chapter 14

Mapping the Walking Accessibility, Bus Availability and Car Dependence:

A Case Study of Xiamen, China

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Abstract: As stated in existing literature, travel behaviour and transportation choice are closely related to urban form and built environment. The study presented in this chapter attempts to conduct a city-wide evaluation of the walking accessibility to urban facilities and the availability of public transport, as well as the relevant potential car dependence. By taking the city of Xiamen, China, as a case study, the research has generated some useful information for both public transport and urban facility providers by illustrating the spatial patterns and indentifying the problematic areas. The methodology developed in the research might also provide a reference for other studies.

1. INTRODUCTION

Since the phrase was coined in 1989 by Newman and Kenworthy (1989), "car dependence / automobile dependence" has been frequently involved in the literature in the fields of travel behaviour, transport planning, traffic management, and urban policy-making. Although there has not yet a common definition by far, the connotation of the phrase might be briefly described as "a high level of physical need or/and mental demand for car transport".

Car dependence is associated with a range of environmental, economic and social problems. In general, increasing car dependence can worsen the transportation structure of cities, retard the construction of green transportation system, intensify the oil vulnerability and the shortage of urban land and infrastructure, aggravate environmental stresses and Greenhouse Gas emissions. Besides, it can also result in the loss of street life and community, isolation in suburbs, access problems for car-less people, as well as failing health for car-drivers. Compared with other forms of transportation, car traffic is of the highest cost, lowest efficiency, heaviest pollution, and most GHG emissions per passenger. Therefore, it is generally suggested to be ranked as the least preferred form in "greening" urban transportation system (CNU, 1999; Huang, 2004; Pan, et al., 2008; China Society of Urban Studies, 2009). A city cannot be considered "sustainable" anyway if it is car dependent (Newman and Kenworthy, 2000). Researchers use direct words, such as "reducing", "overcoming", "combating", "abandoning" and so on, in the titles of their works to distinctly express the opposition to car dependence (Newman and Kenworthy,1999; Stradling, 2002, 2003; Guo, 2010). With the popularity of the sustainable development concept, there has been growing public awareness of the damaging impacts of cars on cities. As the result, reducing car dependence to improve transport sustainability has become a major goal of transport policy in many cities (Cullinane and Cullinane, 2003).

Reviewing a variety of existing literature, we may say that the factors determining or influencing car dependence can make a long list, and vary from place to place. However, according to Gorham (2002), the components of car dependence can be sorted into three categories: (1) *Physical /Environmental Dependence* - caused by the built environment, including urban form, regional structure, the distribution of activities within the structure, and the nature or status of collective transportation modes; (2) *Social/Psychological Dependence* - caused by the symbolic meanings, or say "signs", of cars in the society and in consumption culture, or/and the mental desire for the convenience and comfort of car travel; (3) *Circumstantial /Technological Dependence* - describes a relationship between the technological capacities of car (speed, carrying capacity, privacy, etc.) and the particular requirements of an individual life (e.g. a professional musician needs a car to carry music instrument between home and working place. The instrument itself is large, bulky, and expensive, and therefore not suitable for public transit). In China, it is also the case when people need to travel with pets (pets are not allowed to be carried into public transport in China). "The three types of car dependence outlined above interact significantly", said Gorham, and therefore "it is probably difficult in practice to identify particular behaviour with any one of them".

There is a conventional thinking that the increase of private cars is an outcome of growing wealth. However, owning a car doesn't necessarily mean frequent car use, even car dependence. As shown in the studies conducted by Kenworthy and Laube (1999, 2001) based on the data of over

100 cities from around the world over the period from 1960 to 2000, the patterns of automobile dependence in cities are not significantly related to differences in wealth between cities, but do vary in a clear and systematic way with land use patterns. The most auto-dependent cities (low density cities in US and in Australia) are less wealthy than some other densely-settled and more transit-oriented cities in Europe and Asia (such as Singapore, Hong Kong, and Tokyo) that have very low automobile dependence. Therefore, "there are stronger factors determining automobile dependence" (Newman and Kenworthy, 2000). According to a multiple regression analysis done by Newman and Kenworthy, very strong correlations were found between the level of automobile use (indicated by transport energy use) and the parameters such as the level of public transport provision, public transport speed to traffic speed ratio, length of road and parking provision; but the strongest correlation is with urban density. And "thus, achieving a more sustainable urban form inevitably involves the development of densities that can enable transport, walking and cycling to be viable options (Newman and Kenworthy, 2000)". "Urban structure does matter" in shaping travel behaviour and car dependence (Naess, 2006). In book "*Seven Rules for Sustainable Communities*", Condon (2010) also emphasizes how essential it is to create urban structure and built environment in right way for reducing car dependence and promoting sustainability. New Urbanism, as an dominant planning theory in post-modern society, also advocates "compact urban form", "mixed land use", "pedestrian-friendly built environment", and "transit-oriented development" as the key elements for sustainable urban development (CNU, 2000). Therefore, the increase of car use cannot be simply attributed to growing wealth. We should also think over the way we build and arrange our cities.

That is why urban planning and design is widely recognized as essential in coping with car dependence. By reshaping cities' built environment, planning tools can be used to influence the amount of travel and the proportions carried out by different modes of conveyance. Right design will encourage walk and discourage car use. For doing so, a city-wide evaluation of the car dependence as well as the related walking accessibility and bus availability is necessary. A city-specific analysis of the spatial pattern of car dependence will be even more helpful for local planners and decision makers to get the information about where the problematic areas are and what corresponding solutions there may be. On this account, by taking the city of Xiamen as a case study, with the aid of ArcGIS software, and based on the examination of the walking accessibility to urban facilities and the availability of public transport, the study attempts to evaluate and map the potential car dependence across the city. The result of the study is also useful to identify where is the most appropriate location for new urban facilities as well as public transport services.

This chapter is organized into six sections. Following this introduction, the background of the research is presented in the coming section 2 in order to provide a bigger picture. In section 3, the appropriate level of detail is discussed for measuring the overall walking accessibility from a given block to all types of urban facilities. The reason to start with measuring walking accessibility is that the motor traffic demand will be low if the walking accessibility is good. And then, the availability of public transportation is measured in section 4. The more available the public transit lines in a block, the better the area connect to other areas in a city. In section5, in view of that the level of car dependence is somehow inversely proportional to the walking accessibility and the availability of public transport, the potential car dependence across the city of Xiamen city is measured and then mapped in the hope of providing useful information for local planners and decision-makers. Finally, the chapter concludes with a summary in section 6.

2. BACKGROUND OF THE RESEARCH

Since the reform and opening up, cities in China have generally been experiencing rapid growth and remarkable restructuring. As a result, both the macro and micro landscape of Chinese cities have been changing markedly. While the overall urban form is getting larger and increasingly fragmented, the spatial pattern of people's daily life has also changed. Working and living are getting separated day by day with the commercialization of housing (noteworthily, many of commercial houses are built in newly developed outskirt of a city) and the disappearing of former "work-unit compound" structure (i.e. welfare housing or factory dormitories nearby working place). More and more people have to therefore deal with long, frustrating commutes on a daily basis. Meanwhile, urban facilities (such as shops, hospitals, schools, public transport, and so on) are also totally or partly "commercialized", resulting in certain service vacancy sometime/somewhere when/where the residents density is not high enough to make the services profitable, and bringing difficulties for introducing "TOD"(transit-oriented development) model. Together with the inducement of car advertisements and the increase of people's income, more and more people choose to buy a private car when they can just afford it. As the result, there has been a surge of "car-booming" in China.

In 2009 China overtook the USA to become the world's largest market for personal vehicles, with sales of 13 million cars and light trucks in that year. The annual sales in 2010 and 2011 are projected to 18.06 million and 18.51 million, respectively. In fact, China has become the world’s number one auto maker and seller since 2009, with two-digit rates of annual increase. Road networks in mega cities like Beijing and Shanghai (as well as in many second-tier cities such as Xi’an, Dalian, and Xiamen) have doubled or tripled over the past decade to adapt to the growth of automobile, but still continuously suffer from ever worse congestions and lack of parking. As more cars appear on city streets, more and more pedestrians and cyclists are crowded out. Between 1995 and 2005, it is reported that bicycle ownership dropped 35% in China. In the meantime, the development of public transport is far from satisfactory. As a result, urban transportation is tending to increasingly car dependent in Chinese cities.

The increasing car dependence may be particularly alarming for a city like Xiamen. The city of Xiamen is located on the southeast coast of China (117° 53’ E - 118° 27’ E; 24° 25’N - 24° 55’N), one of the earliest four Special Economic Zones (SEZs) in China and a major city on the west bank of Taiwan Strait with a total population of 3.53 million, about half of which (52.7%) in the Xiamen Island, i.e. the earliest developed area of the city with an area of 131 km^2, and enjoying a fine reputation of “a garden city at sea” and “a winner of the UN Habitat Award” with beautiful natural scenery and living environment. It has also been designated as one of the ten "China's low-carbon pilot cities" since 2010, and set its ambitious target of “making Xiamen a role-model of China’s low-carbon city”. However, one of the biggest challenges has been generated by the rapid increase of motor vehicles (especially private cars).

According to the latest data released by the Department of Traffic Police, the present number of motor vehicles has reached 827.15 thousand by the end of February 2012, among which 43.84 thousand are private cars, accounting for 53.01% of the total. In recent three months, there are averagely 6628 new motor vehicles added every month. The number of newly registered motor vehicles in January alone is 9324. Over 70% of the new vehicles are private cars. According to the figures of the 6th national population census, the resident population in Xiamen is 3.53 million, forming up 1.24 million households. That means car ownership has reached 35.36 per hundred households in the city (or say, one car every 2.83 households, or 12.42 cars per hundred people). Although these numbers seem still modest compared to 94 cars for every 100 people in the USA, the speed at which automobile use is expanding is alarming. The traffic jam has become so serious that the average vehicle speed has fallen to 20 km/h below at peak time, over half of intersections are at the saturated condition, and public parking lots are seriously in shortage. The casualties and economic loss of traffic accident also keep growing, not to mention a series of other negative consequences, such as environment pollution, oil shortage, greenhouse gas emissions, extrusion of public space, access problems for car-less people, and worsening of personal mobility and quality of life. These are not only challenging the city's efforts towards a "role-model of low carbon city" but also seriously damaging its image as a "ecological garden city" and its attractiveness to investment and talents.

The damage of car-oriented transportation have aroused public concerns and complaints. Pressures have also been placed on local authorities at all levels since China announced its goal of “40-45% reduction of carbon emission by 2020 on 2005 level” at the Copenhagen Conference. Besides developing new vehicles driven by alternative “clean energy”, like that described in *China’s National Climate Change Program* (NDRCC, 2007), more and more policy analysts have also seen the manipulation of urban form as a tool to cut carbon emission by reducing travel demand and car dependence. For doing that, a city-wide analysis and region-specific guidance is much needed for local decision-makers about where the problematic areas with highest automobile dependence are and what corresponding solutions there may be.

3. WALKING ACCESSIBILITY TO URBAN FACILITIES IN XIAMEN

3.1 Relationship between walking accessibility to urban facilities and motor traffic demand

It has become a common knowledge that the energy consumption and environmental impact per capita passenger of different transportations increase in the order: walking → bicycle → rails and subway → bus → taxi → carpool → single-occupancy car. So, to develop an environmental-friendly and low-carbon transport system, a major principle is to promote the non-motorized transport, especially walking.

There is a growing acknowledgement that the travel demand and choice (motor or non-motor, transit or car) in urban area are affected by urban spatial structure and land use characteristics. A large body of researches have addressed this issue. A general wisdom is that the enforced dependence on automobile and long distance travel will be minimized in compact cities (indicated by urban density) with well distributed urban facilities and job opportunities. Car dependence can be largely reduced through critical design that create diversity of urban amenities within 10- to 30-minute walking (Newman and Kenworthy, 2006). Overcoming car dependence thus, to a large extent, becomes a question of whether people can access the facilities of a city without a car. Walking accessibility to urban facilities，which refer to the services and activity possibilities that residents and visitors of a city may use and visit，is then become an important indicator. In general, the motor traffic demand will be low if the walking accessibility to urban facilities is good (as walking is a comfortable choice to access needed services, motor transport will be less necessary then); vice versa, the motor traffic demand will be high if the walking accessibility is poor.

3.2 Measuring the walking accessibility to urban facilities

Accessibility is a measure of "the ease of reaching places" (Grengs, 2001). Measuring the walking accessibility of a certain place to urban services/facilities is one of the key steps to evaluate the potential car dependence. Moreover, in planning terms, measuring the accessibility to local services and facilities also allows improvements to be made more precisely to either transport or the way services are provided.

There have been a rich body of literatures addressing the methodology of measuring accessibility. A variety of accessibility measures have been developed. Most published measures of spatial accessibility to urban facilities can be classified into four categories: (1) provider-to-population ratios, (2) travel impedance to nearest provider, (3) average travel impedance to a set of providers, (4) gravitational models of provider influence (Winter, 1992). By taking "path distance" as the indicator of "travel impedance" and with Cooper and Wright's relevant work for the main reference (Cooper and Wright, 2009), the measurement of "walking accessibility" developed in this research is a sort of combination of the second and the third category.

To measure the walking accessibility across a city, it requires a grid of areas at an appropriate level of detail to base its calculations on. This research divides the case city into hundreds of “blocks”, each of which is a grid defined by the city’s second-class roads, excluding the areas of waters, wetland, farmland, forest land, ecology protectorate.

Suppose there are totally n blocks in the city, m types of urban facilities are considered, and d_{ij} stands for the average shortest path distance from the centre of block i to the nearest three facilities of type j. (The nearest three facilities of certain type are the most frequently visited ones for the people living in a certain block). Evidence from many studies suggests that there is a relationship between the path distance and the crow-fly distance. More specifically, as a common rule in the field of transportation planning, the former is roughly 20-30% greater than the latter (Reneland, 2000). The specific number is 31% greater in the case city Xiamen according to a sampling test based on the road map of Xiamen. That means the value of d_{ij} can be calculated as 1.31 times of the average crow-fly distance from the geographic centroid of block i to the nearest three facilities of type j.

Those urban facilities that apparently generate or attract travels within a city are investigated, including:

- *Type1*: shopping centers (supermarkets, department stores, shopping malls) with business space over 5000 square meters each;
- *Type 2*: kindergartens and primary schools;
- *Type 3*: secondary schools;
- *Type 4*: hospitals/medical centers ranked Class I and Class II;
- *Type 5*: major public culture, entertainment, sports centers.

The calculating formula of “the *overall* walking accessibility from a given block (e.g. the block i) to *all types* of facilities ” (Marked as A_i) is designed as the following:

$$A_i = \sum_{j=1}^{m} W_j a_{ij}$$

Where W_j ($0<W_j<1$) is the weighting coefficient of certain type *j* facility (*j=1, 2, …., m*; in the case study, *m=5*), which will be set according to the results of a questionnaire survey about the frequencies that people visit different urban facilities. The index a_{ij} stands for "the *individual* walking accessibility from the block *i* to the type *j* facility". The value of a_{ij} is related to the value of d_{ij} as well as the general opinions that people judge the distance as "travel impedance". According to the investigations conducted by many previous studies, "within 5 minutes" is generally regarded as a "comfortable distance for walking"; most people are willing to walk if it takes less than 10 minutes, and more likely to take motorized transport (public or private) if the time exceeds 15 minutes. Therefore a walking time of 15 minutes can be regarded as a watershed between "good" walking accessibility and "bad". Table 1 shows the correspondences between path distance, walking time, the evaluation score of walking accessibility, and the status of walking accessibility (see Table 1 below).

At last, "the overall walking accessibility to urban facilities from block *i*", namely A_i, can be obtained through above processes. A_i ranges from 0 to 100. The greater the value of A_i, the better the overall walking accessibility from the given block *i* to urban facilities is, and hence, the lower the potential demand for motorized transport there will be. Conversely, the smaller the A_i is, the poorer the overall walking accessibility is, and the higher the potential demand for motorized transport there will be.

All these processes of calculation can be facilitated by GIS software. And the results can be visualized as a kind of “walking accessibility map”, where the values of A_i can be shown in different colours after being classified into five levels.

Table 1. Correspondences between path distance, walking time, the evaluation value of walking accessibility, and the status of walking accessibility.

Path distance (d_{ij}) (m)	0-300	301-600	601-900	901-1200	1201-1500	> 1500
Walking time (minutes)	< 5	5-10	10-15	15-20	20-25	> 25
Evaluation Value of Walking Accessibility (a_{ij})	100	80	60	40	20	0
Status of Walking Accessibility	Comfortable	Easy	Fine	tolerable	barely accesible	difficult to do so
Overall Walking Accessibility (A_i)	> 90	71-90	51-70	31-50	11-30	0-10
Evaluation Level	Very Good	Good	Fine	Tolerable	Poor	Bad

3.3 Data and results

According to the methodology described above, this project carries out an empirical case study in Xiamen, China.

First of all, the "Master Plan of Xiamen City (2010-2020) - The Overall View Map" is taken as the base map of the study after vectorization processing in ArcGIS. According to the road grid, combined with land use classification and terrain maps, the entire city's construction land is divided into 560 "blocks" , each of which is a grid defined by the secondary-class roads, excluding the areas of waters, wetland, farmland, forest land, ecology protection zones. Then using the ArcGIS relevant analysis tools, the "centroids" of those 560 blocks are extracted to be the location of "the centers of the blocks".

Various data of urban facilities are obtained from Xiamen Municipal Bureau of Commerce, Bureau of Education, Bureau of Health, Bureau of City Planning, and so on. There are totally 78 shopping centers, 696 primary schools and kindergartens, 82 secondary schools, 20 hospitals, and 25 public cultural/sports centers. These data are processed in ArcGIS to create a database for the research. The locations of the facilities are marked on the base map.

Then, using ArcGIS analysis tools, the average crow-fly distances from each block's centroid to the nearest three facilities of each type are measured. According to a sample analysis based on the road map of Xiamen, the path distance d_{ij} is 1.31 times of the crow-fly distance. Further, the value of d_{ij} can be converted into a_{ij} according to the score assignment standards shown in Table 1.

After that, through experts inquiry and discussion among the research team, using analytic hierarchy process (AHP), the weight coefficient W_j of each type of urban facility is established: W_1=0.4174 (shopping centers), W_2=0.2634 (kindergartens and primary schools), W_3=0.1605 (secondary schools), W_4=0.0975 (hospitals), and W_5= 0.0612 (cultural/sports centers).

At last, the overall walking accessibility to urban facilities in block *i*, namely *Ai*, can be obtained according to its calculating formula. A_i ranges from 0 to 100. The greater the value of A_i is, the better the overall walking accessibility from the given block *i* to urban facilities is, and hence, the lower the potential demand for motorized transport there will be. In accordance with the standards shown in the last two rows of Table 1, the final results of A_i are assessed into 6 levels: very good, good, fine, tolerable, poor, and bad. Using ArcGIS grading tools, the results can be visualized into Figure 1 (see below). The figure directly reflects the spatial pattern of the overall walking accessibility to urban facilities. It also indirectly reflects the spatial pattern of the potential demand for vehicle transport.

As the Figure 1 shows, there is nowhere in the city achieving the level "Very good"; only the old downtown area on Xiamen Island and a small number of blocks in Haicang district and Tong'an district make it to "Good" or "Fine"; Most of the remaining areas only get "Poor" even "Bad", which means it is not convenient or unlikely to access urban facilities by walking there, and thus may result in high potential demands for motorized transport. Figure 1 also indicates that **a**lmost all types of urban facilities are mainly located on Xiamen Island, i.e. the earliest developed area of the city, leading to an obvious imbalance between inside and outside of Xiamen Island.

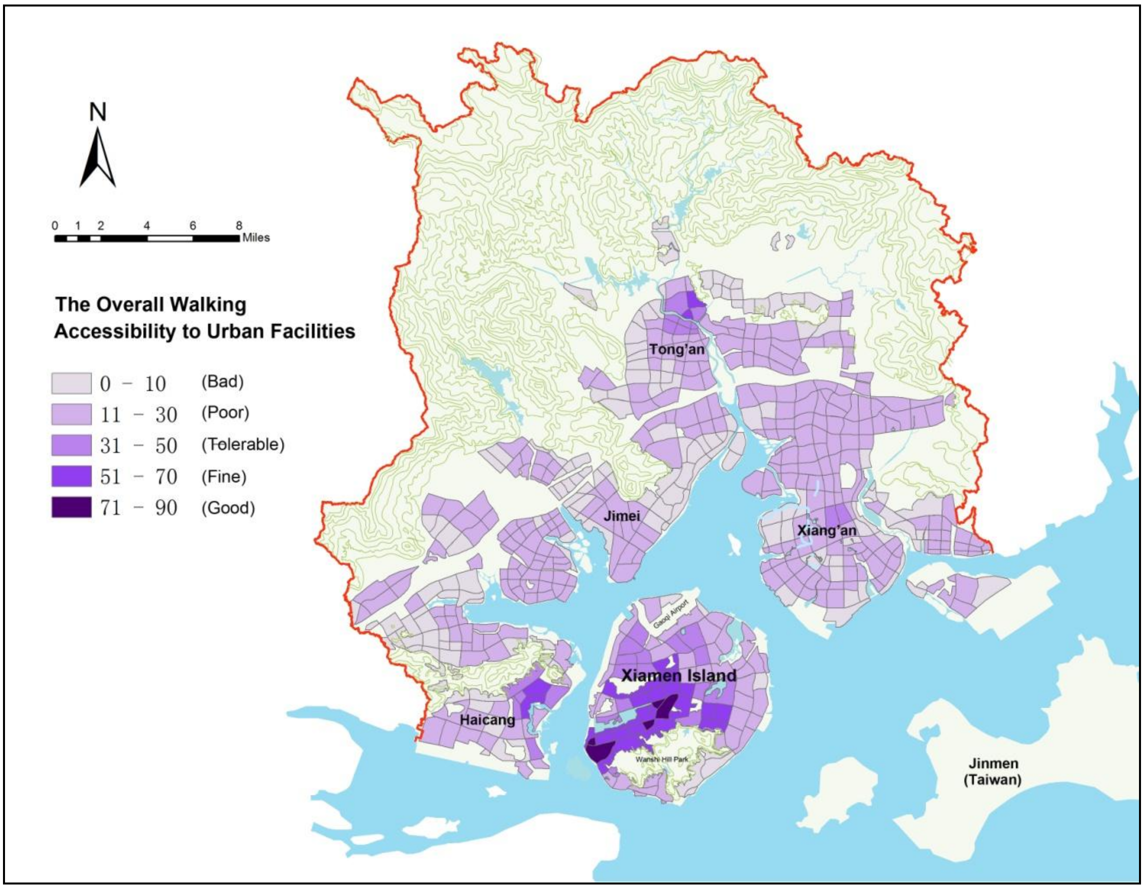

Figure 1. Spatial pattern of the overall walking accessibility to urban facilities in Xiamen city

4. AVAILABILITY OF PUBLIC TRANSPORT IN XIAMEN

4.1 Connection between availability of public transport and car dependence

As stated above, a major principle of developing a sustainable "green" transport system is to promote the non-motorized transport (especially walking). By adding urban facilities in the areas where the pedestrian accessibility is poor (i.e. making facilities closer to people), potential demand for motorized transport can be reduced to some extent. Besides, it can also reduce the probability of long distance travel with single destination. However it is unrealistic to distribute urban facilities to every corner of the city. Besides, those high-order services that demand a 'threshold radius' beyond walking scale cannot stay survival if they are too close to each other. Moreover, as the city expands and its structure gets loose and fragmented, the distances between residence, working, and service facilities are gradually getting larger, normally far beyond the walking reach. These make motorized transport inevitable. Then, "the second choice" will be necessary. Comparatively efficient, fair, energy-saving and low carbon-emitting public transport rather than private cars should be encouraged for inevitable motorized transport. Besides encouraging non-motorized transport (walking, biking, etc.), promoting public transport is also a main solution to the problem of car dependence.

However whether the public transport can become a dominant choice for local residents, and how competitive it is compared with private cars, depend heavily on its availability. "Availability" is a concept containing the meaning of "possibility to obtain it", "ease to access it", and "utility to use it". It is often used to examine whether medical facilities or other resources are fairly allocated, convenient to access, and efficiently used (Winter, 1992; Hearn, 1998). The better the availability of public transport is, the less possible the private cars will go.

4.2 Measuring the availability of public transport

Concerning the public transport, the research introduces the concept "availability" to express the possibility and convenience to get public transport, as well as the utility to use public transport. The availability of public transport in a certain area is certainly in proportion with the amount of public transit stations, but more determined by the number of transit lines relating to those stations. The more the public transit lines there are, the better this area is connected to other areas of the city (i.e. the better the utility to use the public transport will be), and thus the more possible local habitants would take public transport. In view of this, this study measures the "availability of public transport in a certain block" based on the "total number of those public transit lines that set up at least one station within the block" , and then ranks the results through the general comparison of all the blocks with the aid of grading tools in ArcGIS.

4.3 Data and results

Considering that the rail transit system has not yet available in Xiamen and the Bus Rapid Transport(BRT) has only been operational in a small area so far, this study focuses only on the well developed conventional public transport - bus system.

First, according to the data collected from the Xiamen Public Transportation Group, Inc., Tuba (www.mapbar.com), and Mabc (code.mapabc.com), totally 208 bus lines together with all the bus stops are processed into the base map (data items including stop name, stop site with latitude and longitude, line number, line path, etc.).

Then, using the tools of "area + buffer", each of the total 560 blocks and its "border streets" are integrated as a united unit. As a result of this process, when we extract a block from the map, we extract not only the internal area of the block, but also the streets surrounding it as boundaries.

After that, using the relevant analysis tools in ArcGIS, all the bus stops are extracted from each block (including its boundary streets) and the total number of bus lines relating to those stops are counted.

In the results of last step, the minimum value is 0 (which means there's no bus stop in that block), the maximum value is 76 (i.e. there're 76 bus lines with stops in that block). By using the classification tool in ArcGIS and the "Natural Breaks" grading option, all the 560 blocks are divided into 5 levels and differentiated in colours. The final result is shown in the Figure 2. Those blocks with higher values (in deeper colour) indicate that the bus availability is relatively good there, while those with lower values (in fainter colour) mean relatively poor bus availability. Thus, the figure can generally reflect the spatial pattern of the availability of public transport across the city.

As shown in Figure 2, the spatial pattern of bus availability in Xiamen is much similar to that of walking accessibility to urban facilities: only the old downtown area on Xiamen Island and a few blocks in Tong'an district have reached "good" or "fine" level; in most areas it is only "poor" or "bad" level. There is also a significant gap of the availability of public transport between the Xiamen Island (the earliest developed area) and the outside districts on continent (the newly developed areas). This indicates a noticeable lag and insufficiency of the construction of public transport system in those new districts outside of Xiamen Island in the ongoing transition of Xiamen from a "island city" to a "bay city", in which the development of those outside districts is set as the "key strategy" of the plan.

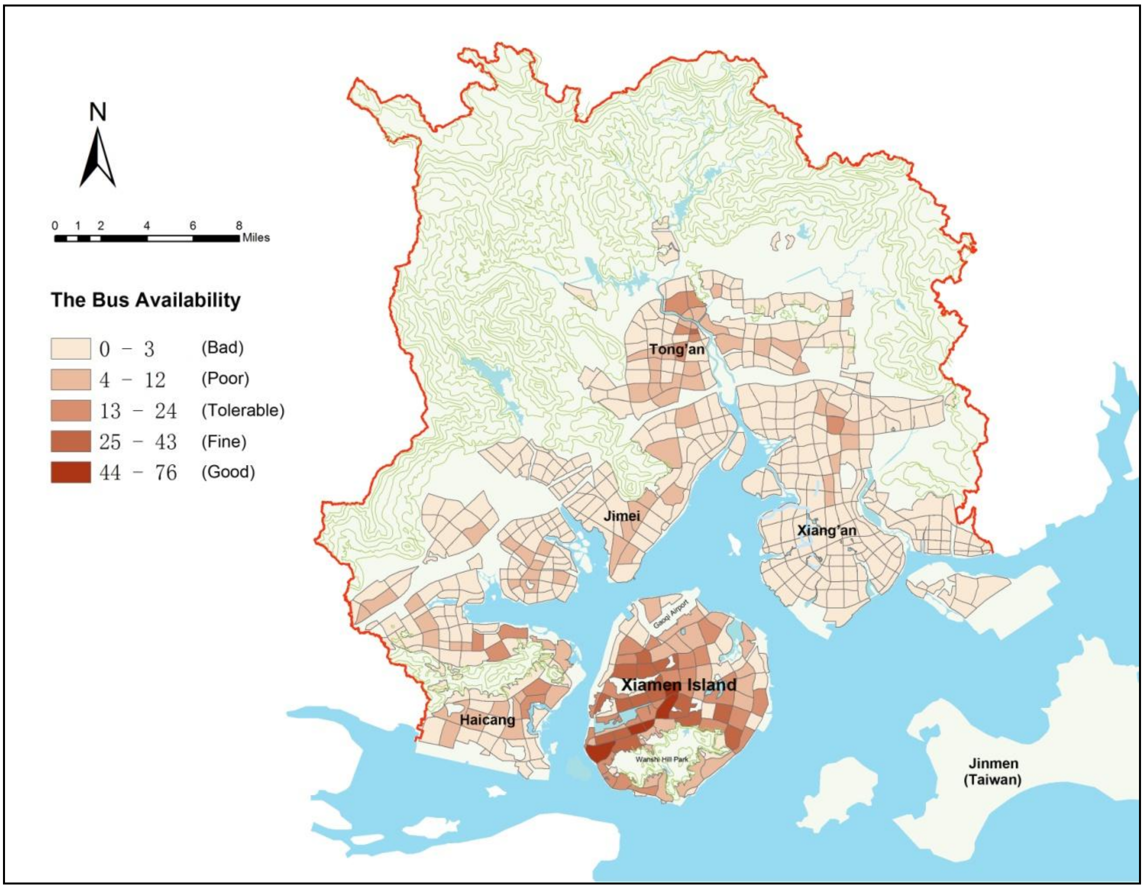

Figure 2. Spatial pattern of the bus availability in Xiamen city

5. MAPPING THE CAR DEPENDENCE

5.1 Relations between walking accessibility to urban facilities, availability of public transport, and car dependence

As stated at the beginning of the chapter, the causes of car dependence can be sorted into three categories: physical/environmental dependence, social/psychological dependence, and circumstantial/technological dependence. And as Gorham addressed, it is probably difficult in practice to identify particular behaviour of any one of the three categories of because they interact significantly (Gorham, 2002). Therefore, it is not that easy to measure the car dependence. And it is even harder to overcome the car dependence in practice, especially the social and psychological dependence (Begg, 1998; Cullinane and Cullinane, 2003; Mackett, 2009). Nevertheless, there are still widely recognized interrelations between the car dependence and the built environment, including urban form, regional structure, the distribution of activities within those structures, and the nature or status of collective transportation modes. Walking accessibility to urban facilities and availability of public transport are essential components of city's built environment. Although there are some arguments about how significantly the urban built environment can impact on the car dependence (Simmonds and Coombe, 2000; Handy and Clifton, 2001), it is still safe to say that the level of the car dependence is somehow inversely proportional to the walking accessibility and the availability of public transport. The better (worse) the accessibility and availability are, the lower (higher) the dependence would be. That's why it is still widely regarded as a meaningful and helpful way to optimize the urban form and built environment and to improve the public transport for overcoming car dependence. Despite some other factors, including social values, automobile culture, personal habits, and psychological needs, that urban planning could hardly have effects on, the performance of both the walking accessibility to urban facilities and the availability of public transport can still reflect the potential extent of car dependence. The analysis of its spatial pattern can provide useful information for urban planning and relevant policy- making.

5.2 Evaluation of potential car dependence

In above sections, the walking accessibility to urban facilities and the bus availability in 560 blocks in Xiamen have been evaluated, and the results are differentiated into five levels: Good, Fine, Tolerable, Poor, and Bad. Considering the situation that car dependence is related to both walking accessibility to urban facilities and bus availability, and the level of walking accessibility may be different from the level of bus availability in a block, the scoring method as following is designed to quantify the potential car dependence in each block:

(1) using "five-point scaling", quantify the five evaluation levels of "Good", "Fine", "Tolerable", "Poor", and "Bad" into "evaluation scores" 5, 4, 3, 2, 1, respectively;

(2) let "the evaluation score of potential car dependence = the evaluation score of overall walking accessibility to urban facilities + the evaluation score of bus availability". And thus the minimum evaluation score of potential car dependence will be 2 (i.e. both walking accessibility

and bus availability are "Bad") while the maximum will be 10 (i.e. both walking accessibility and bus availability are "Good");

(3) divide the possible scores of potential car dependence (2 to 10) into five levels: highest dependence, high dependence, average dependence, low dependence, and lowest dependence (details seen in Table 2).

Table 2. Evaluation score and ranking level of "potential car dependence"

Evaluation score of "potential car dependence"	2	3-4	5-6	7-8	9-10
Possible combination of "overall walking accessibility" and "bus availability"	Bad+Bad	Bad+Poor Bad+Bad	Bad+Good Poor+Fine Poor+Tolerable Tolerable+Tolerable	Poor+Good Tolerable+Good Tolerable+Fine Fine+Fine	Fine+Good Good+Good
Ranking level of "potential car dependence"	Highest dependence	High dependence	Average dependence	Low dependence	Lowest dependence

5.3 Data and Results

Applying the method described above, through layer accumulation analysis in ArcGIS, all evaluation scores of the potential car dependence in total 560 blocks in Xiamen are calculated. And then according the five-level division standards shown in Table 2, scores are converted to corresponding levels. At last "a map of potential car dependence" is generated, on which different levels are displayed in different colours (Figure 3).

As shown in Figure 3, there are distinct spatial disparity of the potential car dependence across the city. Because the best (worst) areas of walking accessibility are very often also the best (worst) areas of bus availability, the spatial pattern of the potential car dependence in Xiamen is similar to the patterns of the former two. The old central area of the city on Xiamen Island is comparatively in the best situation where the potential car dependence is generally at the level of "low dependence" or "lowest dependence". The vast newly developed areas, including the north and east fringe of the Xiamen Island as well as those outside areas such as Haicang, Jimei, Tong'an and Xiang'an, are left behind as disadvantaged areas in terms of urban services and public transport, and hence make the worst situation where the potential car dependence is generally at the level of "high dependence" or "highest dependence". Therefore, there is still an obvious disparity between "on-Island" and "off-Island" in terms of potential car dependence. Similar to Turcotte's findings in Canada (Turcotte, 2001), new and far from city center in low density neighbourhoods are with the highest level of potential car dependence. This means these areas are the problematic areas to be improved. These areas should be deemed a priority for future investment , for both the urban facilities and the public transport services. Otherwise, it would result in an undesired highly car-dependent transportation structure, as well as an inconvenient living environment there. The evaluation and mapping of the potential car dependence, together with that of walking accessibility and bus availability, can therefore provide very useful information for planners and decision-makers on the ongoing development of outside areas of Xiamen Island as well as the structural optimization of Xiamen Island.

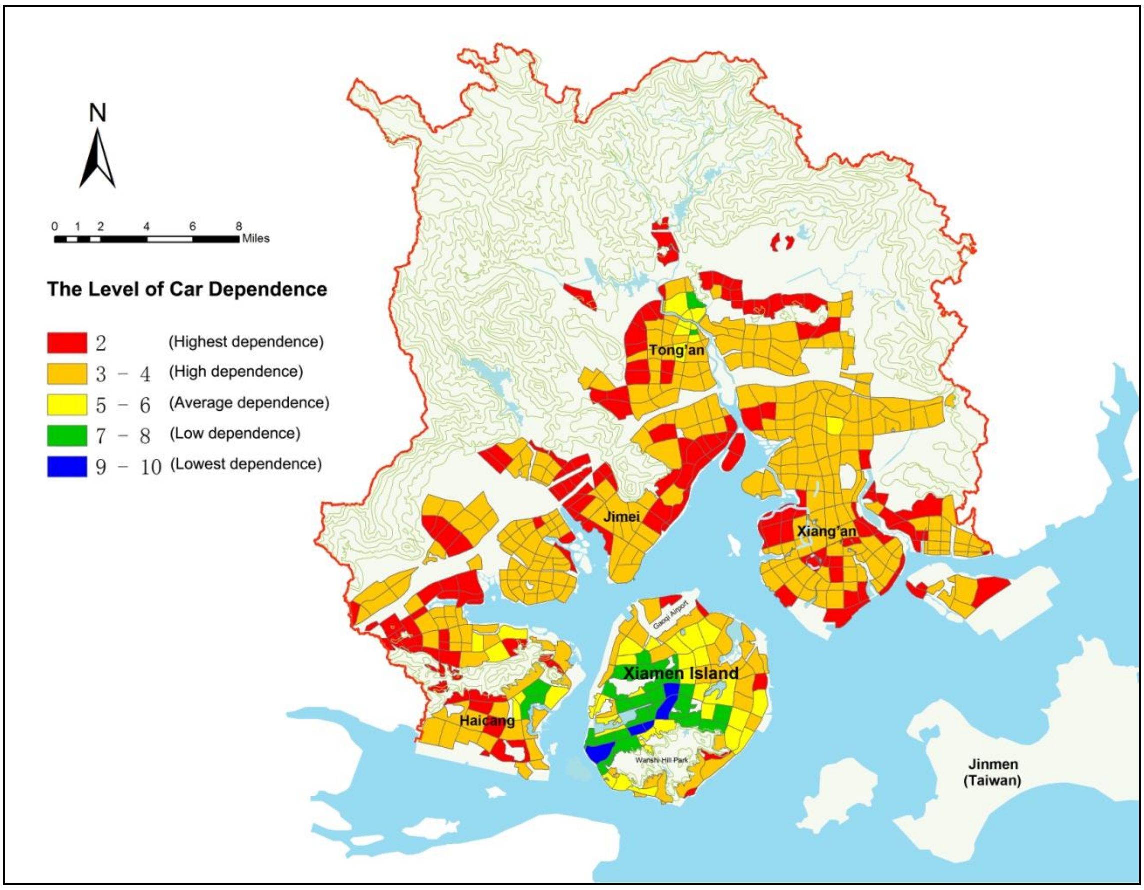

Figure 3. Spatial pattern of the potential car dependence in Xiamen city

6. SUMMARY

Like many other Chinese cities, the case study city Xiamen has been experiencing a marked spatial transformation in recent decades. Since the strategy of "transforming from 'Island City' to 'Bay City' " was established several year ago, under the guidance of the “Overall Planning of Xiamen City (2004-2020)”, the main “battlefield” of the urban development is moving to a much broader space outside of Xiamen Island. The spatial pattern of transportation will inevitably present a divergent distribution by taking Xiamen Island as the centre. It is foreseeable that the travel demand and traffic mileage will thus increase dramatically. The cross-sea traffic flow (unidirectional) to and from the island is estimated to amount to 500,000 person-times a day. How to guide and control this unprecedented transformation, and enable it to lay a foundation for the future sustainable development of Xiamen rather than move towards opposite, is now a crucial issue and stern challenge facing the local decision-makers, researchers, and planners.

The results of this research indicate that the construction of urban facility and public transportation system has not yet timely followed-up with the development of those new areas, leaving an obvious hysteresis. This leads to the result that the vast newly developed areas outside of Xiamen Island are generally suffering from a "bad" or "poor" condition of both walking accessibility to urban facilities and availability of public transport, as shown in the previous sections. The empirical study conducted by this research has highlighted that the worst areas of walking accessibility to urban facilities are very often also the worst areas of bus availability, and thus in the worst situation of car dependence as well. More and more people there have to buy a car when they are just able to afford a car, which make them not only "the mortgage slaves to house" but also the "slaves to car". For the city, the violent increase of cars is absolutely becoming an intractable challenge. And because of the rigidity of spatial structure and road network, as well as the mentally refractory of car dependence, once a car-dependent transportation system is formed, it will be very difficult to be changed again due to so-called "path-dependency" and "lock-in effect". Therefore, it is critical for decision-makers and planners to put “sustainable transportation” on the top of their agendas in order to avoid the trap of car dependence.

By taking the city of Xiamen as a case study, the research presented above has also generated some useful information for both public transport and urban facility providers by indentifying the problematic areas, and allow them to join forces to promote improvement. The methodology developed in the research might also provide a practical reference for other studies.

Problems in an individual city can also reveal important features associated with wider dynamics. The car-booming and car-oriented development is now a common challenge facing Chinese cities. Fortunately, Chinese cities still have a chance to jump over the trap of car dependence and innovate new ways of sustainable living—if they choose. After all, since most people don't own cars yet and haven't begun to drive, their travel habits and preferences can still be shaped in an environmentally sustainable way (Qian, 2010). All in all, cities need to consider more than just road networks and vehicles while attempting to solve transportation problems. It is necessary to examine the urban form and built environment that force people to drive.

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