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The Rise of Electric Two-wheelers in China: Factors for their Success and Implications for the Future

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Factors for their Success and Implications for the Future

By

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The Rise of Electric Two-wheelers in China:

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EXECUTIVE SUMMARY

This dissertation examines the rise, present use, and future growth of the electric two-wheeler (E2W, a.k.a. E2W or e-scooter) in China, the world's most successful electric-drive vehicle. The E2W market has been experiencing tremendous growth with over 30 million now in regular use on Chinese streets. The adoption of E2W technology is significant because, along with their air quality and energy (low-carbon) benefits compared to gasoline powered motorcycles, E2Ws are driving the development of improved and lower cost batteries and may lead to a shift toward larger three-and four-wheel electric vehicles (EV).

This dissertation explores three questions: why the E2W market grew so rapidly in China, what factors are driving and resisting its growth, and how future growth might impact the adoption of electric vehicles. Because these three questions intersect in many domains, such as technology, economics, industrial organization, consumer behavior (the market), and public policy, a multi-disciplinary approach has been used throughout the analysis. In Chapter 1, the context for this analysis is built by describing China's transportation past, present, and future challenges. E2Ws are also introduced and compared with gasoline-powered motorcycles on several metrics, such as performance, air emissions, and energy use. In Chapter 2, data from the literature was collected and analyzed to understand the history and important reasons for E2W growth in China. To supplement these data, the author and colleagues interviewed leaders of E2W and battery companies and toured several manufacturing plants. In Chapter 3, E2W and bicycles users were surveyed to understand how and why they use (or don't

use) E2Ws. In Chapter 4, valve-regulated lead-acid (VRLA) batteries commonly used in today's E2Ws were laboratory tested to determine their performance characteristics. Data were also compiled on their cost, and on the cost and performance of Li-ion batteries. In Chapter 5, the future of E2Ws in China was assessed by integrating data from the previous three chapters and from the literature to create a force-field analysis of the E2W market. This chapter concludes by examining the spillover effects E2W market growth may have on the development of a market for larger electric vehicles. Chapter 6 provides recommendations for policy makers on E2Ws and suggestions of future areas of research on this topic.

In answer to the first question, E2Ws have been successful in China for three principal reasons: gasoline-powered motorcycle bans in large city centers removed E2Ws strongest competitor; E2W technology, specifically motors and batteries, improved significantly during the late 1990's; and due to improving economic conditions nationally, urban household incomes rose causing surging demand for inexpensive private transportation. The history of E2Ws provides an important lesson on the powerful impact of regulatory policy when the evolution of technology produces a market acceptable product.

In answer to the second question on factors driving and resisting growth of the E2W market, three factors are identified as driving growth. First, there were improvements in E2Ws and E2W batteries, both in terms of cost and performance, which can be partially attributed to the unique E2W product architecture and industry structure. Second, growing air quality and traffic problems in cities in part due to rapid urbanization has led to strong political support for E2Ws at the local level in the form of motorcycle bans, and loose enforcement of E2W standards. Third, public transit systems in cities have become strained from the effects of urbanization and motorization, which has stimulated greater demand for “low-end” private transport. There are also formidable forces resisting E2W market growth. The superior performance of motorcycles is a powerful limiting factor, especially in areas where motorcycles are not banned and incomes are high. Bans on E2Ws, which have been enforced in a handful of cities already, could also limit their growth if they spread to more cities. Overall, the driving forces appear to outweigh the resisting forces for future E2W market growth.

In answer to the third and final question regarding the adoption of larger EVs, there are two characteristics of the E2W industry that may hasten EV development. First, the high degree of component standardization in the industry due to E2W’s highly modular product design with simple component interfaces is driving down costs. Secondly, the unique structure of the E2W industry (open-modular with many competitors) is leading to continued improvements in battery cost and performance and the development of larger E2Ws. As preliminary evidence, some E2W manufacturers have already begun producing larger three- and four-wheel EVs. However, there are some major obstacles facing these EVs that will not be easy to overcome in China. The largest is the issue of recharging infrastructure, which will need to be built since EV batteries are not portable like E2W batteries. Cell variability, safety issues related to high-voltage and unstable battery chemistry in Li-ion are other obstacles.

ACKNOWLEDGEMENTS

It is often said in science and other challenging endeavors, we are able to achieve only because we had the privilege to stand on the shoulder of giants. Throughout this dissertation process I've been incredibly fortunate to stand on the shoulder of several titans: my advisors, some of the world's finest minds in the field of alternative fuels, energy, and transportation. I'm forever grateful to them for generously sharing their wisdom with me, keeping me on track when I went astray, and always encouraging me.

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This research has been aided immensely by the work of many people who came before and provided a foundation for understanding electric two-wheelers in China, the unique problems of transportation in developing countries, and China's unique situation and challenges. These authors and their important contributions are referenced in Chapter 7.

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2WV – two-wheel vehicle

AGM – absorptive glass mat

BSEB – bicycle-style electric bike

C-I – closed-integral

CO – carbon monoxide

CBA – Chinese Bicycle Association

E2W – electric two-wheeler

E2W – electric bicycle or scooter (electric two-wheeler)

EV – three or four-wheel passenger vehicle

FFA – force-field analysis

FLA – flooded lead-acid

GDP – gross domestic product

GHG – greenhouse gas

km – kilometre

km/l – kilometres per litre

kWh – kilowatt-hour

Li-ion – lithium ion

LPG – liquefied petroleum gas

m – meter

M2W – motorized two-wheeler

Min – minute

MJ – mega joule

Mpg – miles per gallon

Mtoe – million tons of oil equivalent

NMV – non-motorized vehicle

NOx – nitrogen oxide

OEM – original equipment manufacturer

O-M – open-modular

R&D – research and development

RMB – ren min bi (Chinese yuan)

SO2 – sulfur dioxide

SOE – state-owned enterprise

SSEB -- scooter-style electric bike

T&C – transportation and communications

USD – US dollar

V – volt

VRLA – valve-regulated lead acid

W – watt

W/l – watt per litre

W/kg – watt per kilogram

Wh – watt-hours

WTW – well-to-wheel

1 INTRODUCTION

One billion cars— this is the projected size of the world's vehicle fleet in just 20 years, and a significant increase from the 700 million light-duty vehicles on the world's roads today [1]. The majority of this vehicle growth over the next two decades will occur in non-OECD countries, with the largest growth expected in China and India. The fuel of these future cars is therefore of critical importance, not only to the health of the hundreds of millions who dwell in the densely packed cities of these countries, but to the world community as a whole in preventing global climate change and its potentially calamitous effects.

This dissertation examines the use and future growth of a particular transportation vehicle technology that is experiencing unprecedented success in one corner of the developing world. This application, roughly the price of a cell phone, could have far reaching implications on the future fuel and powertrain of automobiles throughout the entire world. The application is the Chinese electric two-wheeler (E2W).

In this Chapter, the context for this analysis is set by describing China's transportation landscape and the changes it has undergone over the past ten years. E2Ws are introduced and compared to their close cousin, the gasoline-powered two-wheeler (G2W or motorcycles). The research questions, objectives, and scope of the analysis are explained, and a brief synopsis of each chapter is provided.

1.1 China's Changing Transportation Landscape: 1996 vs. 2006

In 1996, China was in the midst of an unprecedented period of rapid economic development and social change. 70% of China's 1.2 billion people lived in the countryside; though with state-owned enterprises privatizing, housing policies relaxing, and incomes rising, urbanization was well underway.

As cities grew, so did demand for transportation. To accommodate this demand, bicycles, public transit, and especially motorcycle use were experiencing tremendous growth. Motorcycle sales had been doubling each year for five straight years. The automobile industry, however, was still in an infant stage, producing slightly less than a half million passenger cars per year. GDP per capita was only $830/yr (2006 US$) [2]. For every thousand persons, 360 owned bicycles, 17 owned motorcycles, and only three owned a personal car. This would soon change as the trends of urbanization and motorization continued over the following decade.

During this same year, Shanghai passed a groundbreaking regulation, becoming the first of many cities to suspend license granting to gas-powered motorcycles downtown due to deteriorating air quality accompanying rapid growth in motorcycle use. The mayor declared to "gradually eliminate gas-powered assist vehicle and actively develop and promote electro-assist technology" [3].

By 2006, China had changed dramatically. The proportion of people living in the countryside fell to 57%. For every thousand persons, 350 owned bicycles, 90 owned motorcycles, and ten owned a personal car. Perhaps most surprising however was the emergence of an entirely new mode of transportation virtually non-existent in 1996: the electric two-wheeler, owned by 30 people out of 1,000.

Figure 1-1 shows the growth in motorized vehicle sales over the past decade [4-7]. By 2006, annual sales of E2Ws equaled those of G2Ws. In terms of sales revenue, E2Ws accounted for $4.6 billion, compared to $19.2 billion for G2W (includes exports) [8, 9].

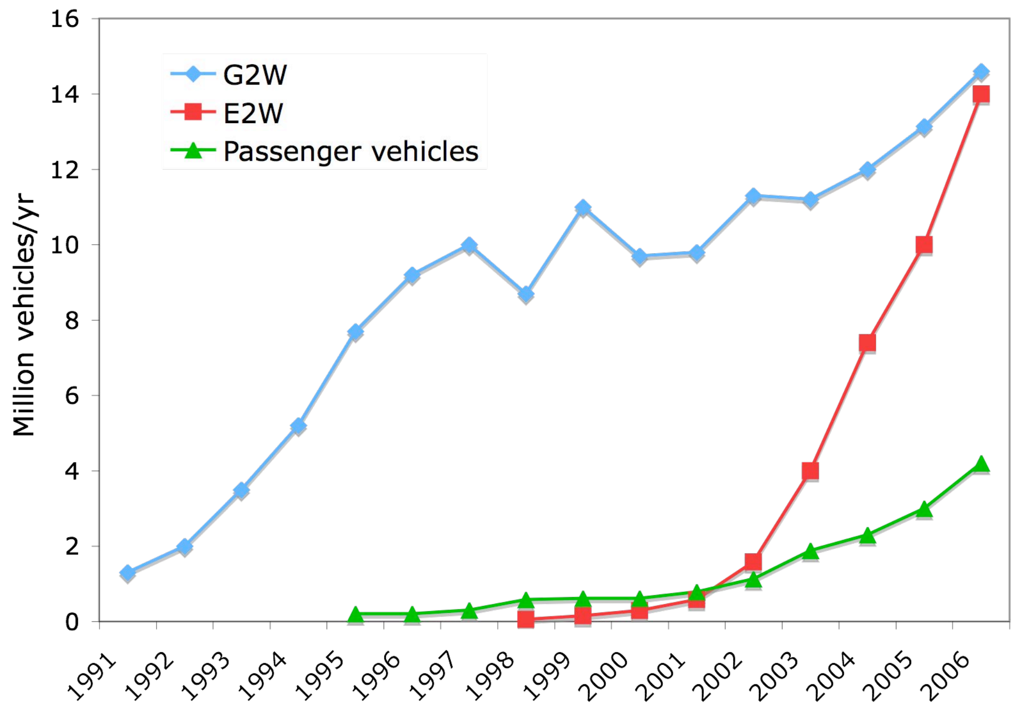

Figure 1-1: Motorized Vehicle Sales in China

Vehicle ownership statistics may underestimate the degree of E2W use in China's cities. Based on limited surveying in ten cities (small, medium, and large), E2Ws make up 28% of total two-wheeler traffic on average, compared to 57% bicycles and 15% G2Ws (Figure 1-2).[1]

[1] Data was obtained by measuring vehicle flow at various intersections throughout each city. Total sample size: 8,297 (Hangzhou 364, Chengdu 487, Nanjing 224, Jinan 356, Xian 193, Shanghai-city 3,226, Shanghai-outer suburbs 1,270, Tai An 219, Weifang 41, Tianjin 976, Shijiazhuang 600,Beijing 341). This average only represents 11 cities throughout China and thus should not be taken as a true national average.
[3] Sustainable transportation, as defined by the World Business Council for Sustainable Development means "the ability to move more freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological requirements" (WBCSD, Mobility 2030 Report, 2004)

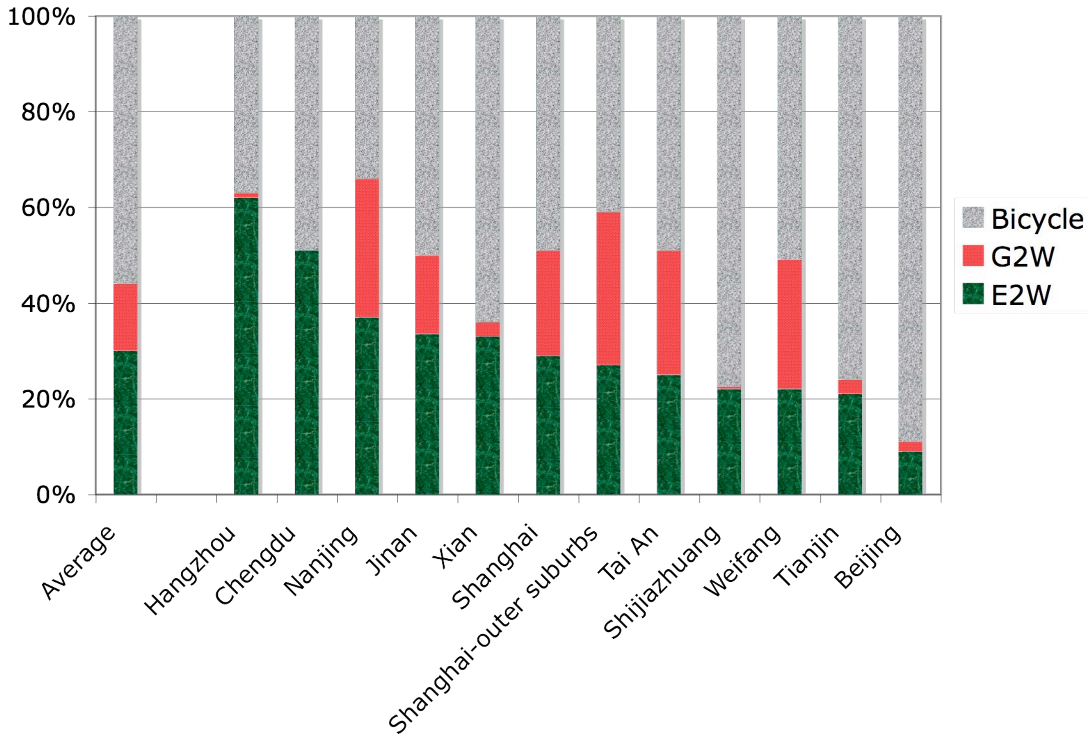

Figure 1-2: Observed 2-wheel Vehicle Proportions in Chinese Cities

To define where E2Ws fit in the Chinese transition to greater personal mobility, today's E2W users are mostly yesterday's bicycle users, public transit users, and (a smaller portion) motorcycles users. Survey results show that 70-80% of E2W users had switched from bicycle and public transport [10, 11]; it is unclear how many of these users used to own motorcycles since they were banned several years ago. Many of these E2W users would have likely chosen a motorcycle over an E2W had motorcycles not been banned. Surveys show that most of today's E2W users are also tomorrow's E2W users, though a small fraction are tomorrow's automobile users.

Urban Transportation in China

Urban transportation is a particular challenge in Chinese cities because of their high population density, relatively low income, and a diverse mix of motorized and non-motorized transportation modes of multiple sizes and speeds. These factors result in low-quality fuels and motorized vehicles used in dense concentrations, resulting in serious health impacts due to air pollution, a subject covered extensively by Walsh [12]. By 2006, air pollution was causing 350,000-400,000 pre-mature deaths per year, as estimated by the World Bank and Chinese State Environmental Protection Agency [13]. While transportation accounted for a small fraction of energy use in China (7.5% in 2006 [14]), it is responsible for a large portion of the air pollution in cities. According to one study in 2000, mobile sources were “contributing approximately 45-60% percent of the NOx emissions and about 85% of the CO emissions in typical Chinese cities” [15]. In China, emissions from gasoline powered vehicles are higher than in developing countries due to poor quality fuel, inferior vehicle engines, and low use of emission control technologies like catalytic converters [39]. A study measuring pedestrian exposure to VOCs, PM_{10}, and CO in urban Guangzhou indicate that automobile emissions are likely the major source [37].

Zegras and Gakenheimer (2006) frame the issues of urban transportation in developing countries using two key terms: accessibility- “the ability to reach the daily needs and wants necessary to survive and thrive”, and mobility- “the movement from place to place” [17]. Accessibility is the goal of most people; mobility is what provides it. Different forms of mobility (e.g. car vs. bicycle) provide varying levels of accessibility. These different forms also create different levels of negative externalities (e.g. pollution, congestion,etc.). The key challenge of sustainable urban transportation systems is to maximize accessibility while minimizing the negative externalities associated with these different forms of mobility. According to Schipper and Ng (2007), transportation in Chinese cities is characterized by high levels of congestion, fatalities, pollution, and greenhouse gas (GHG) emissions [16]. Rapid urbanization is adding further stress to transportation systems in cities that aren't able to keep up with the increased demand for road space and public transit.

While two-wheel vehicles are still the dominant transport mode in China, motorization (i.e. the transition to personal cars) will continue to rise with income. At 8% GDP growth, vehicle ownership is projected to increase to 29 million by 2020 [12]. Personal car growth will result in a large increase in oil consumption and CO_2 emission, which has been modeled in He et. al (2005) [18]. Motorization and its costs and benefits to China are discussed extensively in C.A.E and N.R.C (2001) [2]. This study, undertaken by experts from both China and the US, concludes that while increased motorization will bring many economic benefits, it will also bring many challenges to social, environmental, and economic systems. Schipper and Ng (2007) point out that rapid motorization in China, in contrast to the slower motorization which occurred in developed countries throughout the world, poses more risks because of high population density and an existing urban transport foundation based on non-motorized transport [16].

Many researchers have proposed solutions to the unique challenges of urban transportation in China, though they are often difficult and costly to implement. Zhou and Sperling (2001) conclude that two promising options are "providing an array of high-quality options to travelers" and "special lanes and other infrastructure to accommodate vehicles such as buses, minicars, and bicycles …(in order to) save money and improve traffic circulation" [19]. Another solution is the substitution of gasoline powered vehicles with electric vehicles, which could reduce oil consumption, CO_2 emissions, and other negative externalities associated with motorization [20].

1.2 E2Ws Role in Sustainable Transportation

Without question, urbanization and motorization in China have created significant improvements in people's quality of life and productivity. However, they have simultaneously created some serious problems affecting future growth and prosperity: congestion, growing energy demand and oil dependence, and air pollution. On a global scale, they are also accelerating the rate of climate change.

As part of the solution to these problems, China is trying to develop a transportation system that is sustainable economically, socially, and environmentally. [3] Reducing pollution from vehicles and improving their efficiency is one means of achieving this. E2Ws emerged in the past decade as an alternative-fuel vehicle with unique characteristics to address some of the aforementioned challenges. In terms of air pollution and energy use, E2Ws have an advantage over gasoline-powered motorcycles, as shown in the following two figures [11, 21, 22].

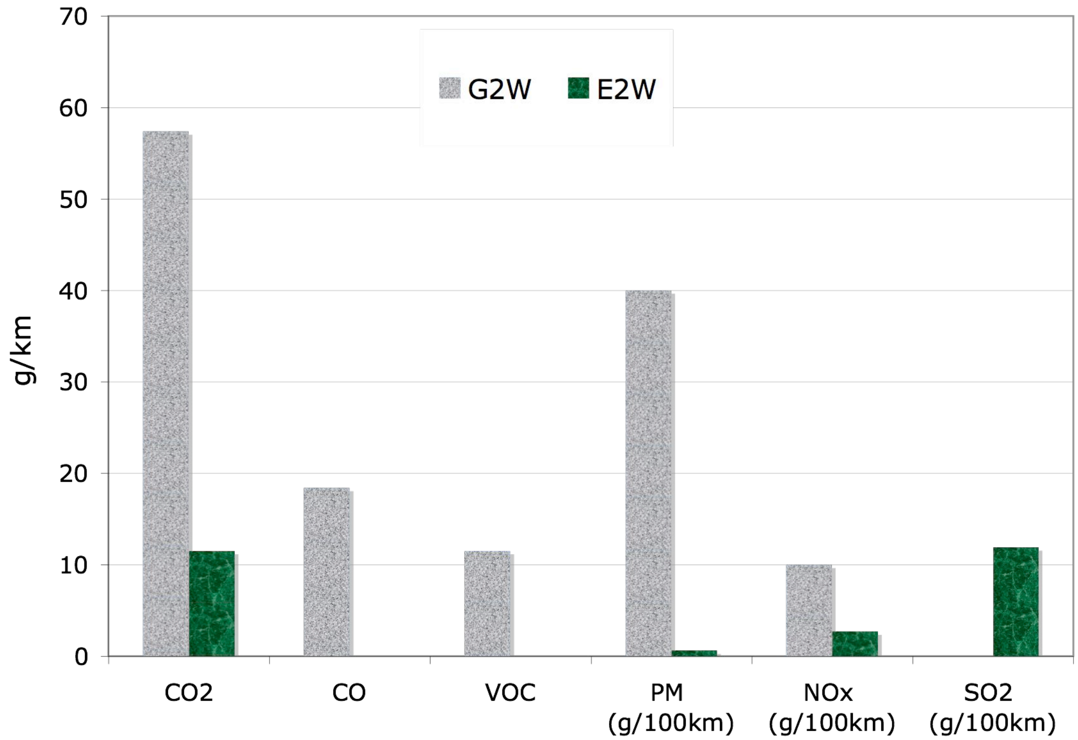

Figure 1-3: Air Emissions of E2Ws vs. Motorcycles

The figure shows air pollutants emissions from motorcycles are higher for all air pollutants except for SO2. E2Ws have high SO2 emissions since 75% of electricity in China is coal-fired (Cherry 2007).

Gasoline powered two-wheelers use 2-7 times more energy than E2Ws on a well-to-wheel basis. The main difference in energy use is at the tank-to-wheels stage, where motorcycles expend 75% of their total well-to-wheels energy per km [22]. In contrast, E2Ws consume the majority of their energy in the well-to-tank stage during production and transmission of electricity [11, 23].

Figure 1-4 shows the well-to-wheel energy consumption comparison for an E2W and a G2W with similar power.[6]

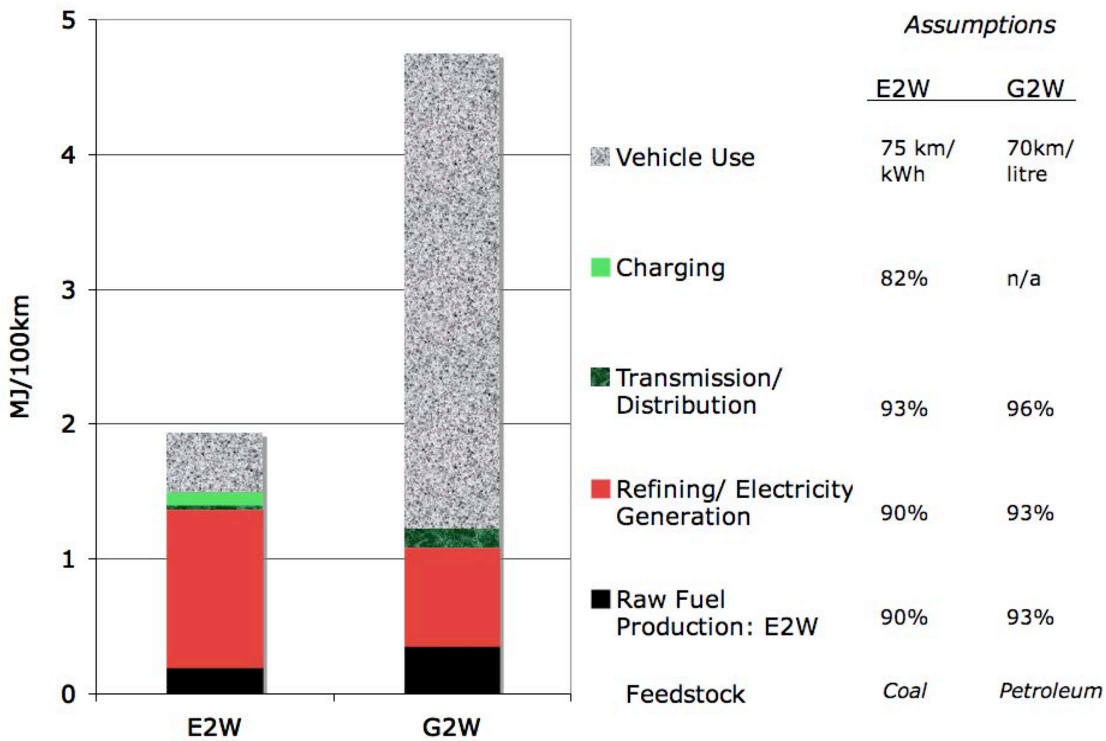

Figure 1-4: Well-to-wheels Energy Consumption of E2Ws and Motorcycles

Cherry 2007 has completed a thorough analysis in his PhD dissertation on the environmental and mobility pros and cons of E2Ws versus buses and bicycles in China. He finds that "while E2Ws have some problems that need to be addressed (namely excessive lead recycling and management of batteries); they provide large benefits and

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[6] The G2W used in this analysis is a 30cc high–efficiency gasoline-pedal bike with claimed fuel efficiency of 70km/l (160 mpg) (Sansen, www.zj-sanxin.com.cn). Though there are very few of these used in China, it provides a more "apples-to-apples" energy comparison by accounting for the power difference between G2Ws and E2Ws.

can be a successful strategy toward a sustainable transportation future.” Cherry quantifies the travel time and accessibility advantages of E2Ws compared to buses and bicycle. He provides data on roadway fatalities of E2Ws vs automobiles to show that E2Ws have lower fatality rates per vehicle-km traveled. He calculates the life-cycle energy use, CO2 and NOx emissions of E2Ws vs. buses and bicycle. While E2Ws provide energy and air quality benefits compared to public transit and automobiles, their lead emissions rate is significantly worse due to high rates of lead loss in China’s lead industry. He concludes that the benefits of E2Ws are substantial and that government could address their largest disadvantage, lead pollution resulting from battery production and disposal, to push improved recycling and the evolution to better batteries.

1.3 Background on Motorized Two-wheelers in China

There are many different types and sizes of two-wheelers around the world. Table 1-1 classifies the two-wheelers types most commonly used in China according to their key attributes.

Table 1-1: Classification of Chinese Two-wheelers

Class	Types	Power (engine size)	Top speed (km/hr)	Fuel Use (/100km)	Range (km)	Picture
Bicycle			10-15	n/a	n/a	
Electric two-wheeler (E2W)	Electric bicycle (BSEB)	0.25-0.35 kW	20-30	1.2-1.5 kWh	30-40	

	Electric scooter (SSEB)	0.3-0.5 kW	30-40	1.5kWh	30-40	
Motorcycle	Gasoline moped/ Scooter	3-5 kW (50-125cc)	50-80	2-3L [24]	120-200	
	Gasoline motorcycle	4-6kW (100-125 cc)	60-80	2-3L	120-200	

Electric Two-wheelers

E2Ws are a category of vehicles in China that includes two-wheel bikes propelled by human pedaling supplemented by electrical power from a storage battery (bicycle style E2Ws, or BSEB), and low-speed scooters propelled almost solely by electricity (scooter style E2Ws, or SSEB). Most rely exclusively on electric power, not human pedaling. In most cities, electric bikes are allowed to operate in the bicycle lane and are considered a bicycle from a regulatory perspective (i.e. helmets and drivers licenses are not required).

The technology of each type of E2W is similar. The main components of an E2W include a hub motor, controller and battery. BSEBs typically have 36V batteries and 180-250W motors. SSEBs typically have larger 48V batteries and higher-powered motors 350-500W. Electric bikes are regulated not to exceed 20km/hr, but many, especially scooters, can travel at speeds in excess of that limit and some are advertised to go 40km/hr. They can vary in speed from 25-40 km/hr and range of 25-50 km on a single charge, which requires 6-8 hours. Electric bike batteries are recharged from a standard electrical outlet and thus require no new infrastructure. The majority of E2W users recharge them at home during the night when electricity is cheaper. In urban areas, this typically means carrying either the battery or the entire E2W into a multi-level apartment building. It is also common to see bikes being charged during the day outside ground-floor shops using standard electrical outlets.

E2Ws have become a popular transportation mode for Chinese consumers because they provide convenient yet relatively inexpensive form of private mobility and are thus an attractive alternative to public transit or regular bicycling. The following figures compare the cost (USD cents/km) and in-use speed of E2Ws vs. other modes.

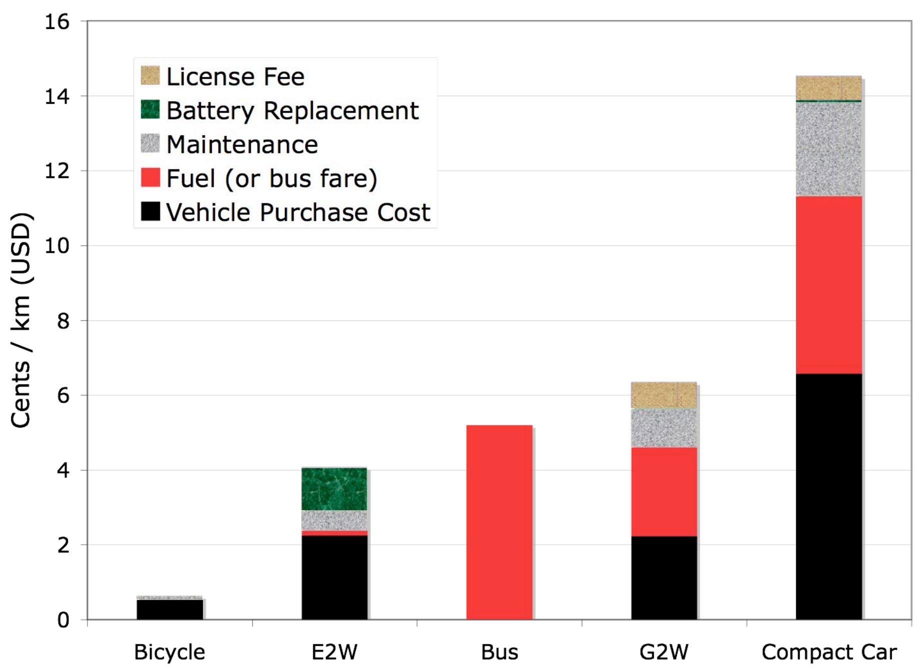

Figure 1-5: Cost of Common Transport Modes in China

This figure shows the key cost advantage of E2Ws over motorcycles is their lower operating cost due to cheaper, more efficiently used fuel, even after accounting for battery replacement cost.[7] While E2Ws also have a lower initial cost than motorcycles, motorcycles presumably have longer lifetime thus levelized vehicle purchase cost is roughly equal.

Not surprisingly, E2Ws are faster than bicycles, as shown in the figure below. Motorcycle speeds (labeled “LPG scooter” in figure) are even higher in free flow conditions. All modes approach the same speed when flow is congested.

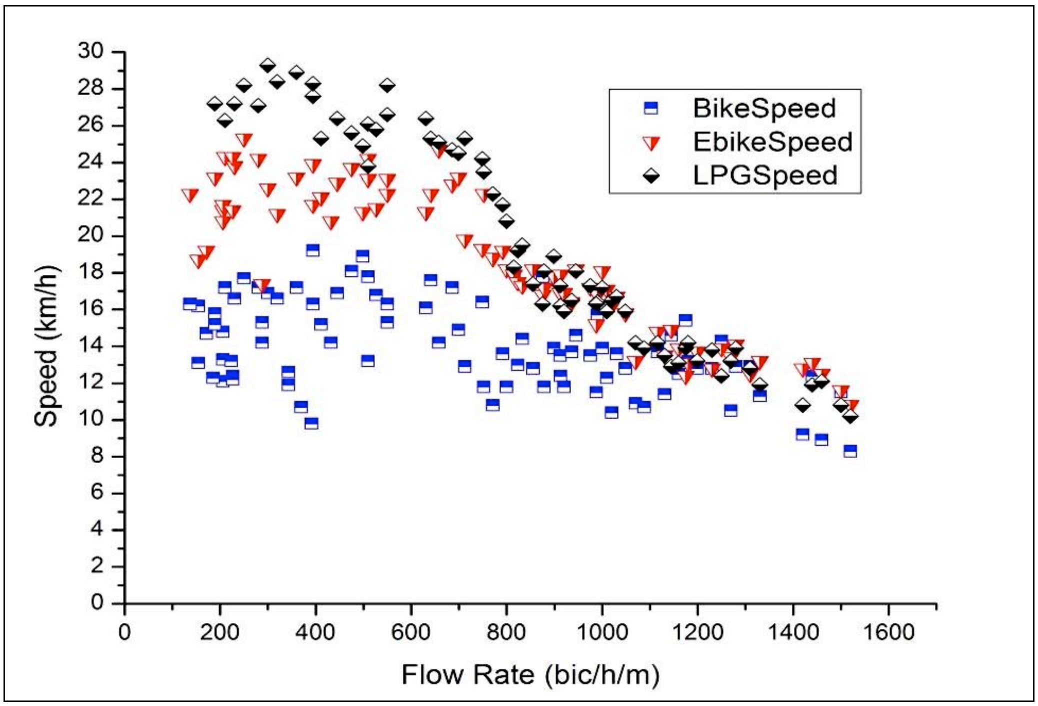

Figure 1-6: Speed vs. Traffic Flow for Two-wheelers in Shanghai (Ma 2007) [25]

E2Ws are promoted by national and many local governments due to their low energy consumption and zero tail-pipe emissions, especially important in China’s congested urban areas. In recent years however, a handful of cities have decided to ban electric

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[7] Assumptions for this cost analysis are provided in Chapter 2 and the Appendix.

bikes, stating reasons related to decreased safety and traffic flow efficiency when mixed with engine-powered cars and trucks. Cities like Guangzhou have banned all motorized two-wheelers in favor of public transportation, bicycles, and cars. Some cities choose to neither support nor ban them. E2Ws as an urban travel mode have both positive and negative attributes, the main ones listed in Table 1-2 below.

Table 1-2: Pros and Cons of E2Ws

Pros	Cons
"0" tail-pipe emissions	75% of electricity in China produced from coal (Cherry 06)
Energy efficient (70-80 km/kWh)	Lead-emissions from battery production & recycling.
Inexpensive	Potential reduction in traffic flow efficiency compared with public transit
Can be "refueled" at home/work	Safety concerns when mixed with vehicles. (quiet, fast, heavy, poor brakes)

Solid waste from E2W operation is significantly higher than for motorcycles. A life-cycle emissions study comparing an E2W to a motor-bike concluded that an E2W generates 2.7g/km of solid waste (63% from coal combustion and 14% from battery disposal) compared with 1g/km for the motor-bike [21]. It estimated that the lead emissions from E2Ws are 0.05-0.10g/km due to inefficiencies in the dispersed, small-scale lead production and recycling process [11, 26].

E2W Issues

Traffic safety is perhaps the most important issue facing E2W growth. In November 2006, Guangzhou became the third city in China to ban E2Ws (behind Fuzhou and Zhuhai), under advice from the traffic management bureau citing traffic safety concerns [27]. Based on conversations with traffic police, this is mainly due to their erratic driving behavior, which impacts vehicle drivers and traffic efficiency. Their high speed, weight, and silent nature also poses a threat to bicyclists riding in the non-motorized vehicle lane. Thus, automobile owners and bicyclists often perceive E2Ws negatively. The safety issue of E2Ws mixed in traffic is a key consideration in the drafting of new National E2W Standards, which are under revision and under intense debate.

Electric bikes are also not the most efficient users of scarce road space. While E2Ws can move more people per lane than cars, buses move more people per lane than E2Ws [28].

In Taiwan, electric two-wheelers were promoted between 1996 and 2003 as a means of improving urban air quality, though that failed. Scientists and engineers who developed the electric scooter in Taiwan discuss their experience and some of the difficulties encountered regarding e-scooter introduction in [29]. The main problem was that their scooters were too expensive due to their high power and energy requirements.

Gasoline Scooters and Motorcycles

Motorcycles in China include three main styles: scooters style, underbone style, and traditional motorcycle style (or horseback type); there are very few mopeds. The following classification from Wikipedia is helpful in characterizing the wide range in motorcycle types:

> "*Mopeds* are small, light, inexpensive, efficient rides for getting around town. Usually started by pedaling (motorcycle + pedals = moped). *Scooters* are motorcycles with a step-through frame and generally smaller wheels than those of a traditional motorcycle. Can be ridden without straddling any part of the bike. *Underbones* are small motorcycles which are a crossover between a scooter and a true motorcycle with step-through frame, popular in Southeast Asia. *Standard motorcycles* (Horseback-type) are characterized by tear-shaped fuel tanks located at the top and just behind the instrument panel, whereas the fuel tank for an underbone motorcycle is located under the seat." [30]

Underbones are also known as "cub" style, since they are based on the original cub motorcycle introduced by Honda in the 60s (verify). LPG scooters are popular in Shanghai because they are exempt from the city-side motorcycle ban. This type is excluded from the analysis however, since they are exclusive to Shanghai. Scooter style is usually equipped with automatic transmission [22].

Motorcycle engine type and style has changed since the early 1990s, as documented in Ohara (2006) [6]. During first half of 1990s, the most prevalent motorcycles were two-stroke, 110cc or below, and horseback type (standard). In latter half of 90s, the market share of 4-strokes scooters with 125cc or greater engine size increased sharply. From 2000 onwards, underbone frame type have gained increasing popularity, and are the most common in Southeast Asia (especially ones based on the Honda C100). By 2002, there were only a few models of 2-stroke motorcycles available due to tightening of environmental regulations. Market share in China by displacement in 2002 was: 125cc (~45%), 110cc or less (~28%), 50cc or less (<8%). Market share by type was: 4-stroke standard motorcycle type (~37%), 4-stroke scooter type (~30%), Underbone (18%). 2-strokes (MC or scooter style) (~11%). By 2002, motorcycle engines had converged to three dominant models: C100, CG125, and GY6, all of which are 4-strokes.

The four largest national markets for motorcycles in 2006 in order of annual sales volume were China (14.6 million), India (8.2 million), Indonesia (4.6 million), and Vietnam (2.3 million) [31]. In terms of vehicle ownership in 2002, there was one motorcycle for every two people in Taiwan, four people in both Thailand and Malaysia, seven people in Vietnam, 15 people in Indonesia, 16 in China[8], and 63 people in Malaysia. Motorcycle ownership in rural households has been growing faster than in urban household since 1998, with 32 per 100 rural households compared with 24/100 urban households in 2003 likely due to the motorcycle bans in many cities which also started in the late 90s [6]. In 2006, China produced half of the world's motorcycles [32]. Most exports from China are sold to the low-end market (Southeast Asia and Africa) [6].

1.4 E2Ws Around the World:

The dominant majority of the world's E2Ws (96%) are concentrated in China. There are other small but growing E2W markets in Japan, Europe, and more recently, in India (Figure 1-7) [5].

[8] Based on ownership of 25 for every 100 households (Ohara 2006) and an assumed household size of 4.

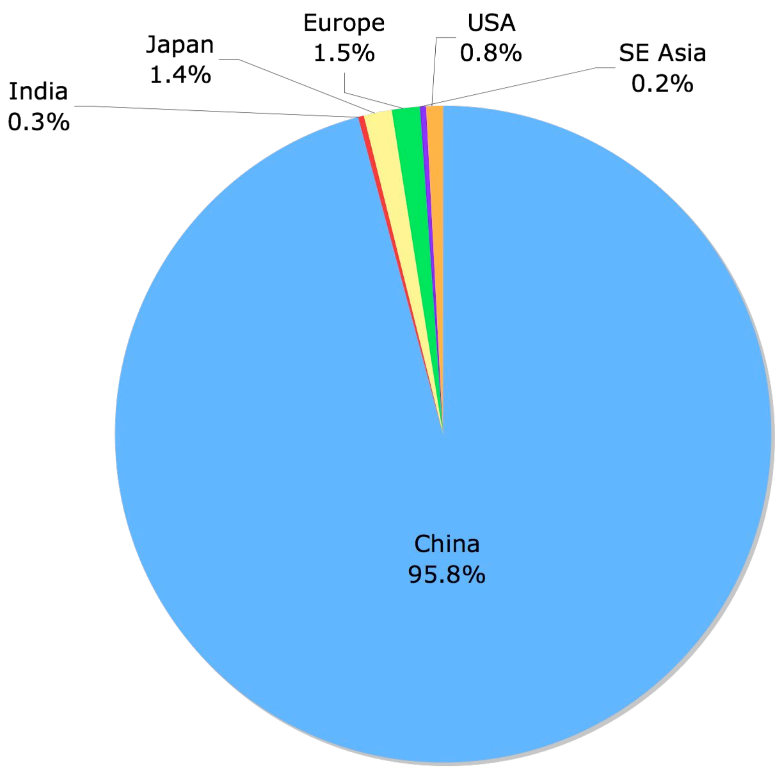

Figure 1-7: Worldwide E2W Sales, 2006

After China, the next largest E2W market is Japan with annual sales of 270,000 bikes/yr in 2006 and 13% average annual growth since 2000 [33]. Pedelecs (a style of E2W driven primarily by human-power with battery assist) are the dominant type of E2W. Most pedelec E2Ws use Ni-MH or Li-ion batteries. Battery capacity ranges from 0.2-0.6 kWh, motor size ranges from 150-250W, and prices range from $700-2,000.

In Europe, the market is estimated at 190,000 bikes/yr in 2006 [34]. Electric bikes in Europe are also mainly pedelec style. Sales in the Netherlands are greatest due to extensive bicycle infrastructure and deep-rooted biking culture. Germany and Belgium are the next largest markets for pedelecs.

India's electric bike market is small, but forecasts for growth are optimistic [5]. In other developing countries throughout Southeast Asia like Thailand, Vietnam, and Indonesia, where two-wheelers are the dominant form of transportation, E2Ws have not gained a significant market share. This may be attributed to the fact that valve regulated lead-acid battery performance (i.e. range and lifetime) degrades quickly in areas where temperatures are very high throughout the year, or very low [35]. Gasoline-powered motorbikes are the dominant mode in the larger cities of these countries. In the United States, the very limited electric bike market is limited mainly to recreational riders who rely on the assistance of the electric motor out of physical necessity. The E2W is not a common commuter vehicle in most cities because commute distance are long, bicycle infrastructure non-existent, and most bicycle commuters do so primarily for recreation [36].

1.5 Research Objective and Research Questions

The objective of this research is to determine the causes for the adoption of E2Ws in China and how it will impact the future success of electric vehicle transportation in China and throughout the world. To achieve this, the following research questions are posed:

1. Why have E2Ws been so successful in China?
2. What are the factors driving and resisting future E2W market growth?
3. If E2W markets grow, what effects will that have on battery technology, and EV technology?

While clean, energy efficient two wheeled vehicles (2WVs) are important for urban air quality in the short term, the critical long-term issue is the development of clean, energy efficient automobiles due to the rapid pace of motorization in China and other non-OECD countries. Thus, a key long-term large-scale benefit of increasing E2W use could be to hasten the adoption of EVs due to the technology similarities between E2Ws and small EVs.

A widespread shift to electric vehicles would have a positive impact on air quality, energy use, petroleum dependence, and carbon emissions, even more so if the electricity were made from natural gas and renewable sources, rather than coal. Air pollution would shift from high-density urban areas to lower density suburbs where power plants are sited. While overall SO2 emissions would increase since 75% of China's grid electricity is produced from coal, NOx and CO levels from gasoline combustion would drop. A shift to electric vehicles may reduce mortality and health impacts from lower overall PM, NOx and CO emissions and lower exposure to emissions. In Beijing, a city with ~2 million vehicles and notoriously poor air quality, PM emissions from vehicles during summer months were found to outweigh PM emissions from coal and biofuel burning [38].

Determining the causes of the rapid adoption of E2Ws in China is important because the lessons revealed may be relevant to other countries facing air quality problems from gasoline powered two-wheelers. Nations such as India, Indonesia, and Vietnam, with poor air quality and high motorized and non-motorized two-wheel vehicle (2WV) populations may be able to improve their air quality by learning from China's experience in adopting E2Ws.

Understanding the forces driving and resisting future E2W growth and their root causes is important for policy makers in Chinese cities regulating transportation. This analysis can be used to help them identify the key leverage points for increasing or decreasing E2W use, depending on their objective. Identifying these forces may also help cities wishing to reduce the negative problems associated with E2Ws.

1.6 Scope and Limitations

This study analyzes the causes of the adoption of E2Ws and the impact this adoption might have on battery technology development and future vehicle electrification. Other important metrics like air quality, energy use, and accessibility have been evaluated by Cherry (2007) and Ma (2007) and thus are not duplicated in this analysis. This overall research objective is complemented by substantial research by colleagues Chris Cherry from UC-Berkeley and Chaktan Ma from Tsinghua University.

Effects of E2Ws on mobility, including travel behavior, safety, transit use, and vehicle purchase choice, are examined in Chapter 3 in order to better understand forces driving the transition to E2W. Cherry (2007) and Ma (2007) have done more extensive analysis on important metrics like safety, accessibility, travel time, and traffic flow with other vehicles thus they are not duplicated in this analysis. Environmental effects such as impacts on air quality, energy use, and lead emissions have also been analyzed in Cherry (2007).

Limitations

Surveys and other data collected on E2Ws are limited to China's urban areas, where the majority of E2Ws are located. This study does not include analysis of E2Ws use in rural areas, and includes only limited analysis in suburban areas though a deeper analysis of these markets would be very interesting since they are growing rapidly. Larger, higher-power E2W designs are being marketed in suburban and rural areas due in part to longer travel distances and frequent cargo/passenger loads.

Growth in the E2W market could affect more than just the development of battery technology. It could also affect the development of key electric-drive components such as motors, controllers, and chargers. The study, however, focuses mainly on E2W impacts on battery technology because it is a key limiting factor in rapid proliferation of electric vehicle technology.

In Chapter 4, Nickel-metal hydride technology is excluded from the analysis. Only 3% of E2Ws produced in China use this type, whereas 87% and 10% of E2Ws use VRLA and Li-ion respectively.

Another limitation of this study on the causes of E2W growth in China is that it does not examine why E2W growth did not occur in other countries in Asia. Examining the similarities and differences between countries like Vietnam, Indonesia, Thailand, and India to China in terms of transportation, economic development, and urban form would likely provide some useful insights about why E2Ws were successful in China only. Time limitations prevented the author from conducting this analysis.

1.7 Dissertation Synopsis and Methodology

To understand the E2W growth phenomenon in China requires a unique approach intersecting several fields of study because it involves many stakeholders operating in a highly dynamic environment. E2W growth affects and is affected by a complex system of stakeholders such as equipment manufacturing industries, local and state regulatory agencies, and the public (both E2W users and non-users). Growth has occurred amidst rapid changes in urban form, technology development, and economic growth. Thus, an inter-disciplinary approach is used.

The inter-disciplinary approach of this dissertation draws from engineering, anthropology, and organizational behavior, using methods ranging from on-street surveying of E2W users and interviews with E2W plant managers, to laboratory testing of E2W batteries. Since the available literature on this subject is limited, these methods are all the more valuable for collecting original data. Integrating these methods together enables a more complete view of the E2W growth phenomenon, why it happened, and where it is likely to lead.

The following synopsis describes the purpose, methodologies used, and key conclusions from the body of the dissertation, chapters 2-5. Methodologies are explained in greater detail in each chapter. Chapters 2,3, and 4 are each papers that have been written with co-authors and published in refereed journals. Their publication information, co-authors, and abstracts are presented below.

Chapter 2: The Transition To Electric Bikes In China: History And Key Reasons For Rapid Growth (published)

Published in: Transportation, 2007, **34**(3), pp.301-318

Co-authors:

CHAKTAN MA,

Institute of Transportation Engineering, Tsinghua University

CHRISTOPHER CHERRY,

Institute of Transportation Studies, University of California Berkeley,

Abstract

Annual electric bike (E2W) sales in China grew from 40,000 in 1998 to 10 million in 2005. This rapid transition from human-powered bicycles, buses and gasoline-powered scooters to an all-electric vehicle/fuel technology system is special in the evolution of transportation technology and, thus far, unique to China. We examine how and why E2Ws developed so quickly in China with particular focus on the key technical, economic, and political factors involved. This case study provides important insights to policy makers in China and abroad on how timely regulatory policy can change the purchase choice of millions and create a new mode of transportation. These lessons are especially important to China as it embarks on a large-scale transition to personal vehicles, but also to other countries seeking more sustainable forms of transportation.

Chapter 3: Electric Two-Wheelers In China: Effect On Travel Behavior, Mode Shift, And User Safety Perceptions In A Medium-Sized City (published)

Published in: *Transportation Research Record: Journal of the Transportation Research Board*, 2007

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Abstract

Despite rapid economic growth in China over the past decade and rise in personal car ownership, most Chinese still rely on two-wheeled vehicles (2WV) or public transport for commuting. The majority of these 2WVs are bicycles. In recent years, concern about poor air quality in urban areas and rising energy costs have caused cities to ban gasoline-powered scooters in city centers. Simultaneously, a new 2WV mode emerged to fill the void: the electric two-wheeler.

This shift to E2Ws is occurring at rapid pace throughout China, especially in its cities. E2W sales reached 10 million per year in 2005 as more bike and public transit users shifted to this mode. City planners and policy makers are undecided on how to plan for and regulate E2Ws because it is not yet clear what effect they will have on travel behavior, public transportation use, and safety. To begin to understand these effects, the authors have surveyed bike and E2W users in Shijiazhuang, a medium-sized city with particularly high two-wheeled vehicle (2WV) use, to identify differences in travel characteristics and attitudes.

We conclude the following: (*partial list*)

E2Ws are enabling people to commute longer distances. This has important implications on energy use, accessibility and urban expansion of cities.

People under-served by public transportation are shifting to E2W.

Women feel safer crossing intersections on an E2W compared to regular bike, however they have strong reservations about increasing E2W speed capability.

Chapter 4: Lead-Acid And Lithium-Ion Batteries For The Chinese Electric Bike Market And Implications On Future Technology Advancement (published)

Published in: *Journal of Power Sources*, 2007, In Press, Corrected Proof

Co-authors:

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Institute of Transportation Studies, University of California Davis

XUEZHE WEI

Tongji University, School of Automotive Studies

Abstract

China has been experiencing a rapid increase in battery-powered personal transportation since the late 90’s due to the strong growth of the E2W market. Annual sales in China reached 17 million bikes/yr in 2006. E2W growth has been in part due to improvements in rechargeable valve-regulated lead acid (VRLA) battery technology, the primary battery type for E2Ws. Further improvements in technology and a transition from VRLA to lithium-ion (Li-ion) batteries will impact the future market growth of this transportation mode in China and abroad.

Battery performance and cost for these two types are compared to assess the feasibility of a shift from VRLA to Li-ion battery E2Ws. The requirements for batteries used in E2Ws are assessed. A widespread shift from VRLA to Li-ion batteries seems improbable in the near future for the mass market given the cost premium relative to the performance advantages of Li-ion batteries. As both battery technologies gain more real-world use in E2W applications, both will improve. Cell variability is a key problematic area to be addressed with VRLA technology. For Li-ion technology, safety and cost are the key problem areas that are being addressed through the use of new cathode materials.

Chapter 5: The Future Of Electric Two-Wheelers And Electric Vehicles In China

Submitted for publication, acceptance pending

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Abstract

Electric two-wheeled vehicles (E2Ws) in China are the most successful electric-drive vehicles in the world. If E2W success continues, it may accelerate the development of batteries and larger electric vehicles. We analyze the technological and market evolution of E2Ws. Force-field analysis method is used to identify forces driving and resisting future E2W market growth, the root causes behind these forces, and important insights about the likelihood of a wide shift to larger three- and four-wheel electric vehicles (EVs).

We conclude that the key forces driving E2W market growth are: improvements in E2W and battery technology due to product modularity and modular industry structure, strong local regulatory support in the form of gasoline-powered motorcycle bans and loose

enforcement of E2W standards, and deteriorating bus public transit service. The largest forces resisting E2W market growth are strong demand for gasoline-powered motorcycles, and bans on E2Ws due to safety concerns in urban areas. The balance of these forces appears to favor E2W market growth. This growth will likely drive vehicle electrification through continued innovation in batteries and motors, the switch from lead-acid to Li-ion batteries in E2Ws, and the development of larger E2Ws and EVs. There are however strong forces resisting vehicle electrification, including battery cost, charging infrastructure, and inherent complications with large battery systems.

2 THE TRANSITION TO ELECTRIC BIKES IN CHINA: HISTORY AND KEY REASONS FOR RAPID GROWTH

Abstract

Annual electric bike (E2W) sales in China grew from 40,000 in 1998 to 10 million in 2005. This rapid transition from human-powered bicycles, buses and gasoline-powered scooters to an all-electric vehicle/fuel technology system is special in the evolution of transportation technology and, thus far, unique to China. We examine how and why E2Ws developed so quickly in China with particular focus on the key technical, economic, and political factors involved. This case study provides important insights to policy makers in China and abroad on how timely regulatory policy can change the purchase choice of millions and create a new mode of transportation. These lessons are especially important to China as it embarks on a large-scale transition to personal vehicles, but also to other countries seeking more sustainable forms of transportation.

Keywords: E2W, electric bicycle, electric scooter, China, two-wheel vehicle

2.1 Introduction

Electric bikes are a category of vehicles in China that includes two-wheel bikes propelled by human pedaling supplemented by electrical power from a storage battery, and low-speed scooters propelled almost solely by electricity (usually with perfunctory pedals to satisfy legal definitions). These vehicles have become a popular transportation mode for

Chinese consumers because they provide an inexpensive and convenient form of private mobility and are thus an attractive alternative to public transit or regular bicycling. They are promoted by national and many local governments due to their low energy consumption and zero tail-pipe emissions, especially important in China's congested urban areas. E2Ws are gaining an increasing share of two-wheeled transportation throughout China, and in some cities like Chengdu and Suzhou, have even surpassed the bicycle mode share.

Understanding the transition to E2Ws is important for guiding the future of personal mobility in China and other developing countries. First, China is on the brink of large-scale motorization (i.e. people buying cars). Understanding how and why a large-scale technology system (E2Ws) is successfully adopted may provide insight and a foundation for a smoother transition to cleaner vehicle/fuel systems for personal cars as motorization continues. Secondly, many other developing nations in Southeast Asia with high two-wheel vehicle (2WV) such as India and Vietnam use are confronting the same air quality and energy issues as China. These countries may be able to learn from China's experience in adopting E2Ws.

Methodology

The literature on E2Ws in Mainland China thus far is relatively limited. Thus this report relies extensively on first-hand interviews. Using a 35-question survey, we interviewed 23 electric bike original equipment manufacturers (OEMs) and component suppliers (including 4 factory visits), 5 E2W dealers, 12 E2W customers and 1 government representative. We asked E2W OEMs and suppliers questions related to their products, manufacturing, the E2W market, suppliers, costs, quality, government regulations, and research and development. We asked dealers about maintenance issues, E2W market demographics, and the impact of government regulations on sales. We asked customers about costs of owning and operating, usage behavior, and their attitudes towards E2Ws versus competing travel modes.

For data on consumer travel behavior and attitudes, we conducted three surveys of over 1,000 E2W users in Shijiazhuang, Kunming, and Shanghai. An in depth analysis of the results of this survey is found in [40] and [28]; relevant results are reported in this paper. Surveys were conducted in these cities to represent medium and large cities with high E2W use.

Other data and historic information have been collected from industry reports, media, trade journals, and academic studies.

The Chinese E2W Industry

The Chinese E2W industry, with minimal governmental financial support and industry supervision, has developed into the largest producer of E2Ws worldwide. The industry grew from under 10 original equipment manufacturers (OEMs) in 1998 to 481 (according to the official estimate) by 2005 [41]. Unofficial estimates for the number of OEMs range from 1,000-5,000.[1] E2W OEMs range in size from as small as 1000's bikes/yr production to 300,000/yr. Most produce between 10,000-50,000 E2Ws a year, but there are six companies with an annual production of over 200,000 E2Ws.

One reason for the large number of companies in this industry is that component technology is mature, the network of suppliers is vast, and manufacturing is relatively simple.[2] Profit margins of eight OEMs average at only 6%. There is also considerable theft of intellectual property by the small to medium companies according to interviews with the managers from larger e-companies. Because of the low barriers to entry and lax intellectual property (IP) protection, there are many unlicensed E2W makers selling poor-quality but low-cost E2Ws. Several OEMs predict that there will be considerable consolidation over the next few years and the number of E2W makers will drop significantly.

The companies that currently make E2Ws come from a variety of industrial backgrounds. Some are established companies producing bicycles, motorcycles, electrical appliances, and even toy cars, which shifted to making E2Ws when demand grew. Some of these companies are over 60 years old, but most did not start producing E2Ws until post-2000. Many companies with no past manufacturing experience entered the industry making E2Ws directly.

E2W Users

From the user perspective, E2Ws offer many advantages to regular bikes and walking. The main reasons for choosing this mode are presented in Figure 2-1 below, based on survey results in three cities in China.

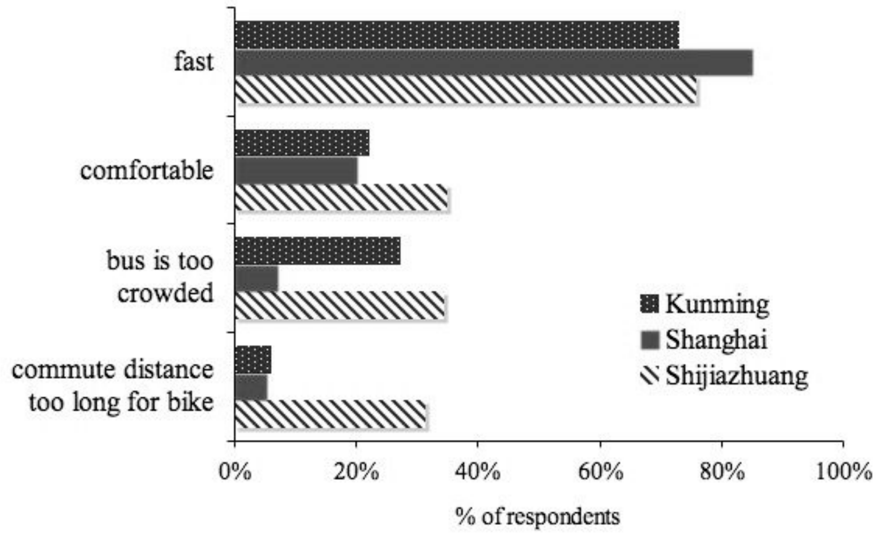


Figure 2-1: Most popular reasons for choosing an E2W

Most E2W users are switching from bicycle and bus (see Figure 2-2). When survey respondents were asked what mode they would choose if they could not travel by E2W, the majority in Shanghai and Kunming selected bus whereas in Shijiazhuang, where bus service is not as good and the city size is smaller, the majority selected bicycle.

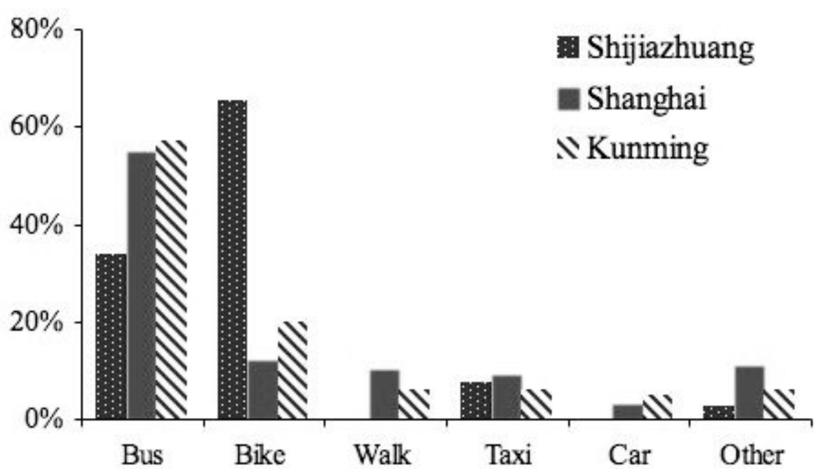


Figure 2-2: Next best alternative for E2W users

2.2 Historical Analysis

The history of E2Ws in China spans over four decades, and can be clustered into four distinct periods [3].

Pre-E2W Phase: 1940s-1970s

The seeds of the E2Ws growth in China can be traced back to the beginning of the bicycle's rise in 1949, the same year the People's Republic of China was founded. During this time, the National government set bicycle production as a national priority and began establishing bicycle infrastructure in cities. It is estimated that national bicycle ownership rose from 0.5 million in 1949 to 1 million in 1958, and reached a maximum of 545 million by 1978. Private vehicle ownership on the other hand was not allowed before the mid 1980's, when only government officials were allowed to own cars [2]. Thus, for most people the bicycle and public transportation served one's daily needs.

Mobility needs for most regular citizens were relatively low in China due to industrial structure and housing policy. Between 1949 until 1978, China's industry was primarily composed of state-owned enterprises (SOE). Most people during this time lived in housing provided by their SOE, thus their commute travel demand was minimal. China had also established a "hukou" system that restricted people to live in the districts assigned to them, preventing people from rural areas migrating to the cities. Incomes remained very low.

In 1978, China began its “Opening Revolution” (Gaige Kaifang), ushering in a long period of rapid economic development, which continues to this day. Government began granting people the freedom to live where they wanted, and slowly closed down the SOEs. Along with more freedom to live where one chose, people also began making more money. In the 90’s the *hukou* system restrictions were reduced significantly.

First Phase (1980s)

Research into E2Ws production in China first began in the 1960s, though actual products did not appear on the market until the late 80’s when consumer demand first began growing. E2W companies first appeared in Shanghai, Zhejiang, and Tianjin. Total annual E2W production reached only 10-20,000/yr. At this time, people knew very little about E2Ws because the average person could only afford a normal bike.

This peak however lasted only 3-4 years. This introduction of E2Ws was short-lived for several reasons. Firstly, E2W technology was not advanced enough to fulfill the demand of consumers. In particular, battery quality was low in terms of performance and lifetime, and costs were high. Secondly, the E2W price was also relatively high due to the high battery cost. E2W use failed to grow during this phase because they could not compete with inexpensive gasoline motor scooters.

Second Phase (early 1990’s)

E2W use experienced a second surge during the early 1990s due to the government’s push for energy efficiency. This period was short-lived however, again due to their inability to compete with gasoline-powered scooters. E2Ws again failed to become widespread and gain significant market share. E2Ws were being developed and sold in Taiwan, but they failed to gain considerable market share despite subsidy, in large part because no restrictions were placed on gasoline-powered scooters [42-45]

Third Phase (late 1990's-current)

E2Ws again emerged into the market during the late 1990s and witnessed considerable growth that has continued up to the present. Table 2-1 lists chronologically important events in the history of E2Ws in China:

Table 2-1: E2W History in China [a]

Year	Event
1987	Electric Vehicle Institute of China Electro-technical society founded
1991	National science Board names E2W as one of 10 main technology projects during 9th 5 year plan period
1993	Shanghai founded electric vehicle industrialization development center
1994	Shanghai lost automobile research bid for developing electric vehicles to Guangzhou; turns to developing E2Ws (via Crane). Tianjin bans the sale of gasoline-powered scooters [46]
1995	Prime minister Li Pong declares support for electric vehicles, leading to "Seminar for E2W Development in Light Industry General Society
1995	100 beta-test Crane E2Ws are deployed [46]
1996	First National Forum on E2Ws held
1996	Shanghai suspends license granting to gasoline-powered vehicles downtown, Mayor declares to "gradually eliminate gasoline-powered assist vehicle and actively develop and promote electro-assist technology"
1997	Crane rolls out first commercial batch of E2Ws (150-180W motor,7Ah battery capacity) [46]

1998	Guangzhou, Shijiazhuang, and Suzhou ban the sale of gasoline-powered scooters. Many other medium/large cities follow suit in the following years.
1999	National E2W standards passed, creating uniform specifications for BSEB and SSEB.
1999	Shanghai began annual inspections of gasoline-powered scooters, eliminating those of which exhaust gas emission was unacceptable- 53,000 were eliminated in 1999-Mayor states desire to replace all motor scooters by electric bike in next 4-5 years
1999	Shanghai Economy and Trade Committee lists E2Ws as one of 12 main construction projects in the "Highland"
1999	E2W licenses are granted in Shanghai, Tianjin, Jiangsu, Zhejiang, Guangdong, Yunnan, Anhui, Hebei
2000	Administrative coordinators nationwide recommend promotion of E2W to Department of State
2000	Dept of State Traffic Control Bureau drafts "Road Transportation Safety Law" to allow E2Ws right to use bike lanes as long as they have pedals and speed is below 20 km/hr
2000	Zhejiang founds Electric Vehicle Preparatory Team, Ningbo hosts E2W Festival, and Shanghai hosts first International EV and components Expo
2002	Beijing issues a ban stating they will cease offering E2W licenses beginning 2006 in order to promote automobile development, Beijing Communicative Administration Department [47]
2002	Fuzhou government bans electric bikes from streets but is later sued by E2W OEMS and citizens, raising the profile of E2Ws throughout China [48]
2003	E2W sales surge after SARS outbreak when many riders shift from public transit [46]
2004	China passes the “Road Transportation Safety Law” (*see 2000 above*)
2005	Annual domestic E2W sales top 10 million
2006	Jan 4, Beijing Public Security Bureau lifts ban on E2Ws
2006	Shanghai E2W population reaches 1.35 million, the highest ownership level of any city in China [49]. E2W production in China in 2006 projected to reach 18 million [50]
2006	Nov 3, Guangzhou announces ban of all electric bikes on city roadways
a. Historical facts extracted from [3] unless stated otherwise	

2.3 Important Factors for Rapid E2W Growth

The reasons for E2W success in the 3rd phase can be categorized into three important development factors: technology, economics, and policy.

Technology Factors

Improvements in battery and motor technology, in particular lead (Pb) acid batteries and in-hub E2W motors, since the 90s helped expand the market for E2Ws. E2Ws, reaching ranges of 50-60 km and 250-350 Watt, could finally compete in performance with the incumbent gasoline-powered scooter.

Batteries

Over 95% of E2Ws sold in China use Pb-acid batteries [51]. While Pb-acid batteries have been in use for nearly a century in automobiles and other applications, there have been important advances in the past decade rendering them more suitable for E2Ws.

During the first phase of E2W introduction, batteries used liquid acid electrolyte instead of the fixed electrolyte used in most Pb-acid batteries today. Liquid-type required more maintenance, and if the battery or bike fell over, electrolyte leaked out and caused property damage. Most E2Ws today use valve-regulated Pb-acid types with gel or absorbed glass mat (AGM) electrolyte, which, in addition to improving energy density, also minimizes maintenance and electrolyte spills due to its sealed nature [51]. Between

1997 and 2006, energy density of E2W batteries increased 33% from 30 Watt-hours (Wh)/kg to 40 Wh/kg while battery life also increased 35% to over 300 cycles. The performance improvements in battery life from one large battery supplier are shown in Table 2-2 below.

Table 2-2: Lifetime of E2W battery vs. time

	1997-1998	2000	2003	2006
Manufacturer Guaranteed Lifetime (months)	3	6	12	12
Anticipated lifetime under normal operating conditions (months)	7-8	12	18	18-24

Motors

In the past decade, E2W motors saw two significant technology advances. The first was the introduction of brushless motors into E2Ws. E2Ws originally used only brush motors because they are simple, cheap, and controllers to regulate current are less sophisticated. In the early 2000s, many E2W makers switched to brushless motors. Table 2-3 compares the characteristics of each and their relative advantages. SSEBs more frequently use brushless motors since users seldom use the pedal function and prefer more power for carrying cargo and passengers.

Table 2-3: Comparison of Brush to Brushless Motors

	Brush Type	Brushless Type
Rotating speed	2,000 rpm	300 rpm
Average Weight	4 kg	6 kg

Advantages	Has gear/clutch so easier to use pedal-only mode. Better for far travel with few elevation changes. Cheap	Longer life, lower maintenance requirements, more powerful (better for climbing hills and carrying goods)
Disadvantages	High rpm requires more frequent maintenance	Controller for this motor type is more expensive (3x more than for brush type)

The second advance was in motor efficiency, which improved from 50% to 85% between 1995 and 2000. This improvement resulted in a 60% increase in range. In the mid 1990's motors were disc-type and used iron-oxide permanent magnets. In 1997, brush-type motors were introduced with a reduction gear system. Around 2000, ruthenium-iron-boron magnets were introduced into E2W motors. In 2006, neodymium magnets have been introduced that are increasing motor efficiency even more. Recent joint ventures with foreign companies have also aided in the improvement of technology

Economic Factors

The most important economic factors explaining rapid E2W adoption in China are the rising income level of the Chinese, the decreasing cost of E2W technology, and the rising cost of gasoline.

Rising income level

The rapid development of China in the past decade has raised the standard of living of its residents, bringing the E2W within closer reach of millions more. Between 1997 and

2004, average disposable income increased 82% from $645/yr to $1180/yr. Survey results in Figure 2-3 show a relationship between E2W use and income. Note Shanghai and Kunming show household income whereas Shijiazhuang reports individual income.

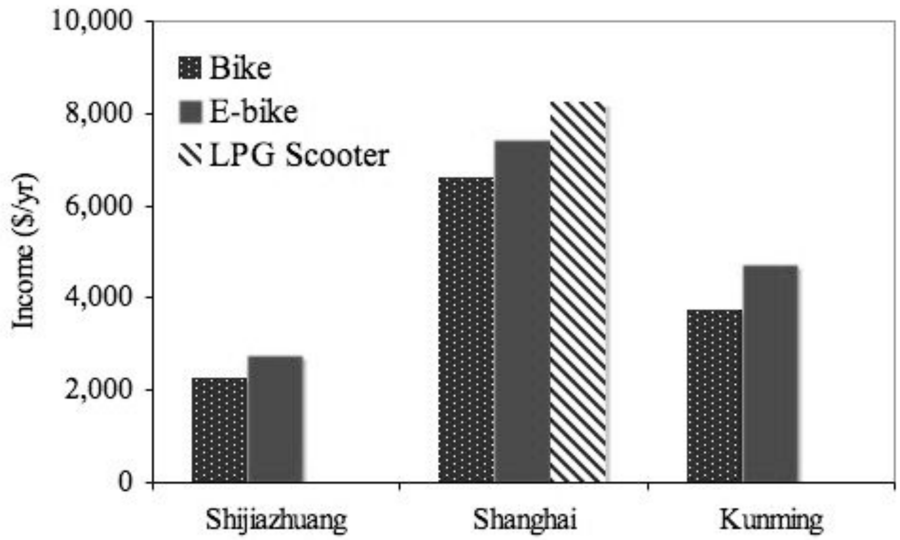


Figure 2-3: Income vs. mode choice in three Chinese cities

However, there are clearly other factors involved in E2W use since there are E2W users in low, middle, and high-income brackets. Discrete choice modeling of electric bike users in Cherry and Cervero (2006) report that travel time is more significant than income in determining electric bike choice compared to alternatives modes.

Vehicle Price

E2Ws price has dropped since their initial introduction while E2W technology and efficiency has improved. In 1999, the BSEBs were ~$310, and fell to $250 in 2000 due to considerable industrial development. By late 2003, average price dropped again to

$188, with the cheapest models reaching a bottom price of $125. As of 2006, average prices still ranged from $125-375, despite far better quality and performance. Currently, the E2W in market is classified into three price levels [48], shown in Table 2-4.

Table 2-4: E2W style and price range

Style	Description	Share
Luxury (>$325)	Mainly SSEB and include few very good BSEB	10%
Moderate ($225~275)	Both BSEB and SSEB	60%
Economical (<$188)	All simple BSEB	30%

Much of this reduction in price can be attributed to larger production scale of both E2Ws and their components.

Fuel and Energy Costs

Fuel price has risen substantially in the past 6 years. Gasoline prices in Shanghai increased 45% since 2002 from $0.39-0.56/liter (excluding inflation). Because fuel cost for gasoline scooters is over 30% of the total annual cost, this fuel cost increase effectively increased the cost of gasoline-scooter 15%. Consumers purchase decisions are sensitive to fuel cost increases since it is a more frequent payment.

Along with rising gasoline prices, electricity prices fell in rural areas. This price decrease was due to significant investment from central government in electricity infrastructure through rural areas nationwide, and the decision to drop rural electricity prices to urban price levels. Before this policy was enacted 1998, electricity price in rural areas was

~50% higher than in urban areas [52]. This decrease in price combined with rising income caused the rural E2W market to expand rapidly.[3] One electric bike company estimates that in 2005 the rural consumers accounted for 20% of their national E2W sales and that rural E2W sales jumped 190% between the first two quarters of 2006.

E2W relative lifecycle cost advantage

Figure 1-1 of Chapter 1 shows that the cost of owning and operating an E2W is the lowest of all personal motorized transportation in China (~4 cents/km). The assumptions and method for calculating these costs are found in the Appendix (section 8-1), results are shown in Table 8-1.

Policy Factors

The following section introduces two important national E2W policies and describes the impact they had on E2W growth. Regional differences in policy will then be discussed using four cities as examples.

National Rules for E2W Use

The national government has set two key policies that have facilitated the development of the E2W market, the “1999 National E2W Standards” and the 2004 “Road Transportation Safety Law”.

National E2Ws Standards: In 1999, national E2W standards were set to establish performance limits for E2Ws with respect to speed, weight, and power. One important part of the specification was that as long as the E2W had functional pedals, it could be classified as an E2W, which allowed SSEBs to be classified under the same rules and regulations as BSEBs.

The effect this part of the standard had was that it opened the doors of what would become a huge, important market for SSEBs. Manufacturers capitalized on this loophole in the standard by making SSEBs with pedals that barely functioned and that could be easily removed after purchase. They realized the scooter style could directly compete with the incumbent technology (gasoline and LPG scooters) since, besides the powertrain, most other features were equal. Many prefer this style to BSEB because it's easier to carry cargo and passengers, more comfortable (larger seat, lower center of gravity), and creates more opportunities for unique, fashionable styling.[4] In Shanghai, it is estimated that >70% of E2Ws are SSEB. This is a common trend in Southern cities, though in Northern cities, BSEB are more popular because batteries discharge more quickly in cold weather, requiring users to pedal often.

The standards allowed further design flexibility by having "required" criteria and "recommended" criteria. The following specifications <u>must</u> be met (or the vehicle cannot be licensed): speed limit (<20 km/h), the brake distance (dry: 4m, wet: 15 m) and frame vibration (quiver test: >70,000 cycles without damage). Many OEMs get around the speed requirement by adding vehicle speed restriction devices that are easily removed after purchase. The rest of the specifications such as weight, width, motor power, pedal capability result in a fine for the OEM if not met and are thus "recommended". The magnitude of these fines is not fixed and is often directly related to the OEM's relationship with the local quality supervision department. The flexibility in meeting this standard has thus resulted in faster, heavier, more powerful E2Ws on the roads.

Through interviews with several OEMs about the standards issue, we noticed a distinct "wait and see" behavior regarding their future plans to expand. Some stated they are holding off on large, potentially risky investments until the new standards come out, and this hesitation is impacting product evolution.

National Road Transportation Safety Law: Drafted in 2000 and finally ratified in 2004, the Road Transportation Safety Law effectively classifies E2Ws as a non-motorized vehicle, giving them the same rights as bicyclists. This allowed users to operate an E2W without a driver's license or helmet, though some larger cities now require E2Ws to be registered. The law, besides giving users the right to ride in the bike lane, gave E2W proponents in industry and government legal standing in defending E2W use and sale in many cities.

Local Policy Differences

While E2W standards and road rules are set by national government, it is up to local governments to decide how to enforce these product standards and manage traffic. Due in part to regional variations in policy enforcement, E2W penetration is noticeably different from city to city. This section examines different policy attitudes towards E2Ws and how it has impacted their success using four Chinese cities as examples: 1) Shanghai & Chengdu (pro-E2W), 2) Beijing (anti-E2W) and 3) Shijiazhuang (neutral). Data on vehicle share was collected by observation at various locations throughout each city at different times and aggregated. In shanghai, the majority of motor scooters are LPG. In other regions, they are gasoline. Chengdu is included in Figure 2-4 to compare a pro-E2W city without an LPG infrastructure.

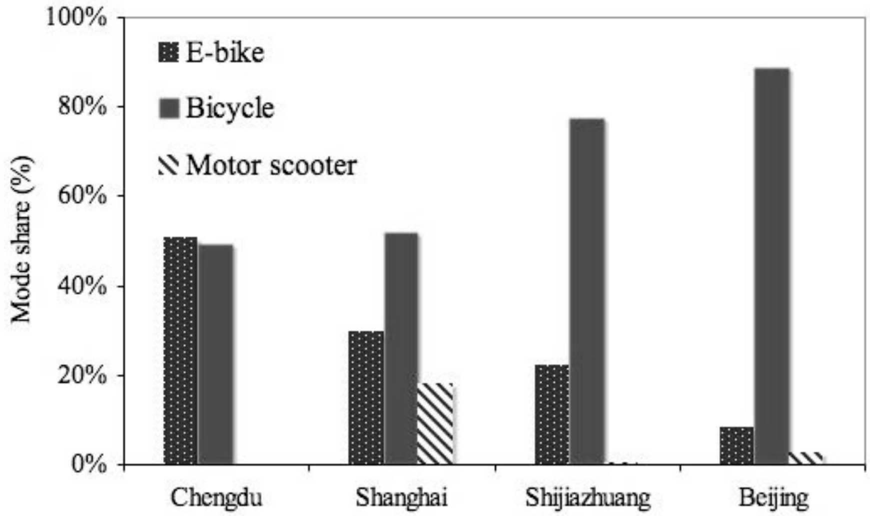


Figure 2-4: 2WV proportions in select Chinese cities

1. Shanghai: Pro E2W

In 1996, Shanghai (population 17.4 million, 2005), confronted with poor air quality and high motorized vehicle use, outlawed the sale and use of gasoline scooters in city centers through license restriction. As of 2006, the only 2WV allowed to operate are LPG scooters, E2Ws, and bicycles. Site observation shows that these rules are effectively enforced; gasoline scooters are rarely seen except in Shanghai's more rural suburbs. The figure below shows the effect of this ban on E2W growth relative to other 2WV modes in recent years. One reason for such high LPG scooter proportion in Shanghai is that in 1998, the taxi fleet switched to LPG, and thus an extensive fueling infrastructure developed throughout the city. In Chengdu, where gasoline scooters are also banned, E2W mode share surpasses bikes.

Figure 2-5 below shows how E2Ws are replacing other 2WV modes in Shanghai [53]. This shift occurred amidst rising level of disposable income of urban households from $1,625 to $2,090 (28% increase) during the same time period [54]. Note that registered bicycles are an order of magnitude higher than the other modes.

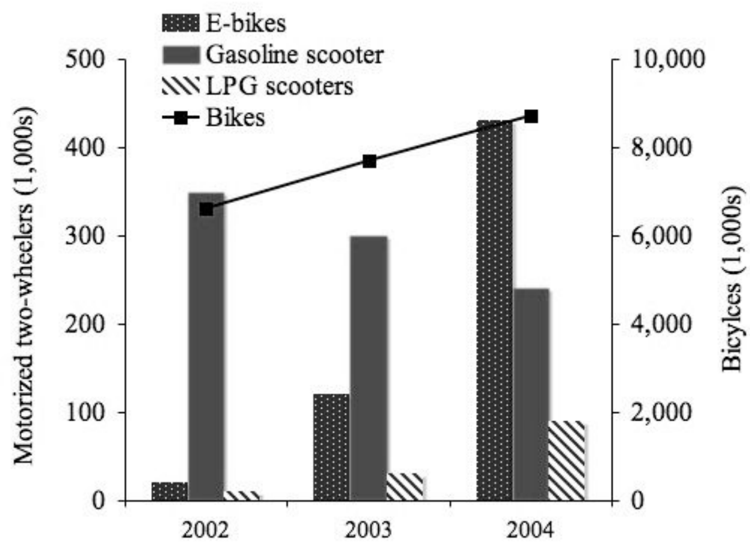


Figure 2-5: Two-Wheeled Vehicle Population Change in Shanghai

2. Anti-E2W

Some cities view E2Ws as just a prolonging of bicycle use, which they are eager to displace in favor of more advanced, modern modes such as the automobile or public transportation. Other reasons for mixed attitudes about E2Ws include concerns about their effect in reducing traffic speeds, creating safety hazards in mixed bike /car traffic, and lead-pollution from poor battery recycling infrastructure [47].

Beijing (pop. 14 million, 2004) is an example of one large Chinese city that proposed a ban on E2Ws in the beginning, but finally reversed itself in 2006. This hostile policy impacted consumer purchase decisions during these key E2W growth years, resulting in lower E2W share than many other cities. Beijing carefully enforces the national E2W standard and restricts E2W dealers from selling SSEBs, further discouraging E2W sales [55]. Guangzhou, Fuzhou, Wuhan and Haikou are examples of other large anti-E2W cities. The rationale in these cities is that E2Ws are unsafe and have negative impacts on traffic.

3. E2W neutral

Shijiazhuang (pop. 9 million, 2005) is example of a city that is undecided about the costs and benefits of E2Ws and thus have adopted a “wait and see” approach to managing E2Ws. They neither promote nor restrict them. This city has few cars, unlike Beijing, which has over 2 million cars.

Changing Urban Form and Travel Patterns

E2W use has also been influenced by changes in travel demand caused by economic development and policy reform. The closing of state-owned enterprises and liberalization of the housing market, which started in the mid-1990s, gave workers the freedom to live farther from workplaces and create more multi-worker families. This in turn induced more travel demand and required more flexible travel modes, which is exhibited in a rising share of income spent on transportation between 1997 and 2005. During this period, percentage of income spent on transportation and communication (T&C) expenditures increased by 5.2% to 11.8% (127% growth). Assuming the portion spent on transportation is 60% of total T&C spending (56% in Beijing 2005 [56]), the average annual transportation budget of a household is $85/yr, not far from the annual cost of owning and operating an E2W ($120/yr, see table 5).

China's rapid urbanization (the flux of rural people into cities) over the past decade, also a product of economic and political changes, is another a factor in E2W growth. Urbanization has led to increased congestion within cities and greater demand for low-cost peripheral housing in their suburbs. Public transportation service in most cities is crowded and slow due to congestion, which is one of the most commonly stated reasons electric bike users choose this mode in Shijiazhuang, Kunming, and Shanghai (See Figure 3). Buses are also inherently inflexible in serving a growing diversity of origins/destinations sets.

Traditional bicycles have also become less and less suited for travel as trips lengths extend and households demand fast, flexible, load carrying modes. The tri-city survey results show that E2W users are experiencing more range and less travel time than bicycles. Trip length and frequency is on average 10%-20% higher than bicycles; average operating speed is 31-35% higher in Shanghai and Kunming. Discrete choice modeling of electric bike users shows that travel time is one of the most significant determinates of electric bike choice, compared to alternatives [28]. Electric bikes will have a market advantage as long as door-to-door travel times remain lower than relevant alternatives.

Other Factors

Other factors explaining the E2W phenomenon are related to demographics, land use and infrastructure. The increasing numbers of women commuters plays a role. Regional differences between cities such as city area, automobile use, level of public transit service, topography, weather also affects the variations in E2W popularity from city to city. For instance, cities with large geographic area and poor public transit service would likely experience a larger shift of bike and transit users to E2W. Cities with high automobile use may have less bike lane infrastructure and more anti-E2W policies would likely have less E2W users. There are also random factors involved, such as the 2003 SARS scare and abnormally hot summer when people shifted away from crowded public transportation and E2Ws sales jumped from 20,000/year to 300,000/yr [57]. These factors and more will be explored and quantified in future analyses.

2.4 Conclusions

E2Ws, though they floundered twice in the 80s and early 90s, experienced extraordinary growth in the late 90s to the present due to a combination of economic, technical, and political factors, summarized below:

- E2W technology, specifically motors and batteries, improved significantly during the late 1990's. Simple technology, a vast supplier base, and weak intellectual property protection made it easier for E2W makers to enter the industry, increasing competition and driving prices down.

- Due to improving economic conditions nationally, incomes of urban households and the share spent on transportation both rose considerably.

- E2W prices decreased, gasoline prices rose and electricity prices in rural areas dropped, making E2Ws more competitive economically with alternatives like gasoline-powered scooters and bus.

- National and local government policy motivated by energy and air quality issues created favorable conditions for E2W growth. Banning gasoline powered motorcycles in large city centers removed the most competitive mode from the choice set.

- National E2W standards with loopholes and flexible guidelines created a rich opportunity for manufacturers to create E2Ws that appealed to more users, namely, scooter-style electric bikes.

- Due to changes in urban form, performance of alternative transportation modes decreased as trips lengths and congestion increased. This made trips difficult to traverse by bicycle and slow by motorized modes, particularly buses and taxis.

The history of E2Ws provides an important lesson on the powerful impact of regulatory policy, given the evolution of technology to a market acceptable product. While technological progress was required to meet the customer demands for economics and performance, the regulatory environment provided strong impetus for the market to grow and for further investment in technology evolution. Without this the E2W market would not have emerged. Support for this conclusion can be found by looking at the lack of growth in “anti E2W” cities. There is further evidence of the sensitivity to local policy in Shanghai, where an alternative (LPG scooters) emerged in a regulatory environment that was otherwise favorable to E2Ws. Where regulatory policy is favorable / neutral, economics and customer expectations will determine market success.

While electric bikes have some positive impacts on transportation and urban air quality, policy makers are not unanimously in favor of this mode resulting in E2W bans in three cities. Safety is the most commonly cited concern due to their silent nature and increasing speed and weight. While E2Ws provide zero tail-pipe emissions, they do emit pollution from power plants, which are mostly coal fired in China. Lead emissions from batteries production and recycling also have serious health implications due to high lead loss rates in the Chinese lead and battery industries.

Recommendations

E2Ws are still in their infancy and many of their negative impacts can be mitigated through technology improvements (particularly increased use of advanced battery technology), improved traffic operation strategies and enforced design and performance specifications. Removing vulnerable road users like bikes and E2Ws and encouraging truly unsafe modes like cars is a poor policy direction. Rather than prohibit electric bikes, the industry, government and users need to address the problematic aspects of E2Ws production, performance and technology. This could make this mode much more sustainable into the future and could significantly impact transportation systems and mode choice as China motorizes.

Looking forward, this analysis hints at future technology evolution paths for China's 450 million bike users, 22 million current E2W users, and burgeoning car population. In smaller cities and countryside where incomes are rising, E2Ws may eventually replace bicycles. China's experience may also have a trickle-down effect in other developing countries with high 2WV use (e.g. India, Vietnam) and mounting urban transportation problems. Speculating on the future of technology evolution and trends in China and these other countries, further technological progress on E2Ws and increasing environmental pressures may create a regulatory environment that ushers in electric 3-wheelers and small battery electric cars.

In any case, the implications of how and where this technology system develops are huge. These implications, both positive and negative, on urban traffic, industry development, energy use, and environmental impacts, warrant further investigation.

Notes:

1. Several interviewed E2W companies noted there are many more than official estimates because many operate without a license. One company estimated that only 24 E2W OEMs in China actually have a license while another company mentioned many don't even have a trademark.

2. One E2W company initially started assembling E2Ws using their and their neighbor's home.

3. China carried out a national electric facilities improvement project, which decreased the electric price in rural areas. (Xinhuanet)

4. Small children often stand on the foot platform while another passenger sits behind the driver. Site observation shows SSEB carry cargo and passengers more often than SSEBs.

3 ELECTRIC TWO-WHEELERS IN CHINA: EFFECT ON TRAVEL BEHAVIOR, MODE SHIFT, AND USER SAFETY PERCEPTIONS IN A MEDIUM-SIZED CITY

Abstract

Despite rapid economic growth in China over the past decade and rise in personal car ownership, most Chinese still rely on two-wheeled vehicles (2WV) or public transport for commuting. The majority of these 2WVs are bicycles. In recent years, concern about poor air quality in urban areas and rising energy costs have caused cities to ban gasoline-powered scooters in city centers. Simultaneously, a new 2WV mode emerged to fill the void: the electric bike (E2W).

This shift to E2Ws is occurring at rapid pace throughout China, especially in its cities. E2W sales reached 10 million per year in 2005 as more bike and public transit users shifted to this mode. City planners and policy makers are undecided on how to plan for and regulate E2Ws because it is not yet clear what effect they will have on travel behavior, public transportation use, and safety. To begin to understand these effects, the authors have surveyed bike and E2W users in Shijiazhuang, a medium-sized city with particularly high two-wheeled vehicle (2WV) use, to identify differences in travel characteristics and attitudes.

The following conclusions are made: (*partial list*)

- E2Ws are enabling people to commute longer distances. This has important implications on energy use, accessibility and urban expansion of cities.

- People under-served by public transportation are shifting to E2W.

- Women feel safer crossing intersections on an E2W compared to regular bike, however they have strong reservations about increasing E2W speed capability.

3.1 Introduction

Two-wheeled vehicles (2WV; e.g. bicycles, E2Ws, motor scooters, motorcycles) have historically been an important component of traffic throughout China and many other developing countries. In medium and large Chinese cities like Shijiazhuang, the dominant 2WVs are bicycles.

Bicycles, estimated at 450 million nationally in 2004 [58], have been and still remain the dominant 2WV in Chinese cities, mainly due to low income, high population density (and thus short trips), and extensive bicycle infrastructure (e.g. lanes, parking). Based on statistical report in 2005, bicycle trip share is still over 50% in many large cities like Tianjin, Xi'an and Shijiazhuang [59].

Gasoline-powered motorcycles (includes scooter & mopeds) used to make up a larger percentage of the overall 2WV population, however, beginning in late 1990s, many large cities (population >1 million) and most capital cities have stopped licensing these vehicles. Total gasoline-powered motorcycles in China numbered 80 million in 2005 [7]. Although numbers are still growing in the wide rural areas and small cities, it is estimated that without urban restrictions, 4~5 million more would be on the roads [60].

In recent years however, due to improved standard of living and rapid urbanization, Chinese are shifting from bike (or public transit) to electric bikes (E2Ws) as they demand more flexible, convenient, and comfortable mobility. In 2005, there were an estimated 20-22 million E2Ws in China [48]. Production is expected to grow 80% annually over the next five years [61].

Throughout China, however, there are mixed views by government about E2Ws and their effect on traffic. In May 2006, a national government agency issued a report promoting E2Ws for their air quality and energy-saving benefit [61]. In November 2006 though, Guangzhou became the third city in China to ban E2Ws (behind Fuzhou and Zhuhai), under advice from the traffic management bureau citing traffic safety concerns [27]. The safety issue of E2Ws mixed in traffic is a key consideration in drafting the new National E2W Standards, which are under revision and intense debate. The standard regulates the performance and specifications of E2Ws (see section below). Bicycle proponents (e.g. China Bicycle Association (CBA)) want to limit E2W performance to make them more similar to bicycle, and for fear that faster, heavier E2Ws will make them dangerous to cyclists. E2W manufacturers, however, want to broaden the limits on weight, width and power to be able to build products that they claim customers want. Whatever new standard is adopted will greatly effect the future direction of E2W development in China.

Shijiazhuang Background

Shijiazhuang city is located in south-central Hebei province. As the capital of the province it has recently developed into an important commercial port of regional agricultural and distribution center of industrial products in northern China. The total and urban population in 2005 was 9.2 and 2.2 million, respectively. Total and Urban Area is 15,900 and 3,850 km^2, respectively. The topography in this area is low (70 meters above sea level) and flat since it is situated in the Huabei Plain of China. The climate ranges from an average high of 26.9° in July and an average low of -2.4° in January.

Shijiazhuang's urban layout follows the typical Chinese model of a mono-centric city with a high-speed ring road encircling the urban area. The urban area is divided into four quadrants by two railways and the city's commercial district is centered around the railway station. Residential areas mainly stand on the northwest, center and east of city.

Bicycles and E2Ws compose the largest daily trip mode share in Shijiazhuang. A previous survey conducted by Shijiazhuang showed that in 2002, cycling trip share was 54% and reached a volume of 3 million trips per day. For comparison, public transit trip share was only 4.3% [62].

3.2 Methodology

Because of the institutional and logistical difficulty in conducting random household surveys in China, the authors designed and implemented an intercept survey of 751 bike and 460 E2W users throughout Shijiazhuang. The survey was administered at bicycle and E2W parking lots along the main travel corridor (Zhongshan Lu) in Shijiazhuang in order to capture a diverse range of respondents from many different parts of the city. The survey was administered on both a workday and weekend day in June 2006, from 7:30-11:30 and 3:00-6:00 to collect as broad a range of respondent types as possible (i.e. workers, retirees, students, etc.). Separate surveys were given to bicycle and E2W riders in order to identify any differences between their travel behavior and attitudes.

Before launching this survey, the authors first administered a trial survey on 50 bike/E2W users to identify the potential problems with the survey and uncover any unintentional biases. We found some of the response choices inappropriate and certain questions confusing. These problems were corrected before administering the final survey.

Potential sampling biases/inaccuracies

Surveyors kept the sample balanced in gender and ages. However, based on site observation, the proportion of male and female E2W users is not evenly balanced; in a random sample of 180 E2W users, 62% were female, 38% were male. This may lead to an under-representation of female attitudes and travel behavior regarding E2Ws since our survey only surveyed 50% women.

The same problem also occurs in representing the elderly age group. Our survey was conducted during the daytime on two days with hot weather. Because elderly people in China are more active in the early morning, and also due the hot daytime weather, this age group may be under-represented.

The survey was carried out only in the downtown areas of Shijiazhuang. This location may result in a slight bias towards higher-income users as well as individuals who use electric bikes for work commute trips.

In order to calculated trip distance, rather than ask people their trip distance directly, we asked respondents to locate their origins and destination using a grid map. We then asked people to estimate their travel time. Our data collection method for trip distance and thus travel speed could have inaccuracies if respondents chose a special route that was longer or shorter than the distance calculated using their origin/destination coordinates.

Data Processing

The results in the section below were calculated using Excel. Data from the survey was input into an Excel spreadsheet, and response choices for each question were added together. The data was sorted by demographics when appropriate.

Since the streets in central Shijiazhuang follow a grid pattern, trip distance was calculated by measuring the ΔX and ΔY from respondents' stated origin and destination which they located using a grid map attached to survey. Trip speed is calculated by dividing calculated trip distance, by stated trip time. Calculated trip speeds were then averaged together to find the absolute average trip speed. Trip speed results exhibit the most uncertainty since our calculated responses ranged from 5-26 km/h for bike users and 4-34 km/hr for E2Ws. Responses under 6 km/hr were thrown out.

3.3 Results

2WV User Demographic Differences

The differences in age, gender, and income between bike and E2W users are presented in the sections below.

Age and Gender

Of the 751 bike riders and 460 E2W users, 49% were male and 51% female. Figure 1 shows the distribution of bikes and E2Ws among men and women of different age groups.

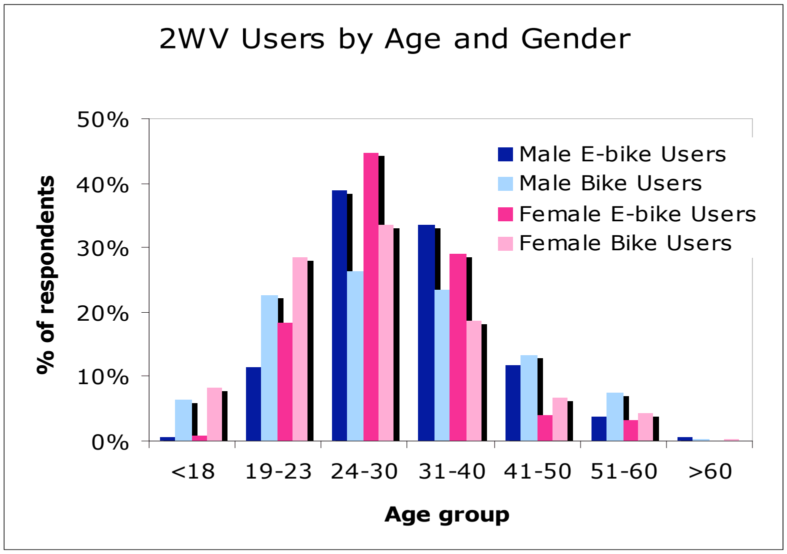


Figure 3-1: Bike and E2W users by age and gender

E2Ws are most popular amongst the "24-30" age group, especially among females. Almost half of all female E2W riders are in this group. Nearly 73% of all E2W users are between 24 and 40, compared to 51% of all bike riders. This could reflect higher-income career-aged commuters choosing E2Ws.

Income

The average income of bike users and E2W users, 18,000 and 22,000 RMB/yr, respectively (8.0RMB = $1 USD) (Figure 3-2). The small income gap indicates that there are other factors behind purchasing an E2W than just price. These other factors are revealed in analyzing the trip characteristics of the two groups in the next section.

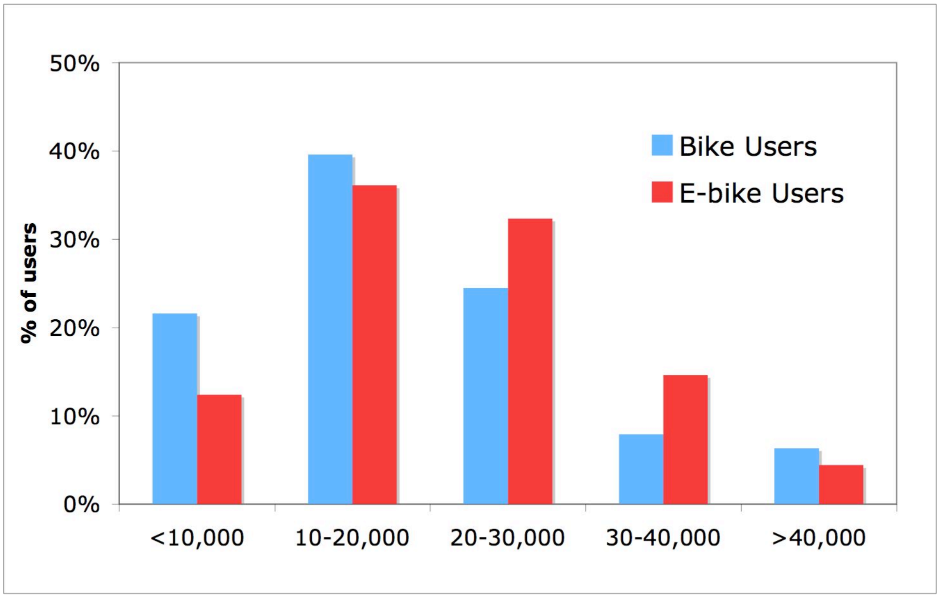


Figure 3-2: Income levels of bike and E2W users (RMB/yr)

Trip Characteristics

The difference in trip characteristics between bikes and E2Ws are explored in the following section. This includes trip distance, time, frequency, speed, and purpose.

Trip Distance

Figure 3-3 shows distribution of trip distance for 2WV in Shijiazhuang. E2W riders in general travel 32% farther than bicycle riders (5.8 vs. 4.4 km/trip average).

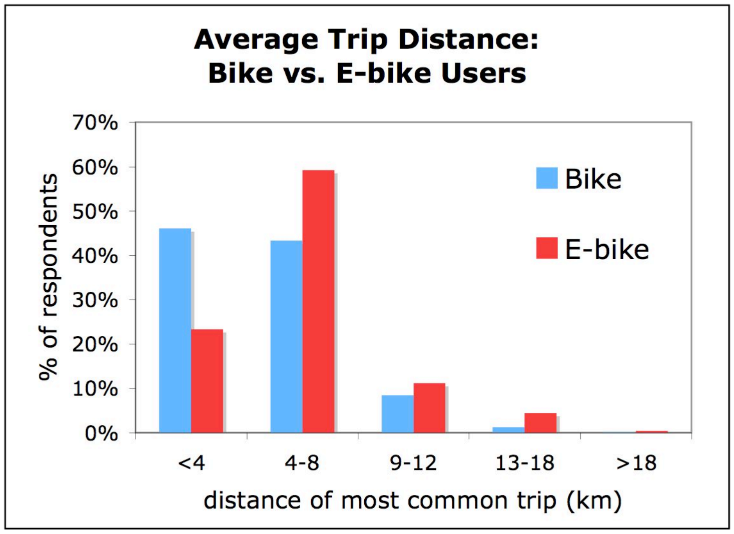


Figure 3-3: Distribution of trip distance for bike and E2W

Trip Time

E2W riders' travel time is about 10% longer on average than bike riders (24.7 vs. 27.2 minutes, respectively). Approximately 80% of bikers make trip less than 30 minutes, which concurs with a previous survey of 14 Chinese cities (population >1million) in 1995 [63]. Only 70% of E2Wrs made trips less than 30 minutes, indicating that people are willing to travel for longer periods of time by E2W.

Trip Speed

E2W average speed is 17% higher than bike users: 14 vs. 12 km/hr. This is not surprising since they travel farther distances over the same commute time, and they are supported by electric propulsion. The statistical significance of this result however is uncertain due to the data collection method. Speed studies in Shanghai and Kunming show about a 30% difference in speeds (14.5 km/hr vs. 11.1 km/hr and 14.7 km/hr vs. 10.9 km/hr, respectively), which is consistent with users in Shijiazhuang with longer trip distances [64]. The difference in speeds might be under-estimated if respondents included their access and egress times. This would more heavily under-estimate the on-vehicle speed of faster modes.

Trip Purpose

Commuting is the dominant trip purpose for both bike and E2W users (61% and 77% respectively). Going to school, picking up children from school, and shopping make up the smaller share of trips. “School” is a more common trip purpose for bike users since, as people under 23 more commonly ride a bicycle.

Trip Frequency

Both bike and E2W users on average make between 2-4 trips per day. There is no significant difference between E2W and regular bike users.

Passenger and cargo carrying

Site observation and survey results revealed that E2W users carry cargo and passengers more often than bicycles. SSEBs users are commonly seen carrying as many as two passengers. Clearly, the increased power offered by the battery and motor makes this behavior much easier.

Vehicle performance in traffic

Due to E2W's higher acceleration and speed (>20 km/hr), they typically lead each wave of NMVs traveling through the bike lane from one intersection to the next. E2Wrs tend to reach the intersection before bicyclists, and thus quickly accelerate through the intersection once the signal turns green, unimpeded by bicyclists. Bicyclists are typically the last to pass through an intersection.

Travel Mode Choice

In order to make better urban planning decisions about road capacity, public transport, and traffic policies affecting bike and E2W users, it is important to understand why 2WV users choose these modes, how they would travel is these modes weren't available, and their plans to switch modes. The following section presents results from the survey regarding these issues.

Reasons for choosing bike/E2W

Respondents were asked why they choose to ride a bike/E2W for commuting. They were given 10 options and could select multiple answers. The five most popular responses for bike and E2W users are shown in Figure 3-4.

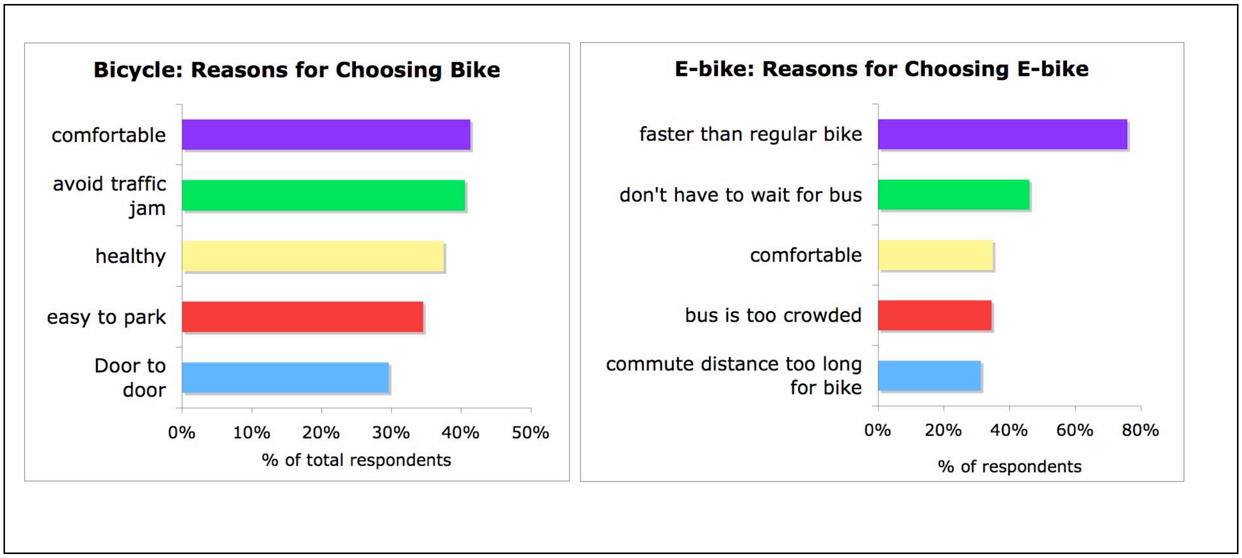


Figure 3-4: Reasons why users choose bikes/E2Ws for commuting

These results indicate the E2Ws are offering users a better alternative to biking and riding the bus. They also reinforce results about trip distance that people are commuting farther to work. For bike users, the results show that people choose to ride a bike for other reasons than just low-income. Road congestion, health, and convenience are also important factors.

2WV Users and Public Transit

The results of the survey indicate that the public transit network in Shijiazhuang is an important part of the 2WV users' transportation system. 2WV users were asked questions about their bus-riding habits and attitudes. They were first asked why they don't ride the bus, and if they sometimes ride the bus, why (Figure 3-5). The majority of 2WV users (~60%) depends on the bus during bad weather and often uses it when their bike is unavailable.

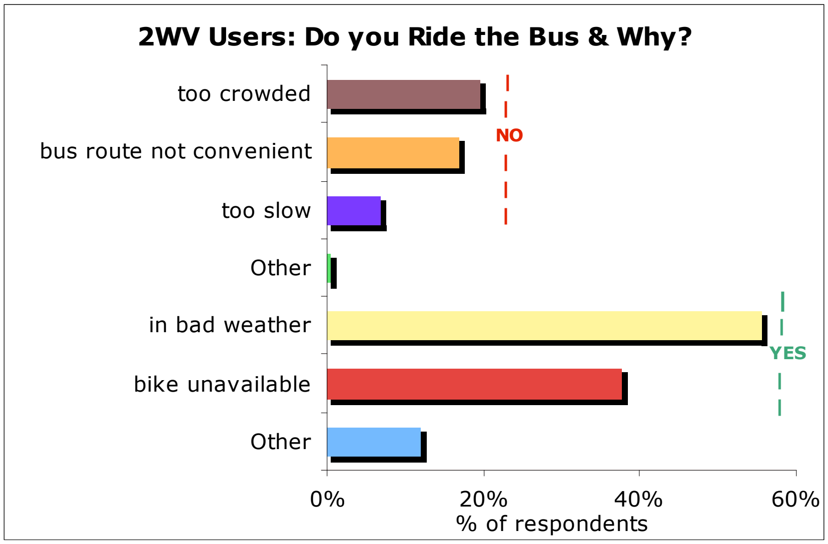


Figure 3-5: Bike/E2W users reasons for choosing/not choosing bus

2WV users don't regularly ride the bus because it is too crowded, the bus route is inconvenient, and it's too slow. Another reason revealed through the survey is that some people are concerned with thieves on the bus, and thus choose to ride a bike.

We also asked 2WV users how they would choose to commute if biking was no longer an option. Figure 3-6 indicates that the bus is the next best alternative for over 60% of bike users. The bus system therefore plays a critical back-up role if the biking option is unavailable. Surprisingly, 7% of bike riders would travel by car, which indicates some are choosing biking for reasons other than economic necessity

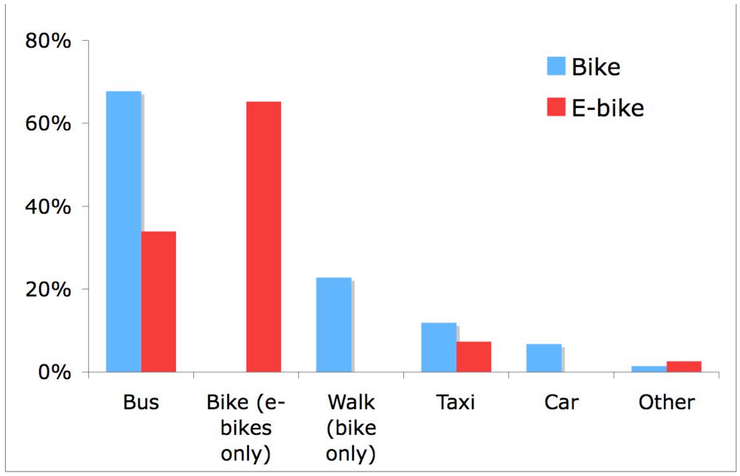


Figure 3-6: Next best alternative for bike/E2W users

A similar survey in Kunming and Shanghai was carried out and found slightly different results. In both of these cities, most of the E2W users would otherwise choose bus for their trips, 54% and 58% for Shanghai and Kunming, respectively. The second most popular response was bicycle, with 12% and 21% of the responses in Shanghai and Kunming, respectively. In both of these surveys, an overwhelming majority of respondents chose bus, perhaps because of higher quality of bus service and city size difference (i.e. longer trip distances), compared to Shijiazhuang.

Future Plans to Change Travel Mode

To understand the future of 2WV use in Shijiazhuang, we asked current 2WV users if they had plans to switch to different travel modes in the next year. Responses are shown in Figure 3-7. We found that the most popular future option for bicyclists is the E2W. Current E2W users plan to switch to a better E2W or a car. Very few 2WV users plan to switch to riding the bus. Many Chinese cities (e.g. Shanghai) believe the improvement of public transport services is the final solution for inner-city transportation challenges, however service has lagged behind demand. Thus users who face long trip distances have resorted to E2Ws.

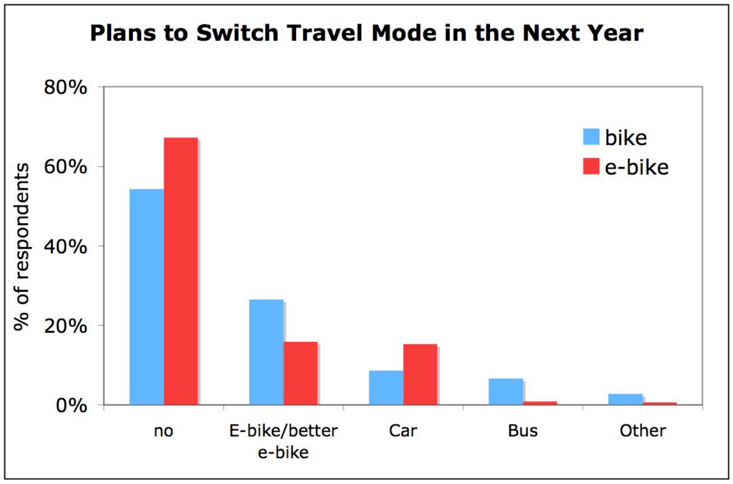


Figure 3-7: Future purchase plans of bike/E2W users

Stratifying results based on income level shows that future purchase plans are dependent on income. Of the low and mid-income bike users that plan to change mode in the next year, the majority plan to switch to E2W. For high-income 2WV users (both bike and E2W) that plan to switch modes, the most popular choice was to buy a private car. Other options such as bus, taxi, or (other) were minimal.

Traffic Safety

Traffic safety for 2WV is a serious problem in China. There were an estimated 500,000 traffic deaths between 2000-2005, 60% of whom are 2WVs users [65]. From site observation and interviews with traffic management, the most difficult and dangerous part of a 2WV users' journey occurs at intersections due to the mix of automobiles, various 2WVs, and pedestrians [62]. In Shijiazhuang, intersections were particularly chaotic due to the massive amounts of 2WVs crossing the street from both directions and their strong tendency to disobey traffic lights.

Another safety issue is the mixing of bikes and E2Ws in the bike lane. We thus surveyed 2WV user attitudes on safety at intersections and E2W speed. Survey respondents were asked to rank how much they agree or disagree to the statements shown in Figure 3-8 (1= Strongly Agree, to 5= Strongly Disagree).

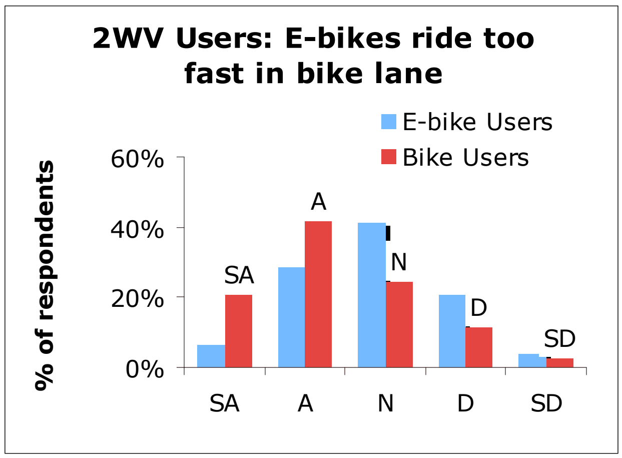


Figure 3-8: Bike/E2W user attitudes on speed of E2Ws

Safety at intersections

Results show that both bikers and E2Wrs generally are satisfied (avg. response= “agree”) and feel safe using this mode of travel, and feel traffic police do a good job maintaining order at intersections (question 1, 3, 5). E2Wrs feel slightly more satisfied with their mode than bikers, but they also feel slightly less safe.

On the other hand, both bike and E2W users were on average neutral about the ease of crossing intersections (question 2) and there were a large amount of both “agree” and “disagree” responses for both bikes and E2Ws. Sorting these responses by gender reveals that female bike riders have the most difficult time crossing intersections, whereas male E2W riders find it easiest. The responses showed that women find it easier to cross the intersection when riding an E2W. This points to one reason why E2Ws are so popular amongst women. Site observation also confirmed that E2W users generally have an easier time crossing intersections. The highly “stop-and-go” nature of intersection makes crossing easier with the aid of electric propulsion.

Conflict between E2Ws and Bikes

We asked several attitudinal questions about the more controversial issues of E2Ws to reveal the nature and reality of the conflict between bike and E2W riders. Regarding E2W speed, the majority of bike riders agree that E2Ws are too fast in the bike lane (Figure 3-8). E2W riders on average felt neutral about E2Ws being too fast, indicating nearly 50% of E2W riders themselves think E2Ws are too fast.

E2W riders were also asked whether they would like a faster, more powerful E2W. Results uncovered a large gender difference in responses. Whereas men have a neutral opinion about this issue, women are strongly opposed.

The second issue relates to the nature of the conflict between E2Ws and bikes (i.e. “who is bothering whom?”). Survey results revealed that a conflict indeed exists between bikes and E2Ws users, however it is bi-directional and also includes pedestrians. Respondents were asked what is most bothersome to them during their commute (they could choose multiple options). Results show that the biggest annoyances to 2WV users are in fact other 2WV users (Figure 3-9). E2W riders feel that other bicyclists and pedestrians are most bothersome. Bicyclists also ranked pedestrians and other bicycles most bothersome. Automobiles were low on the list, most likely because of Shijiazhuang's extensive network of segregated bike lanes and relatively small car population. Other included the bus, improper signal timing, and taxis.

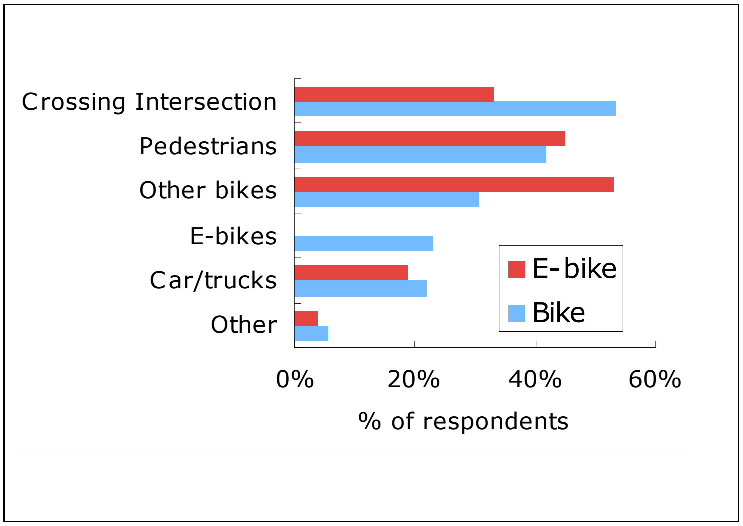


Figure 3-9: Most bothersome aspects for bike/E2W users

One reason for this problem amongst 2WV users and pedestrians is the poor enforcement of traffic rules for this group. Interviews with local traffic police revealed two reasons for weak enforcement: 1) they have a responsibility is to maintain vehicle flow and thus they don't have time to strictly monitor NMVs and 2) NMV population is so large and violations so frequent, they don't have the resources to punish them.

Another reason for this conflict is likely due to the speed difference between bikes and E2Ws, which is easily observed along bike lanes throughout Shijiazhuang. E2Ws generally travel faster, and thus are often interrupted by slower bikes.

3.4 Conclusions

Electric bikes are providing low-income commuters a mode of transportation that provides high levels of personal mobility at low personal cost. As cities expand, E2Ws are allowing people to commute longer distances and reach more goods and services than alternative modes. This improved mobility could lead to further urban expansion in the long term.

People are choosing E2Ws for a number of reasons; including reduced travel times, increased range compared to bicycles, increased cargo or people carrying capacity, comfort and ease of use. Electric bikes have improved the mobility of the elderly, who often have the responsibility of transporting children.

E2W users would mostly use bus or bicycle in the absence of electric bikes. E2Ws seem to be acting as a near-term remedy for people who are under-served by public transportation. This mode seems to fill the transportation niche, providing personal transportation to people who do not have traditional transportation patterns. Many users however still rely on bus transit in the case of bad weather.

Based on mode shifting behavior revealed and stated by the survey, E2Ws will continue to grow in popularity as incomes rise and cities expand. It is clear that income is not the only factor contributing to the popularity of electric bikes; their performance characteristics make them a popular mode for all income classes. Many electric bike owners state that the next step along the transportation pathway will be a personal car, implying that electric bikes could be a transitional mode on the motorization pathway.

One of the reasons cited for regulation of E2W use and performance characteristics is safety. The survey results show that E2W users, especially woman, feel safer when crossing intersections compared to when using a bicycle. Most users feel that bicyclists and pedestrians are the greatest source of traffic conflict. Surprisingly, bicyclists identify the most conflict with other bicyclists, however they do think that E2Ws operate too quickly in the bike lane. Female E2W users are generally opposed to electric bikes with higher speed characteristics.

3.5 Recommendations

Traffic Management

Impose license system for E2Ws. Licensing vehicles makes it easier to enforce traffic laws and control the E2W population, thus improving safety. E2Ws are required to register and have special license in some cities like Shanghai, Tianjin, and Suzhou. But some cities like Shijiazhuang have no specific E2W regulations.

Enhance traffic management at intersections to improve traffic safety for both 2WV and pedestrians. Enforcement of local traffic violations such as red-light running will benefit all road users and improve traffic conditions by reducing vehicle interactions.

E2W Standards

New standards should consider allowing an increase in weight, but keeping speed constant. The survey has revealed that E2W users do not want an increase in speed. However, weight limits should be increased to accommodate larger batteries for longer commute distances and improve E2W safety. Increased weight would enable larger battery capacity, a sturdier frame, better braking systems and more comfortable vehicles.

Areas of Future Analysis

Future studies will examine the regional differences between bike and E2W travel behavior. Shijiazhuang is classified as a medium sized city, it would therefore be useful to examine the differences between a small and large city as well. China is large country and thus the differences between city size, income level, regional climate, terrain, transit service levels, and average travel distance may result in different conclusions.

The effect of land-use policies on travel behavior and the shift from bike to E2W also warrants future analysis. The housing policy reform initiated in the early 90s (employees were no longer forced to live in government provided housing close to work) has had a considerable impact on commuter behavior, travel distance, urban transport and land use. Future study could examine whether E2W use is a result of expansion of cities or partially responsible.

The environmental costs and benefits of E2Ws are not yet fully understood and thus it is necessary to carefully evaluate the positive and negative externalities of E2W use in order to guide the policy debate on E2Ws.

4 LEAD-ACID AND LITHIUM-ION BATTERIES FOR THE CHINESE ELECTRIC BIKE MARKET AND IMPLICATIONS ON FUTURE TECHNOLOGY ADVANCEMENT

Abstract

China has been experiencing a rapid increase in battery-powered personal transportation since the late 90's due to the strong growth of the electric bike and scooter (i.e. E2W) market. Annual sales in China reached 17 million bikes/yr in 2006. E2W growth has been in part due to improvements in rechargeable valve-regulated lead acid (VRLA) battery technology, the primary battery type for E2Ws. Further improvements in technology and a transition from VRLA to lithium-ion (Li-ion) batteries will impact the future market growth of this transportation mode in China and abroad.

Battery performance and cost for these two types are compared to assess the feasibility of a shift from VRLA to Li-ion battery E2Ws. The requirements for batteries used in E2Ws are assessed. A widespread shift from VRLA to Li-ion batteries seems improbable in the near future for the mass market given the cost premium relative to the performance advantages of Li-ion batteries. As both battery technologies gain more real-world use in E2W applications, both will improve. Cell variability is a key problematic area to be addressed with VRLA technology. For Li-ion technology, safety and cost are the key problem areas that are being addressed through the use of new cathode materials.

4.1 Introduction

E2Ws have been by far the most successful battery electric vehicle application in history with estimated cumulative production of ~30 million by 2007 [50]. At the heart of E2W technology is the rechargeable battery. The core rechargeable battery technology used in E2Ws is valve-regulated lead-acid (VRLA), or “sealed”, and lithium-ion (Li-ion). Advances in VRLA batteries and rising gasoline prices over the past decade have made E2Ws increasingly competitive with gasoline scooters in price and performance [10]. E2Ws using VRLA achieve low cost ($150-300) and adequate range (30-70km per 8 hr charge). The power system characteristics of E2Ws are shown in Table 4-1. Because most E2Ws use either VRLA or Li-ion, this analysis will focus on these two battery types.

Table 4-1: Electric two-wheeler power system characteristics

Specifications	**Bicycle-style E2W**	**Scooter-style E2W**
Total battery pack capacity (kWh)	0.4-0.6	0.8-1.0
Maximum current (A)	15	20-30
Voltage (V)	36	48
Modules/pack (typical)	3	4
Cells in series	18	24
Peak motor power (kW)	0.24	.50-1
Maximum depth of discharge (%)	80	80

Motivation

Urbanization and income levels are both rising rapidly in China. As a result, the low and middle classes are demanding faster, more comfortable transportation options. Survey data from three major cities in China indicate that today's bicycle users (450 million) will most likely purchase an E2W as their next mode of transport [40]. This mode shift choice has far-reaching impacts around the world in terms of battery technology development and the future market of electric two-wheelers.

This market development has important implications on the environment and public health. E2Ws are an extremely energy efficient (~50 mile/kWh) mode of personal transportation with zero tailpipe emissions. Life-cycle carbon emissions per km travelled of an E2W are roughly one fifth that of a gasoline-fuelled car [64]. E2Ws are also having positive effects in cities battling poor air quality by displacing gasoline-powered scooters.

Methodology

The analysis relies on literature and data from surveying a variety of companies involved in battery production for E2Ws. The authors visited several battery factories making both Pb-acid and Li-ion batteries. Batteries from some of these manufacturers have been laboratory-tested.

4.2 Transportation Battery Applications and Requirements

Batteries are used for a wide range of applications including consumer electronics, energy, industrial, and transportation. Batteries for transportation applications have much different requirements than most other applications. They are used in three different modes: motive power, auxiliary power, and traction.

Motive power batteries are used to drive automobiles, scooters, and bicycles and thus require high specific energy (Wh/kg) to achieve adequate range. Deep-cycling capability is necessary since it is common for batteries to be discharged to 10-20% SOC. Cost is a driving factor because the battery pack size can be quite large (1-2 kWh for large electric scooters).

Auxiliary power batteries are used in automobiles and motorcycles predominantly for starting, lighting, and ignition (SLI). Power is valued more than energy density and deep discharge capability because SLI batteries are primarily are used to provide high bursts of power output to start an engine (~1-5 kW) and rarely discharged more than 20%.

Traction batteries used in forklifts and underground mining cars experience heavy-duty operation and thus require high abuse-resistance. These applications typically use flooded Pb-acid (FLA). Table 4-2 summarizes these battery applications and their requirements.

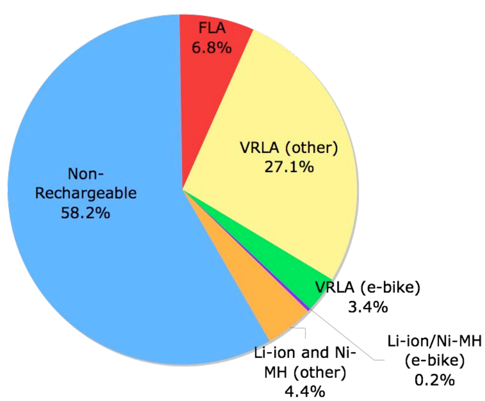
Table 4-2: Battery Applications [1]

Application	Function	Battery Size	Technology	Requirements
Electronics	Portable power	10^1-10^2Wh	Li-ion, Ni-MH	Low weight & volume, high energy
Energy	Remote-area power supply	10^3-10^5Wh [66]	FLA, VRLA	Low maintenance, high reliability, long life
Industrial	Back-up power			
Transportation	Motive Power (hybrid)	10^2-10^3 Wh	Ni-MH, Li-ion	High specific power
	Motive Power (battery only)	10^2-10^3 Wh	VRLA, Ni-MH, Li-ion	High specific energy, low cost

	Auxiliary power (SLI)	10^2 Wh,	FLA, VRLA	Low cost, high reliability
	Traction	10^3 Wh	FLA, VRLA	Abuse tolerant, long life, low cost
1. [67]				

4.3 The Battery Industry In China

The total Chinese battery market in China was valued at $12.4 billion in 2006, 35% of which is for rechargeable Pb-acid type. Estimates on the production volume capacity (kWh) of Pb-acid batteries range from 35-67 million kWh/yr, produced by more than 2,000 companies [50, 68]. 300 of these companies specialize in E2W batteries with an estimated annual production between of 3.5 and 9 million kWh/yr in 2005. Calculations based on the annual E2W sales in 2006 and assumed after-market sales to the existing E2W population reveal a much higher annual production between 15 and 20 million kWh/yr.[9] Figure 4-1 shows the proportions of different battery types in China.



[9] Assuming average E2W battery capacity is 0.53-0.67 kWh, 16 million new sales in 2006, of the estimated 20 million existing E2Ws, 40% replace their battery each year, 60% replace it every other year.

Figure 4-1: The China Battery Market by Battery Type

VRLA batteries were first introduced into UPS applications in America and Europe in the 70's because of their low maintenance requirements and high reliability over traditional flooded lead-acid [69]. The rapid growth in telecommunication and computer networks throughout the world during the 80's created a huge market for this battery type. The VRLA industry finally spread to China in response to their telecommunications boom of the 90's [70]. Prior to the 90's, the Chinese battery industry produced mainly flooded Pb-acid batteries for agriculture and transport (e.g. trucks, train infrastructure). Between 1990 and 1996, sales of VRLA batteries grew from 60,000 to 730,000 kWh, primarily for telecommunications applications. In the late 90s, production of small VRLA and flooded SLI batteries grew in response to the growing automobile, gasoline scooter, and electric bike markets [71].

One of the main problems with China's Pb-acid battery industry is that it is difficult for government to regulate production, quality, and environmental impacts. This is in part due to the large number of relatively small manufacturers spread throughout the country. This high industry decentralization results in lower quality batteries entering the market and batteries containing toxic performance enhancing materials such as Cadmium, and lead waste issues. In 2006, 23% of the E2W battery companies inspected did not pass the minimum quality standards set by the national inspection bureau [68]. It is expected that considerable consolidation within the industry will occur, as occurred in the European battery industry during the 90s [71, 72].

The advanced battery market in China makes up 15% of the total market, which includes batteries using lithium or nickel compounds. These companies primarily produce batteries for consumer electronics applications used throughout the world. Sony commercialized the first Li-ion battery in 1991 in Japan for use in consumer electronics. Few LAB manufacturers in China are making advanced batteries. From one manufacturer's perspective, Li-ion batteries are still dangerous, costly, and the market for LABs is still large and expanding.

VRLA Production

Most of the world's small VRLAs (<25Ah) are manufactured in Asia and exported around the world due to low labour costs, land cost, and loose environmental standards [71]. The process for making large modules is roughly the same as making small modules. Manufacturing is labour intensive yet exhibits low profit margins. Battery quality can be considerably different among manufacturers and is a key distinguishing factor between top brands from the hundreds of smaller competitors. Key differences from company to company are linked to differences in materials (i.e. alloy plate formula, electrolyte formula, AGM material, etc.) and manufacturing (i.e. dust control, quality inspection stations, etc) [73].

Li-ion Production

Li-ion batteries, whether for electric vehicles, electric bikes, and consumer electronics, are all produced using similar processes [74]. Hence, a single manufacturer can produce battery sizes for a wide range of applications, from portable consumer electronics to EVs [75]. Li-ion batteries can be designed for high power or high energy depending on cell size, thickness of the electrode, and relative quantities of material used [74]. High power cells are generally smaller in order to dissipate the higher heat load. Both types use the same current collectors and separators. Lithium resources are abundant in China. As of 2000, they were the 2nd largest producer of Lithium in the world and in 2004 produced 18,000 metric tons [76, 77].

4.4 Batteries For E2Ws

This section describes VRLA and Li-ion batteries for use in E2Ws and identifies the most important battery characteristics in this application. Based on the thriving market, today's batteries appear to satisfy the cost, range, weight, and other requirements demanded by E2W users.

VRLA

In 2005, it is estimated that 95% of E2Ws produced in China used VRLA; the rest use Li-ion, Ni-MH, or Ni-Cadmium though the majority of these are exported [51]. VRLA battery packs consist of three to four 12V modules (12, 14 or 20Ah capacity) for a total voltage of 36 or 48V and energy capacity of 0.4-1 kWh. VRLA for E2Ws differ from SLI VRLAs used in automotive applications in that they are able to be deep-cycled. E2W batteries are typically of the absorptive glass mat (AGM) type, meaning they use an absorbed sulphuric acid electrolyte in a porous separator, as opposed to a gelled silica/acid separator in Gel-type VRLAs. Whereas standard SLI automotive batteries are typically only discharged 10-15%, deep-cycle batteries for motive applications like E2Ws are discharged 80-90% [78]. Battery makers claim the key distinguishing factor of their batteries is lifetime and stability (i.e. mean time before failure). Most domestic manufacturers do not report defect rate of their products, but one study by a battery manufacturer reports a 3-9% defect rate of E2W batteries from three domestic manufacturers.

Lithium ion

Li-ion battery packs for E2Ws range from 24V-37 V with capacity of 5-60 Ah. The market for Li-ion E2Ws in China is still small. In Japan and Europe however, Li-ion and Ni-MH are the dominant battery type, though annual E2W sales in these regions are two orders of magnitude lower than in China.

E2W Battery Requirements

VRLA is the current dominant technology in E2Ws. Li-ion and Ni-MH battery manufacturers are trying to tap into this large growing market. Some Li-ion battery companies are expecting 100% growth in sales in the next year and predict the market for Li-ion battery E2Ws will grow to 20% of total annual E2W sales in the next 5 years. Ultimately, the battery type that succeeds will depend on its performance relative to the alternative based on the several key criteria, described below. These criteria are compared for VRLA and Li-ion batteries in Section 5.

Cost: battery cost is likely the most critical factor in battery choice, as evidenced by the market dominance of VRLA. Despite the significant advantages in energy density and lifetime of Li-ion, VRLA is much lower cost. The emphasis on cost may change as average income increases throughout China.

Cycle life: lifetime of the battery is critical because it affects users long-term operating cost. E2W length of ownership can last 3-5 years depending on use. However, most users find they need to replace their battery after 1-2 years due to serious performance degradation [79].

Weight: Vehicle range is one of the most critical metrics for E2W users due to the long recharge times. Range depends on stored energy capacity, which for a given specific energy (Wh/kg), determines battery weight. Weight for VRLA E2W batteries typically range from 12kg for BSEB to 26kg for large SSEB. There are practical battery weight limitations based on the user's physical strength, since some users require removing the battery from the bike to recharge it in their apartment/home/office. Many users however often roll the entire E2W into their house/apartment if there is an elevator or find a convenient place to recharge on ground level. In terms of practical limitations on consumer for demand range, surveys of E2W users in three medium to large-sized cities show that average commute distance is 9.3 km/day [80]. However, there are high-range E2Ws on the market that can achieve range of up to 80 km/charge.

Charging safety: charging for VRLAs is considerably more flexible and tolerant to improper recharging than Li-ion batteries in terms of risk of damage to self and property. As evidenced by the worldwide Sony battery recall of 2006, Li-ion batteries still entail risk, which is amplified as cell size increases.

Temperature effects: E2W batteries are used over a wide range of temperatures from winter lows of -40 °C in China's northeast to summer highs of +40 °C in the southwest. A batteries performance at extreme temperatures will affect range and lifetime and is thus an important factor.

Other Factors

Volume: volume is likely a secondary factor since the weight constraint of a battery limits energy capacity before volume is constrained. Batteries for SSEBs are usually stored in the floorboard underneath the feet, or for BSEBs along one of the frame's crossbars. The largest battery pack in a SSEB is roughly 9.3L. Extra volume through smaller battery size may be valued slightly for extra storage space.

Speed: top speed is determined by battery power density and motor size. The power density of VRLA 230W/kg is more than sufficient to meet the 350W peak motor power limit of E2Ws. While national E2W standards limit top speed to 20km/h, most BSEBs can reach 25-30km/h, and high-power SSEB can reach 35-40.

Charge time: Since most people charge their battery overnight when electricity is cheapest, the maximum acceptable charge time is likely 8hrs. Full battery capacity should be restored to full charge by an 8-hour charge regime using 220V AC.

4.5 E2W Battery Performance And Price

Advances in VRLA technology over the past decade have made E2Ws affordable, efficient, and practical [80]. Li-ion technology has also improved to a point such that Li-ion E2Ws are now marketed in China, in addition to being exported throughout the world. The technical performance and price of VRLA and Li-ion batteries from Chinese manufacturers are compared in this section.

VRLA

The key performance characteristics and price of VRLA (AGM type) batteries from several manufacturers for two popular E2W battery module sizes (20 and 12 Ah) are compared in Table 4-1. VRLA costs for 12V-12Ah modules from three Chinese and one Japanese brand are compared in Table 4-3. Note that the batteries tested are specifically designed for motive power, not SLI applications, which have different characteristics when deep-discharged.

Table 4-3: 20 and 12Ah VRLA module characteristics of various manufacturers [1]

Manufacturer	Capacity (Ah) (2hr) [2]	Weight (kg)	Volume (L)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Cost ($/kWh)
Ritar	12	4.4	1.39	33	104	86.4
Tian Neng	12	4.1	1.39	35	104	80.5
Chaowei	10	4.1	1.39	29	86	81.9
Panasonic	12	3.8	1.39	38	104	104.3
Sunbright	10	4.1	1.39	29	86	
Huafu	12	4.2	1.39	34	104	
AVERAGE				**33**	**97**	**$88**
Ritar	20	7.2	2.37	33	101	
Chaowei	20	10	3.63	24	66	
Panasonic	20	6.6	2.30	36	104	
Sunbright	20	7.0	2.31	34	104	
Huafu	20	6.8	2.40	35	100	
AVERAGE				**33**	**95**	

Information obtained from company websites. Price data is the purchase price from a retailer.

A "2 hr" rate is a commonly used metric for testing battery capacity. It represents the discharge rate used to completely discharging the battery in 2 hrs

To verify performance, we obtained 12V-12Ah modules from 4 large E2W battery suppliers and measured their performance using an Arbin BT2043 battery-testing device. Current and power levels for these tests were chosen based on the typical demands of an electric bike. Table 4-4 shows the results of the tests. The discharge characteristics are given in Ah, Wh/kg, W/kg at 9.6V. The results from the tests exceed the manufacturers stated claims on energy density and are considered quite good for VRLAs of such small cell size.

Table 4-4: Performance of 12V-12Ah VRLA Battery Modules from 4 Battery Manufacturers (C/2.4 discharge rate)

Company	Mass (kg)	Capacity (Ah)	Specific Energy (Wh /kg)	Resistance (mΩ)	Max power at 9.6V (W/kg)
1	4.24	12.0	34.2	20	272
2	4.05	12.2	36.8	22	258
3	4.27	12.1	34.3	27	200
4	4.00	11.5	35.0	30	192
Average	**4.14**	**12.0**	**35.1**	**25**	**231**

Cycle life

Since cycle-life testing requires over a year, the authors relied on data provided by manufacturers and warranty data. Manufacturers report cycle life between 400-550 cycles, though independent testing of 4 brands by an anonymous manufacturer revealed cycle life of 300-400 cycles. This corresponds with typical 1 to 1.5 year warranties provided by most E2W manufacturers.

Defect Rate

The industry average defect ratio for E2W batteries is 5% while only 0.10% for other types of LABs.[10] The main reason for this large difference is the extreme variation in charging and discharging experienced in E2Ws compared to other applications. There was a noticeable difference in the defect rate of foreign brands compared to Chinese brand LABs. According to interviews with one battery company, improving battery lifetime and stability is the key area of research.

Lithium-ion

Li-ion battery performance and price from various Chinese and international manufactures is compared in Table 4-5. Prices range from $510-760/kWh. Due to the limited amount of companies making Li-ion E2W batteries, price data is presented from only three companies. Data from another Chinese Li-ion battery manufacturer quotes cost between $300-600/kWh (retail price is not provided) [81]. The stated cycle life of Li-ion batteries from 3 manufacturers is 600-800 cycles. The actual warranty on their batteries is 2 years.

Table 4-5: Characteristics of Li-ion modules from various manufacturers

[10] Comparitive study of battery performance from large E2W battery suppliers, conducted by one battery manufacturer, 2006

Manufacturer	Capacity (Ah) (2hr)	Weight (kg)	Volume (L)	Specific energy (Wh/kg)	Energy density (Wh/L)	Power density (W/kg)	Price ($/kWh)
Xingheng - high power	15	0.88	0.43	63	128	1,261	
Xingheng - high power	7.5	0.41	0.16	68	173	1,805	
AVERAGE- high power					**151**	**1,533**	
Xingheng - high energy	30	1.0	0.45	111	249	111	510
Xingheng - high energy	10	0.37	0.15	100	241	200	527
Lantian	60	1.8	0.78	123	286	*unavail.*	*unavail.*
Lantian	18	0.6	0.31	111	215	*unavail.*	*unavail.*
Lantian	4.7	0.14	0.052	124	333	*unavail.*	*unavail.*
Citic Guoan MGL	50	1.95	0.95	97	201	*unavail.*	*unavail.*
Citic Guoan MGL	30	1.1	0.66	104	173	*unavail.*	*unavail.*
Citic Guoan MGL	10	0.47	0.19	81	198	*unavail.*	*unavail.*
Zhengke	11	*unavail.*	*unavail.*				*505*
Panasonic	*unavail.*	*unavail.*	*unavail.*				*761*
AVERAGE-high energy				**106**	**237**	***156***	***$586***

4.6 Battery Transitions In The E2W Market

The transition from VRLA to Li-ion batteries in E2Ws is progressing in China, based on interviews with Li-ion battery companies. The pace and extent of this transition is still uncertain, since the E2W market is currently very cost-conscious. The following section uses the battery performance and cost data and battery choice criteria from the previous sections to compare E2Ws using VRLA versus Li-ion.

Comparison of key factors for VRLA and Li-ion

The characteristics of VRLA and Li-ion batteries are compared in Table 4-6. The batteries are sized for an average 48V SSEB with 60km range (0.90 kWh) and 350W motor. This type of E2W was chosen since it is a popular model for a 3-person family. It sets a practical upper bound to maximum battery size in an E2W, and is comparable in performance to a 50cc gasoline scooter. Battery characteristics assumptions are also listed in the table. An E2W energy consumption of 0.014 kWh/km, and average user travel distance of 15 km/day was assumed in making the battery comparisons. The effect of a smaller battery weight on energy consumption was neglected.

Table 4-6: Comparison of Battery Types (with Assumptions)

Results	**VRLA**	**Li-ion [82]**
Cost ($)	75	424
Mass (kg)	26	8
Lifetime (yrs)	3	9
Volume (L)	10	5
Max Theoretical Power (kW)	6.2	2.9
Recharging Safety	high	low
Temperature effects	moderate	high
Assumptions	**VRLA[1]**	**Li-ion**
Specific Energy (Wh/kg)	35	110
Energy Density (Wh/L)	86	170

Power density (W/kg)	240	350
Cost ($/kWh)	83	505[11]
Cycle Life	300	800
1. Data for VRLA come from Chinese battery measurements and product brochures		

These results suggest that the cost differential between the battery types dominates all other factors. The added lifetime from the more durable Ni-MH and Li-ion is likely not valued very high since the life of an E2W is not much greater than 3-4 years. The 18 kg mass difference between Pb-acid and Li-ion, however, is significant since a 26 kg battery is likely unmanageable for the majority of E2W users. If those users only option to recharge is to carry the battery indoors, they may be inclined to use Li-ion.

Japan and Europe

After China, the next largest E2W market is Japan- with annual sales of 270,000 bikes/yr in 2006 and 13% average annual growth since 2000 [33]. In Europe, the market is estimated at 190,000 bikes/yr in 2006 [34]. Electric bikes in these markets are different from Chinese E2Ws in that these bikes are typically the pedal-assist type or “pedelec”. The user typically pedals but is assisted by a small electric motor when extra power is desired (e.g. acceleration, uphill climbs). Most pedelec E2Ws use Ni-MH or Li-ion batteries. Battery capacity ranges from 0.2-0.6 kWh, motor size ranges from 150-250W, and prices range from $700-2,000.

[11] Zhengke Li-ion battery E2W (anonymous source)

4.7 E2W Market Growth and Battery Technology Advancement

The growing E2W market will necessarily lead to further advancements in battery technology and a gradual transition to more advanced battery technologies. In turn, this battery advancement will expand the market for E2Ws in China and throughout the world, especially in developing countries with high two-wheeler use. This section describes the importance of technology learning to the advancement of battery technology, and the key areas where this learning is most important.

The principal reason for anticipated improvements in battery performance and cost is due to technological learning effects. There are three categories of learning associated with technology development: research and development (R&D), manufacturing, and in-service use. The E2W battery market is accelerating learning in all three categories.

Li-ion battery production, whether for electronics or E2Ws, achieves learning in the first two categories because the materials and manufacturing process for large and small cells are similar [83]. Only E2W battery production, however, will drive the operational learning progress for large format battery cell technology. The key areas of technology improvements for which this type of learning will have the most impact are: safe charging and discharging, cell degradation over time, operation in extreme environments (low and high temperatures), and cell variability within a battery pack and its effects on lifetime. Cell variability is a key issue with VRLA cells. Safety and cost are the key issues with Li-ion cells. These issues are explained in the following sub-sections.

Cell Variability

VRLA batteries exhibit considerable scatter in performance (i.e. no two modules have exactly the same electrical characteristics). This results from slight variations in the properties of materials and the electrodes used to assemble the cells due to the imprecise, labour-intensive manufacturing process [84]. When connecting several modules in series as in the case of a 36V (3 module) or 48V (4 module) E2W battery pack, there is often significant variability in the module voltage. This causes accelerated aging since the "weakest" module of the pack ages more rapidly [84].

Safety

For Li-ion batteries, safety risks such as battery overheating, combustion, and explosive disassembly increase with the amount of energy contained within the cell/battery pack. $LiCoO_2$ is commonly used material for small cell Li-ion batteries, but considered unsafe for large-format batteries [81]. New cathode materials such as $LiFePO_4$ are being introduced into Li-ion batteries for E2Ws, resulting in significantly safety improvements [85]. Hot-box heating and overcharge testing reveal safety advantages of $LiFePO_4$ over both $LiMn_2O_4$ and $LiMn_2O_4$ [86].

Cost

Li-ion battery technology is still relatively new (12 years) so there are potentially many opportunities for cost reductions. Material substitution could make a large impact since 75% of the total battery cost is due to materials [74]. Research and development efforts are focused on using more inexpensive and chemically stable materials such as $LiFePO_4$ and $Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$ for the cathode. Table 4-7 presents the cost, energy density, and cycle life differences between batteries with the commonly used $LiCoO_2$ cathode and these two alternative materials. For $LiFePO_4$, energy density is sacrificed for lower cost and longer life, along with the safety advantages mentioned above.

Table 4-7: Performance characteristic of Li-ion batteries with various cathode materials [1]

Cathode Material	LiCoO2	Li(Ni1/3Co1/3Mn1/3)O2	LiFePO4
Energy density (Wh/kg)	180	170	130
Cycle life (cycles)	400	400	1000
Price (US$/kg)	30	22	12
1. [81]			

4.8 Conclusions

There has been a rapid transition to electric bikes and scooters in China with the market reaching nearly 16 million/yr in 2006. This E2W growth has been in part due to improvements in rechargeable valve-regulated lead acid (VRLA) battery technology in China. Further growth in the market and a transition from VRLA to lithium-ion batteries will in turn lead to greater improvements in performance and cost.

VRLA and Li-ion battery technology for E2Ws has been assessed. For VRLA, a specific energy of 34Wh/kg and a cost of $88/kWh were determined for a number of international brands. Li-ion batteries in China on average have specific energy of 106Wh/kg and cost of $590/kWh. A widespread shift from VRLA to Li-ion batteries seems improbable for the mass market given the cost premium relative to the performance advantages of Li-ion batteries. As both battery technologies gain more real-world use in E2W applications, both will improve. Cell variability is a key problematic area to be addressed with VRLA technology. For Li-ion technology, safety and cost are the key problem areas, which are already being addressed through the use of new materials such as $LiFePO_4$.

5 THE FUTURE OF ELECTRIC TWO-WHEELERS AND ELECTRIC VEHICLES IN CHINA

Abstract

Electric two-wheeled vehicles (E2Ws) in China are the most successful electric-drive vehicles in the world. If E2W success continues, it may accelerate the development of batteries and larger electric vehicles. We analyze the technological and market evolution of E2Ws. Force-field analysis method is used to identify forces driving and resisting future E2W market growth, the root causes behind these forces, and important insights about the likelihood of a wide shift to larger three- and four-wheel electric vehicles (EV).

We conclude that the key forces driving E2W market growth are: improvements in E2W and battery technology due to product modularity and modular industry structure, strong local regulatory support in the form of gasoline-powered motorcycle bans and loose enforcement of E2W standards, and deteriorating bus public transit service. The largest forces resisting E2W market growth are strong demand for gasoline-powered motorcycles, and bans on E2Ws due to safety concerns in urban areas. The balance of these forces appears to favor E2W market growth. This growth will likely drive vehicle electrification through continued innovation in batteries and motors, the switch from lead-acid to Li-ion batteries in E2Ws, and the development of larger E2Ws and EVs. There are however strong forces resisting vehicle electrification, including battery cost, charging infrastructure, and inherent complications with large battery systems.

5.1 Introduction

Electric two-wheelers (E2Ws) are an efficient, low-polluting transportation technology gaining widespread acceptance in China. Their rapid adoption was a response to the timely convergence of some key trends that started in the late 1990s. Incomes were rising, allowing consumers to move from regular bicycles and public transport to E2Ws. Gasoline-powered motorcycles (including scooters) were banned in several cities due to worsening air pollution. Battery and motor technologies improved dramatically, allowing better electric two wheelers [51]. Urban trip distances rose due to rapidly expanding cities, encouraging faster, longer-range bicycles.

In 2006, sales of E2Ws were 13.1 million, nearly equaling the 14.6 million gasoline-powered motorcycles sold that year. It is likely that E2Ws will continue to substitute for bicycles and public transit as incomes rise in China. Depending on policy initiatives, they may also continue to replace motorcycles, and may lead to wider electrification of China's transport sector.

Motivation

This study attempts to understand the future role of E2Ws in China. This includes both their role as a means of transportation, and also the spillover effects they may have in the automotive sector by facilitating the future electrification of vehicles.

It is a study of the key factors driving and resisting a widespread shift to battery electric two-wheelers. The adoption of E2Ws has important implications for air quality, greenhouse gas emissions, energy use, and oil dependence.

Methodology

In this study we use Force-field analysis (FFA) to understand the complex set of forces influencing future E2W growth in China and the relationships between these forces. FFA is useful tool for creating a descriptive model of a complex system that intersects many disciplines (technical, social, political, etc.).

Force-field Analysis Introduction

Force Field Analysis (FFA) is a tool for analyzing the forces pushing a system toward change and the forces resisting it. FFA, created by Kurt Lewin [87], was originally used to study organizational behavior and group dynamics. Since then, it has been used to analyze the factors affecting complex systems, the interactions between these factors, and understanding how the system might respond. The philosophy behind this approach is that "a wider and wider realm of determinants must be treated as part of a single interdependent field and that phenomena traditionally parceled out to separate "disciplines" must be treated in a single coherent system of constructs" [87]. FFA has been used in a wide variety of disciplines from studying the technological innovation process within organizations [88], to analyzing conservation efforts to improve biodiversity [89]. It is also useful for corporations who are considering strategic or technological changes (Alexander 1988, from [88, 90], implementing cost reduction strategies [91], and as a decision management tool [91, 92].

Force-Field Analysis Steps

This analysis has five steps:

1. Identify the system of focus and boundaries (Section 2);
2. Generate list of driving and restraining factors (Section 3 and 4);
3. Determine the inter-relatedness of these factors (Section 5);
4. Quantify the forces (Section 6); and
5. Chart the force field diagram (Section 6).

The data used for this analysis draw upon previous work by Weinert [10, 40, 93], which includes interviews with E2W manufacturers and users of electric two-wheelers and bicycles, on-road observations of E2W traffic, visits to dealerships in ten cities throughout China, and site visits to both battery and E2W factories. The remaining data have been gathered through the available literature, including company websites.

5.2 Background

The system of analysis for this FFA is the future E2W market. This includes current users of bicycles, motorcycles, E2Ws, and public transit. Strong economic development in China over the past 20 years has brought about rapid growth in motorized vehicle sales, which began to take off in the early 1990s. Growth in motorized two-wheelers (M2W) vehicle use is projected to continue over the next 20 years [94]. E2Ws emerged from virtual non-existence in the 90's to achieve annual domestic sales of 13.1 million and sales revenue (includes exports) of $4.6 billion in 2006 [9]. E2W ownership is estimated between 33-45 million [24].[12] In comparison, the domestic motorcycle market reached annual sales of 14.6 million units and is sales revenues (includes exports) are estimated at $19.2 billion [8]. According to official statistics, motorcycle ownership in China reached ~80 million by 2005 [7].[13] For comparison, there are ~460 million bicycles and 13 million cars.

Total M2W ownership is projected to grow until 2025, at which point private cars ownership begins to overtake them [94]. Growth forecasts for the E2W industry are optimistic, with projected sales of 18.1, 22.7, and 30.1 million units in 2007, 2008, and 2010, respectively [95].

5.3 Driving Forces: Shift To Electric Two-Wheelers

The key forces supporting the growth of the E2W market are:

- Cost and performance improvements
- Motorcycle bans
- Local policy support for E2Ws

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[12] 33 million is based on the author's calculation of population from annual domestic sales data and an average vehicle lifetime of five years.
[13] The Asia Development Bank estimates the population in 2005 lower at 55 million (ABD 2006).

- Poor bus public transit service

Force 1: Technology Improvements

Improvements in E2W and battery technology are driving E2W market growth. This section provides evidence of past improvements in these technologies, examines their causes, and discusses why they are likely to continue. This force has three components: the development of technology, the structure of the industry, and structure of the product. Innovations in both product and process have led to these improvements.

Technology Development

Cost reduction and performance improvement of E2W and battery technology has been occurring at a steady rate since E2Ws were first commercialized in the mid 90s. Since the late 90s, there have been improvements in battery lifetime (160%), energy density (30%), and motor efficiency (60%) [10]. By 2006, VRLA battery technology from three top E2W suppliers had reached cost and performance levels achieved by a leading Japanese supplier [93]. Meanwhile, the price of E2Ws has steadily decreased due to a combination of both falling costs and shrinking profit margins. Between 1999 and 2005, average E2W price dropped nearly 30% from $380 to $240 (after adjusting for inflation) [96].[14]

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[14] In a personal communication, one Taiwanese motorcycle manufacturer conceded that E2Ws are beating motorcycles in some markets on the basis of cost.

A indicator of E2W technology improvement is their increasing size, power and speed. At the Zhejiang E2W Exhibition in October 2007, seven manufacturers displayed E2Ws with 500W, 60V battery systems and regenerative braking. Two companies displayed products with power as high as 1 and 1.5 kW, attaining speeds of 60-80 km/hr. Manufacturers indicated these products were for the domestic market and were being sold mostly in suburban areas where commute distances are longer.

The emergence of large scooter-style E2W in suburbs and rural areas where incomes are low, travel distances far, and most importantly, motorcycles are not banned is significant. It could be an indicator that they are becoming competitive with motorcycles, if not on a performance basis yet, at least on a cost-basis. E2Ws are even found in mountainous areas where topography demands higher power.[15] The spread of E2Ws to areas where where the "policy playing-field" is level with motorcycles may be a sign that their value to consumers is approaching that of motorcycles.

Another sign of innovation is the growing proportion of advanced batteries used in E2Ws. The majority of the E2Ws in China use valve-regulated lead acid (VRLA) batteries, though other more advanced batteries are starting to be used, including lithium-ion (Li-ion) and nickel-metal hydride (Ni-MH). Between 2005 and 2006, the share of E2Ws using Li-ion increased from 7% to 10% (0.8 million to 1.6 million) while the share of nickel-based battery types remained constant at 3% [96]. Although the majority of advanced battery E2Ws are destined for export markets (based on observations of E2Ws and dealerships around China), Li-ion battery manufacturers and the E2W

[15] Based on visits to several homes in the countryside, where it was observed that many families own both motorcycles and E2Ws, and roadside observations.

companies they supply are reporting increasing domestic sales.[16] There are at least four battery manufacturers in China producing Li-ion batteries for E2Ws and EVs.[17]

Industry Structure

Technology improvements of Force 1 described above can be partly attributed to the highly decentralized, "open-modular" E2W industry structure. This type of industry structure, coined by (Ge and Fujimoto 2004) [97], is also found in the modern computer industry and several other Chinese manufacturing industries [98]. It is worth examining because it has been shown to drive rapid product innovation and cost reduction via fierce price competition. It contrasts with the more traditional closed-integral structure characteristic of more mature manufacturing industries.

In an open-modular (O-M) industry, manufacturers act primarily as assemblers and source components ("*modules*") produced by a large decentralized network of suppliers. This type of structure is typically found when a product exhibits high modularity, meaning it can be divided into several modules that are copied, mass-produced, standardized, and easily bought on the market. "*Open*" refers to the nature of the relationship between assemblers and suppliers, who are free to design and develop parts independently and thus able to work with multiple firms due to the high degree of product modularity [99]. The O-M structure typically results in increased competition and lower costs.

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[16] Includes Zhejiang's LBH and Tianjin's Lantian
[17] Includes Phylion (Suzhou), Wanxiang EV Company (Hangzhou), Lantian (Tianjin) and Qingyuan EV Company (Tianjin),

In a closed-integral (C-I) architecture, assemblers work together closely with a few key suppliers to develop a product in a top-down approach. The assemblers develop high technical capability and in turn nurture this capability in their few trusted suppliers. This industry structure was adopted by the Japanese motorcycle industry in the 60s, and is characteristic of the automotive industry in general [6]. Figure 5-1 adapted from (Ge and Fujimoto 2004) contrasts the two structures.

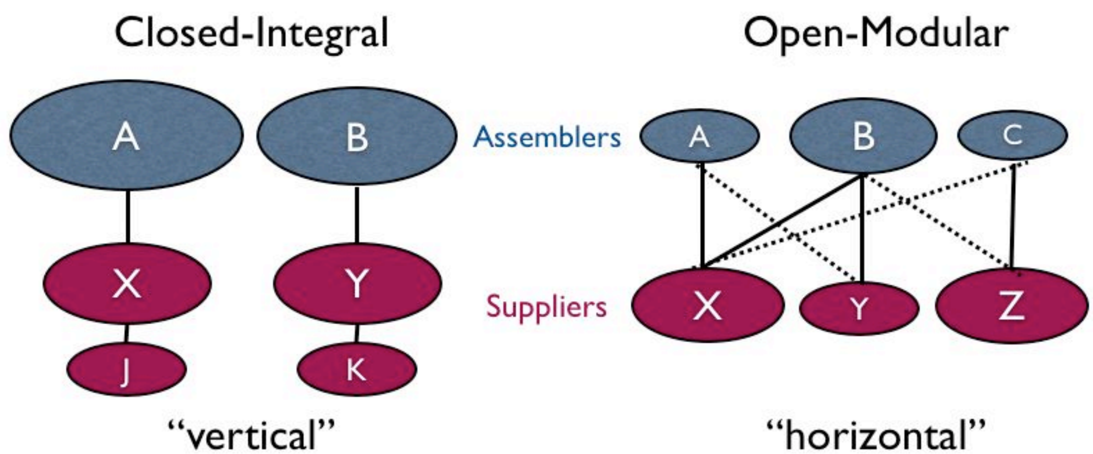

Figure 5-1: Industry Structure Comparison, Closed-Integral vs. Open-Modular

The emergence of open-modular industries is a relatively recent phenomenon, and its effect on innovation has been the subject of much analysis [98, 100-102]. They conclude that this structure (along with other factors) leads to lower production costs compared to a closed-industry structure due to enhanced competition and cross-pollination of ideas. Evidence of this exists in the Chinese motorcycle industry and its ability to capture the lead market share position from the incumbent Japanese motorcycles industry [6, 97, 103]. The key drawback of this structure however, is that assembler firms don't develop as much technological capability and thus risk the threat of “technology lock-in”. Table

5-1 compares the key differences of these two structures, summarizing the work of the researchers listed above.

Table 5-1: Comparison of Open-Modular vs. Closed-Integral Industry Structure

Industrial architecture	**Open-Modular (networked production)**	**Closed-Integral**
Driver of innovation	"Creative destruction", simultaneous competition and cross-pollination [98, 104]	Steady accumulation of tacit knowledge within long-lived corporation
Source of competitive advantage	Cost-cutting	Large R&D budget
Product development	Bottom-up (supplier-driven)	Top-down (assembler-driven)
Process development	Mastering open, codified processes	Developing proprietary processed
Firm size	Small - mid-size	Large
Supplier network	Large, isolated, open, horizontal	Small, integrated, closed, vertical
Firm relationship with suppliers	Arms-length	Close
Component interface between different brands and models	Standardized	Limited to within company
R&D capability	Low	High
Higher Profit margins	Supplier	Assembler
Unit of importance	Environment/Clusters	Firms

Typically, industries are highly decentralized until a dominant design is settled on and considerable shake-out and industry rationalization occur [105]. Despite the emergence of a dominant E2W design, the E2W industry has thus far shown little evidence of concentration. Sales data from the top five manufacturers made up only 15.2% of national E2W sales in 2006; the top ten manufacturers made up 27.2% [96]. Industry average production volume in 2005 was 8,000 units/company compared to 2,400 in 2000 [79]. Some manufacturers believe there are as many as 1,000 more “unofficial” assemblers illegally producing E2Ws [106]. The following diagram shows the large number of assemblers and key component suppliers that make up the E2W industry.

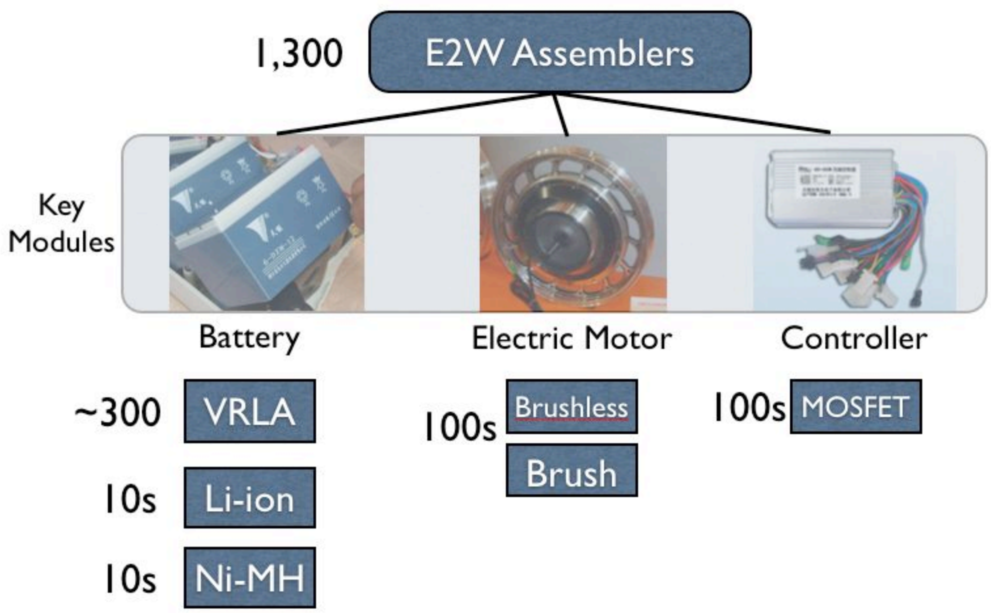

Figure 5-2: E2W Industry Structure

Product Structure

The open-modular structure of the E2W industry and its rapid pace of innovation is due in part to the highly modular product architecture of E2Ws.[18][107] Product modularity

[18] Product architecture refers to the “arrangement of functional elements of a system “and “the specification of the interfaces between interacting components” (Ulrich 1995).

reduces the cost of manufacturing through mass production of standardized components, allows for greater flexibility in design and manufacturing, and lowers barriers to entry for firms.

A product is considered *modular* if it can be segmented into parts that are functionally and structurally independent, do not require much information exchange, and whose interfaces are relatively simple. A computer is an often-cited example of a highly modular product. Modularity in manufacturing is not a new concept, but has gained more attention since the late 1990s due to globalization and increasing recognition of its importance for businesses managing global supply chains [97, 105, 107, 108].

E2Ws meet the first criteria of modularity because most key functions of the vehicle are assigned to just one component (e.g. battery stores energy, motor delivers power). E2Ws also meet the second and third criteria of modularity: simple interfaces with minimal information exchange. For instance, the core modules of the drivetrain are connected through electrical wire interfaces. This both increases design flexibility and reduces assembly cost. Vehicle assembly in most plants is accomplished by unskilled manual labor using pneumatic tools.[19] Machining is not required at the assembly plant because components are pre-fabricated, and interfaces exhibit greater tolerance to error. Designers also have more flexibility in positioning modules to enhance comfort, convenience, and styling, as seen in the various models shown in Figure 5-3 (folding E2W, standard E2W, e-scooter).

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[19] Based on site visits by the author to six E2W plants.

Figure 5-3: E2W Design Flexibility

Interface flexibility and simple information exchange between the interfaces of E2W are one of reason for the wide variance in body style (e.g. E2W vs. e-scooter), module positioning, and module technology substitution (e.g. VRLA vs. Li-ion). In contrast, motorcycle design has inherent limitations in module positioning and fuel flexibility.[20]

The highly modular nature of E2Ws has led to standardized sizes, performance levels, and interfaces. Once standardized, components become easily interchangeable between models and manufacturers, giving assemblers and suppliers more freedom in their choices for partners and facilitating a more open industry structure. Because a supplier's product can potentially be sold to many different assemblers, it leads to increased production volume and lower cost.

Standardization also facilitates substitution of competing battery or motor technologies with little or no redesign required of the other modules. This allows for faster design changes and technology upgrading. It is driving innovation in the VRLA, Li-ion, and Ni-

[20] Shanghai is the only successful market in China of alternative fuel motorcycle use, where they use liquefied petroleum gas.

MH battery industries as each competes for a larger stake in the expanding E2W market, both domestically and internationally. Table 5-2 shows the standardized specifications of the key modules within an E2W.

Table 5-2: E2W Modules and Standardized Options

Component	Standardized Features	Options
Battery	Type	VRLA, Li-ion, Ni-MH
	Voltage	36, 48,60V
Motor	Power	240, 350, 500W
	Configuration	In hub (with or without rim), external to hub
	Type	Brush, brushless.
Controller	Control mode	Brush-type, brushless type
Charger	Input/Output voltage	One size fits all

Standardized technology with simple interfaces has lowered the barriers to entry into this industry, another reason for the large number of firms in the industry. Manufacturers of bicycles, appliances, toys, and motorcycle have all been successful entering the E2W business.[21]

[21] During surveys of E2W manufacturers, one OEM who used to make only motorcycles started producing E2Ws when the market took off stating, "it was easy for us to make the shift to producing E2Ws because the technology is much simpler."

Force 2: Local motorcycle bans

The power of policy in China has given E2Ws a strong advantage via the banning of gasoline-powered motorcycles in many large and medium-sized cities throughout China. This policy, driven by air quality concerns, has spread from 30 cities in 1998 to 148 by 2006 and effectively diminished motorcycle demand [103, 109]. Figure 1-1 in Chapter 1 shows the large difference in the share of motorcycles between cities that allows motorcycles (Shanghai, 32%, only LPG type), and cities where they are strictly banned (Chengdu, 0%).

Force 3: Local policy support for E2Ws

Besides banning motorcycles, cities have adopted other approaches to encouraging the use of E2Ws and the growth of the E2W industry. These local regulatory approaches, including policies aimed at traffic congestion relief, loose enforcement of national E2W and battery standards, and loose enforcement of intellectual property rights, are also driving a shift to E2Ws.

Traffic congestion in urban areas drives regulatory support of E2Ws. While E2Ws are less efficient users of road space than buses (per passenger), they are more efficient than automobiles [11]. In 2006, Beijing reversed their intended ban against E2Ws, in part due to the worsening traffic congestion in the city. A testimony from one E2W user in Beijing illustrates the advantage of E2Ws in congested traffic: "I want to buy an electric bicycle to deliver and pick up my son from school. It's less of a headache and quicker," says the 34-year-old mother. "It takes only 10 minutes by electric bicycle, but a half-hour drive in the Beijing traffic." [110]

National E2W standards are seldom enforced at a local level, allowing manufacturers to produce and consumers to buy larger E2Ws with higher speed and power. These standards set strict limits to performance criteria and require a minimum level of quality, though few manufacturers adhere to them. The strong market demand for faster, higher power models creates an incentive to produce models that violate the standard. This problem is not unique to the E2W industry, and is thought to be due to the way power at a state level is distributed amongst local governments. Though supporting evidence on why this occurs is insufficient, some speculate it is because local governments who control quality inspections like to support local manufacturers to boost tax revenue [111]. This support sometimes comes in the form of exemptions or minor fines for violating the standard [10].

Loose IP protection in the E2W industry has lowered barriers to entry for E2W and battery firms, resulting in a more open-modular industry and lower costs. Several of the managers surveyed by the author from large E2W companies complain that IPR is not well protected in the industry [106]. The thousands of models of E2Ws show very little variation in performance and only moderate variation in design. Many manufacturers model their E2W designs and even their logo to an almost perfect duplication of a more famous company.

Force 4: Deteriorating Bus Public Transit Service

The quality and service level of bus public transit is worsening in cities, causing greater demand for cheap motorized private transportation. For most low and middle-income users, bus public transit's largest user base, E2Ws are their next best alternative. A survey in Shijiazhuang found the majority of E2W users shifted from bus public transit because it was too slow and over-crowded [40]. Another study comparing bus and E2W speeds in Kunming and Shanghai traffic reveals that for travel distances under 18 km, it is faster to take an E2W than bus due to the slow travel speeds of buses on congested corridors [11].

There are several reasons why urban bus transit is losing its competitiveness; the root causes can be traced to urbanization and rising income. Transit systems have difficulty adding capacity fast enough to serve its rapidly growing low-income user base, mainly people from rural areas. Rising income is driving motorization in cities [112], resulting in more private vehicles (two-wheelers and automobiles) on the road, increasing traffic congestion, and making buses slower.[22] As buses become slower, it has the cyclic effect of shifting even more people to private transport. Thirdly, cities expand and decentralize due to the increase in urban population and growing use of private vehicles (both motorized two-wheelers and automobiles) [17]. Decentralization increases the set of trip origins and destinations, an inherent challenge for public transit systems that are most profitable when serving high-corridor routes.

These trends are expected to continue. Between 2006 and 2030, it is expected that 40 million more people will move from the countryside to the city, equivalent to roughly two more Shanghais [16].[23]

[22] Motorization increases with rising income, a pattern followed by every developed country, due to demand for greater accessibility, and safe comfortable travel.
[23] Based on urban population of 560 million in 2006 and a projected population of 600 million by 2030 (Schipper 2007)

Other Forces:

E2Ws have been encouraged by the Development Research Center of the National Development and Reform Commission to support national energy efficiency goals stated in the 11th 5-yr plan. While road based passenger transportation makes up 70 million tons of oil equivalent (mtoe) in China in 2006, it is expected to increase to 165 mtoe by 2020 [113]. E2Ws energy use per km is ~15-20% that of motorcycles on a well-to-wheels basis. They have been recommended by the state as a means of saving energy and improving the environment [61].

The existing legacy of bicycle infrastructure pervasive throughout China's cities is another factor driving E2Ws growth. Users rely on the non-motorized vehicle lane and parking infrastructure to improve travel speed, safety, and convenience. This extensive infrastructure is partially responsible for the current success of E2Ws. Shanghai is restructuring its middle-ring road to create a dedicated lane for bicycle and E2W traffic. It marks the cities first extensive restructuring for cyclists since they first banned cycling in certain parts of downtown during the past decade [114].[24]

5.4 Resisting Forces: Shift To E2ws

The forces resisting a shift towards E2Ws include:

- Strong demand for motorcycles
- E2W bans

[24] In Shanghai, LPG scooters are allowed so this policy will also likely benefit them as well.

- Increasing support for public transit

Strong Demand for Motorcycles

In most of Asia, motorcycles using the internal combustion engine and gasoline (and sometimes LPG) have become the dominant choice for personal mobility because of their high power and speed, low cost, ease of refueling, reliability, and long life. In response to air quality concerns and rising fuel price, motorcycle fuel economy and emissions control technology continues to improve through innovation on engine design and emission control technology [22].

For the higher-income market segment, E2Ws using VRLA battery technology have difficulty competing with motorcycles due to inherent limitations in terms of power, speed, refueling, and lifetime [93]. In addition, their performance (range and lifetime) degrades quickly in areas where temperatures are very high throughout the year, or very low [35]. This partially explains why they have failed to catch on in SE Asia and India where bicycles and motorcycles dominate the roads [5]. For the domestic Chinese E2W market, the benefit to cost ratio of Li-ion batteries isn't yet compelling enough to create a noticeable shift away from Pb-acid batteries, as indicated by the state of the domestic E2W market.

E2W Bans

Seven cities throughout China have banned or restricted E2Ws in recent years, in addition to banning motorcycles. Some officially cited reasons for the bans include improving traffic flow, increasing road accidents, and reducing environmental pollution from worn-out batteries [115]. As automobile ownership grows, it is reasonable to assume pressure to improve traffic flow and allow automobiles to move at a faster speed by removing two-wheelers from roads, will also grow. Two-wheelers (electric or gasoline powered) create several disadvantages to automobiles because of their slower speeds and erratic driving behavior, which disrupt traffic flow and pose safety risks. They also "occupy more road space (compared to buses), and dilute the market for public transport" [17].

Pressure for E2W bans may also increase due to the abundance of low-quality and unsafe products on the market, which can be traced back to loose enforcement of E2W standards. Many users complain that E2W brakes are insufficient for the weight and speed of the vehicle. Low-quality VRLA batteries have poor lifetime and thus lead to greater lead waste. A sample of E2W products from 40 manufacturers in 2006 revealed only 74% of them passed the quality standards [79]. A sample of E2W VRLA batteries from 35 manufacturers revealed only 77% of the batteries passed the quality standards [116]. Thus loose enforcement of standards is a double-edged sword for E2Ws (see Driving Force 3). It allows manufacturers to sell products that violate the standard though are highly desirable by customers, however it also leads to more low-quality products on the market.

Lead pollution from VRLA battery production and recycling use could lead to greater environmental backlash against their use. The lead mining, smelting, and recycling industries in China are highly dispersed and many are small-scale, resulting in high loss rates due to poor management, weak regulation, and the use of out-dated inefficient technologies [11, 26]. It is estimated that 44-70% of the lead from lead-acid batteries in China is released into the environment as waste [11]. Ground water and crop contamination from hazardous chemical and metals has already caused some local health problems throughout the country [117].

Cities banning E2Ws as of 2007 include Guangzhou, Dongguan, Haikou, and Changzhou (no longer licensing E2Ws, preparing to issue a ban). E2Ws are partially banned in Zhuhai, Shenzhen, and Xiamen.

Support for Public Transit

Increasing financial and political support for public transit could prevent the ongoing shift from bus to E2W. Guangzhou and Shanghai have announced in their five-year plans their intention to strongly enhance public transit service, both rail and bus transit.

5.5 Inter-Relatedness Of Forces

The forces and their root causes listed in the previous section are inter-related in complex ways. To add clarity to the complexity of these relationships, they are mapped into visual diagrams (Figure 5-4 and Figure 5-5). Direct relationships (*increasing X increases Y*) are joined with black lines; inverse relationships (*increasing X decreases Y*) are joined with red lines. Thick arrows indicate major force while thin arrows indicate minor, though these rankings are to some degree subjective. The diagrams for driving forces and resisting forces inter-relatedness are separated for clarity, though there are some inter-relationships between the two. While we have attempted to include the most important root causes for these forces, this diagram is necessarily incomplete due to the limited scope of the paper.

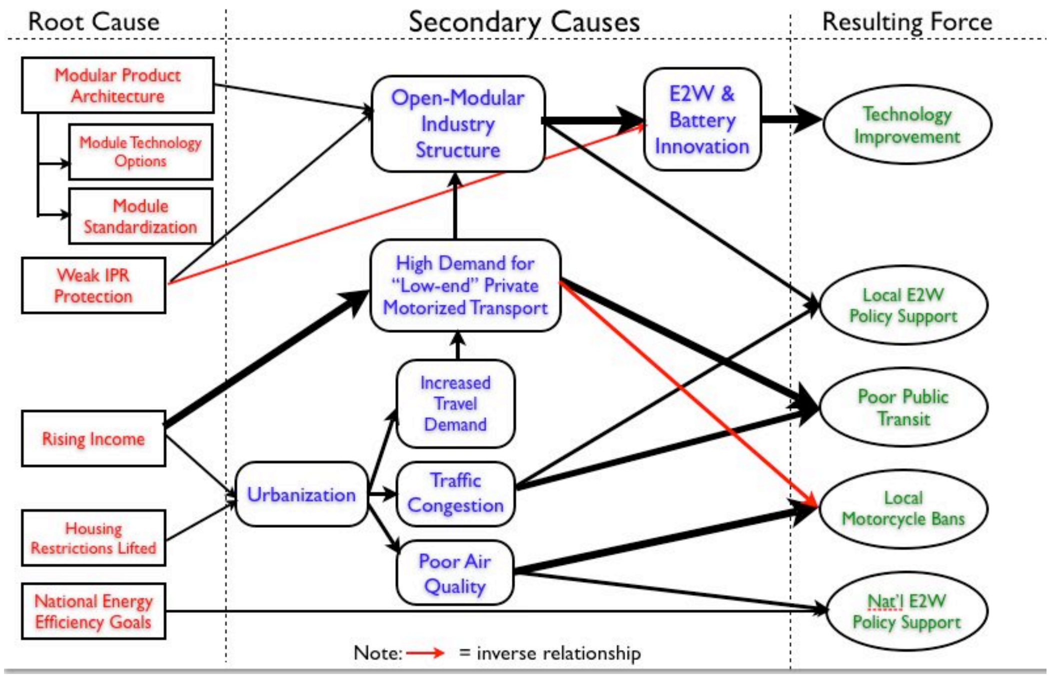

Figure 5-4: Forces Driving E2W Market Growth

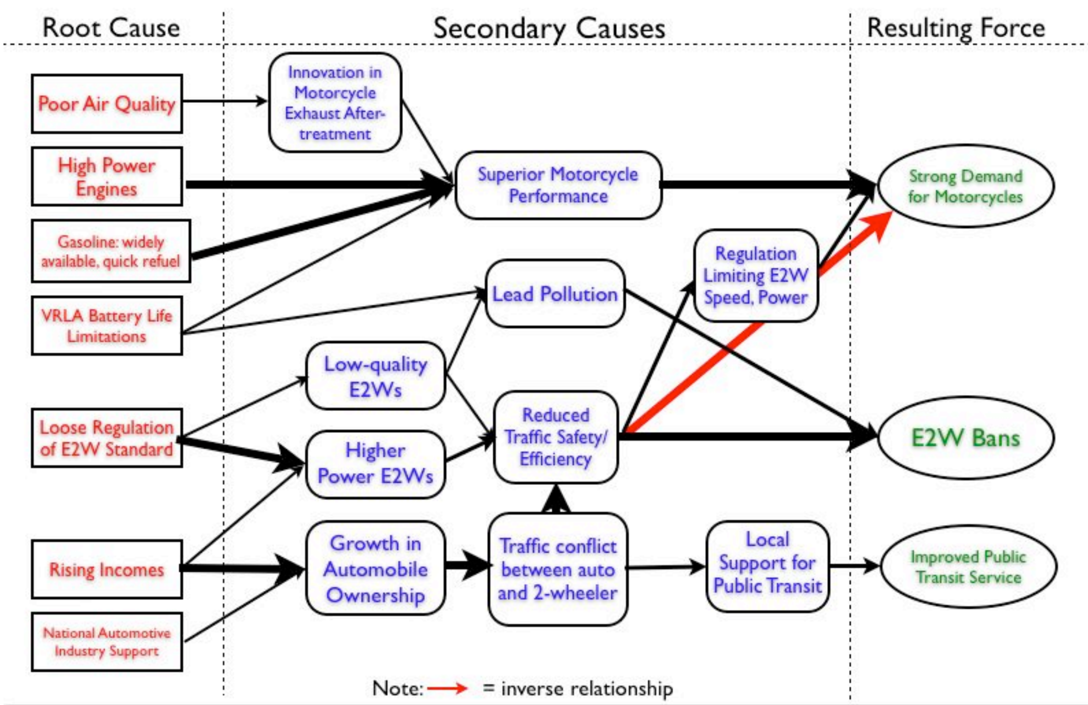

Figure 5-5: Forces Resisting E2W Market Growth

5.6 Quantifying The Forces

The driving and resisting forces described in the above sections are "quantified" by relative ranking. It is challenging and perhaps impossible to assign a measurable quantity to forces involving a market of hundreds of millions of people, several large industrial sectors, and complex regulatory dynamics. Quantification is thus simplified by ranking the effects of each force in terms of magnitude of impact and probability of occurring using a rating of low (L), medium (M), and high (H) (Table 5-3). The ratings are based on an understanding of the root causes for each force described in sections 5-4 & 5-5 though they are of course largely subjective. An improvement to this method would be to ask people within the E2W industry or government officials to rank each factor and compile the results.

Table 5-3: Rankings of Driving and Resisting Forces

Force	Magnitude of Impact	Likelihood	Ranking (L=1, M=2, H=3)
DRIVING			
Technology improvement	M	M	4
Motorcycle bans	H	H	6
Local E2W policy support	H	M	5
Strained public transit	M	M	4
RESISTING			
Strong motorcycle demand	H	M	5
Spread of E2W bans to more cities	H	L	4
Enhanced support for public transit	M	L	3

The rankings above indicate driving forces (via their key effects) outweigh the resisting forces pushing a shift to E2W are charted in Figure 5-6 below.

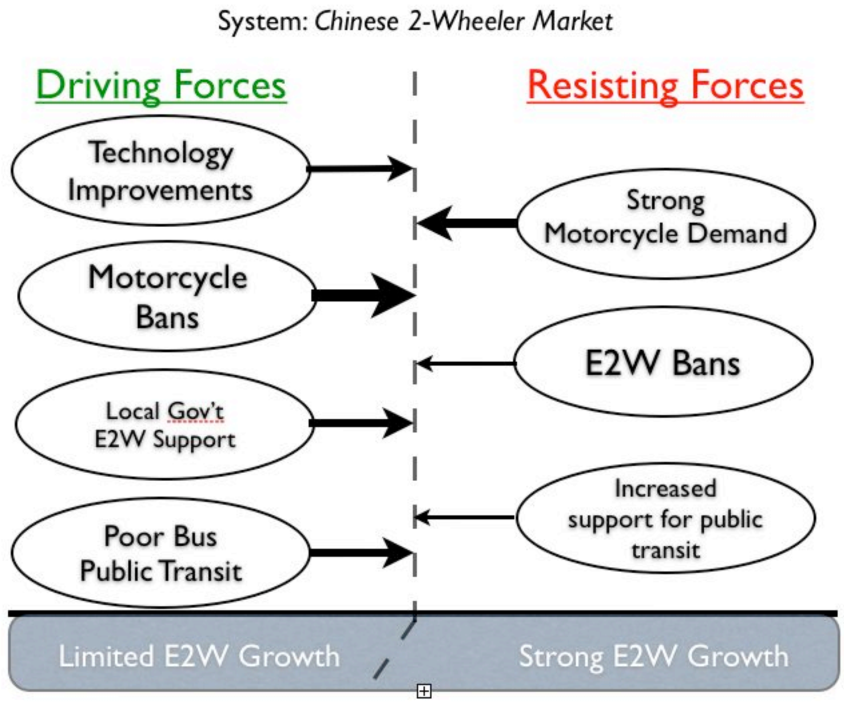

Figure 5-6: Force Field Analysis of Driving and Resisting Forces to E2W Growth

Through this qualitative and semi-quantitative analysis of the key factors driving and resisting growth of the E2W market, driving forces appear to outweigh resisting forces 19 to 12.

5.7 Implications On Vehicle Electrification

The previous sections show that future E2W market growth is likely to continue. This section examines the impact this growth may have on adoption of electric vehicles (sub-compact and 3-wheel type). Using a simplified force-field analysis, we examine the driving and resisting forces to this adoption and their causes.

Driving Forces

Battery Improvements

Based on the pace of innovation in E2W and batteries over the past decade and its root causes (see Figure 5-4), improvements are expected to continue. In 2007, several new products aimed at increasing VRLA battery lifetime and E2Ws with Li-ion batteries were displayed at the 2007 Shanghai Bicycle and E2W Exhibition, and several of the larger manufacturers sell E2Ws with regenerative braking systems.

Innovation in Li-ion battery technology for EVs is dependent on a shift from VRLA to Li-ion in the E2W market. Currently, the domestic market for Li-ion battery EVs is small due to high cost (see Table 1-1), though the market is growing. The rapid rise in lead price since late 2006 may further hasten the shift to advanced batteries for E2Ws in the domestic Chinese market.[25] *[118]* VRLA battery price (75% lead by weight) has increased by 50% since that time.

Because of similarities between E2W and EV batteries, experience gained in R&D, manufacturing, and operation in the E2W battery market will transfer to EVs. At least three Li-ion battery companies are making batteries for E2Ws with the strategy to build

[25] The price spike has reportedly been caused by both the rapid rise in demand in China, combined with a supply constraint due to a mine problem in Australia are the main reasons for this price increase (Walls 2007).

up production volumes with the E2W market and eventually shift to producing batteries for EVs.[26]

Expansion into new product lines

E2W and battery manufacturers are already expanding into producing higher-margin product lines due to the competitive nature of an open-modular industry structure. Companies typically expand into higher-margin product lines to escape fierce cost competition in the existing low-margin product line. Historical evidence of this trend exists in the E2W evolution from bicycle-style to scooter-style to motorcycle-style, and in other open-modular industries in China [111]. According to one E2W manufacturer, profit margin for luxury E2Ws is 8% vs. 5% for standard bicycle style E2Ws [106].

Producing automobiles clearly requires much greater technological capability and resources than producing two-wheelers, depending on the size and type of vehicle. However, the challenges are not insurmountable, as proven by at least one motorcycle manufacturer. Chongqing Lifan, one of China's largest motorcycle manufacturers, has successfully begun producing and selling automobiles in 2007 after three years of preparing its technological capability and receiving authorization from central government [119]. Four of the top ten E2W firms have crossed the chasm from two to four wheels by selling electric three and four-wheel fully-enclosed electric vehicles, each using the same VRLA battery technology from E2Ws (sample models shown in Figure 5-7). Their specifications are listed in Table 5-4.

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[26] Personal communication with one Li-ion battery manufacturer, April 2007

Yadea Incalcu Shiwei

Figure 5-7: Electric Vehicles Offered by E2W Firms [27]

Company	**Yadea 3-wheel EV**	**Incalcu EV**	**Shiwei EV**
Cost ($USD)	$2,600-7,900	$2,600-5,300	$3,800
Range (km)		80-120	100-150
Speed (km/hr)	45±10%	45	45-60
Power (kW)		3	3
Dimensions (l,w,h) (m)	2.9 x 1.3 x 1.7	3.1x1.6x1.5	
Weight	400	650	750
Battery	VRLA	VRLA, 48V, 9 kWh	VRLA, 48V (120Ah,12V modules)

Table 5-4: Specifications of Electric Vehicle Made by E2W Makers

[27] From manufacturer websites: http://www.yadea.com.cn/tezhong.htm, http://www.incalcu-ev.com/product/view.asp?id=1533 , http://www.shiweichina.com/product_info.asp?id=7579

Resisting Forces to Vehicle Electrification

Future vehicle electrification is impeded by high battery cost, lack of recharging infrastructure, and inherent technical challenges of large battery systems. The current high cost of batteries relative to transmission/engine drivelines is the major barrier to EV commercialization. Table 5-5 shows the large cost difference between E2W and EV battery system. Future battery cost is difficult to predict and is a function of cumulative production volume, design, material composition, and raw material price. Material substitution in Li-ion batteries could make a large impact since 75% of the total battery cost is due to materials [74].

Table 5-5: Cost comparison of Battery Systems for E2W and EVs[28]

	E2W Battery System		EV Battery System		Gasoline Engine (20 kW)
	VRLA	Li-ion	VRLA	Li-ion	
Cost ($)	100	420	800	4850	1,000
Mass (kg)	20	8	270	90	60
Lifetime (yrs)	3	9	2	6	12
Volume (L)	10	5	110	60	6
Max continuous power (kW)	2.4	3.8	27	44	20

Assumptions	VRLA	Li-ion	Gasoline Engine
Specific energy (kWh/kg)	0.035	0.11	n/a

[28] The EV in this table is based of the REVA two-door Classe model. Gasoline engine characteristics for a similar sized car (20kW) are provided for comparative purposes.

Energy density (kWh/L)	0.086	0.17	n/a
Max continuous specific power (kW/kg)	0.1	0.5	0.33 [120]
Power density (kW/L)	0.67 [1]	0.74 [1]	3.5 [120]
Cost ($/kWh)	130	500	50 ($/kW)
Cycle Life	300	800	n/a
Battery Energy Required:	E2W=0.84kWh, EV=9.6kWh		
1. Based on specific power and densities of 2.8 and 2.1 kg/L for VRLA and Li-ion batteries, respectively.			

The lack of recharging infrastructure is another obstacle. High-voltage recharging stations would be required for EVs, unlike E2Ws whose batteries are removable and can be charged from the ubiquitous 120V AC outlet. To recharge an EV requires the user to have daily access to a high voltage charging station. In a country where the urban majority live in multi-level residences, it is extremely challenging to provide universal access to recharging facilities.

Managing battery safety and lifetime is one of the key differences between E2W and EV battery systems. Due to the large number of cells in an EV battery pack, it requires careful heat management, cell state-of charge monitoring, and current leakage detection to ensure safe charging/discharging and minimum cell variability in order to maximize battery life.[29][84] This is especially true for Li-ion battery systems, whose safety risks

[29] When connecting several cell modules in series, any variance in cell voltage between modules causes accelerated aging because the "weakest" module of the pack ages most rapidly (Rossinot et. Al 2003).

include battery overheating, combustion, and explosive disassembly. These risks increase with the amount of energy contained within the battery pack.[30]

5.8 Conclusions

This analysis examines the key forces driving and resisting strong market growth of E2W, what is causing these forces, and how these forces are inter-related using FFA methodology. Through this analysis, we conclude that improvement in E2Ws and battery technology is a driving force and can be partially attributed to the open-modular industry structure of suppliers and assemblers. This type of structure was made possible by the highly modular product architecture of E2Ws, which resulted in product standardization and enhanced competition amongst battery technologies. Growing air quality and traffic problems in cities in part due to rapid urbanization has led to strong political support for E2Ws at the local level in the form of motorcycle bans, and loose enforcement of E2W standards. There are softer signs of national support for this mode in part due to national energy efficiency goals. Public transit systems in cities have become strained from the effects of urbanization and motorization, which has stimulated greater demand for “low-end” private transport.

There are also formidable forces resisting E2W market growth. The superior performance of motorcycles is a powerful limiting factor, especially in areas where motorcycles are not banned and incomes are high. Bans on E2Ws could also limit their growth if it continues to spread to more cities. Two factors influencing this spread are

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[30] The high voltage of EVs (300V vs. 36-48V for E2Ws) creates another safety concern during vehicle repair or emergency response.

automobile use and loose enforcement of E2W standards that allow low-quality E2Ws to be sold. Some large cities around China are also trying to promote public transit in order to reduce automobile congestion. Added investment in transit infrastructure may improve the level of service to make it more competitive with E2Ws and other forms of private transit.

Based on results of the FFA, we conclude that driving forces appear to outweigh the resisting forces for E2Ws. This may lead to accelerated adoption of electric vehicles. Growth is dependent on continued improvement in battery cost and performance and the development of larger E2Ws vehicles. Two trends in the E2W industry may facilitate this development, namely its open-modular industry structure and modular product design with simple interfaces to take advantage of component standardization.

However, there are some major obstacles facing EVs that will not be easy to overcome in China. The largest is the issue of recharging infrastructure, which will need to be built since EV batteries are not portable like E2W batteries. Even with advancements in Li-ion specific energy, battery packs will be too heavy to remove from the vehicle to a charging station in or near the residence of the EV owner. Cell variability, safety issues related to high-voltage and unstable battery chemistry in Li-ion are other obstacles.

6 CLOSING THOUGHTS

This dissertation examines why the E2W market grew so rapidly in China, what factors are driving and resisting its future growth, and how future growth may impact the adoption of electric vehicles. Because these three questions intersect many domains, such as technology, economics, industrial organization, consumer behavior (the market), and public policy, a multi-disciplinary approach has been used throughout this work to explore these questions.

The findings of this dissertation indicate that E2W growth will likely continue in the near future as incomes continue to rise, technology improves, and more Chinese move from countryside to city. E2W technology improvement will carry over to EV technology and reduce some but not all the barriers to EV market growth.

6.1 Areas of Future Analysis:

This research is merely a first step at understanding the future significance of E2Ws and their direction of development. There are still many interesting unanswered questions about this vehicle technology application that the author leaves for others, such as:

- Why have E2W thus far only been successful in China? Can E2W success be replicated in other parts of the world? What are the driving and resisting forces to their growth in India, where many predict the market is ready to explode? How important is China's legacy of being the "Bicycle Kingdom" and it's vast network of bike lanes in E2W success in China vs. other countries?

- E2W bans in China: why have some cities chosen to ban rather than manage them? Is there any link between E2W bans and automobile ownership?

- How is the Lithium-ion battery industry in China developing? How will the replacement of Pb-acid batteries in E2Ws by Li-ion batteries progress over time? What new technologies may make this shift happen faster? Will the share of Ni-MH batteries used in E2Ws grow?

- Will the open-modular E2W industry consolidate and eventually develop into the traditional closed integral structure? Do the similarities of the Chinese E2W and motorcycle industry structure teach anything about the future direction of development in China's nascent auto industry?

- How should E2W standards develop over time? Is it better to allow E2Ws to approach the performance level of gasoline powered motorcycles and risk increased safety problems, or is it better to keep their speed and weight low and risk limiting market growth?

- How is the E2W market developing in China's rural areas where there are no bans on motorcycles? Is the E2W becoming truly competitive with gasoline-powered motorcycles in regions where the policy playing field is level?

6.2 Recommendations

For all E2Ws' advantages of cost, convenience, pollution reduction, and energy efficiency, they also have two important negative externalities: traffic safety and pollution from the lead-acid batteries. Rather than banning E2Ws altogether, as a few cities have done already, local governments might consider managing them better. The following recommendations are proposed to reduce the negative externalities of E2Ws:

Better traffic management

Better traffic management would reduce the erratic, lawless driving behavior, improve traffic flow, and increase safety for bicyclists and E2W users. While easier said than done in a country with an urban population of 600 million, better traffic management may be achieved by Imposing enforceable penalties on E2W users who violate traffic laws. It may also be necessary to increase the presence of traffic security guards and police at high-traffic intersections.

Better traffic management may also be accomplished through stricter licensing requirements. Better licensing of E2Ws might allow for easier enforcement of traffic violations while simultaneously curbing rampant vehicle theft. Funds from licensing could be directed towards improving E2W infrastructure like bicycle lanes and parking facilities, or battery recycling programs. With the abundance of fake license issuers in Chinese cities however, strict licensing may be difficult to accomplish successfully.

Stronger enforcement of E2W vehicle performance and quality standards

While this could have the effect of reducing rapid market growth since consumers are demanding larger and larger E2Ws, there could be a net benefit if enforcement leads to E2Ws with more consistent quality and moderate performance. This may naturally occur as incomes rise and customers demand better quality.

Preserve non-motorized vehicle lanes

Separated non-motorized vehicle lanes (i.e. bicycle lanes) are a common sight in most Chinese cities and a unique trait that separates China from most of the world. While some city governments may view this as an undesirable legacy of a bi-gone bicycle era and not consistent with a modern city, this infrastructure is very valuable in providing fast, inexpensive personal mobility. It also reduces the risk of accidents inflicted to E2W users, thus increasing their appeal as a transport mode. City governments should be careful not to under-estimate its value, especially as increasing motorization causes traffic congestion to worsen.

Improve China's lead manufacturing and recycling industry

China's lead industry is still fairly dispersed and has not adopted the more modern equipment of the lead manufacturing and recycling industry in more developed nations. Improvements will naturally occur, however, especially as the price of lead continues to rise. In the meantime, government could impose stricter regulations on small lead mines, smelters, and recyclers, thereby encouraging more rapid rationalization of the industry and the use of more efficient processes.

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8 APPENDICES

8.1 Cost Calculations of E2Ws and other Common Transportation Modes

The cost of various common transport modes presented in Chapter 1 and Chapter 2 are calculated using the following formulas. Assumptions (marked in *italics*) are listed in the tables that follow.

Cost per km ($/km) = Annual cost ($/yr) / VM (km)

VM = Annual average vehicle mileage (km)

Annual Cost ($/yr) = (Total capital cost ($) * Capital Recovery Factor (%)) + Annual operating cost ($/yr)

Total capital cost ($) = New vehicle cost ($) + Vehicle license cost ($)

Capital recovery factor (%) = IR / (1-(1+IR)$^{-VL}$)

IR = after tax interest rate (10%)

VL = vehicle lifetime

Annual operating cost ($/yr) = Fuel cost ($/yr) + *maintenance cost ($/yr)* + battery replacement costs ($/yr)

Fuel cost ($/yr) = Fuel unit cost ($/kWh or $/litre) * (Vehicle fuel efficiency (kWh/km or litre/km) * VM)

Battery replacement cost ($/yr) = Battery cost ($) / Battery lifetime (yrs)

Results

Table 8-1: Cost of Common Transport Modes in China (USD cents/km)

	Bicycle	E2W	Bus	Motorcycle (50cc)	Compact car
Vehicle cost (ammortized)	0.49	2.14	-	2.13	6.25
Fuel Cost	-	0.14	-	1.86	4.50
Bus Fare	-	-	5.20	-	-
Maintenance	0.10	0.50	-	1.02	2.38
Battery Replacement	-	1.25	-	0.03	0.10
license fee (ammortized)	-	0.02	-	0.47	0.61
Cost (cents/km)	0.6	4.1	5.2	5.5	13.8
Levelized Cost ($/yr))	$14	$120	$170	$250	$1,600

Assumptions

Unless stated otherwise, most vehicle and operating cost data is gathered from asking users about their owning and operating costs or from company brochures. The motorcycle and car both run on #91 gasoline. It is assumed interest rate is 10%, and batteries have a 300-cycle (~2 yr) lifetime, and exchange rate is 7.5RMB = 1 USD.

Vehicle Capital Cost

Vehicle	Value ($)	Source
Bicycle	70	
E2W	330	Average of several products from several companies
Gasoline motorcycle	600	Average of several products from several companies
Compact car	5,000	Cost of Cherry sub-compact car

Vehicle License Costs

Vehicle	Value ($)	Source
Bicycle		
E2W	4	
Gasoline motorcycle	130	Cost of license in Shanghai is $190. License fee is lower in most other cities
Compact car	400	Cost of license in Shanghai is $1,000. License fee is lower in most other cities

Vehicle Maintenance Costs

Vehicle	Value ($)	Source
Bicycle	3	

E2W	15	Chen Dingwei 2007 (E2W shop owner): average monthly maintenance cost of 10RMB/month/vehicle for pizza delivery E2W fleet
Bus		
Gasoline motorcycle	44	Jamerson 2005 cites $70/yr [51]. Likely lower in China
Compact car	240	

Fuel Cost

Vehicle	Value ($)	Source
Electricity	8.3 cents/kWh	2006 Shanghai electricity cost
Gasoline	0.56/litre	2006 Shanghai gasoline cost
Bus	0.53/day	Average daily bus fare

Vehicle Fuel Efficiency

Vehicle	Value	Source
Bicycle	n/a	
E2W	55 km/kWh (1.7 kWh/100 km)	Most product brochures state vehicle efficiency of 1.3-1.5 kWh/100km. charger efficiency is assumed to be 82%.
Gasoline motorcycle	35 km/l	Motorbike efficiency is 31 km/l [21], average gasoline motorcycle efficiency is 37 km/l [121]
Compact car	13 km/l	Vehicle efficiency of sub-compact car

Battery Cost

Vehicle	Value ($)	Source
E2W	80	Various E2W repair shops in Shanghai, 48V 12Ah (2006)
Gasoline motorcycle	10	
Compact car	50	

Battery Lifetime

Vehicle	Value (yrs)	Source
E2W	2	Various E2W customers, repair shops
Gasoline motorcycle	5	
Compact car	5	

Annual average vehicle mileage (km)

Vehicle	km/day	km/yr	Source
Bicycle	8.2	2,600	Cherry (2007)
E2W	9.4	3,000	Cherry (2007)
Bus	9.4	3,000	

Gasoline motorcycle	14	4,300	Cherry (2007)
Compact car	32	10,000	

8.2 E2W manufacturer Questionnaire

1	Company name:
2	Location (city)?
3	When was your company founded (year)?

Products

4	Annual production (units/yr)?
5	# of different ebike models produced?
6	Most popular product?
7	Performance attributes (range, power, speed, cost, weight, size, other)
8	Other products sold besides E2Ws?
9	When did you start making ebikes?
10	What did you make before you made ebikes?
11	What's your company's competitive advantage (what sets you apart from the rest of ebike makers)

Market

12	Where are you selling your ebikes mainly (cities)
13	How are you selling ebikes (through what distribution channels)?
14	What are the best distribution channels?
15	who are your best customers (what types of people)?
16	How many other companies are you competing with (estimate)?

Suppliers

17	Do you manufacture the components in your ebike or buy from other companies?
18	Where do you buy the main components of your ebike (battery, motor, controller), frame?
19	What kind of batteries do you use?
20	Does your company plan to switch to a better, more powerful battery?
21	What new technologies are you exploring for ebikes (regen, Li-ion, etc.)?

Price

22	What's the price range of your products?
23	What are the profit margins on selling one ebike (average $2500 price)?
24	What percentage of cost is battery, motor, controller (4 main components)?

Quality

25	How do you provide your customers service/maintenance after purchase?
26	Do you offer a warranty on your bikes or components?
27	What are the failure rates for these components (*)?

Regulations

28	What do you think about national regulations on ebikes (too strict, ok, too loose)?
29	What do you think about local (city) regulations on ebikes (which city?) (too strict, ok, too loose)?
30	Is there any national or regional group that represents the interests of ebike OEMs in China? (lobbyist, NGO, etc.)

Factories

31	How many?
32	Area?
33	Location (city)?

Employees

34	Size (# of employees)?
35	# of engineers?
36	# of PhDs?
37	# of general laborers?
	R&D
38	# of patents?
39	What % of your annual budget do you spend on R&D?
40	Recycling? How do you handle it?

8.3 Manufacturer Interview Results (15 Companies)

	Company 1	Company 2
3	1996	1985
Products		
4	50,000/yr (produce after order)	2,000/yr
5	20~30, updating	10
6	Mainland market: smart and with footplate	
7		
8	Gasoline scooter, bicycle	Toy, e-scooter and e-vehicle
9	2002 in Mainland, China 1996 in Taiwan, China	2000
10	Bicycle	Toy, child vehicle, bike
11	Technology, after service and maintainance service	Technology and quality
Market		

12	Shandong(Yantai), Hebei(Handan), Henan, Liaoning, Shanxi	Export to USA and Japan
13	Direct distributor and area agent	Agent and exclusive stores
14	Various from different areas	Various from different areas
15	20y~50y, retired people and middle age female	Children and elderly
16	There are so many E2W companies in mainland China now, over 1000 regular manufacturers and more small corporations	We are top grade in this field

Suppliers

17	Controller (self development and patent). Except controller, all components are purchased from other corporations	Controller (self development and patent)
18	Domestic companies	Motor purchase from overseas companies, other from domestic companies
19	Pb-acid (most products use Pb-acid batteries)	Li-ion
20	Li-ion batteries (have to reduce the cost)	
21		

Price

22	Middle grade	Over 500 USD (top grade)
23	Very small, only 100~200 RMB/bike	
24	Battery is the biggest cost, the company use German motor so cost on motor are pretty high	The motor and controller hold 2/3 in overall cost

Quality

25		Own network
26	Yes, during the quality insurance period	Yes, we have our own network

27	Different fittings is various, ordinarily the main parts like batteries and the motor perform well	

Regulation

28	Messed-up 1. Lack of clear industry standards 2. The management is loose and unstandardized 3. The problem between light e-motor cycle and ordinary footplate-style E2W	(Just overall situation, not our own market) 1. Market in middle and small cities (Without subway system like Suzhou, Hangzhou) 2. Market in those area which around the metropolis is good
29	Shanghai, Suzhou, Yantai (Need registered)	Because of low income in mainland, Li-ion top-grade E2W are not well-accepted, the market still need to step up
30	Industry association	

Factories

31	1	8-9 (overall, not only ebike)
32		
33	Shandong,Yantai, Longkou	Jiangsu, Kunshan

Employees

34		
35	5	250(overall), 20(E2W)
36		2-3(overall)
37	200(Automatic product line)	1000(all e-vehicle,E2W,e-scooter)

R&D

38		
39		Over 40% of the profit
40		

1	Company 3	Company 4
3	1970	1940
Products		
4	100,000	>200,000
5	15	>100
6	Northern China: Simple style, smart type (small and light). In Southern CHina: luxury style is most popular (motorscycle style)	Depends on area sold.
7		
8	Bicycles, ebikes, motorcycles	Bicycles, LPG motorcycles, toy cars
9	2003	Early 2000
10	motorcycles and bicycles	Bicycles and toy cars
11	very famous reputation	Brand, quality, marketing strategy. We can produce different kinds of products according to the demand of their consumers
Market		
12	Zhejiang, Shandong, Henan (big and middle sized cities)	Throughout the country
13	Different in different areas: they have a province agent, city agent and direct sales stores.	Sell products directly in most areas. In some areas agency is in charge.
14	City agents	Selling product directly
15	Northern China: Used to be farmers who just moved to the city ("City newcomers" from rural area). Southern China: general laborers, people who need to commute long	Commuters

	distance	
16	Not sure, very competitive	Nationally, XinRi (Beijing). In different provinces we compete with diff. Companies
Suppliers		
17	Most of components are purchased from other companies (4 main components)	They don't produce the components, they just assemble them.
18	They first analyze the market, then they choose the best supplier. Optimal path	Battery and other main components we buy from Mainland companies (he thinks the companies are qualified for their standard, their product quality is getting better and better. As good as exports)
19	Pb-acid (all)	3 kinds: Pb-acid, Nickel-metal hydride, Li-ion
20	The whole industry is developing very fast, so they do have a plan to switch to Li-ion. They realize this industry is developing fast and they realize technology advancement is important for competitive edge.	Yes, they use different kinds of batteries on different models. They use more powerful batteries on the bikes exported to other countries.
21		

Price

22	Middle level: 1500-2500 RMB	1800-2900 RMB
23	10% profit	100-200 RMB/bike
24	The E2Ws are sold to distributor without batteries. They let them choose, but make recommendations on which battery to use	>50%

Quality

25	They send technical staff to different agents to train repair maintenance people. All agents have to pay penalty if they can't fulfill their responsibilities. They first check the agent out to make sure they meet	They set-up a contract with agents for them to provide service. They also set up service centers in different provinces as a base and to communicate with agents and collect useful information

	quality specifications.	
26	Yes. Warranty of 4 main parts depends on the supplier.	Yes:
27		

Regulations

28	Regulations are very messed up. Local policies especially. Government's attitude seems to change all the time (sometimes ban, sometimes allow. Not consistent)	Even if new standards of the industry is enforced, there will still be no change in the market. Unfair competition will still continue. Difficult to enforce such regulation or standard. Gov't should view this problem from the standpoint of the consumers, fulfill the demand of the consumers.
29	Zhejiang and Shandong, the environment for ebikes is much better more favorable.	Too loose
30	There are industry associations in different areas (no specific info) They don't care so much about this because they don't think they can really affect national policy.	No

Factories

31	3	10
32		
33	Tianjin (North market), Jiangsu Nantong, Guangzhou	Shanghai, Jiangsu, Tianjin

Employees

34	200 in each	Don't know
35	6-7 in each	Engineer team in every factory
36	1 in guangzhou	no
37		

R&D

38		

39	5-10% of annual profit.	Very high
40		

1	Company 5	Company 6
3	1970s	1950s
Products		
4	225,000	150,000-200000
5	7 or 8	40-50
6	Simple and light bike	Simplified Style (70%) (Bike style)
7		
8	Traditional bicycle and fittings	Bicycles
9	2000 Taiwan, 2002 mainland China	early 1990s
10	Bicycles	Bicycles
11	Strong R&D capability. Technology is very advanced. They have good reputation	They make it themselves, quality and brand
Market		
12	30% to Japan and Europe. 70% in China	More than 20 provinces
13	Very mature sales network. They sell throughout their old channels. Direct sales stores. Exclusive stores and agents.	Agency and exhibition (take part in different kinds of large exhibition), advertisement in journals, newspapers.
14	Exclusive stores	Agency

15	Young people in the city, general laborers	Some styles are attractive to commuters, some are attractive to young ladies. We focus mainly on the mid to high-level consumer
16	All the famous companies (like Heping)	Many (more than 5000 factories produce ebikes in China)
Suppliers		
17	Both	They purchase the main components from other companies
18	Battery is from Panasonic. Motor is from Sanyong, self-developed controller.	Mainland companies
19	70% are Pb-acid. 30 are li-ion and Ni-MH	Lead-acid
20	They will use more and more advanced battery	Yes, but sensitive to cost
21		
Price		
22	top grade and middle grade (2000 RMB for Ni-MH ebike	1,500-3,000 RMB
23	not very profitable (small)	5%-8%
24	The main part of cost of ebike is battery	66%
Quality		
25	Yes, they have customer service network.	When they choose the agents, they set up contract in which agents are asked to provide special cusomter service. They do specific training for the agents.
26	Warranty on product	Yes, Motor and battery (2 years)
27		
Regulations		
28	It's a mess. Competition is fierce, industry needs to be organized.	Too loose. There should be a uniform and compulsory standard for every

		factory in China. Gov't should strengthen supervision, pay much more attention to the tax problem (some companies illegally avoid paying taxes). Gives them an unfair advantage
29	In Nanjing and Shanghai, the environment for E2Ws is good because city gov't is mindful of city traffic and air quality so they encourage E2Ws	Not much difference between national and local standards
30		no

Factories

31	1	6 (some factories also produce regular bicycles as well)
32		
33	Kunshan	Jiangsu and Tianjin

Employees

34	400 (3,000 total)	200 / factory
35	30	15%
36	5 in charge of design, technology, etc.	No
37		

R&D

38		
39	20% of profit	25%
40		

1	Company 7	Company 8
3	1956	1994
Products		
4	200,000	50-60,000
5	>30	>100
6	Bicycle-style	Bicycle-style
7		
8	Motorcycles, light trucks, engines	
9	2001	1994
10	see above	Nothing
11	Technology, brand, human resources, distribution channels	Quality, IPR
Market		
12	Shandong, Henan, Hebei, Anhui, Beijing, Shanghai, Jiangsu	Throughout the country and export (France, Italy)
13	Agencies in different provinces (which can sell different brands), they own stores and sell bikes directly	Agency (in different provinces, can sell different brands), they own stores which sell their brand only) (only in Shanghai)
14	It's a 50/50 split	Agency
15	Commuters	Each product has different kinds of customers (bicycle-style focuses on commuters). The more modern scooter-styles are attractive to young people
16	A lot	>3,000 (only 24 are actually licensed)
Suppliers		
17	Produce all components in-house (compared to producing motorcycles, E2Ws are so simple)	They produce every component themselves (the four key parts)
18		
19	Pb-acid	Pb-acid, Ni-MH is only for export

		products
20	Yes, but this will affect cost so we don't think customers can afford this kind of E2W	Yes, but they will switch according to demand of their consumers and their ability to afford it.
21		

Price

22	800-4,000 RMB	1,700-3,400 RMB
23	50-200 RMB/bike	10-100 RMB per bike
24	50%	70%

Quality

25	They provide different kinds of service according to distribution channels. If it's their own dealer, they provide service directly. Agents are in charge of repairing. After repair they can contact company to tell them the problems. The rule is, whoever sells the E2W is in charge of service.	They have their own tech service dept. Their duty is to train the service staff of the agents in order to provide technical service
26	Yes, different according to different parts.	Yes, different according to different parts.
27	no comment	

Regulation

28	Too loose. There's no order in the market. Lot of disorder. Manager said maybe the gov't should supervise and lead the companies, tell them what to do and what not to do in order to protect their interests. The small unqualified companies should be closed at once. The market should have regulation and allow companies to compete fairly.	Too loose. It almost seems like there's no regulation. Many companies complain there is no standard for the industry. Maybe there is a regulation, but there's no one in charge to supervise the companies so it seems that few companies observe the regulations. Gov't should administrate the industry according to different kinds of products. Regulations should be based on different types of products (E2W vs. e-scooter.
29	Too loose	

30	No	Shanghai Bicycle Association

Factories

31	2	1
32		
33	Jinan	Shanghai

Employees

34	500	200
35	10%	50%
36		0
37		50%

R&D

38		very high
39	10%	no comment

1	Company 9	Company 10
3	1985	No data

Products

4	80,000-100,000	100,000 (800,000 total bike production capacity)
5	40	26
6	North China: Bicycle-style, light. South China: Scooter-style (Luxury)	Scooter style (luxury)
7		
8	Motor, batteries	Light motorcycle
9	2002	2005
10	Motor, Batteries	E2W and light motorcycle fittings

11	Motor, batteries, charger and controller	Low cost (produce fittings in-house)

Market

12	Shandong, Henan, Jiangsu	Shandong and Henan
13	Sales agent and exclusive store	Small area agent
14		
15	General labor (common income lever)	Middle-age female
16	Many, up to 2006, there are over 2000 companies in China produce E2Ws, some of them don’t even have an trademark.	E2W companies all over the country

Suppliers

17	Only purchase frame and small fittings, from domestic companies.	Manufacture some component, purchase others
18		Domestic companies
19	Pb-acid	Pb-acid
20	Li-ion, Ni-MH	
21		

Price

22	Middle class	economic style, low-end
23		Subtracting marketing and customer service cost, only 70-80 RMB/ bike
24	The 4 parts take over 60% of the overall cost	

Quality

25	Sales agent	
26	Yes	
27		

Regulation

28	The regulation is far behind the market	Malignant competition is too furious, leads the industry to low profit and unsustainable
29	Shandong, Henan	Kunming, Beijing, Shanghai and cities in Jiangsu are the main market
30		

Factories

31	1	1
32		
33	Zhejiang Changxin	Wuxi

Employees

34		
35	20-30	12
36	3-4	
37	400	185

R&D

38		
39	10%, nearly 500,000 RMB	
40		Theoretically, the batteries should all be recycled. The customers could exchange the new batteries by the former waste one with E2W sales agent, and the E2W companies sent them back to batteries companies together after they collect it from the agents. It is benefit both batteries company and E2W users

1	Company 11	Company 12

	(Factory visit on 5/15/06)	(Factory visit on 5/16/06)
3	2002	2002

Products

4	100,000	150,000
5	>100	30+
6	Simple style	33%: scooters for leisure, 33%: conventional ebikes, 33%: e-motorcycles style, 1,000-2,000: high end electric ATVs
7		
8	motor (used in E2W)	Gasoline scooters, ATVs, dirt bikes, water scooter. they have some innovative products (like the eletric wheel chair for the disabled)
9	2002	2002
10	Car components and electric equipment fittings	Nothing
11	Import technology and patent from Japan	Unique products

Market

12	All over the Mainland China, export to US and Euro market	98% are exported to other countries.
13		They have one office in US, and joint ventures in Thailand and Korea.
14		
15	All different type of people's requirement	High-end consumers. They design different models for different people.
16		Not as many competitors in the high-end market like they are.

Suppliers

17	The motor is self-developed and manufactured. All other components	They make the controller and plastic fittings themselves.

	are purchased.	
18	Also supply motor to other domestic companies	Batteries: panasonic, motors from domestic companies, buy frames closeby, but they bend the frames and modify them themselves
19	Pb-acid	Pb-acid
20		They're developing wind power generating equipment. Put this equipment on road lights. This will be used especially in rural areas
21		Electric gasoline hybrid scooters

Price

22	Middle-class	Hybrid scooter is 3600 RMB, they have some products that are over $1,250 USD
23	only 3%-7% of the total cost, the competition is furious and the market is still immature	Export: 15%, domestic: 7-8%
24		Usually 60% of total cost

Quality

25		No, it's all exported, so they have to pay close attention to quality control.
26		No
27		

Regulation

28	The government didn't support E2W development in the beginning. The technical standard is unreasonable and ignores actual requirements of the market. The gov't quality control department enforces a high cost penalty for ebike OEMs who violate the standards. Consider why do so many companies have to disobey the present regulations. Maybe gov't keeps the regulation like this because they need this the income from	Since 1996, Taiwan had very advanced E2W technology, but mainland china doesn't. Now it's growing very rapidly. Total output production in 2006 could reach 12,500,000. The key factor that stimulates ebike dev't is gov't banning use of motorcycle (Taiwan never banned motorcycle). Technology is becoming more and more mature. Only 5 companies produced over 200,000 ebikes a year. Less than 20 companies

	penalties	over 100,000.
29		Most ebike companies in china are simply assemblers (they don't develop or produce any components). That's why there's so many similar ebikes on the market, they get the same components from the same motor suppliers, frame suppliers, etc.
30		

Factories

31	1	1 factory (Wuxi) (300,000/yr capacity)
32		
33	JiangSu,Yixing	

Employees

34		513
35	30-40	55
36		0
37	400	~300

R&D

38		
39		over 10 million RMB/yr (50% of annual profit)

1	Company 13: (Factory visit on 5/10/06)
3	2002

Products

4	12,000/yr, plans to increase to 60,000/yr (they plan to build two more factories soon
5	At any one time, they produce 4 models on one assembly line. When one

	model is introduced, they eliminate an old model.
6	515V (see brochure)
7	
8	Xi an, they have a research institution in order to develop some new kinds of batteries and controllers. The reason why they built it there is because Xian has a lot of famous universities they can cooperate with.
9	2002, 2005
10	Nothing
11	Two advantages: technology of their ebikes, brand. Price is a bit higher than other products, they try to make their products different from others to provide something attractive to consumers that cannot be provided by others. They are mostly very focused on brand definition, making their brand stand out. The people who like to buy their products are more wealthy. This helps them avoid the competition at the low end, which is all about price. They can focus more on quality.

Market

12	Shandong, Jiangsu, Liaoning, Hebei, Gansu, Tianjin, not in Shanghai. In the Shanghai market, customers are more focused on price, so shanghai has become a market with lower price. In Shanghai, the image of the ebikes is lower because there is such fierce price competition among companies. In the other areas, where public transpotation isn't as available, their products sell better. People in downtown shanghai (the more wealthy) don't need ebikes. In the outskirts of Shanghai, these are the people that need ebikes, they are focused on price. Difficult for them to sell bikes here. In smaller cities or towns, it's not very common or easy to purchase an ebike, so they use the ebike to show off their status. They'll buy a better brand to show off high-quality.
13	Generally two types of channels: sold directly at direct stores or use agent. In provinces in the North west of china, they'll choose agents to help them sell their products. In such places, the costs to transport their products is high. They'll lose control of the selling process The relationship between the direct stores and E2W OEM companies is contractual. They simply train employees and technicians.
14	Depends on area: In Tianjin (Southeast areas too), they can directly transport their products to these areas so direct stores are better. In the hinterlands, transport costs are higher. To choose an agent is better. They hire professionals to transport products to the agents
15	Every type. They have different types of products for different types of customers

16	

Suppliers

17	The core components are produced by themselves. Batteries and motors are purchased from other companies. Components assembled in factory. Even if the batteries are not produced by themselves, the battery company will produce based on their special demands, so their quality is higher than average on the market. They can maintain high quality standards even if they don't directly produce.
18	Other companies. One ebike contains two major components, plastic and framework. Around Shanghai, you can easily purchase plastic components. Scooter style has more plastic style components.
19	Pb-acid
20	Yes. Li-ion is now being tested in experiment labs. Once they can get high quality in real use, they will start to put these types in their E2Ws and sell them. They need to think about whether their customers can afford such bikes with higher price.
21	

Price

22	1,900-2,500 RMB, highest is 3,300 RMB (this is the price they sell to the agents or stores) The price sold at the store will be maybe 500 RMB higher
23	6% profit margin. If they enlarge the scale of factory, they will rise to 8%. Net interest margin. Gross profit margin is 15%
24	0.5

Quality

25	Whoever sells the ebike is responsible for customer service, their duty is to train the technicians at these places and provide components.
26	Yes. Whole E2W 1 year. Motor warranty 3-5 years. Components from suppliers like battery, 1 yr
27	0.5%-15%, most problematic component is the controller

Regulation

28	The regulation development is slower than the developoment of the technology. There's a big distance between what the customers want and the regulation. Customers want faster, longer range, more attractive, but standards regulate that they should not meet these desires. He thinks there

	should be two standards according to ebikes. One for E2Ws, one for e-scooters (E-motorcycles), (E2Ws will be under "non motor vehicles" e-motorcycles will be regulated more heavily. E-motorcycles would become a big revenue source for gov't. (become a bigger tax burden). New standards are coming soon, they may be enforced soon (2006-7) but not sure when for sure. Taxes: most companies pay taxes properly in this area. Companies that produce high price products, taxes have less impact. So, he can focus more on quality and service, rather than on price.
29	The most important problem in the China market is that there is no predictable policy in China. Tough to plan. No explicit policy in China, this will limit the planning of the company because of the potential risks. Their principle is to walk, not run. Go step by step, look at the gov't direction, then control speed of development accordingly. The development of the e-motorcycle type products, they treading carefully because they don't know how the regulation will change. The development of E2W style in Tianijn in proceeded more rapidly. He understands why gov't hasn't issued new standards. If gov't issues new standards, there will be many new problems on the roads, like which kinds can be used on which roads, and tax problems. Government is observing the actions of companies; they think most companies are not qualified for the new standards. If the gov't thinks the companies are qualified, of course they will then implement the new standards. Conclusions: he thinks the enforcement of the new standards and regulations depends on cooperation between gov't and E2W companies. The situation of ebikes in China is interesting because the market is mature, but the industry is not. The amount of ebikes per family is very high, but the companies are not mature. The scale of the market is about 20 billion RMB. But there are over 1,000 ebike companies in China. In such a large market, there should be few companies that have revenues of 1 or 2 billion. Right now, the industry is in a period of hesitation. Once the policy becomes clear, there will be great change throughout the industry. The large companies will start to purchase the small makers and become larger, the small unqualified companies will disappear. At the end, there will be 3-4 very big E2W companies in the market. They hope they will become one of these. The industry has not yet converged, meaning companies are not big, strong enough. One major reason is the unclear policy.
30	Yes, the NBA and SBA but he thinks the major duty of this association is to help communicate between the gov't and the companies, but they haven't done their job very well. The originated from several big state owned companies. They would meet every year, publish journals or newspapers of the industry, organize an exposition

Factories

31	2 (one in tianjin one in Shanghai), the reason is the company focuses on the different advantage of resources in different regions. The suppliers available in different areas. In shanghai, they make scooters mainly, in Tianjin, they mainly make BSEB. Require different kinds of suppliers. Zhejiang, Jiangsu province, they can purchase their supplies easier. Transportation costs are lower. Right now, there's just one in Shanghai, but soon there will be 3

32	5000 m^2, 10-12,000 m^2
33	Shanghai, maybe set up a factory in Kunshan. This will be bigger than either factory in Tianjin or Shanghai, but this depends on policy. Once the policy becomes clear, they would like to expand production to 1 million per year.

Employees

34	<40
35	4
36	Shanghai=0, Tianjin has 2
37	

R&D

38	No
39	400,000-500,000 RMB in R&D. Batteries, ebike security, and new products development
40	They do little in the process of recycling, they leave this up to the market. If someone can make 30 RMB/cell to recycle a battery, someone will do it. The market price for an old battery is at the lowest 30 RMB, so someone will take care of it. In order to make additional products, direct stores or agents will tell their customers to bring back their old batteries in order to make more profits. The customer can buy a new battery pack at 80-100 RMB lower. When the agents or dealer who collect battery to make money, they take the batteries to the battery companies, these companies take the old batteries and make use of them to produce more batteries will even lower quality. So overall, the quality of batteries will get lower and lower. In the beginning, battery quality is pretty high, but it's been degrading over time due to the shuffle through the industry, recycling process.

1	Company 14: (factory visit on 5/16/06)	Company 15 (factory visit on 5/17/06)
3	1995	1997

Products

4	178,000 (2006 Quarter 1(Jan-April): 90,000 ebikes produced.)	100,000 (capacity 300,000)

5	15 or 16, but every month they put one or two new models on the market.	30
6	Hard to say, they sell to the whole market. 60% of product is luxury style(SSEB). 40% is simple style (BSEB).	Scooter style vs. simple style (50/50). Varies by region
7		
8	none	none
9	1997 (company funded in 1995), first product in 1997	1997
10	no	nothing
11	Very good technology and reputation (boss is very well educated in battery and motor technology).	Quality and reputation. Earliest professional ebike company in China. They know the technology very well.

Market

12	North market prefers simple style because the cold weather impacts battery performance, need to use pedals more often. Lead acid batteries perform worse in cold market so people may have to ride more. Tiianjin also has the biggest traditional bike base. 70% in urban area, 30% in rural. Luxury style (SSEB) is more popular in rural area (people go farther, need to carry goods)	Shanghai, Jiangsu, Anhui, Henan
13	Best is exclusive stores because their after sales service is better. Exclusive stores sell 90% of their products. 10% sales to super markets.	They have exclusive stores and dealers, depends on the city.
14	Exclusive stores because every store has their own repair and maintenance facility. The staff that work in the exclusive stores understand the technology more.	depends
15	Market is 70% in urban areas, 30% in rural.	Females
16	5-6 are in their range. Angell and	over 1,500 ebikes companies in

	Small antelope are formidable.	China, only 20 can produce over 100,000 per year

Suppliers

17	Both	The motor and frame are made internally
18	Controllers: they make 50% in-house, buy 50%. Motor: make 20%, buy 80%. Recharge: make 60%, buy 40%. Frame: make 60%.	Adjacent area (Changzhou, other cities nearby)
19	Pb-acid	Pb-acid
20	Yes.	Yes, the technology is not the limit. The regulation limits a more powerful motor. 240 W is a little low. Sometimes people want to use bikes for transport, therefore they need more power.
21	CPU engine management system. Regenerative braking	

Price

22	too many products, didn't mention	1,500-2,400. Their prices are a little high
23	8% for luxury product, 5% for simple.	0.2
24	Battery 22% Motor: 27% Electric: 18% costs (controller, charger) O= 33%, lights, display panel, etc.	Battery 25%, Motor 25%, controller <5%, charge is <5%

Quality

25	Service centers, Exclusive stores, and repair center, train repair workers and suppliers. They record contact info for every customer. They send them text messages to remind them about regular maintenance times.	yes, they train their agents to handle after sales repairs.
26	yes. Similar to others	Batteries: 1yr; motor: 2yr; whole ebike: 2 yr. The quality in this industry is still not good enough compared to

		other electric products
27		

Regulation

28		Jiangsu and Suzhou, the policies are very good, suitable for ebike development. In Fuzhou and Guangdong its bad.
29		
30	The CBA will probably have a negative impact on industry development. They keep very strict limits on ebikes, use range, etc.	The industry association isn't that effective, they just organize trade shows. They don't really promote communication between government and industry

Factories

31	1 large factory (2 parts, they also make motors at one factory). Hefei factory makes controllers and charger.	1
32	13,000 m^2.	
33	Jinhua and Hefei	Suzhou

Employees

34	960 employees total. 886 here, another 100+ in Hefei. Including service and repair workers throughout country: >2,000	300
35	44 in Jin hua	30
36	1	0
37	5-600	200

R&D

38	30+	17
39	Doesn't know exactly. Technical Center in Jinhua has 40 engineers. 20 in Hefei. Many joint R&D programs with suppliers on certain technologies	10-15%

40		The life-cycle of the E2W: lifetime is 10 years (their first batch of production is still being used today). In the beginning, their quality was really good, but now the quality has deteriorated a bit.

8.4 E2W Dealer Questionnaire

1	Company name:
2	Location (Address)?
3	When start doing business?
4	When did you start selling E2Ws

Products

5	How many E2Ws do you sell per month (average)
6	How many do you have in the store right now
7	How different ebike models do you offer
8	How many different brands?
9	Most popular product?
10	Other products sold?
11	What did you sell before selling ebikes?
12	What's your store's competitive advantage (what sets you apart from the rest of ebike dealers)

Market

13	who are your best customers (what types of people)?

Suppliers

14	Does your shop supply the batteries for the E2W you sell or do they come with batteries
15	Where do you buy the main components of your ebike (battery, motor, controller)
16	What kind of batteries do you use?
17	Do you handle any recycling of the batteries

Price

18	What's the price range of your products
19	What are the profit margins on selling one ebike (average $2500 price)
20	Can customers select different batteries for their ebike?

Quality

21	How do you provide your customers service/maintenance after purchase?
22	Do you offer a warranty on your bikes or components?
23	What is the most common maintenance problem?

Regulations

24	What do you think about local (city) regulations on ebikes (which city?) (too strict, ok, too loose)?
25	What do you think about national regulations on ebikes (too strict, ok, too loose)?
26	Do customers have to register their E2W upon purchasing? (buy a license?). Cost?
27	Any other comments suggestions about ebikes?

8.5 E2W Dealer Interview Results (4 Dealerships)

1	Dealer 1	Dealer 2
2	Huang Du (suburb of Shanghai)	Huang Du
3	2003	2003
4	2005	2003

Products

5	10-20/month	15/month (last year 25, now so many stores to compete)
6	10-20 (it varies). She orders E2Ws once or twice a month, then they deliver the bikes	<10 at one time
7	Not the same all the time. It depends on how they sell. Some months, a certain model is hot. Whichever model sells best, she'll order more of.	2
8	1-3	1-3
9	Ta4 Ban: scooter style	Both have the same selling performance
10	Motorcycles	No
11	Motorcycles. More and more people are attracted to E2Ws. The two important reasons are 1) those who want to buy motorcycles need to get two licenses in Shanghai. It's impossible for people from outside of Shanghai to get the one license. It's even difficult/complex to get the second license. The other reason is the price of oil is high.	Nothing
12	She has a lot of friends who introduce other people to buy her E2Ws. The quality of different brands are almost the same, the prices are all the same too, so if you have a lot of friends who can help make introductions, that can give you a competitive advantage. Price and quality are very important. Tendency in the past few years. Before people were more focused on	Lower price

	the brand or quality, now they're just focused on the price.	

Market

13	3 types: people who come from outside of Shanghai to work. These customers are usually very young. Local customers: middle aged people, more focused on price. 3) Women, ebikes are more attractive to females. For the young male customers, motorcycles are more attractive than ebikes.	Different kinds:

Suppliers

14	They buy the ebikes with batteries included.	no
15	We don't buy any components directly, if customers have something to ask the company to repair. The dealer acts as the communication point between the customer and the ebike maker. Repairs, money goes to ebike company, not dealer.	He doesn't buy the main components
16	No idea	He can't decide which kinds, the ebike company decides
17	Different ways of recycling batteries. Customers can take battery directly to her store or the company, depends on the customer. The dealers have the duty to recycle the batteries but it is not compulsory. Depends on the decision of the consumers. She does not give any money to the customer to bring their battery back. If the battery is out of warranty, the customer has to buy a new battery. With this dealer, recycling is not compulsory	No, the company will handle the recycling. Companies take the batteries directly to the companies. He doesn't sell batteries

Price

18	~2,000. If a dealer's ebike is very attractive to the customers and they buy the bike at other stores, the dealers can set a higher price in the market, make more profit. In most	1,500-2,200 RMB

	cases, the dealer has to set a lower price because there is so much competition. Profit margins are very small.	
19	<100 RMB / ebike (she sets the price 100 higher than she buys, but profit margin is smaller because she has to pay taxes and other costs).	10's of RMB (<100)
20	No	No

Quality

21	In most cases the ebike company is responsible for customer service. They'll go to the dealer directly. Then the company will send the workers to the dealer's store to repair the ebike.	The ebike companies are in charge of customer service. If it's a little problem, the dealer will repair it. If big, the company will send an employee to dealer store to repair.
22	Yes, it's different for different components. Batteries: 1 yr. Motor: 2-3 yr. Charger and controller: 1 yr. Frame: 2-3 yr. The motor warranty depends on the type of motor. Brushless motor: 3 yr. Brush-type motor warranty is shorter.	yes. Same as Dealer 1 store
23	Not many problems up until now, she just started the business a year ago.	Motor and controller problems

Regulation

24	No idea	There's no distinct regulation in place, so the dealers have no idea of the regulation on industry, so they cannot observe such a regulation. In his view, government does this on purpose in order to make more profits. Government supports the state-owned companies, they want to have just a few companies in the ebikes market. Smaller companies will disappear. Bribery exists in order to obtain useful information from officials about the standards. Local government doesn't support the development of small dealers. Huangdu government told them that they cannot show their products outside their stores, it's

		illegal. But they still do this anyway.
25	No idea	
26	The E2W company is responsible for registering the ebike for the customer. Dealer will contact the company, they will bring it back to the company to mark it (register). If the customer insists, they can take the bike to get registered themselves, but in most cases, the company will do it. $11 RMB, same as the license for a bicycle.	E2W registration has halted now, he heard that the reason is the gov't is going to raise the price of a license
27	If the battery can be charged while riding (regenerative charging), that would really make bikes attractive, market grow fast.	

1	Dealer 3	Dealer 4
2	Huaxin Town	Huangdu
3	Jun-04	1970 started repairing bikes and motorcycles
4	Oct-04	2002
Products		
5	5-10	20-30/month
6	~10	<10
7	1 brand (MS)	Several kinds
8	Brand：（上海白鹤）， model: Yi ke 伊科 (Built in Shanghai)	1 or 2
9		Depends on selling performance. There's no most popular product, everyone has their favorite kind. The luxury types sells well. He thinks the market is becoming saturated. Over 80% of families in Huangdu have ebikes.

10	They also sell motorcycles and motor scooters	No
11		repaired motorcycles and bikes.
12	Quality	Price, quality, and customer service. He can do minor repairs on ebikes

Market

13	Commuters, (probably male prefer this style)	

Suppliers

14	The bikes come with batteries, the shop also sells batteries	
15	All from the manfacturer	
16	Pb-acid	
17	They handle recycling, according to the attitude of the customer. If the customer wants to give the battery to them, they will recycle (no $$ incentive). Two ways: battery factory will directly take the batteries. 2) some recycle dealers will take the batteries directly	

Price

18	2,000-2,500	
19	n/a	
20	No	

Quality

21	They provide maintenance and repair after purchase.	If ebike has some big problems, they'll get repaired at the large store. If it's a small problem, he can handle it.
22	Motor warranty lasts for 5 years.	
23	brake system	

Regulation

24	No opinion. They will follow the regulation accordingly	
25		
26	For his type of large scooter-style E2W, they cannot sell it because local government will not allow it to be licensed. It is is too big and fast (more like a motorcycle). This decision happened only two weeks ago. Before this they were able to get a license. Most manufacturers put a speed controller on the motor, but most customers just cut the line to this controller (very simple). The company that makes these products also export them to Japan and other countries.	
27	Huaxin Town	

8.6 E2W User Interview

E2W General

1	Bike Brand Model
2	E2W Type
3	Odometer reading
4	Length of Ownership (years)?
5	Where did you buy it (town) (small shop, dealer, department store)
6	Main purpose of E2W?
7	Why did you buy an ebike (and not a gas-powered scooter?)
8	What did you use for transportation before buying the ebike?

Performance

9	How far can you go on one full charge? (km)
10	Original Max range (when you first bought the bike)?
11	Top speed?
12	Original top speed?
13	How much did you pay for the E2W?

Charging

14	Where do you normally charge the battery for your bike?
15	About how much does the electricity cost to charge your bike? ($/month)
16	How long does it take to get a full charge? (hours)
17	Do you know of any E2W charging stations anywhere?

Maintenance

18	Have you had any repair problems with the bike?
19	If you have a problem, how do you get it fixed?
20	Is their a warranty on your bike, how long?
21	How much have you spent so far (total) on ebike repairs (~)
22	How many times have you replaced the battery?

Use

23	about how many km/week do you ride?
24	Any problems with theft?
25	Did you need to purchase a license? How much?

User info

26	Education
27	Where do you live? (general area)
28	Age

29	Gender
30	Monthly salary

8.7 E2W User Interview Results (12 Users)

E2W General

	User 1	User 2	User 3
1	Camopower (长摩 美洲豹）Leopard	Ya ge (雅鸽）	(see interview sheet)
2			
3	SS	SS	SS
4	1.0	2.8	0.6
5	Huangdu		Huangdu
6	Commuting	Commuting (sometimes uses bike in the rain)	Also for shopping
7	Convenient for carrying goods, or people. Gas powered scooter not sold in her area	It ws given to her. She has to recharge it every day. A big hassle	Low price, more quiet, less pollution
8	Bike (wants to buy a car later)	bike	Bike

Performance

9	25	5	40
10			
11			
12			

13		>2,000 RMB	2,150 RMB

Charging

14	Home (but the bike was currently being charged at her work)	Home	Office or home
15	1 kWh every 3 days (0.61 RMB/kWh)	0.1-0.2 RMB/day	Not sure, but cheap
16	6.5	several hours	5
17			

Maintenance

18	Yes.	Yes, once.	Brakes
19	The repair shop where I bought the bike. It is under warranty for a year	Go to Huaxian	Repair shop where purchased
20	Yes, 1 year		1 year
21	0		
22	0	0	Once. Poor performance. Former battery lasted 3 months. Asked the dealer to replace, they did it free of charge

Use

23	16-20 (2km between work and home)	2trips/day x 15minutes/trip x 5days/week	28
24	No	No	no, but outside of campus, you need to use an additional lock to lock the battery
25	No, included in total price	Yes.	Included in the total price. The price of an ebike license is the same price as a bike license.

			Not considered "motor powered vehicle". Gas powered (CNG or LPG) need two licenses (green or yellow). Yellow can carry passengers. Green is cheaper by 2,000 RMB. Green is ~1,500 RMB

User info

26	Huangdu	Huaxian	
27	40's	50s	30s
28	Female	Female	Female
29	1,500-2,000 RMB/month	~600RMB/month	~1200RMB/month

E2W General

	User 4	User 5	User 6
1	Xin Da zhou 新大洲	Sinski (新世纪）（New Century)	Shanghai Kai li (凯利）
2		1,460	
3	SS	SS	SS
4	0.7	0.4	0.8
5		Huangdu	
6	Commuting	Commuting	
7	Convenient and cheap because it doesn't require gasoline	Economical, doesn't need gasoline (very dissatisfied with this brand because it doesn't live up to the advertised performance)	Convenience and economy. Gas scooter is much more expensive
8	Bicycle	Motorcycle (gasoline) (he's used 3 in his	Bicycle

		lifetime)	

Performance

9	45	35	40
10		50	
11		40 km/hr	Initially 45. Now 40
12			
13	2,400 (battery price is 500 RMB, can use it 1-2 year)	2,500 RMB	2,200

Charging

14	Office and home	Home (Anting)	Office or at home
15	0.1-0.2 RMB/day	0.24/charge	Doesn't calculate (sometimes charges at office)
16	6	6	8
17			

Maintenance

18	Flat tire	motor switch failure. He had to have this replaced	None, very satisfied with her ebike. It can even overcome steep slopes.
19	If he has small problem, he can go to any repair shop. If he has a big problem, he'll go to the place where he bought the bike.	Huangdu (where he bought it)	no problems yet
20	1 year, battery is 1 yr, brushless motor, 3 yrs	Battery is 1/2 year, ebike 1 year.	1 year.
21	4	15	0
22	no	0	0

Use

23	40 km/day (280 total)	40 km/wk	70 km/wk
24	no	no	no
25	Included in total price	30	Yes (included in the total cost)

User info

26	Xujing (MingHang District)	Anting	
27	Late 30s	45-52	40-45
28	Male	Male	Female
29	~1,500/month	~1,500/month	~1,200/month

E2W General

	Owner 7	Owner 8	Owner 9
1	Ya ge (雅鸽）	Odyssey	Xing Da zhou pai le (新大洲，派乐）
2	No	No	
3	BS		SS
4	1.9	1.3	0.2
5	Friend, Jiading	Xiao Xinshi, dealer	Huangdu, (Specialized E2W seller)
6	Commuting from home to work	Commuting, shopping, visiting friends.	1.Envir. Friendly, 2. Convenience 3. Economic (But he thinks the speed is a little slow)
7	Safe human power, low operating cost. More environment friendly. Don't need a driver's license, if you have a motorcycle, you need one	Operating cost is low, safer than motorbike because top speed is not very high.	Doesn't know much about gas-powered scooters, so he was not interested. He thinks maybe too expensive.

8	Bicycle	Bicycle	Bicycle (household also has a car, but usually used by his wife)

Performance

9	20	25	35
10	30	30	45
11	22-25	35	35 (but cannot trust the speedometer, it will show higher than actual speed)
12	30	35	35 (but travel behavior suggests its only 25)
13	500 RMB	1900	2400

Charging

14	home	Home	Home, campus
15	Doesn't calculate	so low, it can be neglected	Very little
16	7.5	12 hours at first, now 6-8 hours is sufficient	7.5
17	No	No	He knows of some, but he doesn't go to those places because you have to wait

Maintenance

18	Yes, brake failure. Now battery is broken, doesn't run.	if you maintain it well, you can use the battery for 3-4 years. If not 1-2 years, if you ride a lot, 1 year	None yet
19	Went to small repair shop to get fixed.	No problems	Go back to the shop to get it fixed
20	No	1 year	Motor, 2 yrs: ebike and other parts 1 year
21	150	0	0

22	A new battery costs 200 RMB so it's not economic to get it repaired.	0	0

Use

23	50	80 at least	45 km/wk
24	No	No	There is a knob where you can adjust the max speed of the bike.
25	No. You don't need it. If you have one, you're a good citizen, but no big deal if you don't.	No need. The law isn't strictly enforced. The ebike license doesn't have any real function. It's of no use. Gov't banned motorcycles where he lives.	No included in purchase of bike

User info

26	Jiading City	6-7 kms from work	Anting New town (7.5 km away, 20 minutes)
27	40-45	25	30
28	Female	Male	Male
29	~2000	<2000	~3000

E2W General

	Owner 10	Owner 11	Owner 12
1	Aupa (欧豹）	Feida (飞达）	Forever
2	~25,000		
3	BS		
4	3.6	0.8	1.3
5	Jiading, small shop. When she bought it, there were no E2W	Anting (dealer)	Huangdu (dealer)

	shops in Huangdu)		
6	Convenience, carry goods (but she can't carry others)	Commuting	Commuting
7	Using a scooter causes much trouble. You have to add gasoline, costs more money.	Safety, if the power is used up, you can also ride like a bicycle	Doesn't need to add gasoline, more cheap
8	Bicycle	Moped (gasoline powered). This moped-to-ebike phenomenon is very popular in their community	Moped (gasoline powered)

Performance

9	5	18	20
10	25	24	30
11	25	30	25
12	30	30	25
13	2650	1800	1400

Charging

14	Campus (originally shy to say)	Home	Home
15	Very little	Negligible	Negligible
16	7	8	8
17	No (and no speed limit switch)	No	No

Maintenance

18	Brake and flat tires. Repaired in Huangdu	Problem: 3 spokes of the wheel broke	No
19	Huangdu	Repaired in Huangdu	No
20		1 year for everything (dealer will replace	1 year

		freely)	
21	10	10	0
22	Now thinking about buying a new battery. It'll cost her 430RMB. She doesn't know about recycling, but she would give the battery to the shop freely.	0	0

Use

23	35 km/wk (before, she worked farther away probably)	36/wk	40/wk
24	No	No	No
25	Same as bike, 12 RMB	Yes, bought license, 12 RMB	Yes, bought license, 12 RMB

User info

26	Huangdu	Huangdu	Huangdu
27	44	44	44
28	Female	Female	Female
29	800-1,000/month	~1000/month	~1000/month

8.8 Chapter 3 E2W User Survey

ENGLISH VERSION

Dear Sir or Madam:

Thank you for participating in this important survey! Your feedback will be used to improve bicycle and E2W transportation in Shijiazhuang.

SEX: ☐1 Female ☐2 Male

AGE: ☐1 <18 ☐2 19~23 ☐3 24-30 ☐4 31~40 ☐5 41~50 ☐6 51-60 ☐7 >61

1. The most common trip that you make by E2W is to:

☐$_1$ Work ☐$_2$ School ☐$_3$ pick up child from school ☐$_4$Other_________

Home (origin) #____ Destination #____

2. How long does it usually take to make this trip (minutes)?
☐ 1 <10 ☐ 2 10~20 ☐ 3 20-30 ☐ 4 30~45 ☐ 5 45~60 ☐ 6 >60min

3. Why did you choose to ride an E2W instead? (check all that apply)

☐1 faster than regular bike ☐2 Easy to park

☐3 Door to Door ☐4 Do not have to wait for bus

☐5 Bus is too crowd ☐6 Easy to carry goods/people

□7 Less operational cost □4 Commute distance is too long for bicycle

□6 Comfortable □8 Other ________________________

4. How did you make this trip before buying an E2W?

□1 Bus □2 Bike □3 Taxi □4 Other______

5. How many times do you use your E2W on an average day?

□ 1 2 times □ 2 3-4 times □ 3 5-6 times □ 4 >6 times

6. Do you have any plan to switch to another travel option in the near future?

No, □1

Yes, □2 Better E2W □3 Car □4 Bus □5 Taxi □6 Other_________

7. Do you ever ride the bus? Why or why not?

Yes, □1 In bad weather □2 E2W unavailable □3 Other __________

No, because □4 too slow □5 Bus route not convenient □6 Too crowded

□7 Other (fill in) ________

8. What bothers you most while riding your E2W in ShiJiaZhuang:

☐ 1 cars/trucks ☐ 2 other bikers ☐ 3 pedestrians ☐ 4 Crossing intersections ☐5 Other (fill in): __________________

9. What is the biggest problem for E2W riders in ShiJiaZhuang:

☐1 Lack of NMV lane ☐2 Not enough minor roads ☐3 Inconsistent of bike lane facilities

☐4 Bad quality of secondary road ☐5 Inadequate enforcement of traffic laws ☐6 Over crows during the rush hours ☐7 Other (fill in): ____________________________

10.For the next few questions, please choose the option that best describes your attitude about this bicycling.

Note: **SA**= Strongly Agree, **A**= Agree, **N**= Neutral, **D**=Disagree, **SD**= Strongly Disagree

	SA	A	N	D	SD
1. General, I feel safe to ride E2W	☐	☐	☐	☐	☐
2. While crossing large intersection, I feel safe	☐	☐	☐	☐	☐
3. I am generally satisfied using an E2W for commuting	☐	☐	☐	☐	☐
4. E2Ws are too fast in bike lane	☐	☐	☐	☐	☐
5. Traffic Police do a good job maintaining order at intersections	☐	☐	☐	☐	☐
6. I would prefer a faster, more powerful E2W	☐	☐	☐	☐	☐

Your household's income for the last years?

□1 Less than 10,000 RMB

□2 10,000 RMB ~ 20,000RMB

□3 20,000RMB ~ 30,000RMB

□4 30,000RMB ~ 40,000RMB

□5 40,000RMB or more

CHINESE VERSION

尊敬的先生（女士）

非常感谢您的参与！您提供的信息将有助于改善石家庄的非机动车交通状况。我们保证您所提供的信息完全保密并仅作为研究之用。

您的性别：□1 男 □2 女

您的年龄：□1 <18 □2 19~23 □3 24-30 □4 31~40 □5 41~50 □6 51~60 □6 >61

1. **您使用电动自行车主要用来**:

☐1 上班☐2 上学☐3 接送孩子上学☐4其它_________

出发地（编号#）____ **目的地（编号#）**____

2. **您使用自行车每次的出行时间？（单程）**

☐1 <10**分钟** ☐2 10~20**分钟** ☐3 20-30**分钟** ☐4 30~45**分钟** ☐5 45~60**分钟**

☐6 >60**分钟**

3. **您为什么会选择电动自行车出行？** (**多项选择**)

☐1**比普通自行车要快** ☐2 **容易停放**

☐3**门对门直达目的地** ☐4 **不需要花时间等公交车**

☐5**公交车太挤** ☐6 **载人或载货容易**

☐7**使用成本低** ☐8 **骑人力自行车上、下班路程太远**

☐9**比较舒适** ☐10 **其它** _______________________

4. 在使用电动自行车之前，您主要使用哪种交通工具?

□1 公交车 □2自行车 □3 出租车 □4 其它______

5. 您在未来1年是否计划选择其它的交通方式？

□1 否

是，□2更好的电动自行车 □3私家车 □4公交车 □5出租车 □6其它______________

6. 您一天内使用电动自行车的次数?

□1 2次 □2 3-4次 □3 5-6次 □4 >6次

7. 您是否乘公交车出行？

是，□1天气不好的时候 □2电动自行车不能用时 □3其它 __________

否，□4太慢 □5公交线路不方便 □6公交车太拥挤 □7其它_________

8. 您在骑电动自行车时，对您干扰最大的是:

□1 小汽车/货车 □2其它自行车 □3 行人 □4 穿越交叉口时

□5 其它（补充说明）: ____________________

9. 对电动自行车使用者最大的问题是:

□1非机动车专用道不足 □2没有足够的小区支路 □3自行车道不连通

□4小区支路路面质量差 □5相应的法规条例不完善□6 高峰时非机动车道太拥挤

□6其它______________

10. 对于下列问题，请选择最能表达您态度（看法）的选项

SA完全同意 A同意 N不确定 D不同意 SD完全不同意

		SA	A	N	D	SD
1.	总体上说，我感到骑电动自行车很安全	□	□	□	□	□
2.	感觉很容易穿越交叉口	□	□	□	□	□
3.	我觉得骑电动自行车上下班很好	□	□	□	□	□
4.	在非机动车道行驶的电动自行车太快了	□	□	□	□	□
5.	在路口，交警对维持交通秩序起了很大的作用	□	□	□	□	□
6	我偏爱速度更快、马力更强劲的电动自行	□	□	□	□	□

. 车

去年您的家庭年收入：

☐1 少于10000元 ☐2 10000 元~20000元

☐3 20000元~30000元 ☐4 30000元~40000元

☐5 40000元或以上

8.9 Chapter 3 Bicycle User Survey

ENGLISH VERSION

Dear Sir or Madam:

Thank you for participating in this important survey! Your feedback will be used to improve bicycle transportation in Shijiazhuang.

SEX: ☐1 Female ☐2 Male

AGE: ☐1 <18 ☐2 19~23 ☐3 24-30 ☐4 31~40 ☐5 41~50 ☐6 51~60 ☐6 >61

1. The most common trip that you make by Bike is to:

☐1 Work ☐2 School ☐3 pick up child from school ☐4Other_________

Home (origin) #____ Destination #____

2. How long does it usually take to make this trip (minutes)?

☐ 1 <10 ☐ 2 10~20 ☐ 3 20-30 ☐ 4 30~45 ☐ 5 45~60 ☐ 6 >60min

3. Why do you choose to ride bike? (check all that apply)

☐1 Can only afford bike ☐2 Door to Door

☐3 Easy to park ☐4Avoid traffic jam

☐5 Comfortable ☐6 Healthy

☐7 Can take short-cut

4. How would you choose to make this trip if biking was no longer an option? (or: "if you could no longer ride a bike, how would you instead make this trip").

☐1 Bus ☐2 Walk ☐3 Taxi ☐4 Car ☐5 Other______

5. Do you have any plan to switch to another travel option in the near future?

☐1 No

Yes, ☐2 E2W ☐3 Bus ☐4 Taxi ☐5 Car ☐6 Other______

6. How many trips do you make by bike on an average day?

☐$_1$ 2 ☐$_2$ 3-4 ☐$_3$ 5-6 ☐$_4$ >6 times

7. Do you ever ride the bus? Why or why not?

Yes, ☐1 In bad weather ☐2 bike unavailable ☐3 Other __________

No, ☐4 Too slow ☐5 Bus route not convenient ☐6 Too crowded

8. What bothers you most while riding your bike in ShiJiaZhuang:

☐ 1 cars/trucks ☐ 2 other bikers ☐ 3 Pedestrians ☐ 4 E2Ws ☐5 Crossing intersections ☐6 Other (fill in): __________________

9. What is the biggest problem for bike riders in ShiJiaZhuang:

☐1 Lack of NMV lane ☐2 Not enough minor roads ☐3 Inconsistent of bike lane

☐4 Bad quality of secondary road ☐5 Inadequate enforcement of traffic laws

☐6 Over crowd during the rush hours ☐7 Other (fill in):___________________

For the next few questions, please choose the option that best describes your attitude about this bicycling.

Note: **SA**= Strongly Agree, **A**= Agree, **N**= Neutral, **D**=Disagree, **SD**= Strongly Disagree

		SA	A	N	D	SD
1.	In general, I feel safe riding my bike	☐	☐	☐	☐	☐
2.	I feel easy to cross the intersection	☐	☐	☐	☐	☐
3.	I am generally satisfied using an bike for commuting	☐	☐	☐	☐	☐
4	E2W is too fast in bike lane					
5.	Traffic Police do a good job maintaining order at intersections	☐	☐	☐	☐	☐
6.	I would like to buy an E2W	☐	☐	☐	☐	☐

Last year, your total household income was:

☐1 Less than 10,000 RMB ☐2 10,000 RMB ~ 20,000RMB

☐3 20,000RMB ~ 30,000RMB ☐4 30,000RMB ~ 40,000RMB

☐5 40,000RMB or more

CHINESE VERSION

尊敬的先生（女士）

非常感谢您的参与！您提供的信息将有助于改善石家庄的自行车交通状况。我们保证您所提供的信息完全保密并仅作为研究之用。

您的性别：□1 **男** □2 **女**

您的年龄**：**□1 <18 □2 19~23 □3 24-30 □4 31~40 □5 41~50 □6 51~60 □6 >61

您使用自行车的目的主要是用来：

□$_1$ **上班**□$_2$ **上学**□$_3$ **接送孩子上学**□$_4$**其它**__________

出发地（编**号#）**_____ **目的地（**编**号#）**_____

您使用自行车每次的出行时间**？（单程）**

□1 <10**分钟**□2 10~20**分钟**□3 20-30**分钟**

□4 30~45**分钟**□5 45~60**分钟**□6 >60**分钟**

您为**什么**选择骑**自行车？（可以多**项选择**）**

☐1只能够负担得起自行车 ☐2门对门直达目的地

☐3 容易停放 ☐4 可以避开交通堵塞

☐5 舒适自在 ☐6比较健康

☐7可以穿街走巷，找小路和捷径

如果您不选择自行车出行，那您会选择下列哪一种交通方式？

☐1 公交车 ☐2 步行 ☐3 出租车 ☐4 私家车 ☐5 其它______

您在未来1年是否计划选择其它的交通方式？

☐1否

是，☐2 电动自行车 ☐3公交 ☐4 出租车 ☐5 私家车 ☐6 其它_______

您一天内使用自行车出行的次数：

☐1 2次 ☐2 3-4次 ☐3 5-6次 ☐4 >6 次

7. 您是否乘公交车出行？（可以多项选择）

是，☐1天气不好的时候☐2自行车不能用时☐3其它 __________

否，☐4太慢 ☐5公交线路不方便 ☐6公交车太拥挤

8. 您在骑自行车时，对您干扰最大的是：（可以多项选择）

☐1 小汽车/货车 ☐2其它自行车 ☐3 行人

☐4 电动自行车 ☐5 穿越交叉口时 ☐6 其它（补充说明）: ________

石家庄对自行车使用者来说最大的问题是：（可以多项选择）

☐1非机动车专用道不足 ☐2没有足够的小区支路 ☐3自行车道不连通

☐4小区支路路面质量差 ☐5相应的法规条例不完善 ☐6 高峰时非机动车道太拥挤

☐7其它______________

对于下列问题，请选择最能表达您态度（看法）的选项：

SA完全同意 A同意 N不确定 D不赞同 SD完全不赞同

		SA	A	N	D	SD
1.	总体上说，我感到使用自行车很安全	☐	☐	☐	☐	☐
2.	我感觉很容易穿越交叉口	☐	☐	☐	☐	☐

3.	我觉得骑自行车上下班很好	☐	☐	☐	☐	☐
4.	在非机动车道的电动自行车太快了	☐	☐	☐	☐	☐
5.	在路口，交警对维持交通秩序起了很大的作用	☐	☐	☐	☐	☐
6.	我想买一辆电动自行车	☐	☐	☐	☐	☐

去年您的家庭年收入：

☐1 少于10000元 ☐2 10000 元~20000元

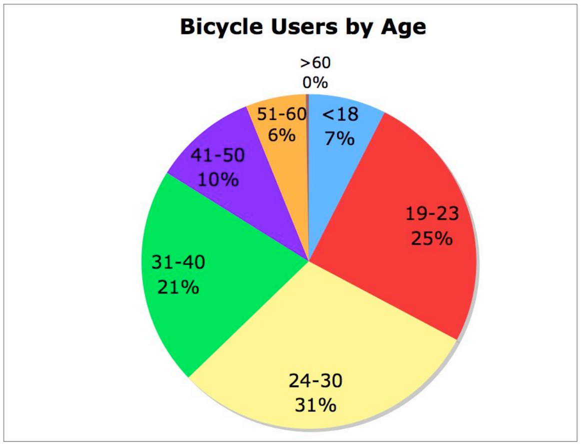
☐3 20000元~30000元 ☐4 30000元~40000元

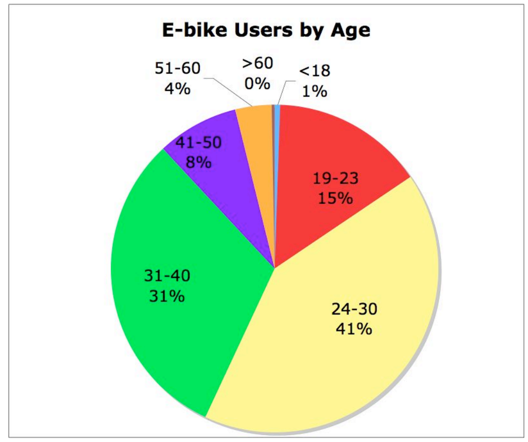
☐5 40000元或以上

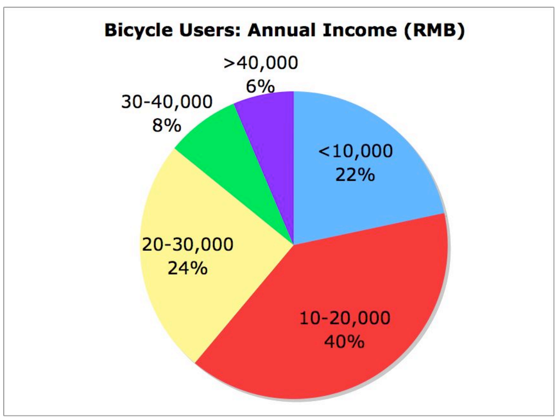
8.10 Chapter 3 Survey Results

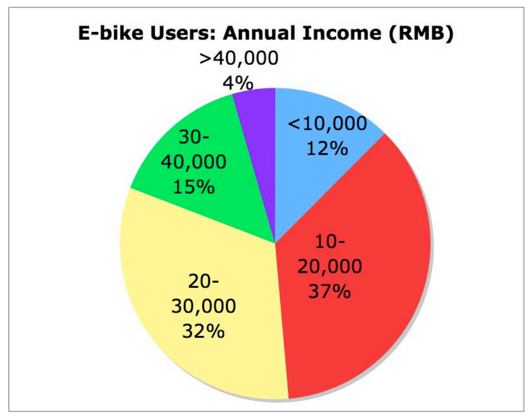
User Demographics

In total, 751 bicycle users and 429 E2W users were surveyed, 49% male and 51% female.

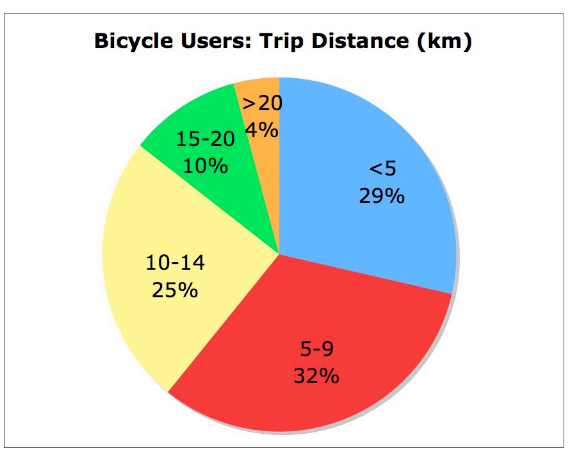


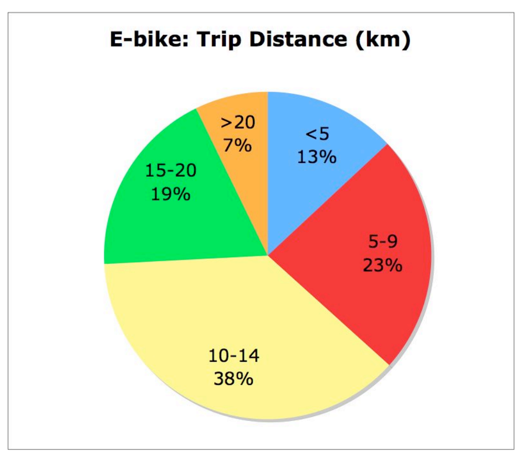


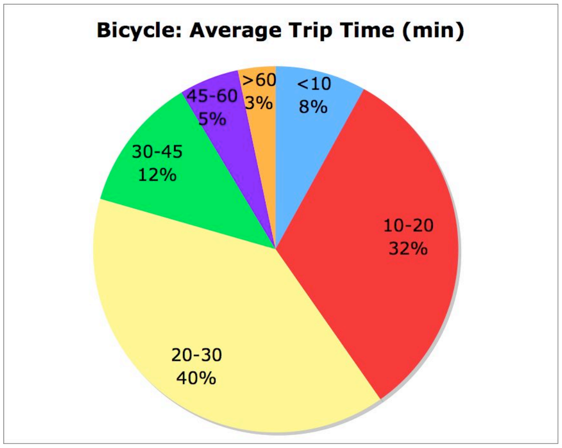


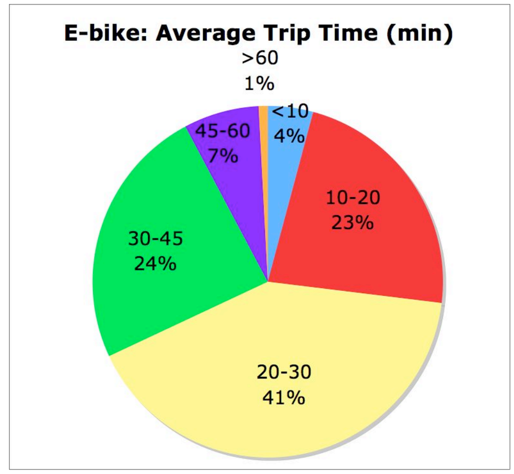


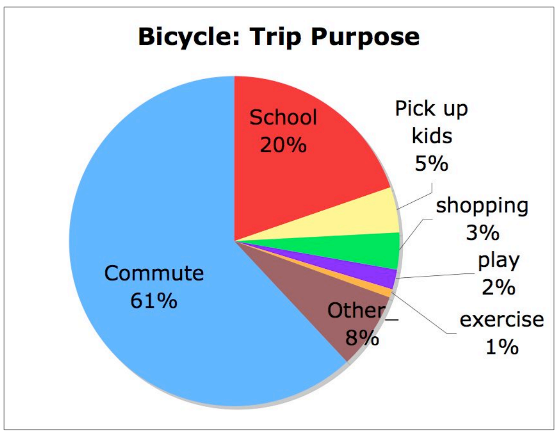
Travel Behavior

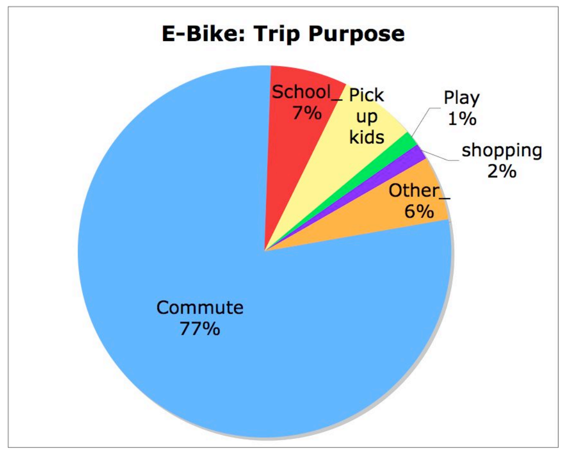




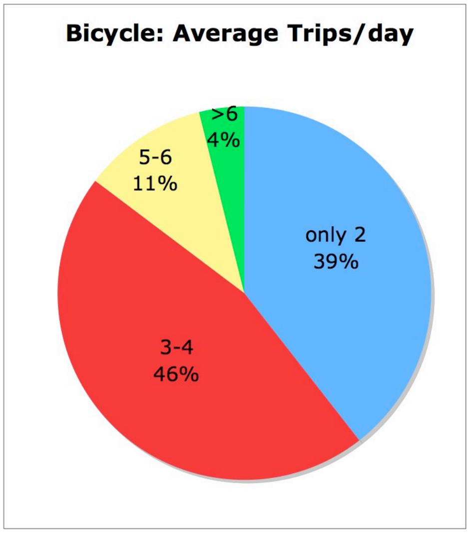


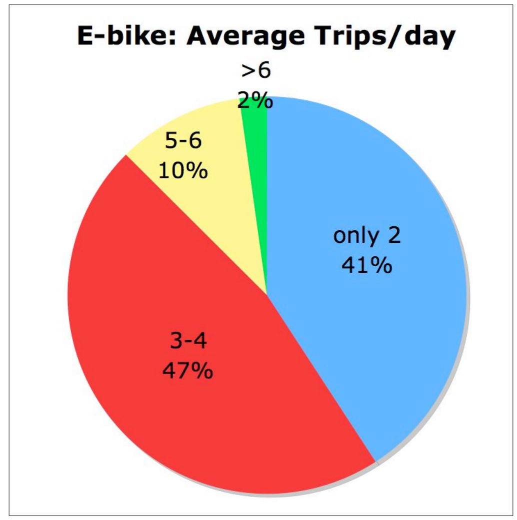


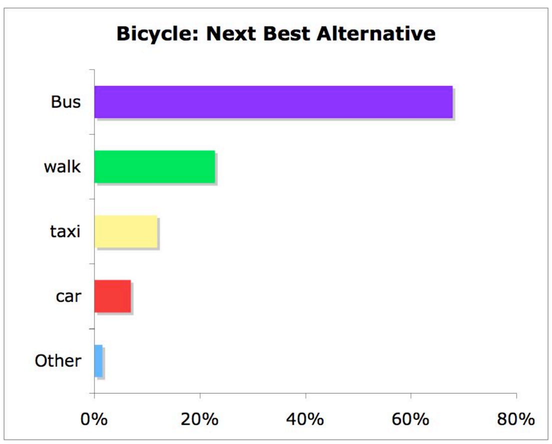


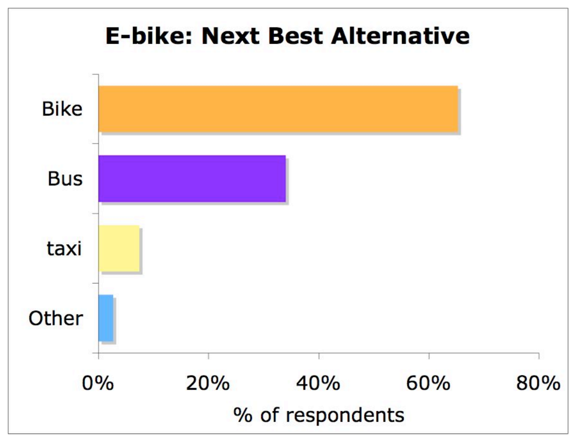


Other trip purposes: going to see doctor



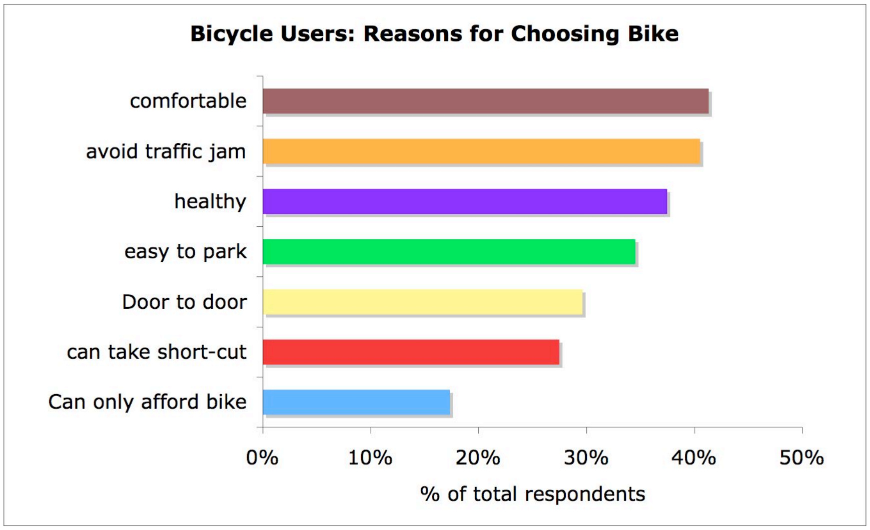


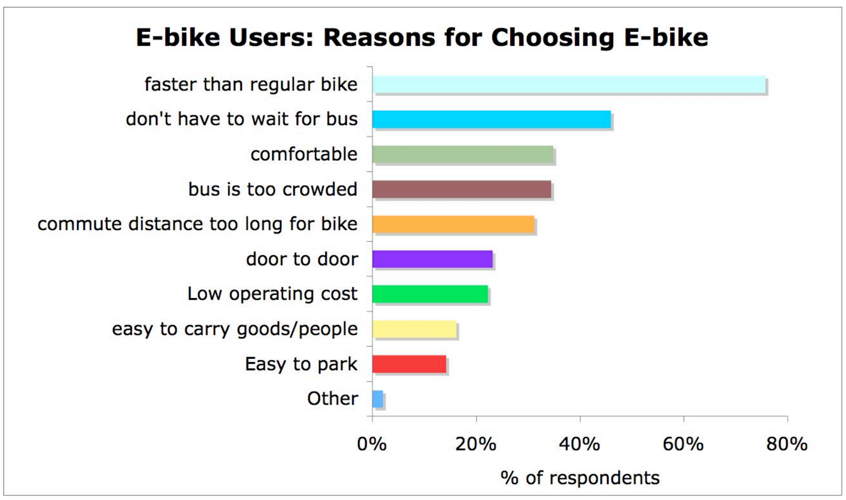


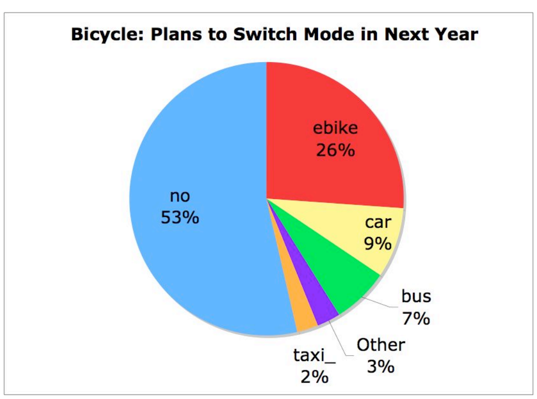


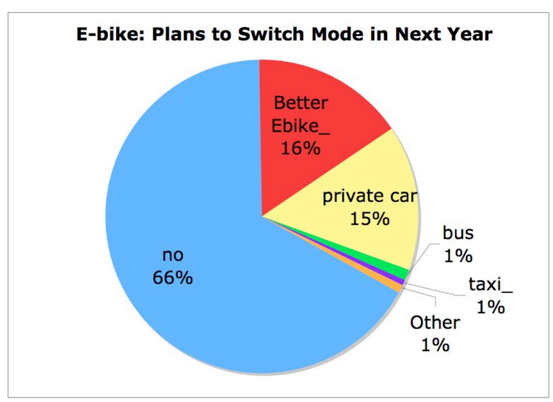
Other alternatives: ebike and motorcycle

2WV User Attitudes (Part 1)



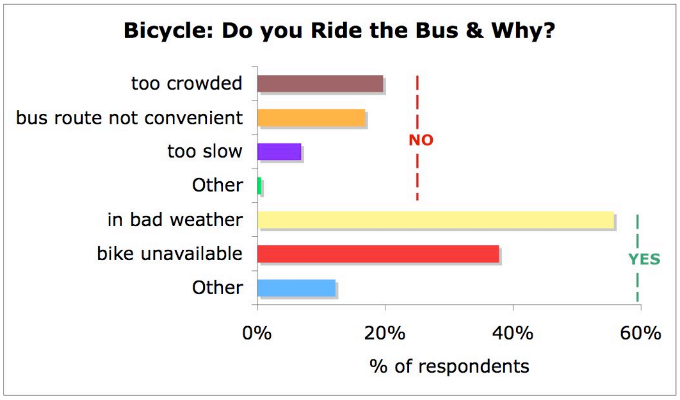


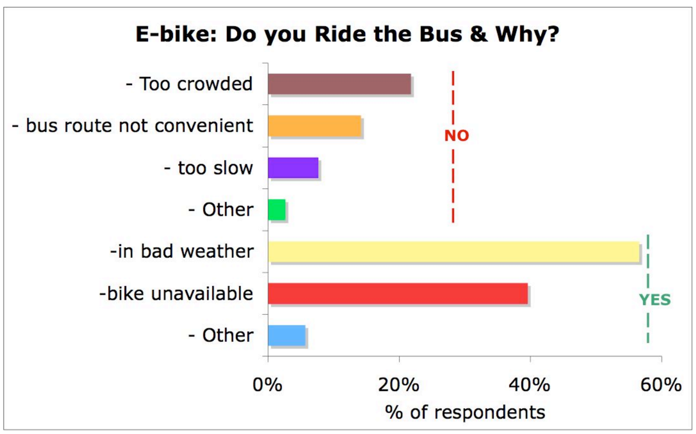


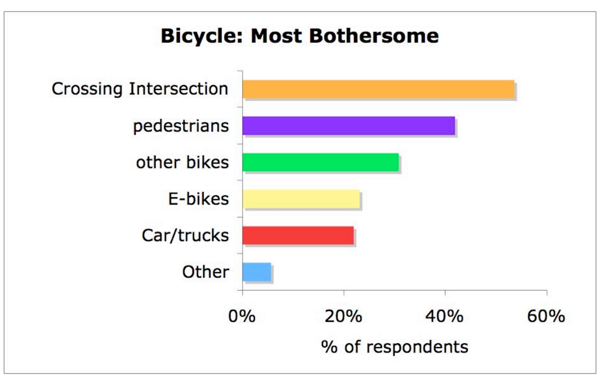


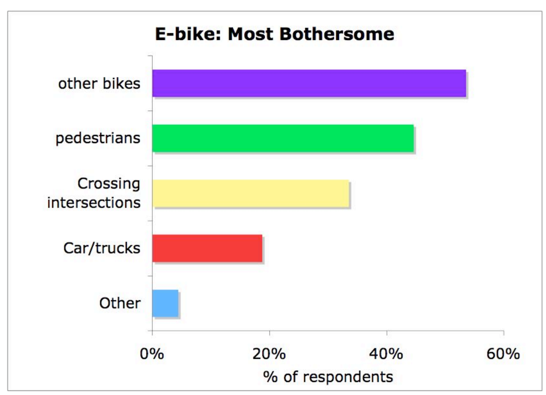
Other modes: motorcycle

2WV Users and Public Transit

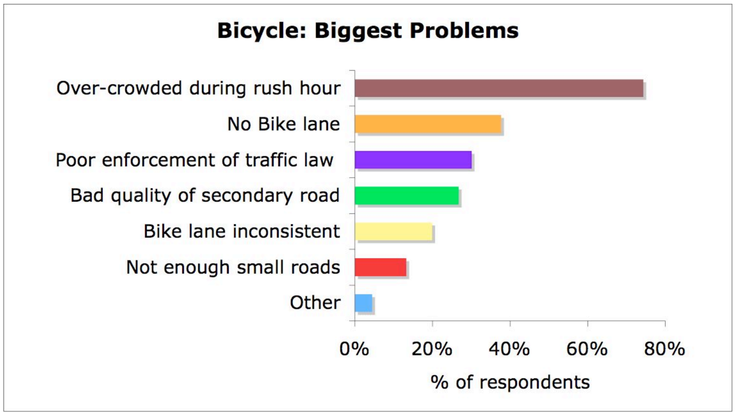


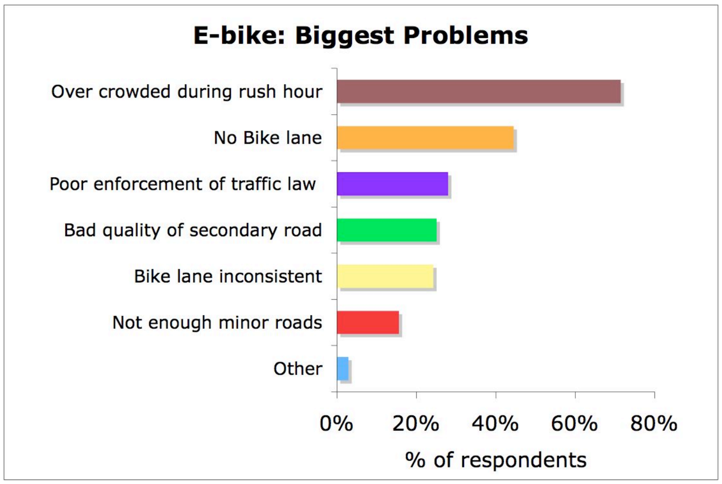






Other Responses: Bus, Signal not proper, Taxi





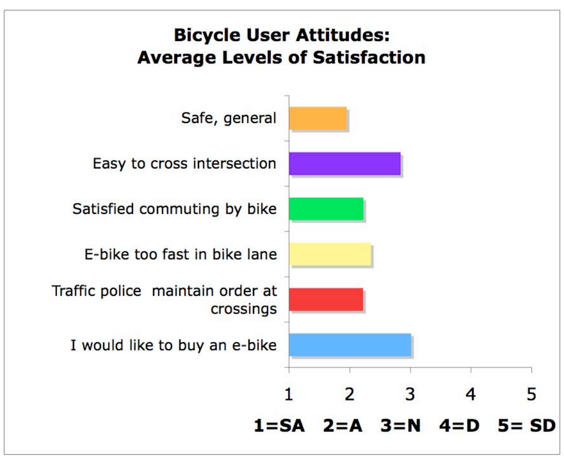
Other Problems: Easy to be stolen, MV takes up non-motorized lane, signal time isn't proper, difficult to park, inconvenient to take bus, poor education, people don't obey the traffic law, dirty to ride bicycle

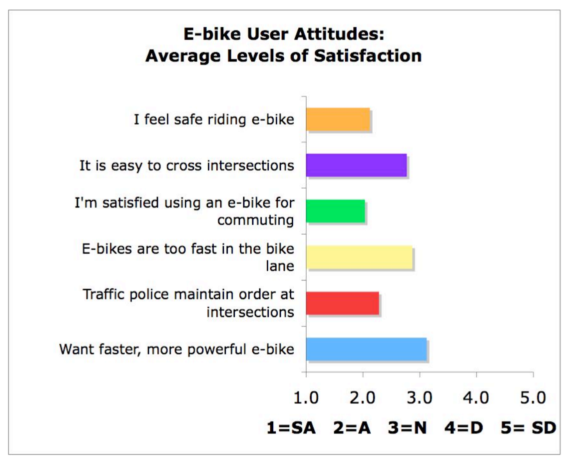
2WV User Attitudes (Part 2)

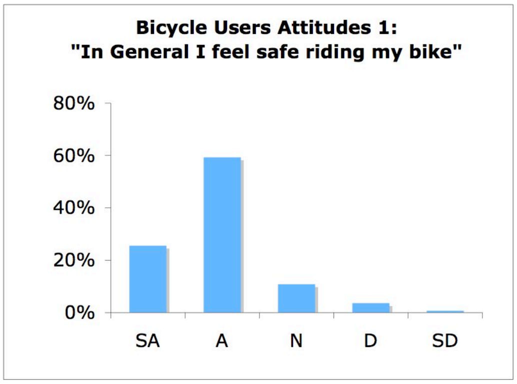
In this section, we asked read the following statements and decide if they agree or disagree. **1**= Strongly Agree, **2**= Agree, **3**= Neutral, **4**=Disagree, **5**= Strongly Disagree

Question	Average	Average	Standard Deviation	Standard Deviation

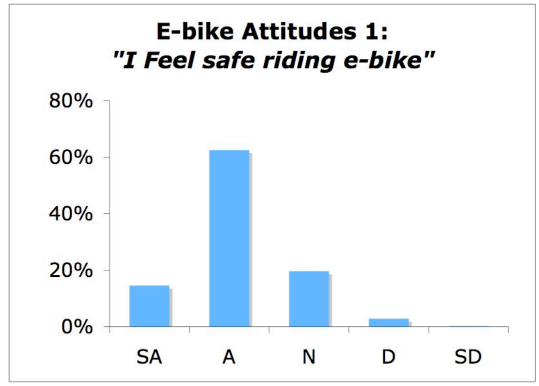
	(bike)	(E2W)	(bike)	(E2W)
1. Generally, I feel safe to ride bike/E2W	1.9	2.1	0.75	0.68
2. It is easy to cross intersections	2.8	2.8	1.06	1.01
3. I am generally satisfied using an bike/E2W for commuting	2.2	2.0	0.88	0.74
4. E2Ws are too fast in bike lane	2.3	2.9	1.01	0.94
5. Traffic Police do a good job maintaining order at intersections	2.2	2.3	0.95	0.94
6. I would like to buy an E2W / I wish my ebike was faster & more powerful	3.0	3.1	1.26	1.20



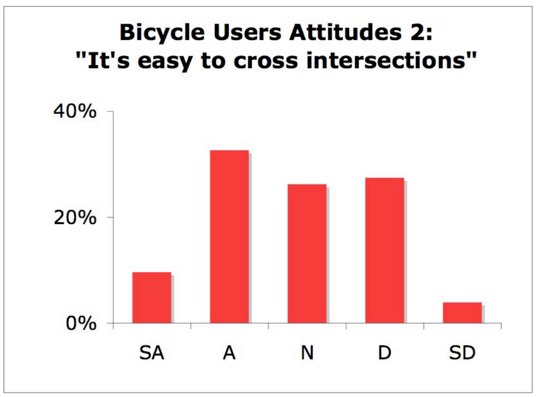




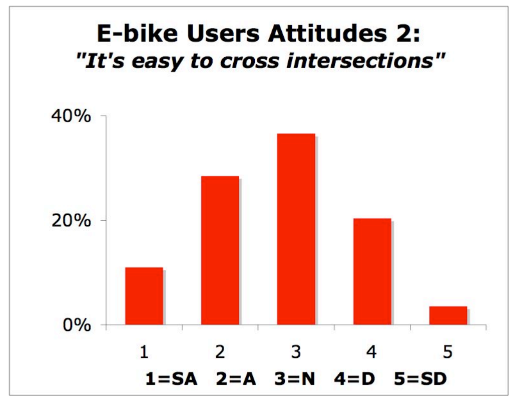
Bicycle Users Attitudes 1:
"In General I feel safe riding my bike"
80%
60%
40%
20%
0%
SA
A
N
D
SD



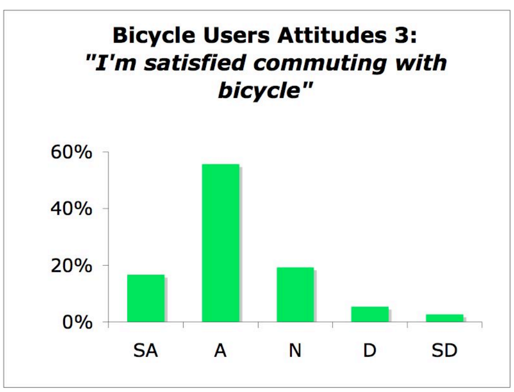
E-bike Attitudes 1:
"I Feel safe riding e-bike"
80%
60%
40%
20%
0%
SA
A
N
D
SD



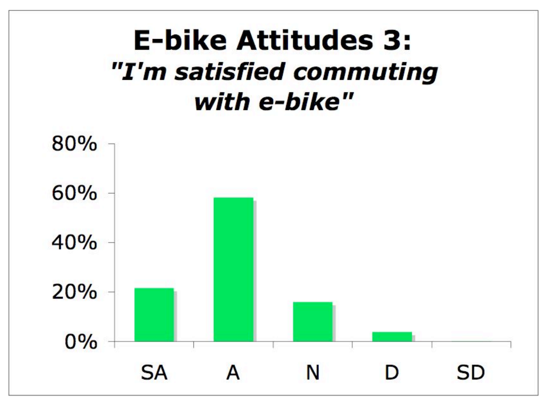
Bicycle Users Attitudes 2:
"It's easy to cross intersections"
40%
20%
0%
SA
A
N
D
SD



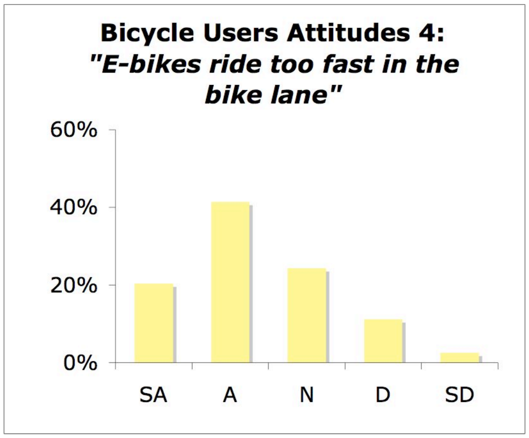
E-bike Users Attitudes 2:
"It's easy to cross intersections"
40%
20%
0%
1
2
3
4
5
1=SA 2=A 3=N 4=D 5=SD

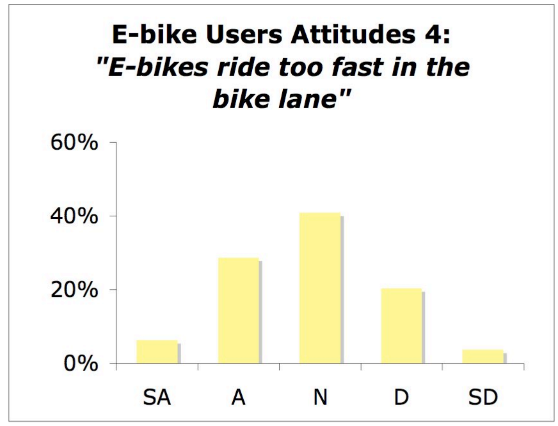


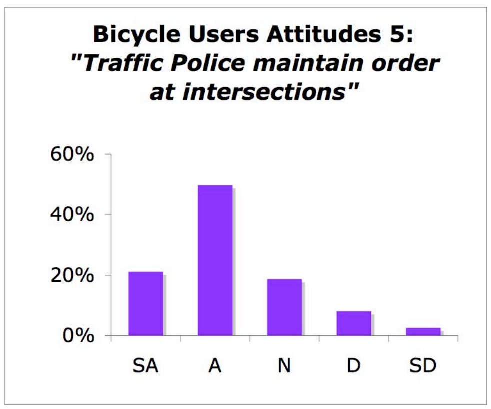
Bicycle Users Attitudes 3:
"I'm satisfied commuting with bicycle"
60%
40%
20%
0%
SA
A
N
D
SD

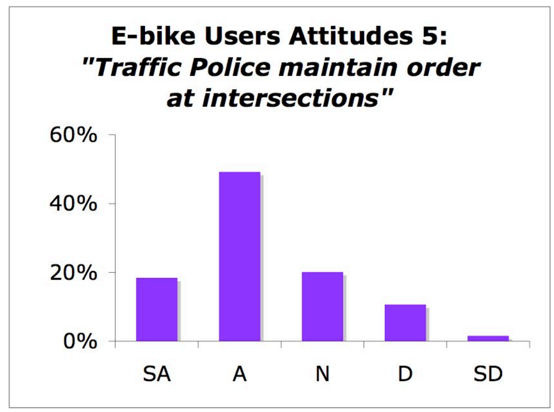


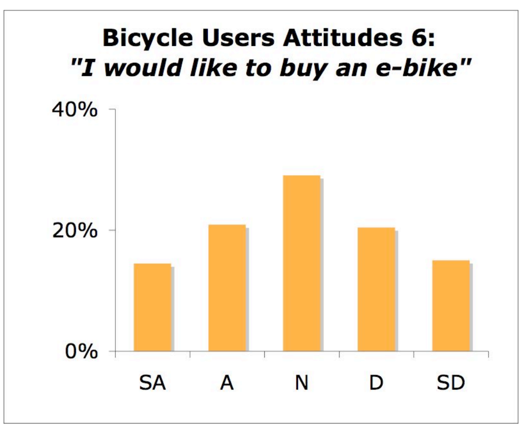
E-bike Attitudes 3:
"I'm satisfied commuting with e-bike"
80%
60%
40%
20%
0%
SA
A
N
D
SD

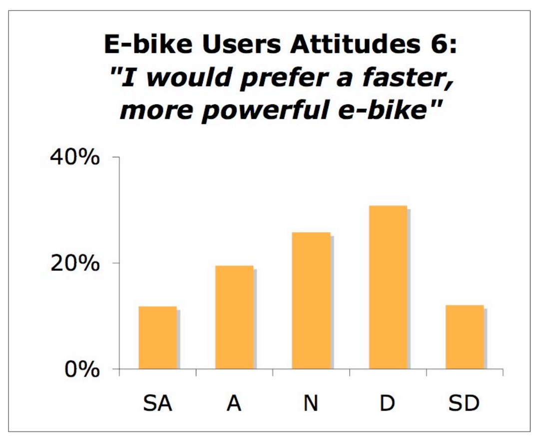

Bicycle Users Attitudes 4:
"E-bikes ride too fast in the bike lane"
60%
40%
20%
0%
SA
A
N
D
SD


E-bike Users Attitudes 4:
"E-bikes ride too fast in the bike lane"
60%
40%
20%
0%
SA
A
N
D
SD


Bicycle Users Attitudes 5:
"Traffic Police maintain order at intersections"
60%
40%
20%
0%
SA
A
N
D
SD


E-bike Users Attitudes 5:
"Traffic Police maintain order at intersections"
60%
40%
20%
0%
SA
A
N
D
SD


Bicycle Users Attitudes 6:
"I would like to buy an e-bike"
40%
20%
0%
SA
A
N
D
SD


E-bike Users Attitudes 6:
"I would prefer a faster, more powerful e-bike"
40%
20%
0%
SA
A
N
D
SD

THE END