Enhancing Accessibility of Mass Transportation in Metropolitan Taipei by Formulating a Portable Personal Electric Vehicle

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Abstract: Walking access to transit drops dramatically with distance from transit stations (Federal Transit Administration, 1996) In order to increase access to locations that are not accessible by mass transportation, this study attempts to enhance the future role of personal electric vehicle (PEV). Firstly, literature research was undertaken on daily traveling patterns of Taipei metropolitan population. Secondly, a study of existing personal electric vehicles (PEVs) were carried out, in which existing PEVs were categorized according to their cruising speed, cruising range and riding posture according to the investigating scenarios. Distance to get to MRT stations is between 0.4-3km for Taipei commuters. Thus, the advised speed of PEVs is 5- 15km/h, with an average riding time of 4.8-12 minutes. Proper vehicle weight is suggested between 10-50kg, while ideal cruising range of the PEVs is between 15-45km. As for riding postures, for slower rides, it is suggested to use stand-on riding posture, while semi-seated and sit-on design should be adopted to ensure safety for faster rides.

Key words: personal electric vehicle (PEV), usability, riding posture.

1. Introduction

As the economic constantly develops and the income continuously increases in Taiwan, the demand and use for motorbikes and cars are also rising. As a result, the networks in urban cities are over-congested during both morning and evening commuting periods. The traffic congestion problem is even worsening in the last decade due to insufficient land areas and saturated urban roads. Therefore, how to suppress the use of private modes and promote the use of public transportation is an important issue the government would like to deal with. Currently, the multi-transportation network is developing to overcome the situation and encouraging the people to utilize the walking or public transportation instead of driving as the current trend. Access to transit stations is a significant barrier to transit use in many urban regions. Station parking during peak hours is often limited, and most people are only willing to walk about one-quarter mile to transit stations (Cervero, 2001).

Only 5.4 percent of all trips (Hu. and Young, 1999). 2.68 percent of all commute trips (U.S Census Bureau, 2003), and 8.5 percent of all commute trips five miles or less are made by foot (Pedestrian and Bicycle Information Center, 2003). In addition, it is well known that walking access to transit drops dramatically with distance from transit stations : approximately 85 percent of transit access trips are made by foot within a quarter mile, ten percent within one mile, and two percent within two miles (Federal Transit Administration, 1996).In order to increase access to locations that are not accessible by mass transportation, and lower door-to-door trip times for short distances, this study attempts to explore the future role of personal electric vehicle (PEV) with feasibility and usability examined. This report documents the results of a two-part project: (1) literature research was undertaken on daily traveling patterns of Taipei metropolitan population and (2) work commute mode choice about district station and surrounding employment centers station. Secondly, a study of existing personal electric vehicles (PEVs) were carried out, in which existing PEV was categorized according to their speed, weight, cruising range, riding posture, and possibility of universally usable to the best time of PEVs to link between MRT in Metropolitan Taipei. As a result, guideline was established including specifications of personal electric vehicle design. The result of this study proposed a suggestion for future PEV design for urban transportation.

2. Daily Traveling Patterns of Taipei Metropolitan Population

Taipei City Department of Transportation (2005) presented that the urban commuters' mode choice in metropolitan Taipei is 26.5% primarily by the motorcycle, secondly is 23.8% by car , 43.1% by public transportation (bus, MRT, train, taxi etc), and others are 6.26%.(see Figure.1)

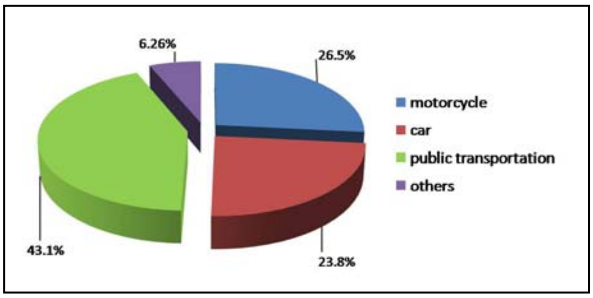


Figure.1 Urban Commuters' Mode Choice in Metropolitan Taipei

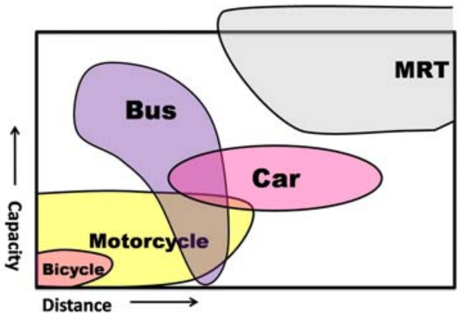


Figure.2 Daily traveling patterns

About the daily traveling patterns of metropolitan, when people start their trip from walking, they could complete their trip via one or several transportation according to their requirement. These transportations could be vehicle bus, rail or subway way etc. It causes the inefficiency of transportation and incomplete gasoline burning. Currently, the multi-transportation network is developing to overcome the situation and encouraging the people to utilize the walking or public transportation instead of driving as the current trend. (Wu, 2006). PEVs can provide important links among destinations and transport systems. They can also help link up different trips. (see Figure.2 and Figure.3)

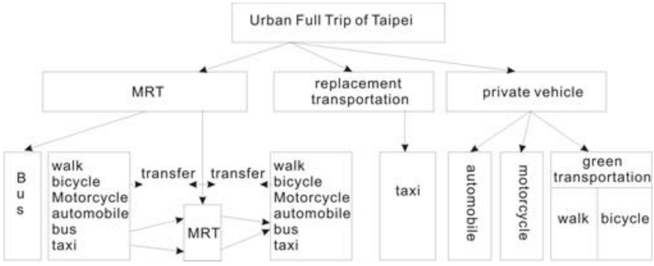


Figure.3 Urban Full trip of Taipei

Adapted from Development of Urban Full Trip Cost Models

(1) Start service in 1997, the Taipei Metro Network consist of 9 lines, with 90.5 kilometers railway and 82 stations presently. Average Daily Transport Ridership in July 2009 counts 1,326,558 and is stably increased (Taipei Rapid Transit Corporation, 2009). The construction and operation of a mass rapid transit (MRT) system for Taipei provided a good solution to its traffic problems. However, until 2009, 58.21% of urban daily journey still used private cars and motorcycles, compare to 12.19% of MRT journey (cite).Taipei MRT needs to extend lines and stations before a inclusive network of public transport is completed. Ironically, more than half of those using MRT for daily journey actually using variety of vehicles to have access to MRT stations (Taipei Rapid Transit Corporation, 2009). Needs of parking space around MRT stations has increased tremendously and cause much trouble. A light-weighted and easy-carry personal electric vehicle (PEVs) is proposed to fulfill residents' needs of short distance transport for access to public transport.

(2) Taipei MRT has operated for more than ten years. Though the basic traffic network has been built up to serve more citizens, the number of cars and motorcycles is still increasing. Although city government targeted to have 60% of daily journey using public transportation system, it is just not the case.

(3) Taiwan has a 0.277 average cars ownership, motorcycles 0.405 (Motor Vehicles Office, Taipei City Government, 2007), making a total of 0.682 per person of motor vehicles ownership and maintain a 1 percent annual growth rate. Under a fixed road surface situation, the congestion of rush hour traffic situation is becoming increasingly serious.(Liu, 2008).

2.1 About walking distance

Gang-Li Wu (2002) pointed out that the viable walking distance to a station should be no farther than 400 meters. Therefore, housing and office should best be located within 400 meters away from an MRT station. This is the so-called "walking distance" in transit-oriented development (Lin, et al., 2003). When the walking distance exceeds the acceptable range, people would use vehicles instead, in order to shorten the long, tiring path. According to a survey by Department of Budget, Accounting and Statistics, Taipei City Government, more than 50% of the people in this densely populated Taipei city use private vehicles to commute. These private vehicles are highly mobile, and they can link up trips.

2.2 Parking space insufficiency around the MRT stations

Just like residents in Taiwan, people in other countries often ride bicycles and motorcycles to MRT stations or other transport systems before they transit. However, parking spaces for these vehicles around the stations are usually poorly organized. What happens in Taiwan is that, there are either no parking spaces for bicycles and motorcycles around transit stations at all, or the spaces are not enough to accommodate. As a result, people have to park their vehicles on pavements. This not only makes it inconvenient for pedestrians to pass but also crams up the area (see Figure.4).

		
a.MRT at Taipei	b. Station at Denmark	c. Metro at Japan

Figure.4 Parking space insufficiency around public transportation

PEVs can assist people who have to walk before taking transport by saving time and linking up trips. It can also increase the travel volume of transit stations—which shall effectively improve traffic jam in metropolitan Taipei and the lack of parking spaces for private vehicles.

2.3 The Development of Personal Electric Vehicles

With their governments' support, private sectors of the US, European countries, and Japan have all been actively developing and promoting PEVs. Segway (Figure.5) from the America and Toyota (Figure 6) from Japan, for example, have both developed various types of lightweight PEVs. In Taiwan, since the 80s, the government has invested heavily to develop lightweight PEVs, and the Executive Yuan has recently re-stated its determination to promote electric motorcycles. As with the private scooter, more and more companies have begun research in this area, too.

	
Figure.5 Segway (image source：www.segway.com)	Figure.6 TOYOTA Winglet (image source：www.toyota.com.tw)

Therefore, lightweight PEVs can not only provide short-distance transport services. They are also easily portable and less polluting. They link up the transfer among MRT stations, reduce the use of private vehicles, and increase the travel volume of transit stations. In this paper, the transit stations trip-linking function of PEVs will be discussed. Complex ways of transport has contributed to the formation of several important traffic nodes in Taipei city. As these nodes link up more and more transport systems and routes, the transit distance among various spots increases, too.

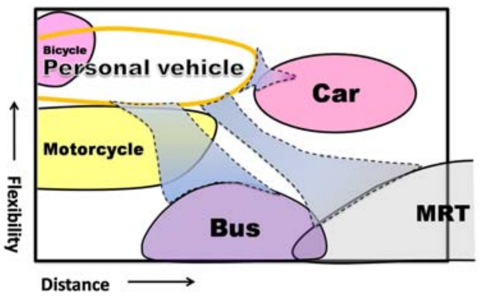


Figure.7 Developed as the missing link between MRT stations and the private vehicle

2.4 Personal Electric Vehicles will play the Future Role

According to the above research and based on a study "personal electric vehicles offer several potential benefits to consumers and to society" (Ulrich. 2006) PEVs offer several potential benefits to consumers and to society: (1)

Use as auxiliary transportation with public transportation: As distance from the center of an urban area increases, access to public transportation by walking. (2) Use as auxiliary transportation with an automobile: PEVs can be used in combination with automobiles by parking in satellite areas and traveling the last few kilometers. (3) Lower door-to-door trip times for short distances and/or in dense urban environments: Trips of 3–5 km present challenges. They are slightly too long to travel by walking, because the walking distance people acceptable range is 400 meters. (4) Reduction of automobile use in congested urban environments: Use of automobiles can impose substantial societal costs associated with air pollution, noise, consumption of non-renewable resources, congestion, parking, and traffic accidents. PEVs offer the prospect of delivering transportation services more efficiently in these environments, for at least some trips. (5) Quiet and clean transportation: PEVs offer the additional benefits of operating in near silence and without noxious fumes, high-temperature exhaust components, or dripping fluids. (6) Mobility for those with limited ability to walk: PEVs offer the prospect of extended mobility for people those aged 65 and older, have diminished. PEVs can effectively increase the travel volume of transit stations, make way for pedestrians, and reduce energy consumption; the government has to make it convenient for its citizens to use PEVs to link up trips first. Only under this win-win situation between the government and the citizens will the public replace cars/motorcycles with PEVs to improve traffic in metropolitan Taipei while enjoying less tiresome trips to MRT stations.

2.5 Light-duty Electric Vehicles Definition and Category

Generally considered to be a vehicle, sometimes as a motor vehicle or a class of hybrid vehicle, motorized bicycles are usually powered by electric motors or small internal combustion engines. Some can be propelled by the motor alone if the rider chooses not to pedal; while in others the motor will only run if the rider pedals. Some early motorized bicycles were powered by internal combustion engines whereas some utilized electric motors. With lighter batteries and better storage density, the electric motor has recently seen an increase in popularity.

Table 1. Various types of Electric vehicles

Category	Description
Electric vehicles	1.Referred to as an electric drive vehicle. (1) Electric car. (2) Large-scale electric transport: energy and motors: Electric bus、Rapid transit…etc. (3) Small scale electric vehicles: electric cars, light trucks, neighborhood electric vehicles, motorcycles, motorized bicycles, electric scooters , golf carts, milk floats, forklifts and similar vehicles.
Electric scooters	1.Two-wheeled Vespa-styled scooters 0-60 mph (0-100 km/h) 2.Two-wheeled Stand-up scooters (like a kick scooter) 0-25 mph (0-40 km/h) 3.Two-wheeled, side-by-side stand-up scooters like manufactured by Segway PT 0-12 mph (0-20 km/h) 4.Two-wheeled Seated scooters 0-25 mph (0-40 km/h) 5.Three-wheeled standup scooters like manufactured by Zap 0-15 mph (0-25 km/h) 6.Three- and four-wheeled Mobility scooter (disability riders) 0-10 mph (0-15 km/h) 7.Three- and four-wheeled Seated scooters/golf carts 0-25 mph (0-40 km/h)
Electric bicycle	1.Referred to as a light electric vehicle (LEV), is a bicycle with an attached motor used to assist with pedaling.
Electric motorcycle	1.Two-wheeled—greater than 30 mph (about 50 km/h).
	1.Three-wheeled—over 31 mph (50 km/h) (1) wheel in front and 2 in back, known as a delta design or the traditional trick (tricycle) design. (2) wheels in front and 1 in back, known as a tadpole design.
Self-balancing unicycle	1.another type of electric vehicle that is sometimes described as a electric motorcycle.

Source: Auroraz Scooters Inc.

In many metropolises around the world, PEVs are regarded as formal road vehicles to fully replace bicycles or partially replace motorcycles. They can also provide easy and convenient trips between households/offices and MRT stations. PEV manufacturing is still a fledgling industry. Therefore, PEV standards/definitions vary in different countries and institutions, especially the lightweight ones. Just in the US, Taiwan, and Japan, consumers understand about PEVs quite differently. The different definitions of lightweight vehicles in these three countries are listed as follows: (described in Table 2)

Table 2. Category of Electric vehicles

Category	America	Japan	Taiwan
Electric bikes & scooters	(1) Stand-on scoter、Sit-on cycles、Electric bikes(Non-road) (2)Multi/Light Electric cycles	(1) Substitute Light Electric cycles for 50cc motorcycle (2) On road	(1) Top speed：limited to 25km/h，Weight:（not including battery）40kg--- two wheel vehicles (2) Light Electric cycles
Light-duty electric vehicles	(1)Neighbr Electric Vehicles (2) small,four wheels, less than 10 miles City EVs (3) Safety.	(1) Light trucks (2) Hybrid Fuel Cell Vehicles (3) Safety	
Other On-road EVs	(1) Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) (2) Light duty (passenger vehicles) (3) Medium duty (trucks etc.) (4) Heavy duty (heavy equipment)	Electric Bus	
Non-road EVs	Forklifts, Golf carts, Sweepers, Personnel carriers, Tow tractors, Clean mobility center, etc.	approximately same with the left description	

Source: Cycle Electric, Alternative Fuels Commercialization Report

In the above Table 2：About the category and description of PEVs, there is not so much relevant document by comparing Taiwan with U.S. and Japan governments' statement. But also the researching area is not exactly the same. According to above, the author drew conclusion as below: PEV is different with other transportation vehicles and it is possible to have more detail classify on the definition and scope. It would make PEVs related research closer to traffic environment of Taiwan and using requirement for Taiwan people.

3. Distance from residences or offices to MRT stations and PEVs Ride Time Analysis

Taipei City Department of Transportation (2000) presented, Table 3. (below) illustrates that distance to MRT stations in Taipei：「less than 0.5km」(41.45 %)、「0.5km－1km」(28.53 %) and「1km－2km」(12.64 %)

Table 3. Distance to MRT stations.

Distance to MRT station (km)	less than 0.5(km)	0.5-1 (km)	1-2 (km)	2-5 (km)	more than 5(km)	total
people	754	519	230	162	154	1819
percentage (%)	41.45%	28.53%	12.64%	8.91%	8.47%	100%

Source：Taipei City Department of Transportation（2000）

Reference to Chiu (2004) A Study on Urban Commuters' Mode Choice Behavior design to Figure 7：distance between residences and transit station less than 1km(52 %),more than 2km(32.4 %)；distance between office and transit station less than 1km(64.4%), more than 2km(21.5%)；Average distance respectively is 1.29km and 1.05km.

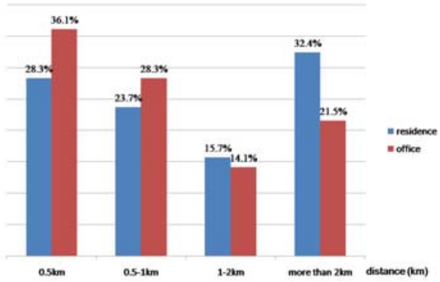


Figure.8 Distance from residences or offices to MRT stations

Based on **2. Daily traveling patterns of Taipei Metropolitan Population**：Walking distance to a station should be no farther than 400 meters and the above chart. This study to infer the following analysis：(a) Distance to a station=0.4-3km、(b)PEV riding speed：5-35km/h.

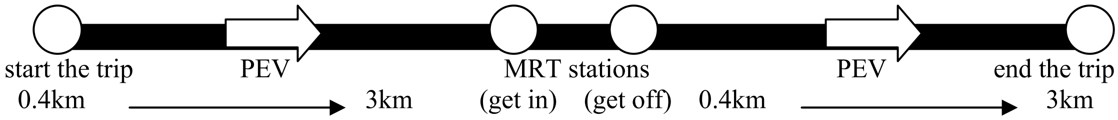
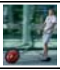


Table 4. distance about 0.4km and 3km, top speed 5km-35km to spent time and PEV's scattergram

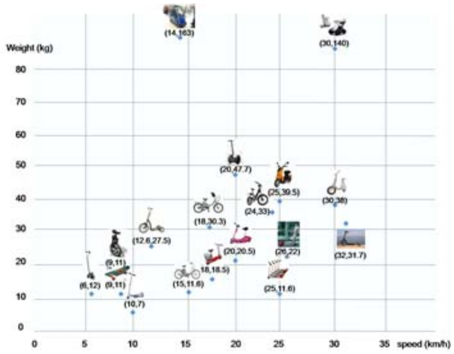
distance(km)	top speed (km/h)	PEV ride time (min)	PEVs (electric scooter/bike/ skateboard /motorcycle/others) top speed (km/h)		
0.4	5	4.8	Toyota Winglet	Self Balance	Electric Skateboard
					
3	5	36	6	9	9
0.4	10	2.4	HKES-045	NAVAJO-TR04N	Cabin Scooter
3	10	18			
			10	12.6	14
0.4	15	1.6	Lafree-432	NAVAJO-ES302	GIANT Lafree
3	15	12			
			15	18	18
0.4	20	1.2	Segway	HKES-001	A2B electric bike
					
3	20	9	20	20	24
0.4	25	0.9	ewalker -Petite	FP-S500	Easy Glider
3	25	7.2			
			25	25	26
0.4	30	0.8	Toyota i-Real	GRO Design	Zuumer
3	30	6			
			30	30	32

Above the Table 4, if the commuting distance is 0.4km. PEV's speed will best be 5-10 km/h, and the trip time shall be around 2.4-4.8 minutes. If the distance is 3km, PEV's speed will best be 15-20 km/h, and the trip time shall be around 9-12 minutes. According to a study survey result presented that motorcycle rider who can endure the average time that walking from the parking location to the destination is 12.6 minutes. (Chen, et al., 1997) Therefore, for the distance mentioned above, PEV's speed should best be 5-15 km/h, and it will take about 4.8-12 minutes to arrive.

Table 5. above Table 4 personal electric vehicle products' speed、weight and cruising range

products						
top speed (km/h)	6	9	9	10	12.6	14
weight (kg)	12	11	11	7	27.5	163
cruising range (km)	10	19	10	10	22	45
products						
top speed (km/h)	15	18	18	20	20	24
weight (kg)	11.6	18.5	30.3	47.7	20.5	33
cruising range (km)	5	16	40	38	22	32
products						
top speed (km/h)	25	25	26	30	30	32
weight (kg)	11.6	39.5	22	140	38	31.7
cruising range (km)	45	51	20	30	45	32

3.1 Relationship between speed and vehicle weight for personal electric vehicle



(speed , weight)

Figure.9 Relationship between speed and vehicle weight

(1) Figure 9 shows that speed and weight are not obvious. (2) PEVs average speed is 19km/h and whose speed is 35km/h are mostly between 10-50 kg. (3) Usually, with transportation design that meets safety standards, the lighter the vehicle is, the faster it goes. However, from the above chart, we can see that as PEVs get lighter, the speed becomes slower. Therefore, PEV design is different from other types of transportation design, which awaits more research and discussions in the future.

3.2 Relationship between speed and riding posture

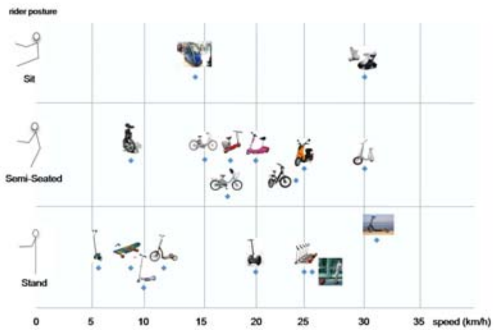


Figure.10 Relationship between speed and riding posture

Based the above figures, I suggested to categorize into three different types according to PEVs' riding posture. There are (1) Stand: standing straight ahead and it is highly mobile.., (2) Sit: as in a chair or have the backrest.

The posture is more comfortable. (3) Semi-Seated: high-seat and it is similar the posture which riding a horse or straddling vehicle. Users of semi-seated PEVs can change their riding postures at will. (Keegam, 1953)(1) From the above scattergram, we can see that the PEVs with a speed of 5-35km/h are 50% stand-on and 50% semi-seated. (2) Stand-on PEVs become more prevalent in categories of lower speed. In higher-speed categories, more semi-seated or sit-on PEVs are included.

3.3 Relationship between speed and riding posture

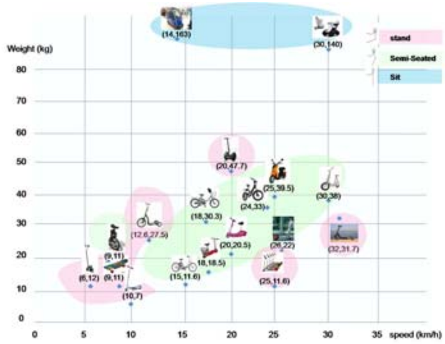


Figure.11 Relationship among speed、weight and riding posture

(1) From the above scattergram, we can see that stand-on PEVs are more scattered and semi-seated ones are more concentrated. Therefore, stand-on PEVs are highly mobile, and semi-seated PEVs are both mobile like stand-on PEVs and comfortable like seated ones. Users of semi-seated PEVs can change their riding postures at will, too. (2) Seated PEVs are heavier than the other two types. (3) If riding stand-on PEVs at a high speed, riders should be more careful about their safety because the vehicles are light. (4) The lower the center of gravity is, the more balance is. Therefore, semi-seated PEVs are safer than stand. (5) If the commuting distance is about 0.4-3km, the speed of the PEV should best be 5-15km/h. stand or semi-seated PEVs would suit this type of trips. (6) The results of riding posture suggest: Mobile：stand > semi-seated > sit；Comfortable：sit > semi-seated > stand；Safe：sit > semi-seated >stand.

4. Conclusions

PEVs offer the prospect of extended mobility for us. The PEV therefore offers many intriguing possibilities for extending the human range of mobility from about 0.4-3km (via walking) to 5km or more. This study proposes analysis and suggestions on PEVs for Taipei MRT stations commuting in the great Taipei area. (1) There are no clearly defined definitions of PEVs in Taiwan's laws and regulations. Moreover, no specific traffic policies have been made to ensure a safe environment for PEV users either, resulting in the dispersion of affair rights. It is suggested that more in-depth assessment and policies should be made to manage all related aspects of the use of PEVs. (2) Distance to get to MRT stations is between 0.4-3km for Taipei commuters. Thus, the advised speed of PEVs is 5-15km/h, with an average riding time of 4.8-12 minutes. Proper vehicle weight is suggested between 10-50kg, while ideal cruising range of the PEVs is between 15-45km. (3) As for riding postures, for slower rides, it is suggested to use stand-on riding posture, while semi-seated and sit-on design should be adopted to ensure safety for faster rides. (4) To obtain the high mobility of stand-on PEVs and the stability of sit-on PEVs at the same time, semi-seated ones can be taken into account. It is hoped, through the above analysis, to provide the government and PEV manufacturers some reference for law-making and PEV design in the future.

5. References

[1] Urban Commuters' Mode Choice in Metropolitan Taipei (2005) Taipei City Department of Transportation.

[2] Federal Transit Administration (1996) USA.

[3] Cervero. R. Walk–and–Rider: Factors Influencing Pedestrian Access to Transit, (2001) *Journal of Public Transportation.*, Vol. 3, No. 4, pp. 1-25. USA.

[4] U.S. Census Bureau. (2003) Census, (2000) Supplementary Survey. USA.

[5] Hu. P. S. and Young. J. R. (1995) Nationwide Personal Transportation Survey., Department of Transportation.

[6] Pedestrian and Bicycle Information Center. Walkinginfo.org. USA.

[7] Ulrich. K. T. (2006) Estimating the technology frontier for personal electric vehicles, Elsevier Transportation Research Part C 13.448-462. USA.

[8] Wu. Y. C. (2006) Allocation and Evaluation of Short-Linking Transit System in a Specific Area., Institute of Traffic and Transportation, National Chiao Tung University, Hsinchu.

[9] Wu. G. L. (2002) *Developing Homeplace Identity to Promote Sustainable Science City Development.,* National Taiwan University for the Research Project on Special Topic, NSC89-2415-H-259-013-SSS. Taipei.

[10] Taipei Rapid Transit Corporation (2009). Ridership Counts. <http://www.trtc.com.tw/e/future.asp> Cited at 30 Aug. 2009.

[11] Motor Vehicles Office, Taipei City Government, (2007). <http://www.mvo.taipei.gov.tw/>

[12] Liu. T. W. (2009) A study on relationship among service quality, passenger satisfaction and royalty of Taipei rapid transit systems., Graduate Institute of Urban Planning, National Taipei University. Taipei.

[13] Chang. S. K. and Guo. Y. J. (2007) Development of Urban Full Trip Cost Models., Transportation Planning Journal,Vo1. 36, No. 2, pp. 147-182. Taipei.

[14] Lin. J. J.; Feng. C. M. and Hu. Y. Y. (2004) Analysis of Corridor Development before and after MRT Blue Line Opening in *Taipei. Transportation Planning Journal,* Vol. 3, No. 2, pp.361-389. Taipei.

[15] Research of Urban Motorcycles Trend Analysis in Taipei., (2001) Institute of Transportation, Ministry Of Transportation and Communications, Important Abstract of Research Topic. Taipei.

[16] Chiu. C. S. (2004) A Study on Urban Commuters Mode Choice Behavior, Institute of Civil Engineering, National Chi Nan University. Nantou.

[17] Auroraz Scooters Inc. (2007) China. < http://www.scooterschina.com/scooter-resources.htm>

[18] Cycle Electric Organization in America and California Government. (2006) *Alternative Fuels Commercialization Report.* USA.

[19] Taiwan Electrically Auxiliary Bicycle and Electric Bicycle Safe Examination Laws and Regulations. (2000) Taipei City Department of Transportation. Taipei.

[20] Chen. T. Y.; Chung. C. L. Hwang. S. F. (1999) Using Habitual Domains Theory to Explore the Interaction Between Attributes in the Decision Making of Mode Choice., *Transportation Planning Journal*, Vol. 26, No. 1, pp.1-36. Taipei.

[21] Keegan, J. J. (1953) Alterations of the lumber curve, *Journal of Bone and Joint Surgery.*, 35.