected urban roads. Although new urban roads still conformed to the three-section layout with bicycle lanes (in order to conform to the national standards), road space for bicycles was increasingly reallocated to motor vehicles (MV) and parked cars encroached on bicycle lanes.

Failure of single-transport-mode-predominant roads. Many cities, such as Shanghai, developed a system of bicycle-only and MV-only roads in the late 1990s. Counterintuitively, this type of system was often the first step in marginalizing bicycles and getting rid of them altogether. While this concept could have worked (see Amsterdam below), it failed in Shanghai because MV-only roads tended to be implemented without the counterpart bicycle ones. The concept was not comprehensive enough and only applied to part of the network.

The new superblocks also did not favor bicycles. Unlike the work unit compounds of the 1980s, the new superblocks were gated residential communities. Primary roads separated these and forced cyclists either to abandon cycling in favor of the private car or make long detours using the primary road system not designed for bicycles.

Urban sprawl was another threat to cycling. As cities have expanded, people's homes became more distant and disconnected from their work. They required longer commuting times usually not feasible by bicycle. For example, in 2010, *China Daily* quoted average commute times of 52 minutes for Beijing, 48 for Guangzhou, and 47 for Shanghai. *China Daily* (2010).

Wuhan provides infrastructure for the car. Wuhan embarked on a substantial program of road construction illustrated in Table 2, which shows a 100 percent increase in road length in the 15 years between 1992 and 2007 and a 315 percent increase in road area.

Table 2: Wuhan road infrastructure indicators. WMEDRI (2009).

Year	**Vehicle population (vehicles)**	**Total length of road in the urban area (km)**	**Total area of road in the urban area (ha)**	**Road length per vehicle (m)**	**Road area per vehicle (m^2)**
1992	122,700	1,257	1,150	10.2	93.7
2007	760,000	2,515	4,771	3.3	62.8
%age change	519% increase	100% increase	315% increase	67.6% decrease	33% decrease

In particular, the five-year period between 2000 and 2005 saw an unprecedented increase of road length by 39 percent and road area by 58 percent as shown in Figure 6.

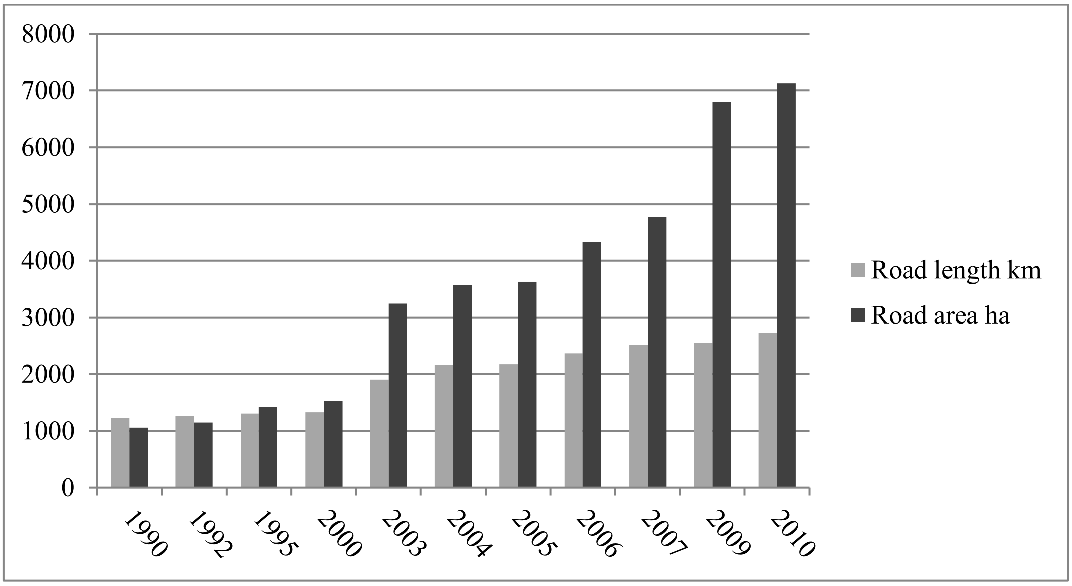

Figure 6: Wuhan road length and road area (1990-2010), WMEDRI (2014).

These statistics show that the new roads tended to be wide major arterials, typically with eight to 10 lanes and comprising single-section roads often with no central reserves.

No Functional Road Hierarchy (FRH). New road construction in Wuhan comprised vast swathes of asphalt cutting the city into large sections and severing communities. The lack of a FRH—whereby roads are classified by their functions rather than their physical characteristics—has had serious impacts on cycling and walking because mobility for these modes is hampered by a lack of road layouts that favor Non-Motorized Transport (NMT).

Failure of Wuhan's Public Bicycle Scheme (PBS). The implementation of Wuhan's PBS from 2010 to 2012 was a misguided attempt to reinvigorate bicycle use. It was a huge project with almost 23,000 bicycles at 814 locations (compare this to London's initial scheme in 2013, which had 6,000 bicycles at 400 locations). It failed not only because of the lack of government support and too much burden placed on the private sector, but also because there was no investment in bicycle infrastructure. Cycling around the city was dangerous due to the lack of segregated facilities and the presence of faster E-bikes in bicycle lanes; it was also unpleasant due to vehicle emissions; and it was inconvenient due to the road network favoring cars and the lack of bicycle parking facilities. Today, in 2015, heaps of broken and rusting bicycles can still be seen all around the city at obsolete docking stations.

3.4. *The Netherlands' transport policies*

Tackling road safety. During the 1950s and 1960s, government policy began to focus on providing for cars as the country began to motorize after World War II. At the same time, road safety became an issue with increasing numbers of accidents.

Subsidies for bicycle infrastructure. To complement infrastructure geared toward bicycles (discussed below), policies to foster bicycle safety were developed and local authorities provided financial support for innovative approaches to develop bicycle use, including subsidies for constructing bicycle lanes and paths.

Second Transport Structure Plan (1990). The 1990 Second Transport Structure Plan set out transport policy to the year 2010 aiming to prioritize PT and bicycles, and develop a Transport Demand Management (TDM) strategy to manage demand as opposed to a "predict and provide" strategy. The key elements were presented in a positive manner: (1) to manage transport demand by car by improving vehicle emissions, limiting infrastructure and parking facilities for cars, and restricting vehicle access in urban areas; (2) to manage mobility by restricting land use so that there would be shorter distances between residence, workplace, service, and leisure facilities for citizens; (3) to provide selective accessibility by road in that not all places should always be completely accessible by all modes of transport; (4) to improve the alternatives to the car by improving bicycle transport, PT, and carpooling; and (5) capacity building.

Bicycle Master Plan (1992). The 1992 Bicycle Master Plan complemented the 1990s Structure Plan. It had the objective of increasing bicycle safety and the appeal of the bicycle. Prior investments in road construction had not solved the mobility problems. Furthermore, there was an increasing budget deficit and detrimental effects from vehicle emissions. Three key targets for 2010 were set compared to a base year of 1986: (1) to limit the expected 70 percent growth of car use to 35 percent; (2) to reduce traffic fatalities by 50 percent and serious injuries by 40 percent; and (3) to reduce vehicle emission levels by 75 percent (nitrogen oxide) and 10 percent (hydrocarbon and carbon dioxide).

Decentralized, integrated, and customized approach in Amsterdam. The central government was the catalyst providing the innovation, knowledge, financial support, and the necessary legislation and regulations. Municipalities develop local policies and implement local schemes, often with different approaches. Each municipality has a different approach to cycling. Some municipalities implement an independent bicycle policy, while others integrate bicycle policy in the general traffic and transport policy. In Amsterdam, cycling policy is an integral part of its mobility policy and is based on four elements: road safety, infrastructure, parking, and education. City of Amsterdam, (2014).

Public information and education campaigns promote bicycle use. The Dutch government developed information campaigns focusing on the benefits of cycling. It highlighted that it was generally quicker to cycle than to use other modes of transport in dense urban areas for trips up to 7.5 km. The bicycle was also heavily promoted as an individual door-to-door transport mode with a reliable and stable travelling time. Bicycle parking took up less space than car parking as one car space could accommodate eight to 12 bicycles. Bicycles were environmentally friendly modes of transport with no noise or emissions. Finally, cycling was inexpensive and healthy.

Amsterdam's long-term bicycle plan. In 2011, the *Meerjarenplan Fiets* 2012-2016 was initiated. This did not develop any new policies or a new bicycle network—as these were already considered to be excellent—instead it was aimed at tackling problems associated with the rapid increase in bicycle use. The plan seeks to create an extra 50,000 bicycle parking spaces; to improve connections to PT; and to improve road safety and comfort.

3.5. *The Netherlands' infrastructure and measures*

Investment in car infrastructure (1960s-1990s). Between 1950 and 1990, the built up area of the Netherlands increased by a factor of 3.4 with a decrease in population density, which led to longer travel distances. In the 1960s, new high-rise residential areas were built 25-50 km away from city centers and commuting by car increased. In 1994, private car ownership for the whole country was 5.8 million; lower than in other countries, but still a high number of cars/km^2. Mopeds were at their peak in the mid-1990s then rapidly declined as people shifted to cars. Until the 1960s, passenger kilometers travelled by bicycle were still higher than those by car, but that position was reversed in the 1970s as a result of rapid motorization and suburbanization, and bicycle space reallocated to car use.

Investment in bicycle-friendly infrastructure accelerates from 1990s onwards. In the late 1970s, the government realized that large-scale car use was unsustainable. Bicycle use began to slowly recover assisted by infrastructure investments targeted toward bicycles. By the early 2000s, Amsterdam's area for transport, including roads, railway, subway, and trams, comprised 16.1 percent of the total area of the city, 13.36 km^2 out of a total area of 219.07 km^2, being 50.8 m^2 per car (263,000 cars in 2005), less than Wuhan. Decisions on infrastructure were made at the municipality level. It was difficult at first because road space had to be allocated to bicycles from car space and some initiatives were unsuccessful.

For example, Bicycle Superhighways (similar to what are currently being developed in London) were trialed in 1975 in The Hague and Tilburg. However, they were considered expensive and did not lead to increased bicycle use. Cities developed an alternative approach. Amsterdam concluded that what was needed was a spread of bicycle routes—not only segregation, but also hierarchical networks of bicycle routes within a dense road network. Central government subsidies enabled the construction of bicycle lanes and paths in cities. This strong expansion of bicycle infrastructure stopped the decline of bicycles and regenerated bicycle use.

In Amsterdam, 90 percent of streets are considered to be bicycle-friendly. In 2014, there were 500 km of segregated bicycle routes surfaced in red asphalt (a national standard) with another 500 km of protected bicycle routes where planners have to consider bicycles in every planning decision.

Amsterdam parking plan as Transport Demand Management. This comprised a zonal parking system with differentiated charges. Car parking spaces were reduced and reallocated to bicycles. Car parking policy remains strict and expensive at around €5/hour in cities. There is a waiting list for car parking spaces and residential parking permits. This plan presents clear evidence that parking controls and pricing can be relatively easy Transport Demand Management (TDM) measures to implement.

Woonerven (Home Zones). The concept of *woonerven* was developed in the late 1960s in Delft. A *woonerf* or "residential yard" is a residential street in which the living environment, rather than vehicle infrastructure, predominates. Through the physical alteration of the street, the *woonerf* provides space for cars while fully accommodating residents' needs. The objective is to change the way streets are used and to improve the quality of life in residential streets by designing them for people, not just for traffic. Here pedestrians, bicyclists, and motor vehicles share the street with pedestrians and bicycles having priority over cars. The street is designed without a clear division between pedestrian and vehicle space with no continuous curbs, so motorists are forced to slow down. A *woonerf* transforms the street into a livable and attractive environment for a variety of activities. Since 2000, *woonerven* have comprised over 90 percent of roads in urban areas.

Sustainable safety. In 2000, Amsterdam adopted a new national standard traffic system called "sustainable safety." The speed limit is 30 km/h in the *woonerven* while the urban speed limit is 50 km/h.

Groningen role model. Amsterdam was inspired by the city of Groningen. This small city with a population of 190,000 in 2010 has had a pro-cycling policy since the 1970s. Traffic-management arrangements favored bicycles. Groningen adopted a traffic-cell-traffic-calming scheme, which divided the city into "environmental cells" that were linked only by bicycle and PT roads; there were no through routes for cars between the cells. Groningen also invested substantially in bicycle infrastructure.

Potential of two transport mode-predominant roads. Amsterdam is always innovating and being proactive on cycling. Amsterdam's Mobility Plan in 2013 (the *MobiliteitsAanpak Amsterdam*) is in the process of rethinking the city's infrastructure and is proposing a system of "Plus Nets" as shown in Figure 7. This is a new kind of Functional Road Hierarchy not based on land use but on transport modes whereby no more than two modes of transport should predominate on a street—for example, PT and bicycles; cars and bicycles; PT and cars. This proposes to replace the need to accommodate all transport modes on each street. In contrast to Shanghai's ill-conceived attempt at this (discussed above), it is envisaged that this system could be the future in Amsterdam.

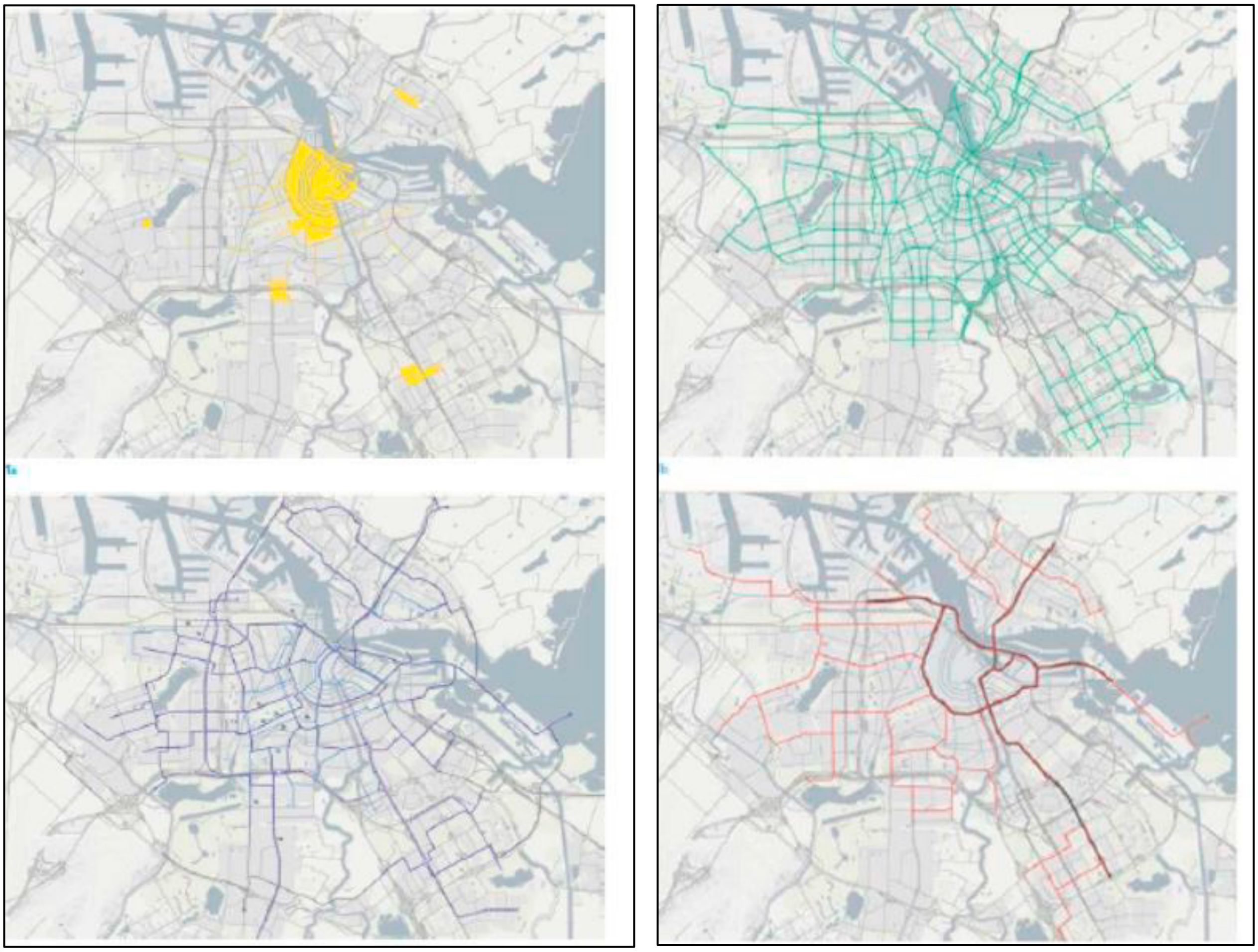

Figure 7: Amsterdam's proposed "plus nets." From top left clockwise, "plus net" for pedestrians, bicycles, cars, and PT. City of Amsterdam (2014).

3.6. *Conclusions*

In China and Wuhan, in particular, it is clear that the provision of road infrastructure disadvantaged bicycles. Bicycles were marginalized by the focus on building wide roads with several lanes for cars and by reallocating bicycle lanes for cars and parking. In the Netherlands and Amsterdam, in particular, the opposite is true. Here, road construction slowed and cities developed the *Woonerven* (Home Zone) system where the street is shared by pedestrians, bicyclists, and motor vehicles with pedestrians and bicycles having priority over cars in a 30 km/h speed limited zone.

4. Trip modal shares

4.1. *Preamble*

Trip modal shares show how transport modes are used. This section illustrates the decline of bicycle trips in Chinese cities with the rise of bicycle trips in the Netherlands.

4.2. *China and Wuhan trip modal shares*

Evolution of trip modal split shows the decline of bicycle trips. In a sample of large cities in the 1980s, bicycle trip modal split averaged 46 percent, with walking at 37 percent and public transport at 15 percent. Zhang (1994). Cities such as Beijing, Chengdu, Hangzhou, Wuxi, Shijiazhuang, and Shenyang had over 50 percent bicycle trip mode share while Wuhan, Changchun, and Guangzhou had around 35 percent as shown in Figure 8.

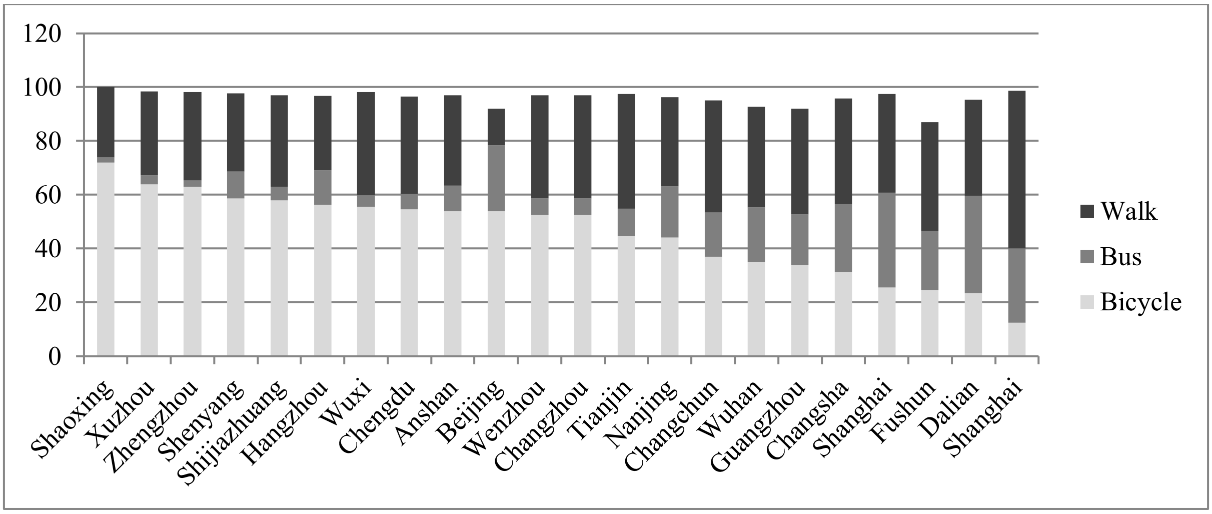

Figure 8: China selected cities modal split, 1980s, Zhang Jian (1994).

The days of bicycle dominance have since vanished and the role of the bicycle in China is now less for commuting and more for leisure. The dominance of the bicycle lasted about 20 years. By the late 1990s, the term “the Kingdom of the Bicycle” was no longer true. While bicycle ownership remained high, bicycle usage plummeted. In Beijing, in 1986, bicycle trip vehicle mode share was 58 percent; in 2005, it was 39 percent; and in 2011, it was 15 percent, while private car share increased from 5 percent to 33 percent over the same period. Other Chinese cities show similar trends. In Guangzhou, in 1984, bicycle trip mode share (including walking) was 39 percent; in 2005, it was 9 percent. BTDRC (2012).

Wuhan bicycle modal share plummets. In Wuhan, in 1987, bicycle trips accounted for 35 percent of trip modal split. Welleman (1995). In 2008, these had plummeted to 7 percent as shown in Figure 9. E-bikes start to impact the modal share from 2003 onwards.

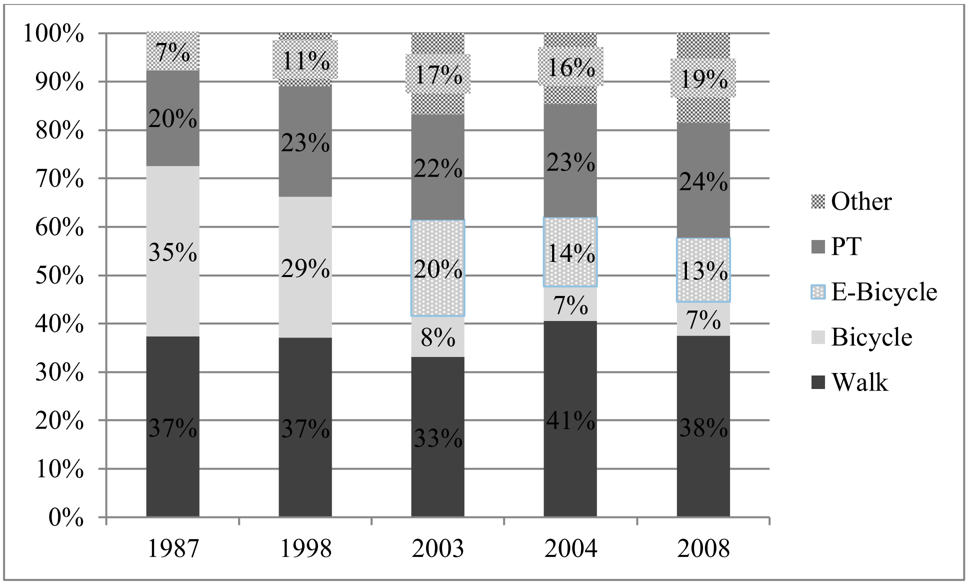

Figure 9: Wuhan trip modal split (1987-2008). Note: "Other" is mainly passenger car, but also includes taxi, WMEDRI (2009).

Wuhan's bicycle trips are forecast to decline further along with E-bikes (although this will depend on future E-bike policies) as both PT and passenger cars grow.

4.3. *The Netherlands and Amsterdam trip modal shares*

Since the 1990s, the bicycle has been the main mode for short trips. In the Netherlands, the bicycle is the main mode of transport for distances up to 2.5 km; and for distances up to 7.5 km, which comprise 70 percent of all trips, the bicycle remains a significant mode of transport. In Amsterdam in the 1990s, while PT was very well developed, bicycles were a key mode with four trips by bicycle for every trip by PT for trips under 5 km, shown in Figure 10.

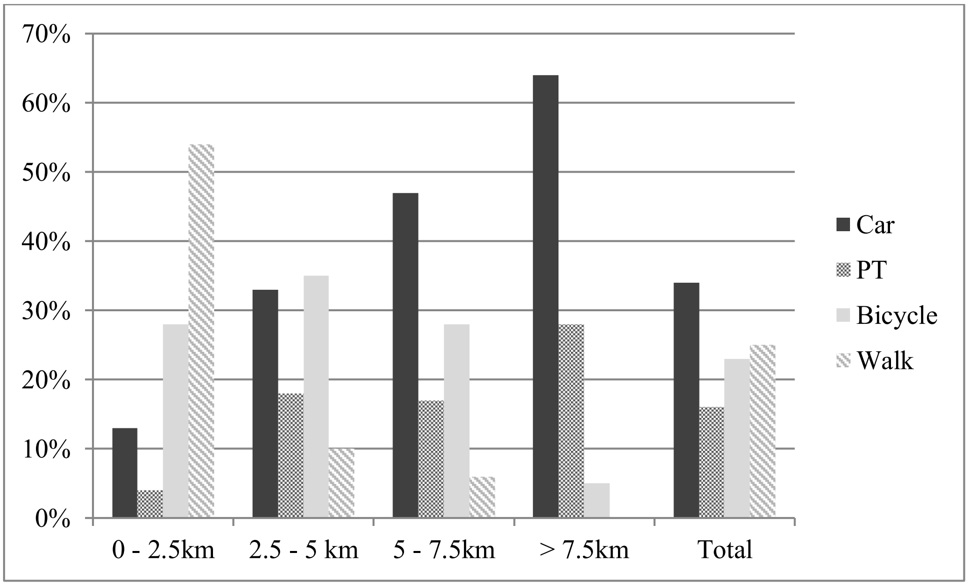

Figure 10: Amsterdam mode split for different trip lengths (1991-1993), Welleman (1995).

Amsterdam's bicycle trip modal share increases at the expense of cars. In 2014, the bicycle mode share in Amsterdam was more than 50 percent overall and 62 percent in the inner city. **Figure 11** shows the trend from 1986. Over 2 million km/day are ridden by cyclists in the city with an average of 2.9 trips/person/day.

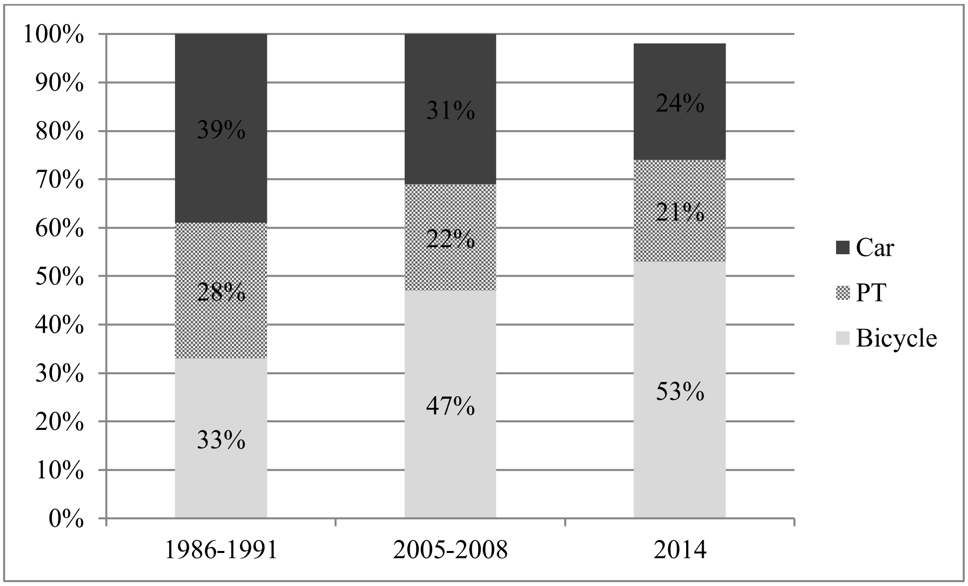

Figure 11: Amsterdam trip modal share (1986-2014). Jorritsma (2012), City of Amsterdam (2014).

4.4. *Conclusions*

In Wuhan, in 1987, bicycle trips accounted for 35 percent of trip modal split. By 2008, this number had plummeted to 7 percent. In contrast, in 2014, bicycle mode share in Amsterdam was more than 50 percent overall and 62 percent in the inner city. The difference is stark and it highlights the different paths that each city has taken.

5. Energy savings

Bicycles have zero operational fuel consumption and require low capital costs for implementation. Bicycles are clean and quiet with no fumes and minimal noise. They produce very little carbon dioxide—only in manufacture and disposal. In a globalized world, bicycles can be a key element of an energy security policy by reducing oil dependency and increasing transport resilience in the event of oil price fluctuations.

Road infrastructure for bicycles causes less severance and requires less space for parking than providing for cars. In congested urban traffic conditions, bicycle use can support higher passenger flows per meter of road width than cars. This considerable operational advantage can often be overlooked in discussions concerning road space allocation. The benefits include improved air quality, lower operating costs for users and providers, and space-efficient infrastructure requirements.

Today, there is a strong argument for implementing bicycle-friendly programs and infrastructure. This was not necessarily apparent during the heyday of the bicycle in China in the 1980s when its advantage was seen in terms of an individual door-to-door mode rather than an environmentally-friendly transport mode. It rapidly became apparent in the Netherlands, however.

Bicycles are a key part of the jigsaw of measures required to reduce greenhouse gas (GHG) emissions. In order to address the challenge of climate change, the international community has adopted a common goal of keeping the rise of the Earth's temperature to below two degrees. COP21 (2015). In Europe, this resulted in the EU Transport White Paper whereby agreement was reached to reduce GHG by 20 percent by 2030 and 70 percent by 2050 compared to 2008 levels. Europa (2011).

Half of all CO_2 emissions in cities come from transport and the best way to reduce these is to restrict the use of motor vehicles by promoting other transport modes, including public transport, walking, and cycling. Motor vehicles are the largest producers of CO_2 in the transport sector and, therefore, have the highest potential to reduce GHG. The aim should be to reduce trips by car— cycling has a role to play here along with E-bikes for trips up to 15 km. But rendering increases in bicycle use into GHG emission reductions requires two steps: converting these increases into reductions in kilometers travelled, and converting these reductions into reductions in GHG emissions. While promoting walking and cycling for short daily trips is feasible, longer trips that are responsible for most carbon emissions have much less potential to be replaced by cycling.

Strategies that facilitate increased bicycle use have the potential to reduce vehicle trips and vehicle kilometers travelled by shifting trips from cars to bicycles and public transport. Bicycling strategies fall into two main categories: (1) infrastructure projects that improve bicycle accessibility, safety, and convenience, either while traveling or at the end of the trip, and (2) programs that promote bicycling directly or indirectly through education, community events, advertising, and other activities. We have seen how Amsterdam has invested heavily in bicycle infrastructure and has extensively promoted cycling while Wuhan has gone in the other direction.

A German study examined the potential for cycling to reduce GHG emissions. Cycling has an impact on motor vehicle kilometers travelled when a bicycle trip replaces a driving trip if the cycling trip is not just for leisure. It was calculated that if 25 percent of short trips previously made by car were shifted to bicycle then energy savings of 8,000 tons/day could be made out of a total 281,000 tons/day for the whole country.

In the United States, Handy (2014) examined both the effects of the provision of bicycle infrastructure and the promotion of cycling as a mode had on bicycle use. For infrastructure, it was found that a 1 percent increase in length of segregated bicycle lanes was associated with a 0.35 to 0.36 percent increase in the share of workers commuting by bicycle. For bicycle programs, the increase was more significant as can be seen in Table 3.

Table 3: Long-term increases in cycling mode share for various cities, Handy (2014).

Long-term increases in cycling mode share for comprehensive bicycle programs	**Cycling mode share at start of program**	**Number of years after start of program**	**Increase in cycling mode share**
Barcelona	0.7%	2	135%
Paris	1.0%	6	150%
Bogota	0.8%	8	300%
Portland	1.1%	18	445%
Boulder	3.8%	26	132%

In 2015, a TRACE (Tool for Rapid Assessment of City Energy) diagnostic for Wuhan was carried out to try and get an idea of the potential reductions in GHG emissions if more environmentally-friendly transport measures were implemented. WITP (2015). TRACE is a simple tool that quickly diagnoses inefficient energy performance across a city's systems and offers a range of potential solutions embedded with implementation guidance and case studies. An energy efficiency analysis was carried out citywide as well as for the transport sector.

The TRACE tool showcased a range of interventions, all of which have been successfully used, to a greater or lesser extent, by Amsterdam, including: (1) enforcement of vehicle emissions standards; (2) traffic-flow optimization; (3) Public Transport development; (4) Non-Motorized transport mode development; (5) parking controls; (6) controls on car use; and (7) education and awareness-raising.

Using the TRACE tool for Wuhan, it was estimated that potentially 31 percent could be saved for public transport energy cost and 20.2 percent for private vehicles as shown in Table 4.

Table 4: Potential energy savings for Wuhan, WITP (2015).

Sector	Estimated Percentage of Energy Consumption Reduction	Cost of Energy Used (USD)	Potential Energy Cost Savings (USD)
Public Transportation	31.0%	253,006,268	78,437,455
Private Vehicles	20.2%	989,163,063	169,925,734

6. Lessons

China is no longer "the Kingdom of the Bicycle" and Wuhan exemplifies this trend. The rise of private vehicle ownership with little restriction on car use, underinvestment in PT, development of sprawling cities, and massive investment in car-oriented road infrastructure has resulted in the dominance of private cars at the expense of bicycles. Nationally, there was no cycling strategy and Wuhan, like other Chinese cities, had no cycling plan. While bicycle ownership remained high, bicycle use declined dramatically.

Wuhan focused on ownership of private vehicles that provided individual door-to-door travel—first the bicycle from the 1980s through to the 1990s, then the private car from the 1990s onwards. Unlike many other Asian countries, motorcycles were restricted in China so this mode was skipped over.

The focus on providing for the private car has resulted in excessive construction of road infrastructure (encouraging urban sprawl and unsustainable city forms), emerging congestion, and pollution. Investment in public transport has been too little, too late, and Wuhan is now playing catch up with a large metro construction program. *Ad hoc* attempts have been made over the years to restrict the use of private vehicles (such as license-plate restrictions and piecemeal road tolls), but these have been ineffective. While a congestion charge has been talked about for years, no schemes have been implemented. Recent belated attempts to reinvigorate bicycles through Public Bicycle Schemes have generally failed.

The bicycle in Chinese cities, including Wuhan, was not recognized as an energy efficient, eco-friendly, healthy, and sustainable mode of transport. Rather, it was seen as a convenient and affordable stopgap solution to transport problems that saved cities from investing in public transport. It was seen as backward and its decline was rapid. The legacy is that PT has not developed as much as needed and citizens now expect individual door-to-door transport, preferably by car.

Road infrastructure disadvantaged bicycles. Bicycles were marginalized by the focus on building wide roads with several lanes for cars and by reallocating bicycle lanes for cars and parking. But bicycles also suffered from so-called bicycle-friendly infrastructure whereby a system of segregated NMV and MV routes did not benefit bicycles because the NMV routes were not sufficiently developed and were not enforced. This type of infrastructure purported to benefit bicycles, but in reality disadvantaged them.

It is unlikely that road-safety issues brought about the decline of the bicycle. According to Chinese national statistics for 2010, bicycle riders accounted for only 2.4 percent of fatalities and 4.17 percent of serious injuries. MPS (2011). Notwithstanding this, the casualty totals are high with nearly 1,600 bicycle rider fatalities and over 100,000 serious injuries to cyclists. In Wuhan, data on bicycle rider fatalities and serious injuries are not available, but general accident and casualty trends are upwards (in contrast to the situation nationwide) probably due to increased motorization.

Finally, Wuhan had no role model to follow. And it failed to become a role model in its own right.

The Netherlands is indeed the "Bicycle Kingdom" these days and Amsterdam vividly illustrates this description. From the 1970s onwards, a combination of public pressure, policy, planning and design, and infrastructure investments has resulted in bicycles being a key transport mode in Amsterdam. The disbenefits of increased car use (congestion, emissions, road safety, unlivable city forms) were seen in the 1970s and action was taken to avert these poor outcomes and to engender a different kind of society and transport system.

Road construction slowed and cities developed the *Woonerven* (Home Zone) system where the street is shared by pedestrians, bicyclists, and motor vehicles with pedestrians and bicycles having priority over cars in a 30 km/h speed limit zone.

There was an innovative proactive approach with a national cycling policy and devolution of control to municipalities to develop local measures. One size did not fit all and individual cities developed their own measures. There was time to plan, even though bicycle development was as rapid as in China where systematic planning did not seem possible due to cities being overwhelmed by bicycles. Amsterdam managed the increase in bicycle ownership and use and responded proactively.

Transport Demand Management (TDM) measures were key policies. While car ownership was not controlled, car use was controlled by developing a type of road infrastructure that favored bicycles and through parking controls. There was no need for congestion charges or vehicle restrictions. Amsterdam showcases the successful use of parking controls as a relatively easy TDM measure.

Finally, Amsterdam had a role model in Groningen, and Amsterdam itself became a role model.

What can Wuhan learn from Amsterdam to improve its bicycle mode share and livability? The comparison between innovation in Amsterdam versus stagnation in Wuhan is stark. The rapid increase in bicycle use and the resulting problems were tackled in different ways in each city. Wuhan saw this as a problem, marginalized the bicycle, and futilely attempted to enable a mode shift to private car. Amsterdam tackled the problem by identifying bicycle parking as the issue and increasing parking spaces for bicycles.

Both cities went through the same journey (albeit 20 years apart), but while Amsterdam recaptured its bicycle share and expanded it, Wuhan has not and may never achieve this.

A key lesson is that cities need a spread of bicycle facilities. They should not be restricted to using specific routes or roads. Bicycles need to be able to travel on almost every urban road other than motorways/expressways.

In summary, Wuhan needs to do almost everything that Amsterdam did from policy measures to decentralization; from infrastructure measures to education and promotion; from seeing bicycles as the solution and not the problem; and from developing a city form and infrastructure that is human-scaled, dense, diverse, and designed.

Acknowledgments

This research was supported by ESMAP (www.esmap.org). The opinions expressed are solely those of the authors and do not reflect the views of the World Bank or its Board of Directors.

References

BTDRC, 2012. "Beijing Transport Congestion and Carbon Reduction Situation Report," Beijing Transport Development Research Centre. Note: Vehicle trip mode splits, excluding walking.

China Daily, 2004. http://www.chinadaily.com.cn/english/doc/2004-11/11/content_390685.htm. Retrieved September 12, 2015.

China Daily, 2010. http://www.chinadaily.com.cn/china/2010-06/07/content_9940222.htm. Retrieved September 14, 2015.

City of Amsterdam, 2014. “Plan Amsterdam, Cycling Policy and Design: Putting Knowledge into Practice,” City of Physical Planning (DRO).

COP21, 2015. Paris, http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm.

Europa, 2011. Roadmap to a Single European Transport Area.

Frame, G. 1994. “The Preservation of Historic Beijing and the Threat from Motorization.” Qinghua (Tsinghua) University, Beijing.

Frame, G, 2008. “Guangzhou Urban Transport Improvements Implementation Schemes (GUTS4), Non-Motorized Transport Topic Report.” MVA Hong Kong Ltd.

Handy, S. et al. 2014. “Impacts of Bicycling Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions,” Policy Brief, California Environmental Protection Agency.

Hilhorst, R., 2014. “Amsterdam Cycling Policy,” Meeting with Gemeente Amsterdam (Amsterdam Municipality).

Iamsterdam.com 2015. Amsterdam Media Centre: http://www.iamsterdam.com/en/media-centre/city-hall/dossier-cycling/cycling-facts-and-figures. Retrieved September 12, 2015.

Jorritsma, P. et al.; 2012. “New Drivers in Mobility: What moves the Dutch in 2012 and beyond?” KiM Netherlands Institute for Transport Policy Analysis.

Langenberg, P., 2000. “Cycling in Amsterdam: Developments and Policies.” Department of Infrastructure, Traffic and Transport, City of Amsterdam.

MOC 1995. GB 50220-95, 1995. “Code for Transport Planning on Urban Roads,” National Standard, Ministry of Construction.

MPS, 2011. “People’s Republic of China Road Traffic Accident Statistics Yearbook 2010,” Traffic Management Department., Ministry of Public Security.

MVA, 1993. “Beijing Transport Planning Study,” Chapter 4, MVA Consultancy, Hong Kong.

MvVW, 2009. “Cycling in the Netherlands,” Ministerie Van Verkeer en Waterstaat, (Ministry of Transport, Public Works and Water Management), Fietsberaad (Dutch Cycling Knowledge Base), the Netherlands.

NBSC, 2001. National Bureau of Statistics of China, Table 10-9.

NBSC, 2014. National Bureau of Statistics of China, Table 6-3; Table 8-26.

Open Data Netherlands, 2016. https://opendatanederland.org/. Retrieved on February 10, 2016.

PADECO Co. Ltd; 1993. “Non-Motorized Vehicles in Asian Cities for the World Bank.”

Shen, D., et al., 1994. “A Study of Non-Motorized Passenger Transport in China”; in Ren Futian, and Liu Xiaoming, Proceedings of NMT ’94 International Symposium on Non-Motorized Transportation, 23-25 May 1994, Beijing.

Welleman, A. G. et al., 1995. “Bicycles in Cities”; in Stares S, and Liu Z, “China’s Urban Transport Development Strategy: Proceedings of a Symposium in Beijing, November 8-10, 1995.” The World Bank and the Dutch Ministry of Transport.

WITP, 2015. “City Energy Efficiency Report: Transport Sector Wuhan,” TRACE (Tool for Rapid Assessment of City Energy), Wuhan Integrated Transport Development Project Team.

WMEDRI, 2009. “Feasibility Research Report for Wuhan Second Urban Transport Project.” Wuhan Municipal Engineering Design and Research Institute.

WMEDRI, 2014. Study on Non-Motorized Traffic System of Wuhan Main Urban Area, Wuhan Municipal Engineering Design and Research Institute (WMEDRI).

Zhang, J., 1994. “Prospects for the Development of China’s Urban Bicycle Traffic,” in Ren Futian, and Liu Xiaoming, Proceedings of NMT ’94 International Symposium on Non-Motorized Transportation, May 23-25, 1994, Beijing. Note: mode share includes walking.