INVESTIGATING THE SPATIAL AND TEMPORAL CHANGES OF TRAVEL PATTERN BETWEEN 2005 AND 2010 IN BEIJING

by

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(Under the Direction of Xiaobai Yao)

ABSTRACT

Since the economic reform of the 1980s, Beijing has been experiencing a tremendous increase in population and motorized vehicles, which brings an explosive rise in daily travel demand. Based on the road datasets with classification in 2005 and 2010 and travel flow data aggregated by traffic analysis zones of 2005 and 2010, this study aims to analyze the spatial and temporal pattern of traveling in 2005 and 2010 in Beijing as well as the changes over the 5 years. A spatial interpolation tool in ArcGIS was developed to interpolate travel flows to a common spatial zoning scheme, and the User Equilibrium Traffic Assignment was applied. The findings from this study will be particularly useful for transportation planners seeking information to understand the urban spatial structure, predict travel demand and improve the transportation service and management.

INDEX WORDS: Travel pattern, trip generation, spatial interpolation, traffic assignment

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TABLE OF CONTENTS

LIST OF TABLES

Page

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LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Travel is the movement of people or goods between relatively distant locations. In modern society, travel in the city has had a large impact on human life, such as leading to the extensive growth of city size and resulting in the proliferation of suburbs. To adequately evaluate a region’s transportation system, it is necessary to examine people’s daily travel patterns from home to various destinations including work, school, and shopping. Nowadays with the rapid increase in people’s daily communication, frequent daily travel becomes an essential part of urban life, not only in urbanized areas but also in the urban fringe. According to the Census Transportation Planning Package data (CTPP), 97% of the US workers in 1990 and 96.7% in 2000 reported that they commuted to work (Sohn, 2005). By 2008, there were 128.3 million commuters in the U.S. using all kinds of transportation mode in total (US DOT statistics). In China, the number of motor vehicles increased by an average of 14 percent annually to over 169 million between 1987 and 2008. Moreover, the number of private passenger vehicles was 62.4 million at the end of 2011, a threefold increase on the 18 million at the end of 2005 (National Bureau of Statistics in China).

In Beijing, the capital of China, as the population exceeded 17 million at the end of 2008, travel demand is booming. The number of private cars had reached 3.25 million with an annually increase of 15% during the same period (Zhao, 2010). These increases in travel and modes of travel indicates a huge potential growth in traffic flows and commuting trends, and thus increases in traffic congestion and air pollution. Also, as transportation demands are increasing rapidly, travel times are increasing greatly as well, particularly in major cities of China. According to a report by the Chinese Academy of Science, commuting time in Beijing was 38 minutes on average under normal traffic conditions and 52 minutes during traffic congestion, which is the longest commuting time in China. The increased travel time will cause other severe problems as well. A survey-based study by Zhang and Yi (2006) showed that the dramatic increase in commuting time had caused serious problems affecting the quality of urban life and had become a major barrier for planners to establish Beijing as a 'liveable city.' Road transport-related air pollution accounted for 23% of the total air pollution, close behind the industry pollution (Huang, 2009). Thus, understanding the patterns of daily travel within a city becomes a key factor for researchers and policy makers when they analyze major infrastructure changes, evaluate transportation demand, and recommend management and traffic control strategies, such as congestion pricing, so as to ameliorate the problems mentioned above.

1.2 Travel Patterns in China

The change and development of travel patterns in developing countries are quite different from those of North American and European countries since the pattern of urban growth in developing countries is quite different. In the case of China, since the economic reforms in the 1980s the large cities have experienced accelerating and dramatic change in urban spatial form and structure, which was also called urban spatial restructuring (Ma, 2004). Consequently, some new procedures appeared in the explosive urban development, including:1) rapid housing and industrial urban space expansion on the fringes of the city; 2) suburbanization caused by the migration of population and other industries from city centers to outside places; and 3) the growth of sub-centers and industrial zones in suburbs (Zhao el al. 2010). As a result, the restructuring of the Chinese urban form contributed to the development of the transportation patterns, housing alternatives, and new employment patterns (Gaubatz 1999). Furthermore, new associations between job-housing balance and new travel patterns on urban and suburban areas had also developed.

Because of the economic transformation from a political-oriented or centrally planned system to a market-planned system, the relationship between travel patterns and urban growth in China is much more complicated than it is in the U.S. and European countries. Additionally, due to the coexistence of a new market system alongside the old system, individuals' travel behavior and travel time became more uncertain and more difficult to explain (Zhao and Lu 2010). In the restructuring era, China went through three fundamental processes: decentralization, marketization and globalization, which makes the urban forms much more complex and different in China (Wei 2001).

China's suburbanization results from the combination of government-led industrial development and market-oriented real estate and commercial development (Zhao et al. 2009). However, unlike western countries where suburbanization caused employment decentralization in all kinds of industries, suburbanization in China was always associated with residential decentralization, and employment decentralization was only taken up by manufacturing and construction industries, while commercial industries, finance industries, and other high-income industries still grow rapidly in the city centers (Zhou 1997, Zhou 2000). Moreover, research showed that high-income households in China were more likely to live in the areas near the center of the city due to the high accessibility to the high-income job location and good infrastructure and service (Zheng et al. 2005), while in western countries the same group prefers to live in suburban areas. In China, low income households or workers often live in suburban areas because they are not able to afford the high price housing in the central areas. In addition, the supply of housing and residential land is still tightly regulated by government, which makes the residential structure more complex than in western countries where there is a high degree of market-oriented housing. As a result, such a different urban growth and development pattern will result in different and complicated travel commuting patterns. Therefore, the investigation of travel patterns in China will provide an efficient way to understand and explain the urban structure and its relevant economic development. Results of this study will be helpful to evaluate the infrastructure demand, and to improve the transportation management and service so as to develop sustainable system for transportation in the city.

1.3 Research Objective

Since the economic reform in 1979, cities in China have been experiencing the rapid growing process of urban sprawl, urban restructuring and suburbanization. As a result, the travel patterns and the commuting ways in which people interact in space and time have become much more complicated. In Beijing, as the population and number of vehicles are booming during recent years, travel demand is increasing drastically as well. Consequently, travel becomes a major cause for the traffic congestion, air pollution, and the fundamental impetus for highway construction due to concentrated travel time during the day. This research aims to analyze the spatial patterns of traffic in 2005 and 2010 respectively, as well as the changes of those patterns in Beijing. To achieve the overarching research goal, three research objectives are identified in the thesis study:

Objective 1 Evaluate and process Beijing's road data in 2005 and 2010

The road dataset of 2005 was digitized based on the remote sensing images of Beijing, and the dataset of 2010 was contributed by volunteers in the online street map. Due to the scarcity and inaccuracy of the dataset in general, it is necessary to evaluate and process Beijing's road data and to even collect some new data before the road network data can be used in the research. There are several specific reasons for which data editing and processing are particularly demanded. First of all, the original road datasets in 2005 and 2010 includes only the attributes of road type and road length, which is insufficient. Some other attributes, such as speed limit and practical capacity, are important as well. Therefore, the further collection of these data is needed. Secondly, there are bi-directional and one-way roads in the dataset. For those one-way links, the direction should be checked and corrected to match the real situation. Thirdly, for network analysis, it is essential to evaluate and correct the topology for the network. However, topology was neither ensured nor checked in the original dataset. Based on the street map of Beijing in 2011 from ArcGIS online, the topology network will be checked to make sure roads in the network are connected where they should be. Fourthly, for the road dataset in 2005, the accuracy of the digitization is low, for it only included expressways, ring roads and primary roads. Other low level roads, such as the residential roads or local roads were missed. In addition, the datasets failed to exclude rails from the roads of vehicles. For consistency, the digitized 2005 road dataset will be used as a reference, the new 2005 road dataset will be created by removing the roads built after 2005 in the 2010 road dataset. The removed roads will be double checked based on the images in 2005 on Google map and their construction years will be checked with the online source as well.

Objective 2 Assign aggregated trips to roads in 2005 and 2010 in Beijing, and analyze the changes of trips over 5 years

In order to make a good transportation planning system, to provide good public transportation service, and to alleviate transportation problems such as traffic congestion in peak hours, it is necessary to be informed of traffic volume on each route in the road network. Trip flow data between geographic units or zones plays a very important role in explaining and understanding the spatial interactions in urban areas and are often used to estimate traffic on roads. In this study, the investigation of the spatial and temporal changes of travel patterns in Beijing will be achieved by estimating the daily travel patterns based on Beijing's road network for both years using traffic flow assignment methods. After the traffic flow assignments, it will be clear how many travelers are on each route, where the traffic congestion is most likely to happen, what people's travel trends are, and where the infrastructure and transportation services need to be improved. Such information will help planners or policy makers in evaluating and improving transportation systems and related facilities, providing good public transportation service, and alleviating transportation problems such as traffic congestion in peak hours.

In this objective, I will assign aggregated trips to roads for both 2005 and 2010 by using the User Equilibrium Assignment method. The method will assign the trip to roads based on the fact that drivers choose a route so as to minimize his/her travel time and on the assumption that such a behavior on the individual level creates and equilibrium at the system level. The travel pattern of the whole city will be examined in detail, and the difference between years will be analyzed as well.

Objective 3 Develop a toolbox in ArcGIS by using Python for flow interpolation, then apply the tool to bring travel flow data of two time periods onto a common spatial zoning scheme

There are two possible ways to analyze the changes of trip flows on the roads of the network in Beijing over a 5 year period. The first approach is comparing the trip flow assignment results on roads of 2005 with the results on the same roads of 2010, and then analyzing the differences. However, due to the changes and developments of roads during the five years, the major barrier of this approach lies on the difficulty to locate the same road from two different time-period sources by the road ID in the attribute table. In this case, the change detection cannot be obtained directly by subtracting results in 2005 from results from 2010. The other approach is assigning the changes of the trip flows aggregated for traffic analysis zones over the five years to the roads directly. However, this method requires the flow data to be aggregated by the same zoning scheme, which make it possible to derive the differences on the same zone between different years.

With the urban transformation in Beijing during the past decades, the traffic analysis zoning (TAZ) schemes of census statistics units that generate or attract travel flows often vary. The boundaries of (TAZs) are different in 2005 and 2010. This inconsistency makes the time-series analysis of travel patterns difficult. Jang and Yao (2011) proposed a flow interpolation technique which can serve the purpose. However, no tools are readily available to carry out the process; therefore, I developed a toolbox in AcrGIS written in Python, which can automatically bring the travel flow data of two time periods onto a common spatial zoning system and then calculate the travel flow based on that zoning scheme. The output of this script tool will be a DBF file including the new Origin-Destination (O-D) pair and related flow data in ArcGIS.

CHAPTER 2

LITERATURE REVIEW

Travel patterns contributed greatly to the development of urban spatial structure and economic or social growth. Travel pattern is a very good and important indicator for urban structure, for urban spatial structures can be easily revealed by travelling trends ((Sohn, 2005; Timmermans et al. 2003). Among many factors that influence travel patterns at a city level, spatial change of urban form is proven to be particularly important (Zhao et al. 2010). On the other hand, the variation in travel patterns can be attributed more to socioeconomic reasons (Stead, 2001). Differences in travel patterns can be effectively explained by both urban form and economic level (Giuliano and Narayan, 2003). The literature has seen many studies exploring the relationship between travel patterns and land use pattern, socio-economic characteristics and other factors. However, few of them extend the study to analyze the real patterns of traffic flows at level of individual roads in the network.

2.1 Land Use and Transportation Interaction

During the last decades, many researchers have studied the relationship between urban form or spatial structure and commuting patterns (travel to work). Since commuting is a derived activity to deal with spatial separation between residential location and work place, exploring commuting patterns came to be a general way to understand and investigate urban structure. Some researchers hold the view that urban form and land use pattern fundamentally determine the urban commuting pattern. Gordon et al. (1987) used a cross-sectional analysis to examine the effect of metropolitan spatial structure on commuting behavior and commuting time with several variables, such as urban size, population density, economic structure, income and carpooling, concluding that polycentric and dispersed metropolitan areas facilitate shorter commuting times. Moreover, Gordon et al. (1991) made a comparison of auto commuting trip durations from the 1985 American Housing Survey and data from the 1980 census for the top twenty largest metropolitan areas. They found that in that period the average trip time either fell or remained the same, which would not be resulted from the widespread traffic congestion. One preferred explanation for the decline in the commuting times is that enough commuters were making location adjustments, either for the work place or residence to avoid increasing the time cost when the traffic congestion was getting worse. They also noticed that commuting times are much higher in dense cities than they are in dispersed cities, and commuting times tend to be shorter in rapid growing cities.

Some researchers also looked at the effect of jobs-housings balances resulted from the changing spatial pattern of cities, insisting that jobs-housing balance would reduce the traffic congestion and air pollution. For instance, a study made by Nowlan and Stewart (1991) could offer an understanding on the effect of land use and urban spatial structure on commuting patterns, especially how the jobs-housing balance altered the commuting. They found that in the period between 1970s and 1980s when there was a booming of office space in downtown of Toronto, commuting trips to the Central Area had not risen as rapidly as would be expected, because the rising residential construction attracted people worked in downtown, which reduced the lengths of commuting trips. Cervero (1996) made a cross-sectional study in census tracts of San Francisco Bay Area in 1980 to explain the relationship between jobs-housings imbalances and commuting flows by using a gravity model. He found suburban residents commute farther than ever despite the steady migration of employments to suburbs because undersupply of housing existed and the rent and housing costs were too high in some local communities.

However, Giuliano and Small (1993) argued that conclusions made by Cervero were less than fully persuasive or even misleading. In order to examine the presumption that local jobs-housings imbalances strongly influence people's commuting patterns, they tried to look at the commuting pattern of Los Angeles in 1980 because its actual spatial distributions of job and housing location would theoretically minimize average commuting time or distance. As a result, they found that there was an inconsistency between required commuting and actual commuting, as well as their variations, indicating that jobs-housing balance would have only a minor effect on commuting. Later on, Giuliano (1995) elaborated his conclusion, arguing that the connection between transportation and land use was weakening. Similarly, Wachs et al. (1993) made a case study about changing commuting patterns among 30,000 employees of a major health care provider in Southern California over 6 years between 1984 and 1990. By tracking the residential and work location of those employees, the study found that commuting patterns and locations revealed little evidence of an increasing jobs-housing relationship since distances of commuting trips had not increased, which was contrary to the jobs-housing imbalances hypothesis. They also found that the commuting times grew because of the traffic congestion caused by the growth of local work force. Journey to work issues would have little impact on the residential location choice when compared to other factors, such as quality of neighborhood and schools and perceived safety, which corresponded with Giuliano's findings.

While many studies attempted to explain the commuting patterns based on urban spatial structure and land use type, Sohn (2005) made an effort to examine how well the commuting pattern can reflect the corresponding urban spatial structure. In the study, he applied an adjusted gravity model to estimate and derive the locational variables for commuting trip origin and destination with commuting data from the Seoul Metropolitan Region in 1987, 1990 and 1995. From an empirical analysis on the locational variables and its related coefficients, Sohn found that the employment distribution in that urban region could be reflected correctly by the urban spatial structure derived from the commuting patterns and the urban density distribution, while the distribution of employed residents could not.

From the examples above, it is obvious that researchers have diverse views and conclusions on whether urban form and land use pattern have impacts on the commuting. The measurement and analysis they used to examine the relationship did have some shortcomings and disadvantages. In order to grasp a full understanding towards travel patterns, many other variables, like socioeconomic factors also need to be taken into account. Generally speaking, varying patterns of travelling in city can be linked to different population groups classified by their socioeconomic and demographic characteristics, such as race, ethnicity, income, gender, household structure and disability. The exclusion of other factors in the measurement and modeling will make the results inconvincible and unpersuasive.

Tkocz and Kristensen (1999) derived a function of distances of residential locations to city centers and sociological determinants of residents, including population, age, number of children, household structure, income and education level, to explore the differences by gender in travel distance for monocentric and polycentric cities. They found that compared to men, women were more likely to work in city centers. Single men had shorter travel distances than married men, while single women did not. In addition, women’s travel patterns were more dependent on urban structure than that of men. Fourth, age had a negative impact on the travel distances for both men and women.

Many researchers used aggregate data that relate to certain spatial unit to examine the relationship between travel pattern and land use pattern, and other factors (Newman and Kenworthy), which made the results a little bit obscured since travel choices are made by individuals or households. In order to explore and understand the differences in aggregate travel patterns between countries, it is essential to examine individual travel patterns under the local condition. For example, Giuliano and Narayan (2003) tried to find the relationship between land use patterns and individual travel pattern from a comparative international perspective, between U.S. and Great Britain, which included many factors: housing, land use and tax policy, cultural preferences, spatial structure of US metropolitan areas and per capita incomes. They found the US had a more pronounced significant inverse relationship between residential density and travel distance than Great Britain had. Later on, Giuliano and Narayan (2004) continued to make a similar comparison between work and non-work travel in two countries, concluding that different demographic factors, like lower per capita income in Great Britain are keys in explaining the difference in travel patterns. In addition, Giulianoet al. (2005) applied a structural model with both daily travel and car ownership data and a reduced form model with only the daily travel data, adding a new conclusion that differences could be also explained by country specific differences in costs of car ownership and use, transport supply and other factors that were out of control.

2.2 Travel Pattern and Social-Economic Characteristics

Sultana and Weber (2005) investigated the journey to work commuting pattern of workers in two Southeastern metropolitan areas with 2000 Census Transportation Planning Package (CTPP) Data. From their results of the analysis of variance, it was clear that workers living in the sprawl areas experienced a longer commute in terms of time and mileage than those living in higher density areas. However, their multivariate statistical results also indicated that workers' socioeconomic characteristics could exert more importance on predicting the commuting behaviors than urban structure.

Moreover, according to Taylor and Ong (1993)'s research, the commuting patterns would also be affected by race. The study used American Housing Survey data from 1977 to 1978 and in the year 1985 to examine the commuting patterns for different races, including whites, blacks and Hispanics in US metropolitan areas, especially focused on the patterns of workers living in predominantly minority residential areas. According to Kain (1968), the segregation of the minorities that persistently lived in the central of the cities always combined with the decentralization of metropolitan employment to create a spatial mismatch for minority workers. As a result, the declining employment in the central cities tended to make minorities, especially the blacks, commute longer to suburbs in order to find jobs. As the urban continued to decentralize and sprawl to outlying spaces, the employment would move outward as well, and the commuting times of workers of minorities in central city would be expected to increase faster than it of workers in other places. In contrary to the aggregate, cross-sectional method of most jobs-housing balance and spatial mismatch hypothesis, Taylor and Ong used a unique dataset to explore the relationship between racial variation and commuting patterns. Based on the linear regression examinations they found that the commutes of the black and the Hispanic workers living in the central minority areas between 1977-78 and 1985 were shorter and increased slower than those of white workers and worker living in other areas. Further, a longitudinal analysis they applied here showed that those non-moving workers in the minority areas tended to have shorter commuting times during the time period. None of this conclusion would support the spatial mismatch hypothesis.

Another study made by Shen (2000) aimed at exploring the variations rules of travel time among neighbors in the 20 largest U.S. metropolitan areas and what factors can explain those variations with five regression models. Model 1 incorporated the variables that represented the socioeconomic characteristics of residents in those neighborhoods and the variables that could describe their travel mode. In Model 2, the variables that represented the socioeconomic characteristics of residents were replaced by the general employment accessibility, while the variables that depicted the travel modes were kept. Model 3 combined Model 1 and Model 2, whose results would reveal both spatial and social dimensions of commuting. Model 4 used the same structure with Model 3, but it replaced the variable of general employment accessibility in Model 3 with the variable of percentage of households owning at least one automobile. Model 5 added the occupational composition of the labor force to Model 3. In conclusion, Shen found that low-income minorities living in the central cities tended to have longer commuting times, which countered with the conclusion of Taloy and Ong (1993). Besides, he concluded that the urban structure was highly significant and very important in explaining the variations in commuting time, and other factors, like socioeconomic variables, including income, education, race, gender, cultural background and household characteristics, would have measurable effect on commuting durations.

Many studies that explored the relationship between commuting patterns and socioeconomic and demographic factors were conducted zonal census data. They are highly generalized at each geographic unit, such as travel time and job availability at city or county level. However, the results from the zonal data source are not able to explain the variation in commuting patterns for workers with different socioeconomic and demographic backgrounds since such characteristics of workers are not homogenous. In Kim et al. (2012)'s research, a disaggregate journey to work spatial interaction model was used to disaggregate Census Transportation Planning Package zonal data by gender and occupation into the number of commuting flows and average commuting distance so that the heterogeneity of commuting by these two groups can be easily understood with a relatively fine spatial resolution. The results showed that commutes vary by gender and occupation, while occupational variations are bigger than gender variations. Also, gender differences in commuting distance exist in most job categories, indicating that commuting patterns should be summarized with excluding one gender from the other even in the same job category. Finally, a linear regression model that could examine the relationship between commuting patterns and demographic and socioeconomic variations implied that commuting distance is a result of mixed and complex process of people and place.

Another study that disaggregated U.S. census dataset (Sang, O'Kelly and Kwan, 2011) took commuter's gender and occupation into consideration as well. Based on the commuting flows data classified by gender and 9 job categories (18 worker groups) from US Census Transportation Planning Package for Rochester in Minnesota, they used a trip distribution model called information minimization (IM) model, which was developed by O'Kelly and Lee (2005) to explore the commuting pattern. Also, a doubly constrained spatial interaction (SI) model was used to estimate each unknown flow between two zones. Consequently, they had a fully understanding on the spatial structure of the labor market among those 18 worker groups behind the commuting pattern. In sum, differences in workers' gender and occupation would result in differences in commuting patterns. Such differences would usually be reflected in commuting distance, job or residential locations. All of these findings confirmed the results from previous studies, such as the study of wage gap theory in that low wages of women caused longer commutes, and the study of gender difference in terms of employment location.

The findings from disaggregate data source are not able to generalize the travel patterns and the relationship between travels and other variables especially for the land use pattern for an aggregate geographic unit such as the city, county, census tract or traffic analysis zone (TAZ) level. Antipova et al. (2011) used a multilevel modeling approach which incorporated individual level data and neighborhood level (TAZ) data to explore the combined effects of socioeconomic and demographic attributes and land use patterns on the travel time and distance in Baton Rouge Metropolitan Area in Louisiana. In their study, they applied three models, among which Model 1 examined the effect of individual level spatial factors only, Model 2 added individual socioeconomic and demographic variables, and Model 3 added neighborhood level socioeconomic attributes. The spatial factors included land use type where each individual resided, jobs to workers ratio around an individual respondent's home and an individual respondent's proximity to a high-performing school. Such a multilevel model could provide a comparison of results between individual and neighborhood level data, suggesting that land use measurements used here and individual and neighborhood level socioeconomic characteristics are important and useful to explain the commuting patterns.

Sandow (2008) applied a binary logistic regression model to examine how different socioeconomic, demographic and geographic factors affect an individual's travel behaviors in sparsely populated area in northern Sweden based on a longitudinal set of geo-referenced data. In the binary logistic regression model, the socioeconomic and demographic independent variables included age, education level, income level, employment sector, family status, presence of children in different age groups and gender; the geographical independent variables contained employment opportunities and residential density; the dependent variables referred to the short travel distance (shorter than 50 km) and a long travel distance (longer than 50 km). As a result, Sandow found that a gendered labor market made women commute shorter distance than men did. Moreover, besides women, old worker, low-income earners, those with low education levels were less likely to accept or make a longer commuting distance, which confirmed the conclusion of previous study (Tkocz and Kristensen, 1994). All of these conclusions could provide much useful information for policy makers, planners and researchers. For instance, women's shorter commutes mean they had more propensities to search job close to home, which would produce a different employment pattern and then cause occupational segregation. Besides, the areas where geographical expansions of local markets were likely occur would be to some extent indicated by the commuting patterns of the highly educated group.

While policy makers, urban planners and researchers pay attention to the commuting efficiency, excess commuting also became a hotspot in the research of commuting patterns. It refers to the measure of the extent to which the average actual commuting cost in an urban area exceeds a theoretical average minimum commuting cost where individuals are, on average, assumed to commute to their closest possible destination in terms of some measure of separation e.g. commuting time or commuting distance (Murphy, 2009). Bruce Hamilton (1982) raised the question whether or not commuting journeys of urban workers were too long or "wasteful". In order to test the monocentric urban model that could predict the workers' commuting journeys, he made a comparison between the actual average commuting journey length for a group of workers in the U.S. and the minimum commuting length for those workers, As a result, he found that the actual average commuting length of those workers was nearly eight times as the minimum average commuting journey length, and the difference between this two figure was "wasteful commuting".

In White (1988)'s research, unlike the method used by Hamilton (1982), he applied the assignment model approach to calculate new estimates of the average minimum commuting journey length predicted by the monocentric urban model. White found that there were three separate factors resulting in the extra commuting in Hamilton's measure of wasteful commuting, which were (1) differences between the spatial distributions of employment concentration and residential locations; (2) the commuting journeys did not proceed along straight-line routes because the actually road network was not ubiquitous; (3) the existence of commuting trips that could be shortened if workers made location adjustments for either jobs or residences. In conclusion, comparing the estimates from the assignment model and the results from the monocentric model, he found that only a very small amount of the actual urban commuting was wasteful.

Frost (1998) considered the applications of an urban zonal travel optimization model that could estimate the minimum average commuting distance between ideal residences and workplaces to the actual commuting patterns between residential locations and workplaces in a group of large British cities in 1981 and 1991. The results suggested that the strongest influence on increasing commuting length had been the changing urban form, and the significant fractions in urban structures increased the excess commuting as well.

Besides the studies mentioned above, there are many researches similarly explored the differences between minimized travel cost and actual travel cost (Hamilton, 1989, Small and Song, 1992, Giuliano and Small, 1993, Scott et al, 1997). However, Horner (2002) presented an alternative view of excess commuting based on a theoretical maximum commute calculation developed by White (1988). In the study Horner calculated the theoretical minimum and maximum commutes so that he could look at the commuting capacity of a selection of US cities. The numerical and visual results showed some details of the relationship between the jobs-housing balance of a city and its related observed commuting patterns. Moreover, the theoretical maximization calculation could to some extent reveal the degree of decentralization of urban form.

2.3 Spatial and Temporal Changes of Travel Pattern

While many studies have examined the relationship between travel patterns and jobs-housing balance or urban form and land use, especially how the change of latter ones could affect the former one, there has been very little research that focused on the spatial dynamics of travel or the spatio-temporal travel patterns and its related variation over a specific period at either a spatially disaggregated or aggregated scale.

Similarly, Horner (2006) investigated and analyzed the changes in commuting patterns and land use types in Tallahassee, Florida between 1990 and 2000 by using the CTPP data. In the model, urban and commuting changes were examined at two scales (the regional scale and local level) by using the measures of jobs-housing balance, commuting efficiency and other statistics. The results showed that there was a relatively strong relationship between jobs-housing balance and observed commuting pattern in 1990 and 2000. Despite the continual expansion and growth of urban area in the study region, the jobs-housing relationship kept stable during the decade, suggesting that urban structure remained the same. These findings confirmed the conclusion made by previous studies (Giuliano and Small, 1993; Sultana, 2002).

Li et al. (2012) explored the dynamic changes in commuting between 1996 and 2006 for South East Queensland in Australia by using journey to work data. In their study they concentrated on identifying the pattern of changes in commuting distance and flows. Two maps, one for the average commuting distance of each zone and the other for the jobs-housing ratio of each zone were used to make the comparison and quantitative analysis. In order to assess the significance of the local relationships between change in jobs-housing ratio and commuting distance, Local Indicators of Spatial Association (LISA) and local bivariate Moran's I statistics (Anselin, 1995) was used as well. In conclusion, the modeling results demonstrated there were no dramatic changes in commuting behaviors (commuting distances here) during the decade although the study area had a rapid growth during that period. However, on the other hand, there was a strong relationship between the changes in commuting patterns and the changes in jobs-housing ration at the local scale.

Pendyala et al. (1991) proposed a research to analyze the impact of telecommuting on spatial and temporal patterns of household travel in California. In temporal aspect, they found substantially difference between commuting days and telecommuting days not only in trip making but also in travel distances and highway uses. Furthermore, their spatial analysis had shown the introduction of telecommuting led to contracted travel space near home among telecommuters for non-work trips.

Another study made by Chen et al. (2010) focused on the spatial and temporal changes of travel patterns in Central Texas. Based on the journey to work data provided by CTPP, they analyzed the changes of the distribution of travelling workers, the change of average travel time, the change of inter-county travel flows and the change of traffic volume on the routes in the study area. In particular, the calculation of traffic volume was achieved by assigning the number of vehicles to road segments based on the shortest paths between origins and destinations. As a result, the spatial and temporal changes of travel patterns had been fully examined from four aspects mentioned above.

2.4 Travel Pattern, Traffic Problem, Public Transportation Ridership in Beijing

Due to the different situation in China, the travel patterns in Chinese rapid growing cities tend to be more complex compared to patterns in the US and European cities. Zhao et al. (2009) and Zhao et al. (2011) explored the impact of the jobs-housing balance and urban growth on travel patterns. They found that in the transformation era the jobs-housing balance had a significant relationship with worker's travel time. The higher the jobs-housing balance is, the shorter the workers' commuting time would be. In addition, the clustered and compact urban development in planned sub-centers is likely to reduce workers' need for long-distance travelling. Zhao et al. (2010) used location choice theory to analyze individual travel behavior, especially the choice of destination. In the study they applied the multinomial logit model that incorporated people's socioeconomic characteristics and urban form to explore their impact on travel pattern. They found urban expansion and trend in improving transport service and accessibility in the expansion areas will be likely to increase both travel distance and time, and cause traffic congestion in the urban center.

In Wang and Chai (2009)'s study, Danwei, a special work unit was taken into account when examining the relationship between travel patterns and jobs-housing balance. They found workers living in Danwei had different travel pattern from those who lived in houses from the market sources, indicating that the market-oriented reform in Chinese cities might have increased travel demand. Ling et al. (2010) conducted a study that concluded the temporal and spatial features and the rules of travelling in Beijing. In the study five types of spatial travelling between workplace and residence were divided: internal commuting, inward commuting, reverse commuting, side commuting and cross commuting. Ling et al. also constructed three layers: commuting, employment and residence, and then analyzed their spatial and temporal changes so as to extract the economic and social characteristics of development that revealed by commuting patterns in Beijing.

However, although many studies had examined the relationship between travel pattern and urban form, socioeconomic characteristics and job-housing balance, no previous studies were made to explore the traffic flow distribution and congestion in the peak hours in a major Chinese city, particularly the rapid growing city such as Beijing. Moreover, nothing of spatial travel patterns and their changes over time was seen in the literature either.

CHAPTER 3

METHODOLOGY

3.1 Study Area and Data

The city of Beijing is China's capital. Consisting of 18 districts at the time of the study period, Beijing has a land area of 16,410 square kilometers, and its total population was 15.38 million in 2005 and 19.61 million in 2010 (BSB [Beijing Statistic Bureau]). Travel flow data were collected by individual surveys, and then they were aggregated for 1118 Traffic Analysis Zones (TAZ) in 2005 and 1911 TAZs in 2010. Beijing has been undergoing rapid growth both in urban structure and facilities since the early 1980s. As a result, the transportation network in Beijing has changed considerably between 2005 and 2010. In this study, the road networks of the whole city in these two time periods are presented, and the travel flow data was assigned to the road networks in order to analyze the spatial and temporal changes.

I also have road datasets of Beijing in 2010 and 2005. The road dataset of 2005 was digitized based on the remote sensing images of Beijing in 2005 by Beijing, and the one of 2010 came from the online open source. As a result, there are differences in the reliability and the accuracy between the two datasets. The dataset of 2005 provides only road features, and there is no other information about the road name and road type. The dataset of 2010 includes all kinds of roads in Beijing, such as expressways (equal to the interstate highway in the United States), primary roads, secondary roads, ring roads, residential roads and so on. However, as mentioned in Objective 1, there are data quality issues in road direction, road connection and the topology that need to be manually checked, evaluated and processed in the Geodatabase in ArcGIS.

Beyond that, the speed and capacity information for the 2010 dataset is unavailable. A good way to solve

this problem is to collect this information by the road classification. Detailed processing procedure can be read in the following section. Moreover, based on the online street map of Beijing in 2010, a few roads that were missed in the original dataset of 2010 would be added.

The quality of the road dataset for 2005 is more limited than the one for 2010; for example, it did not provide any information about the road direction, speed limit, practical capacity and even road classification. Thus, I compared the two datasets carefully, and then constructed a revised 2005 dataset based on the 2010 dataset but omitting data for roads constructed after 2005.

The trip flow data for 2005 and 2010 was collected by transportation surveys. They represented the trips between given origin to destination pairs that were made during a normal week day in 2005 and 2010 respectively with all kinds of transportation modes. In this study, the patterns of travel by cars were examined specifically. The information on modal split of cars in both years is given in Table 1:

Table 1 Shares of Motorized Trip mode in 2005 and 2010

Mode	**2005 (%)**	**2010 (%)**
Employer-provided bus	2.25	2.18
Private car	15.60	28.02
Employer-provided car	3.18	2.40
Taxi	1.75	1.99
Total	22.78	34.59

3.2 Interpolation of Spatial Flow Data

Spatial interpolation has been widely used to mediate the spatial data between inconsistent zoning schemes, or improve the spatial granularity of data. However, traditional spatial interpolation methods that only deal with point or area data are not suitable for interpolating flow or line data which represent the spatial interactions between geographic units. There are many research studies that have been performed for point and areal interpolation (Lam 1983, Burrough 1986, Flowerdew and Green 1994, Goodchild et al. 1993, Fisher and Langford 1995). One of the simplest and most popular interpolation methods is called the areal weighting interpolation method, which was developed by Lam (1983), Flowerdew and Green (1992) and Goodchild et al. (1993). Assuming the data are uniformly distributed in the source zones, this method could result in a fraction of data in the source zone to a target zone, in proportion to the intersection area between the target zone and the source zone. The mathematical definition of the Equations for this method can be seen as below:

$$Y_t = \sum_{S=1}^{n} \frac{Y_s A_{s \cap Z}}{A_s} \tag{1}$$

$$Y_t = \frac{Y_s A_t}{A_s} \tag{2}$$

Where, Y_t= data in the target zone, Y_s = data in the source zone, $A_{s \cap Z}$ = areas of the intersection between source and target zone, A_s = areas of the source zone, A_t = areas of the target zone and n = total number of source zones.

Jang and Yao (2011) developed a spatial interpolation model to convert spatial flows among spatial units in one zoning scheme to those in another scheme. This method can be used to bring spatial travel flow data of two time periods onto a common zoning scheme. Similarly as the areal weighting interpolation mentioned above, this method assumed that the origins and destinations of all the trips were uniformly distributed in zones. The Equation that calculates the trips between i and j in the target zoning scheme based on the travel flow information in source zoning scheme is presented as below:

$$F_{ij}^{t} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[P^{a} * P^{b} * T_{ij}^{S} \right] \tag{3.1}$$

Subject to:

$$P^{a} = \frac{A_{iO}^{s\cap t}}{A_{i}^{S}} \tag{3.2}$$

$$P^{b} = \frac{A_{iD}^{s\cap t}}{A_{j}^{S}} \tag{3.3}$$

Where, F_{ij}^{t} = travel flow of target zone scheme, i = origin unit of flow in source scheme, j = destination unit of flow in source scheme, O = number of origin location, D = number of destination location, T_{ij}^{S} = travel flow of source zone scheme, P^{a} = proportion of origin areas of the intersection between origin unit in source and origin area in target, P^{b} = proportion of destination areas of the intersection between destination unit in source and destination area in target, $A_{iO}^{s\cap t}$ = areas of origin flow unit in the intersection between source and target zone, A_{i}^{S} = areas of source zone in original unit of flow, $A_{iD}^{s\cap t}$ = areas of destination flow unit in the intersection between source and target zone, and A_{j}^{S} = areas of source zone in destination unit of flow.

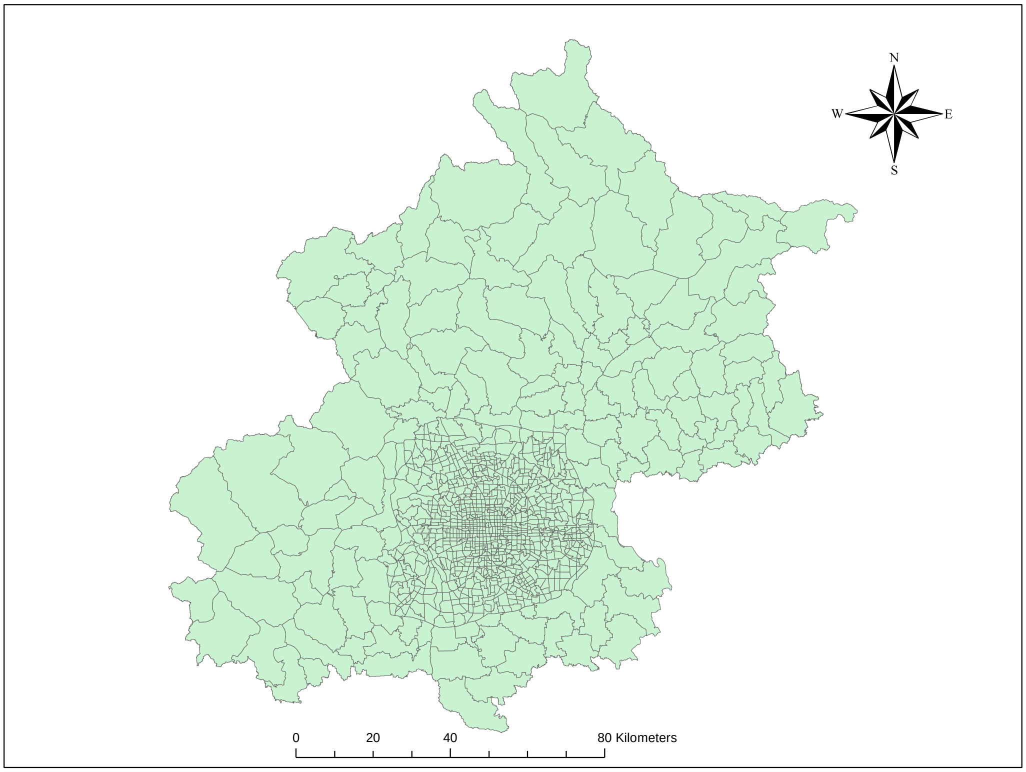


Figure 1 Spatial zoning scheme of TAZs in 2005

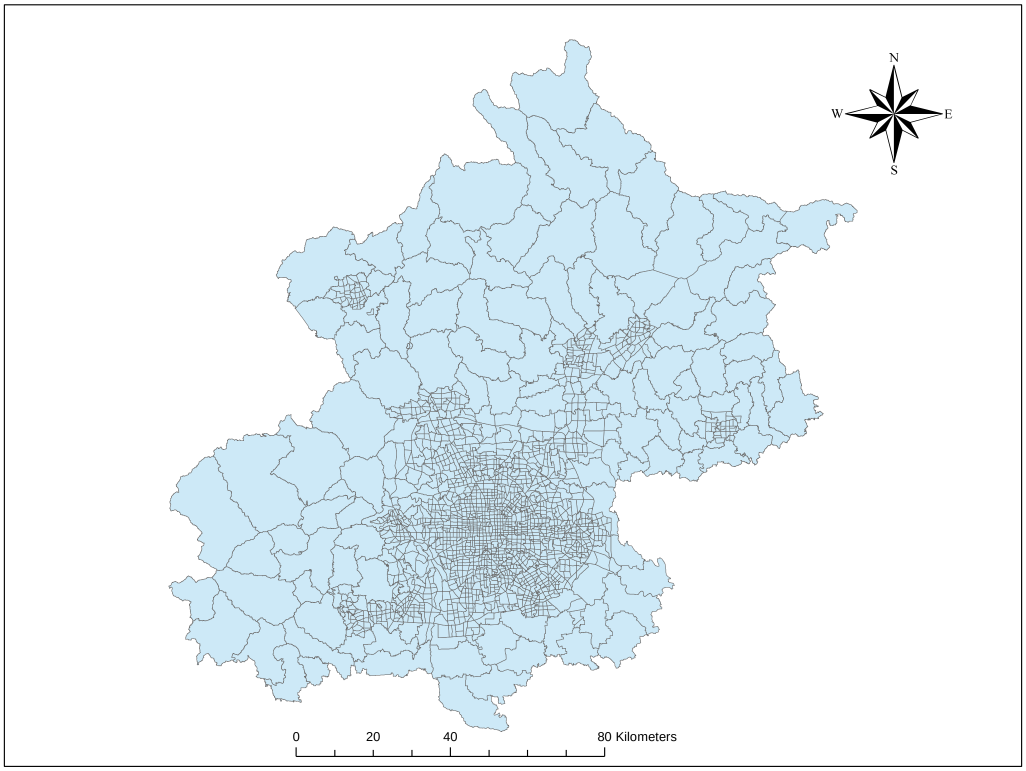


Figure 2 Spatial zoning scheme of TAZs in 2010

The toolbox for spatial interpolation in ArcGIS programmed in python was created based on the algorithm above.

3.3 Traffic Assignment

For many transportation planning objectives such as to determine facility needs and costs and benefits, to obtain good aggregate network measures and reasonable travel flows, and to identify heavily congested routes or alleviate the excess commuting problem, it is essential to know the number of travelers or trips on each route and link of the transportation network. For these reasons researchers can also examine the travel patterns by undertaking the trip assignment model. In this study, I will assign the traffic flows generated in rush hours of morning and afternoon between each origin and destination pair to both 2005 and 2010 road network, and then analyze the spatial pattern and temporal changes.

In early years, the Chicago Area Transportation Study (CATS) researchers tried to estimate the number of cars on each route for both local street system and freeway system with diversion curves. When working with complex networks, they used the Moore algorithm to determine shortest paths by which they could assigned all traffic to roads, and this was called All or Nothing Assignment since either all of the traffic flows from origins to destinations along a route or it does not.

Wardrop (1952) first found Equilibrium Traffic Assignment method, which assumes that players select a route that minimizes the time or cost incurred in its traversal. In the model, Wardrop stated two principles that formalize the notion of equilibrium: *The journey times on all the routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route; At equilibrium the average journey time is minimum*. Traffic flows satisfying the first are generally referred to as flows at "User Equilibrium" (UE) state, and flows satisfying Wardrop's second principle are referred to as flows at "Social Optimum" (SO) state. In the traffic analysis, Wardrop's equilibrium model is frequently used for the prediction of traffic patterns in the network in order to predict or potentially prevent the congestion on the roads. Later on, based on these two principles, Beckmann, McGuire and Winsten (1956) formulated and analyzed the first static mathematical model of origin-destination flows and user-equilibrium route flows for a congested road network, which allowed the computation of both the UE and SO states.

Although many researchers criticized Wardrop and Beckmann's equilibrium assignment model, and then proposed their own arguably improved models (YurriNesterov et al. 2003), Wardrop and Beckmann's models are still regarded a reference assignment model used by traffic analysts to model real traffic network around the world. However, it is clear that if the equilibrium algorithm for traffic assignment cannot result in flows that resemble the actual observed flows, it would be worthless. In the past years, many studies had been performed to examine the validity of equilibrium traffic assign models. Huber et al.(1968) carried out a work by using data from the cities of Pittsburgh, PA., and Raleigh, NC, to forecast traffic based on both travel time and distance parameters using various diversion curves. Since they applied the "All or Nothing" trip assignment model in the research which could not produce the equilibrium flows, the conclusion they made were not satisfactory enough to support Wardrop's first principle. Florian and Nguyen (1976) used an equilibrium trip assignment to assign traffic to the roads network of City of Winnipeg, Canada. By comparing the predicted results from the model and the observed results, they found that the differences between predicted and observed values were only partially attributable to limitation of the model. Overall, the validity of the equilibrium method was well established, especially for traffic in peak hour.

Almaani (1988) proposed a study to explore trip assignment procedures using the Bureau of public roads function that incorporates the free flow travel time and the volume/capacity ratio raised to the fourth power in order to compute for congestion. The applicability of three assignment algorithms (All or nothing method, Stochastic incremental method and User-equilibrium method) were compared, and user-equilibrium was proved to better assign flows on aggregate networks.

Some other researchers paid attention to the ways to connect aggregated zones and the road network data in the static traffic assignment. Sheffi (1985) defined the centroid of traffic zone as the representation of an aggregation of all the actual origins and destinations within its zone. Recently, Qian and Zhang (2012) tried to investigate the influence of centroid connectors on the results of static traffic assignment with three different networks. Large fluctuations on resultant link volumes, maximum volume capacity (V/C) ratios, average V/C and total travel time were observed when random connector selection had been put.

I will use the user equilibrium assignment method to assign the traffic flow to road network of Beijing in this study. The user equilibrium assignment is based on Wardrop's first principle, which states that no driver can unilaterally reduce his/her travel costs by shifting to another route. It can be written for a given O-D pair as:

$f_k(c_k - u) = 0 : \forall k (4)$

$c_k - u \geq 0 : \forall k (5)$

Where, f_k is the flow on path k, c_k is the travel cost on path k, and u is the minimum cost.

Equation (2) can have two states:

(1). If$c_k - u$ = 0, from the equation (4) $f_k \geq 0$. This means that all used paths will have same travel time.

(2). If$c_k - u$≥ 0, then from equation (4) f_k = 0. This means that all unused path will have travel time greater than the minimum cost path.

There are three assumptions in User Equilibrium Assignment:

(1). Users have perfect knowledge of the path or travel cost on a road network and will choose the best route;

(2). Travel time on a given link is a function of the flow on that link only;

(3). Travel time functions are positive and increasing.

As listed above, these behavioral assumptions on the individual level will eventually create an equilibrium at the system (or network) level, and the flows on links will be in equilibrium as well when no trip-maker can improve his/her travel time by unilaterally shifting to another because the travel time of links not carrying the flow is greater than the minimum O-D travel time.

The second assumption considers travel time on link to be flow-varying. As the flow increases towards the capacity of the stream, the average stream speed reduces from the free flow speed to the speed corresponding to the maximum flow. The relation between the link flow and link impedance is called the link cost function, and is given by the equation as shown below:

$$t_a = t_0[1 + \alpha \left(\frac{x}{k}\right)^{\beta}] (6)$$

Where, t_a and x is the travel time and flow, respectively on the link, t_0 is the free flow travel time, and k is the practical capacity of the link. The parameters α and β are specific the type of link and is to be calibrated from the field data. In the absence of any field data, following values could be assumed: α = 0.15 and β = 4.0.

The equilibrium problem of flow on the network is equivalent to the following nonlinear mathematical optimization program:

Minimize Z = $\sum_a \int_0^{x_a} t_a\,(x_a)dx$,(7)

Subject to $\sum_k f_k^{rs} = q_{rs}$: $\forall r, s$(8)

$x_a = \sum_r \sum_s \sum_k \delta_{a,k}^{rs} f_k^{rs} : \forall \alpha$ (9)

$f_k^{rs} \geq 0 : \forall k, r, s$ (10)

$x_a \geq 0 : \alpha \in A$ (11)

Where, k is the path, x_a refers to equilibrium flows in link a, t_a refers to travel time on link a, f_k^{rs} is the flow on path k connecting O-D pair r-s, q_{rs} is trip rate between r and s.

3.4 Evaluate and Process Road datasets

3.4.1 Collect Road Information

TransCAD 5.0 was used to perform the User Equilibrium trip assignment method so as to visualize the travel patterns with the road network in Beijing for 2005 and 2010. The required attributes for the User Equilibrium assignment in TransCAD are free flow travel time and road capacity. My original road dataset for 2010 only provided information on road class and directional flow (one-way vs. two-way flow). Based on Code for design of urban road engineering in China and road functional classification in Beijing, I assigned the speed limit, the number of lanes, and road capacity to each link. For those major classes, including motorway, trunk way and primary road, their exact numbers of lanes were cross-checked by Google map. The road classification and attributes can be seen in the Table 2. Due to the differences in the traffic situation and the design objective of road network between China and the United States, the road classification is more complicated in China. The expressway and motorway (ring road) in China function like the interstate highway and local highway in the U.S. respectively, while the trunk way represents the national primary road.

Table 2 Road Attributes by Road Classification in Beijing

Type	Example	Lanes	Speed limit (Km/h)	Capacity/Lane/Hour	Total Capacity
Expressway	Jingjin Expressway	4	90	1800	7200
	Beijing-Chengde Expressway	3	100	1800	5400
	Airport Expressway	3	120	1800	5400
	Jinshen Expressway	3	110	1800	5400
	Jingkai Expressway	3	110	1800	5400
	Other Expressway	3	110	1800	5400
	6th Ring Road	2	120	1800	3600
Ring Road	4th Ring Road	4	80	1600	6400
	2nd Ring Road,	3	80	1600	4800
	3rd and 5th Ring Road	3	100	1600	4800

Primary	Wanshou Rd, XidanNanjie	3	60	1600	4800
Secondary		2	40	1300	2600
Tertiary		1	30	1300	1300
Residential		1	20	1100	1100
Track		1	30	1300	1300
Unclassified		1	30	1300	1300
Special Links	Motorway_link	1	80	1600	1600
	Trunk_link	1	60	1400	1400
	Primary_link	1	60	1400	1400
	Secondary_link	1	40	1300	1300
	Tertiary_link	1	30	1300	1300

3.4.2 Topology Check and Correction

After collecting the required road attributes of for User Equilibrium Traffic Assignment, it is necessary to check and correct the topology of road network in ArcGIS in order to ensure the correct connectivity. There are four kinds of topology errors in my network: dangles, overlapped links, pseudo nodes on links and intersections. ArcGIS online street map was used as the base map to check these problems.

In the topology network, a line from one layer must not overlap lines from the same layer. To find out and delete the overlapped lines, in the topology check in Geodatabase, the rule “Must

Not Overlap' was used, and then I manually removed the overlapping line segment that was causing the errors.

In the next step, I went to the pseudo nodes problem. Lines that connect to another line are said to have pseudo nodes, which will result in the disconnection between those lines in the network. In the topology checking, the rule "Must Not Have Pseudo Nodes" was implemented, and the error points were fixed by merging them to the longest lines.

Due to the inaccuracy in the road dataset, the endpoints of some roads in the network did not touch with the lines nearby, while in the actual case they should have connected them. By implementing the rule "Must Not Have Dangles", all the dangles were located. Based on the Beijing Street Map in ArcGIS Online, I manually extend the dangling end of line features to the roads that they should have connected with.

At last, since the major classification of the roads in the dataset are created as one way road, it is important to determine the real intersections among all the crossing lines, particularly for the motorways and trunk ways. Although, some roads, pass across each other on the map, they did not intersect or connect each in reality. By implementing the rule "Must Not Intersect or Touch Interior", I excluded all the intersections which were not supposed to be the connection point, then split the rest.

3.4.3 Direction Validation

Another problem I encountered is the direction of the links. In my dataset, not all of the roads are created as one way. With the exception of the major roads, the others represent the bi-direction ways. For those one way links, the direction they represent in the network should match the direction from their start point to end point. With the base map from ArcGIS Online, I finished checking and correcting all the directions for one way roads.

3.4.4 Data Analysis

After the road data evaluation and processing, spatial interpolation of travel flows in 2005, and traffic assignment in the road network of 2005 and 2010, the spatial and temporal changes of travel patterns in Beijing between 2005 and 2010 was investigated and analyzed from the following aspects.

3.4.5 Distribution of Trip Production and Trip Attraction

With the results from interpolating travel flows of 2005 based on 2010 TAZ zones, the distribution map of trip production and trip attraction for both years was made so that we can explore the spatial patterns about where the travels originated and ended. Furthermore, the changes of trip production and attraction was computed and mapped as well in order to identify the areas that experienced an increase or decrease of trip production and trip attraction from 2005 to 2010 in Beijing.

3.4.6 Average travel time

Once the additional road data has been fully collected, and the topology has been correctly checked, the travel time in the peak hour between each origin and destination pair can be computed after the traffic assignment. Consequently, the maps showing the average travel time in the morning peak hour (7:00 am to 8:00am) of each TAZ was generated.

3.4.7Analysis of traffic assignment

The traffic assignment will assign traffic flows to routes in the road network. As a result, the traffic volumes on the road segments as well as the volume to capacity ratio can be easily computed. The spatial and temporal changes of travel pattern can be visualized and then analyzed.

CHAPTER 4

RESULTS

4.1 Roads Datasets of 2005 and 2010

Between the years 2005 and 2010, although many new roads have been constructed, most of them are secondary, tertiary or residential roads. Figure 3 shows the road network with classification in Beijing.

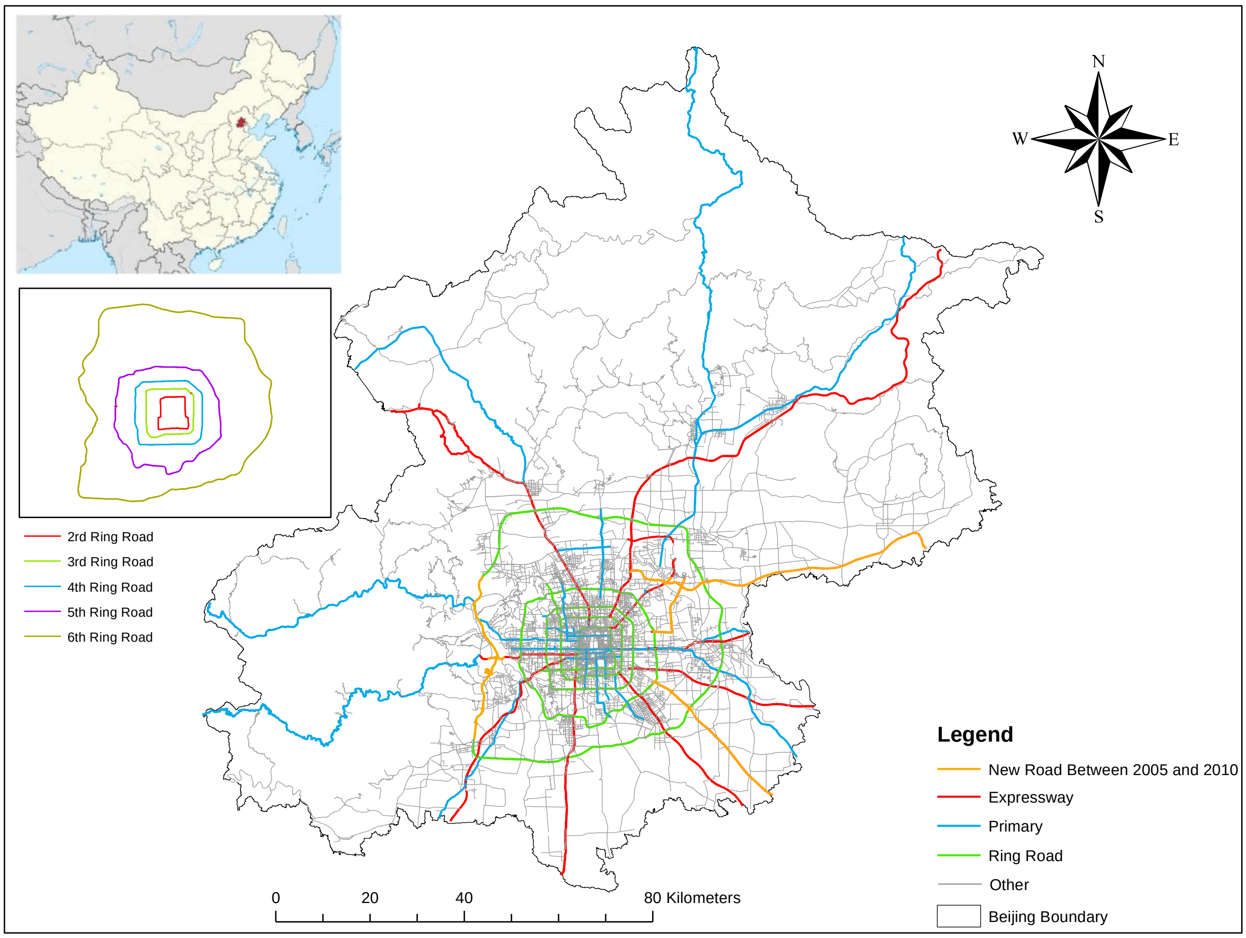


Figure 3 Road network of Beijing between 2005 and 2010

The changes between 2005 and 2010 are presented as green in the map above. These green lines include west 6th Ring Road, Airport South Expressway, Jing Jin Expressway and Jing Ping Expressway. All of these roads belong to the city expressway.

In the data processing, all the overlapped lines were removed by using the split tool in ArcGIS. The pseudo points had been carefully validated as well. Based on the street map from ArcGIS online, pseudo points that should have connected the nearest lines were correctly extended. Beyond that, all the intersections of one-way roads also were evaluated and checked. In the real case, ramps and overpasses play very important roles in connecting different kinds of roads in the complex transport network of Beijing. In topology checking, the real intersections were split as nodes, while other intersections where overpasses existed were kept as disconnection. After the fixing process, the number of the links in the road network for both years can be seen in Table 3:

Table 3 Numbers of Road Links in the Dataset of 2005 and 2010

Year	Number of Links
2005	27396
2010	27786

4.2 Python Scripting Interpolation Tool for ArcGIS

There are two parts for this spatial interpolation tool. The first part deals with the calculation of the proportion in equation (3.2) and equation (3.3). The second part is used to calculate the interpolated flow between O-D pairs under the target or new zoning system.

4.2.1 Proportion Calculator

With the Union Function in ArcGIS, users can easily perform a geometric union of the source zoning feature and target zoning feature. In the attribute table of the output feature class, all the information from the source zoning feature and target zoning feature were recorded. As a result, each feature in the output feature class has information about the TAZ ID for both years. Based on the information in the field of TAZ ID, the proportion was calculated and then recorded in a new field created in the process. The interface of this script tool can be seen in Figure 4.

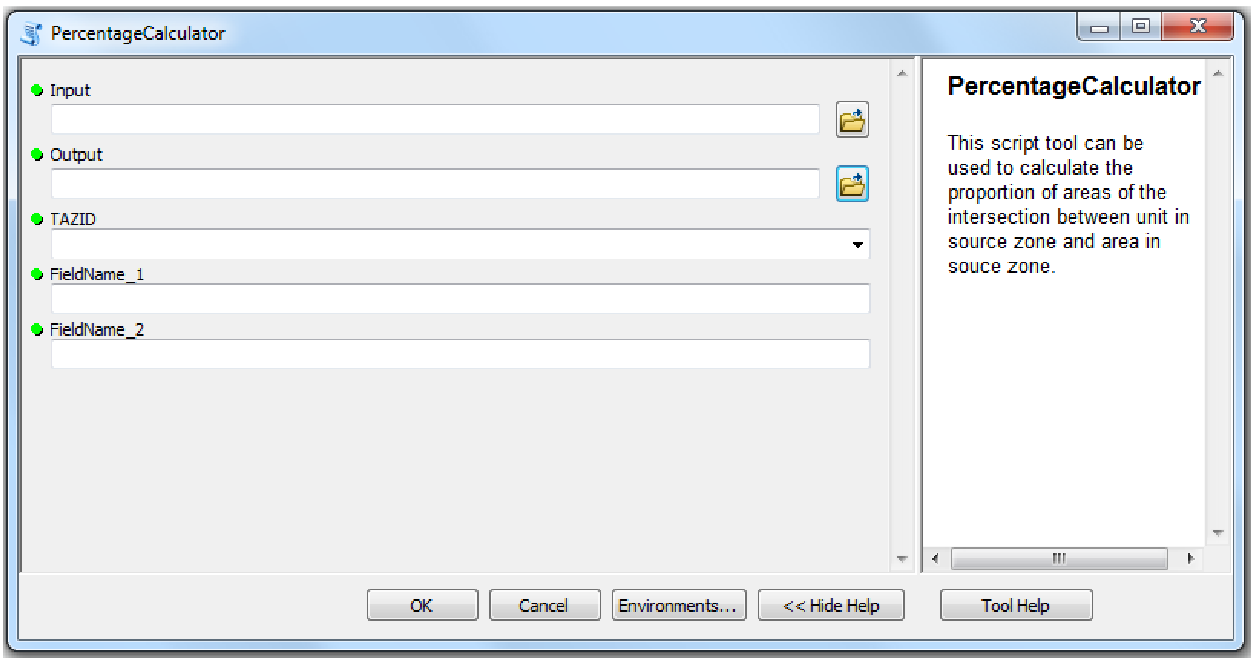


Figure 4 Interface of "Percentage Calculator" of the Spatial Interpolation Tool

There are five parameters that need to be pre-defined in order to get the proportions. "Input" refers to the resulted shapefile of the union function. "Output" will be the new shapefile whose attribute table will be sorted in ascending order by the values of ID of the traffic analysis zone in source zoning system. "TAZID" is the field that records the ID of the traffic analysis zones in the input file. "FieldName_1" is the name of the new field that records the areas of each traffic analysis zone in the source zoning system in the output, and "FieldName_2" is the name of the other new field recording the proportion in the output file. When the calculation has been finished, the message was written into the result window to inform the end of the running.

4.2.2 Spatial Interpolation

After the calculation of proportion, the interpolated flow in the target zoning system can be easily computed by this script tool. The input files needed in this tool should be the output of the last tool and a DBF table that records the information of flow between each O-D pair in the source zoning system. The output of this tool will be either a DBF table created in ArcGIS or a TXT file.

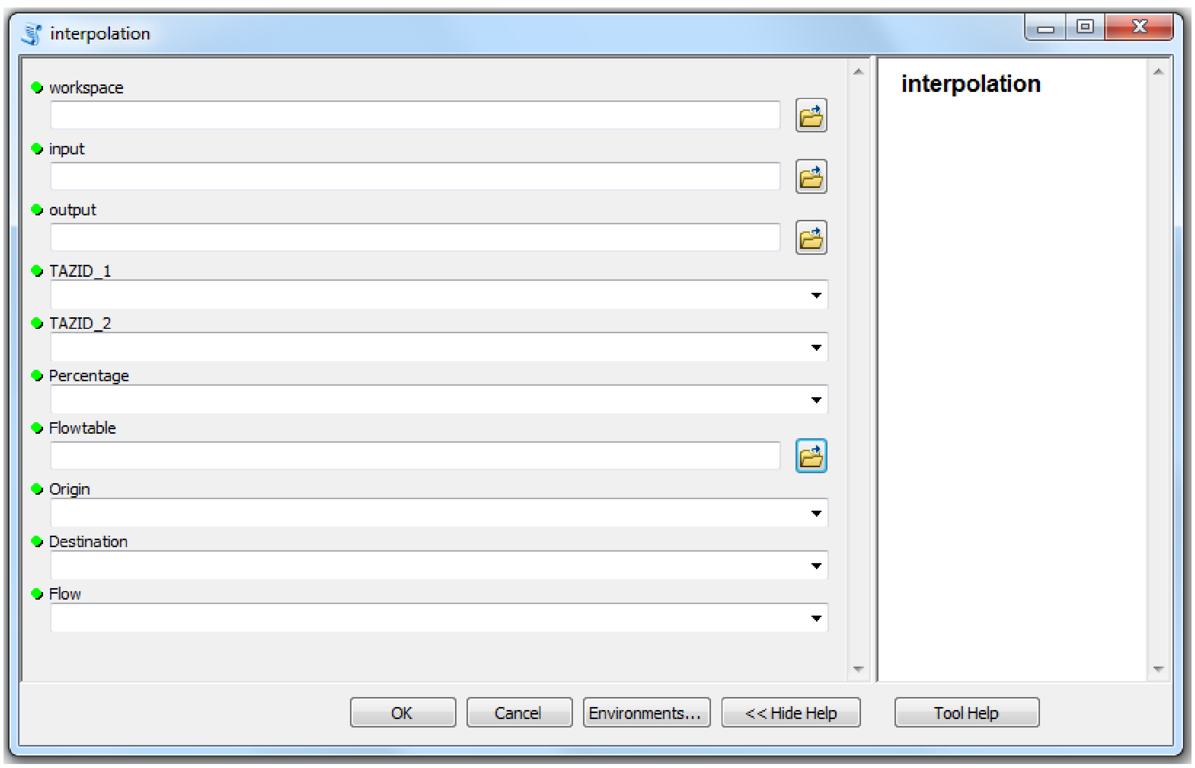


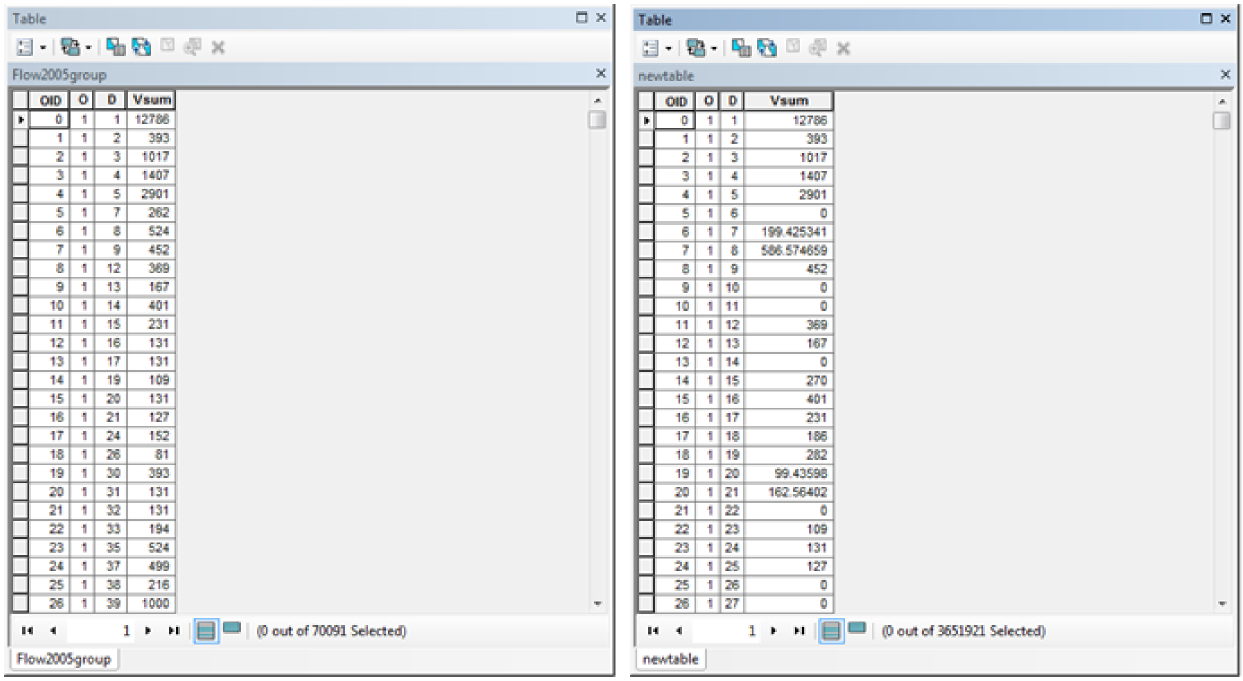
Figure 5 Interface of Spatial Interpolation Tool

There are ten parameters that need to be pre-defined in this tool script. "Workspace" refers to the folder that the output DBF table will be put into. "Input" refers to the result obtained from the first tool script. "Output" is the result that will be sorted in ascending order by the traffic analysis zones ID in the target zoning system; "TAZID_1" refers to the field in the input file that records the ID of each traffic analysis zone in the target zoning system. "TAZID_2" refers to the field in the input file that records the ID of each traffic analysis zone in the source zoning system. "Flowtable" should be the DBF table that records the information of flow between each O-D pair in the source zoning system. "Origin" should be the field that records the ID of each origin in the source zoning system. "Destination" should be the field that records the ID of each destination in the source zoning system. "Flow" should be the field that records the flow data between each O-D pair.

In the result window, the message will be added when the sorting has finished, the DBF table has been created. Moreover, another message will be added when the calculation of the flows started from the specific origin ID has been made to inform the user how much does the calculation finish.

4.2.3 Interpolation Results

After the spatial interpolation, the zoning system in 2005 was transferred to the scheme of 2010, and the flows between 1118 traffic analysis zones in 2005 have been converted to new flows between 1911 TAZs. There are 1911*1911 records of flows between each O-D pair in the output DBF file in Figure 6:



Table

Flow2005group

OID	O	D	Vsum
0	1	1	12786
1	1	2	393
2	1	3	1017
3	1	4	1407
4	1	5	2901
5	1	7	262
6	1	8	524
7	1	9	452
8	1	12	369
9	1	13	167
10	1	14	401
11	1	15	231
12	1	16	131
13	1	17	131
14	1	19	109
15	1	20	131
16	1	21	127
17	1	24	152
18	1	26	81
19	1	30	393
20	1	31	131
21	1	32	131
22	1	33	194
23	1	35	524
24	1	37	499
25	1	38	216
26	1	39	1000

(0 out of 70091 Selected)

Flow2005group

Table

newtable

OID	O	D	Vsum
0	1	1	12786
1	1	2	393
2	1	3	1017
3	1	4	1407
4	1	5	2901
5	1	6	0
6	1	7	199.425341
7	1	8	586.574659
8	1	9	452
9	1	10	0
10	1	11	0
11	1	12	369
12	1	13	167
13	1	14	0
14	1	15	270
15	1	16	401
16	1	17	231
17	1	18	186
18	1	19	282
19	1	20	99.43598
20	1	21	162.56402
21	1	22	0
22	1	23	109
23	1	24	131
24	1	25	127
25	1	26	0
26	1	27	0

(0 out of 3651921 Selected)

newtable

Figure 6 Example of output of the Spatial Interpolation Tool

4.3 Trip Production and Attraction in 2005 and 2010

Table 4 gives us information about total trip generation and trips by motorized mode in morning peak. Between 2005 and 2010, the number of trips with all kinds of mode on a weekday in Beijing increased from 22,181,347 to 47,891,946. In 2005 and 2010, trips occurring between 7:00am and 8:00am account for 19.1% and 21.0% of all trips respectively. Also, in this period, the share of motorized mode (excluding bus mode) increased drastically from 22.78% to 34.59%. As a result, in 2005 and 2010, trips by motorized means occurring in the morning peak account for 965,105 and 3,478,823 respectively.

In order to interpret the travel patterns effectively, the city of Beijing were divided into two parts: The areas inside of the 6th ring road are called urban core areas, and the rest that is outside of the 6th ring road is called peripheral areas.

Table 4Trip Generation by Motorized Mode in Morning Peak in 2005 and 2010

	2005	**2010**
Trip generation (all modes)	22,181,347	47,891,946
Morning Peak (7:00-8:00am)	19.1%	21%
Share of motorized mode	22.78%	34.59%
Total	965,105	3,478,823

4.3.1 Trip Production in 2005 and 2010

Figure 7 is a choropleth map of trip production of each TAZ using the natural break classification method. In the trip production map, the darker color of the TAZ represents the higher number of trip production. In 2005, most of the trips generated inside of the 5th ring road, accounting for a percentage of 78.91 of total trips, and trips generated within the 6^{th} ring road accounted for 90.25% of total trips. Besides the urban core areas, TAZs in the west of Beijing that were close to the 6^{th} ring road also had a high trip production. In the morning peak (from 7:00 to 8:00am) of a normal weekday in 2005, there were only 26 TAZs out of 1911 TAZs that produced more than 4100 trips, and most of these TAZs are located in the center of Beijing. The TAZ zones located near the intersection between ring roads, expressways and primary roads also have high trip production which might be due to the high accessibility to the transport network. Besides the urban center, some suburb centers located in the outside areas of 6^{th} ring road had a higher trip production than other peripheral areas as well.

Table 5Percent of trips generated within the area to total trips in 2005 and 2010

Year	2nd Ring Road	3rd Ring Road	4th Ring Road	5th Ring Road	6th Ring Road
2005	23.38%	47.86%	66.11%	78.91%	90.25%
2010	9.54%	21.84%	36.74%	51.04%	75.31%

In 2010, there were more areas that had high trip productions than there were in 2005. In addition to TAZs with high trip productions located within 5th ring road, other clusters with high trip production appeared around the 6th ring road, and also extended along with major roads. Unlike 2005, the TAZs with the highest trip production were located dispersedly in the periphery of suburb centers in the southwest, northwest and east of Beijing instead of the urban center, indicating the extensive development of suburbs over the 5 years. Trips that generated inside of the 5th and 6th ring road accounted for 51.04% and 75.31% of the total trips respectively, with decreases of 27.87% and 14.94% over the 5 years.

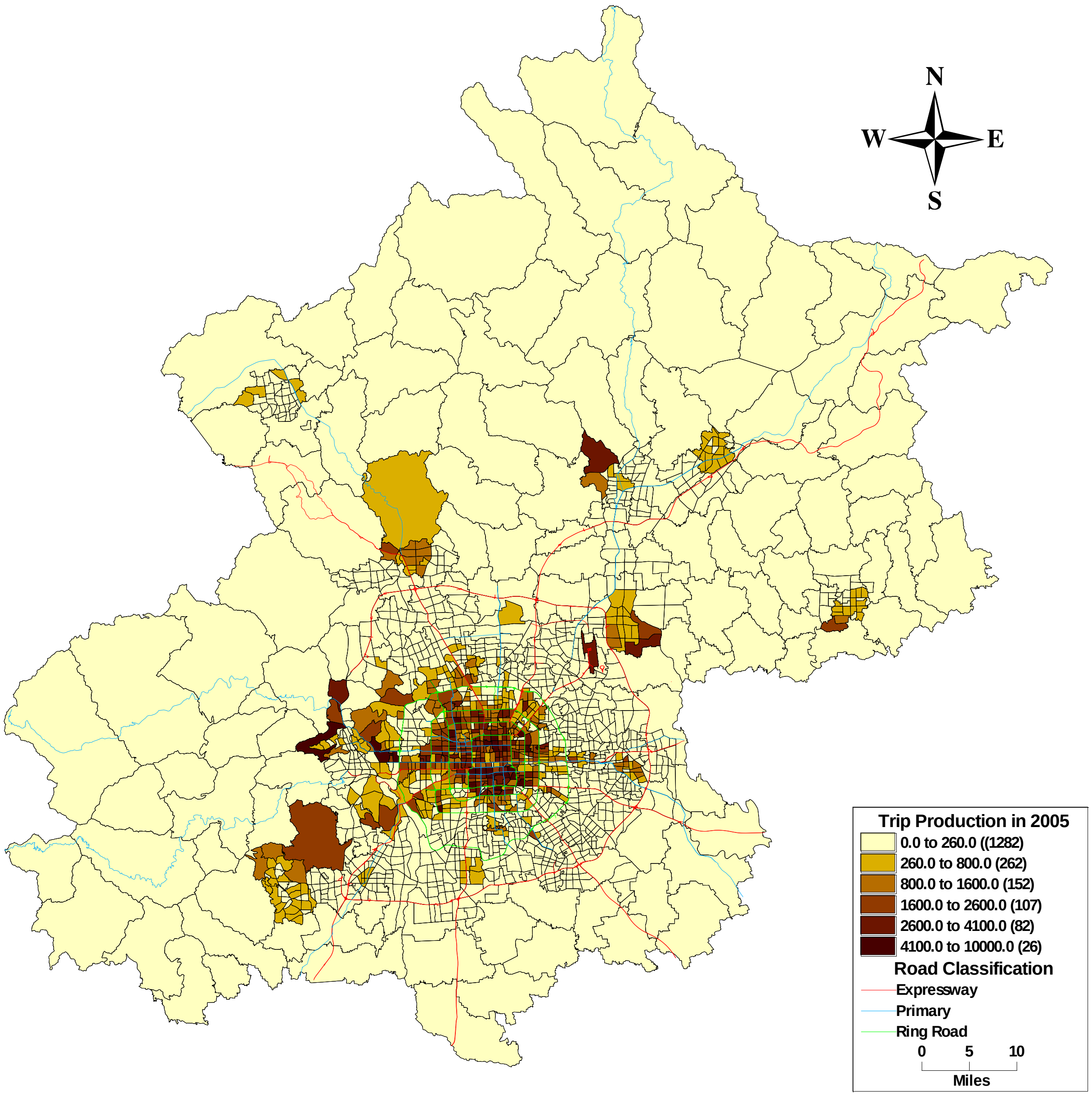


Figure 7 Trip production in Beijing in 2005

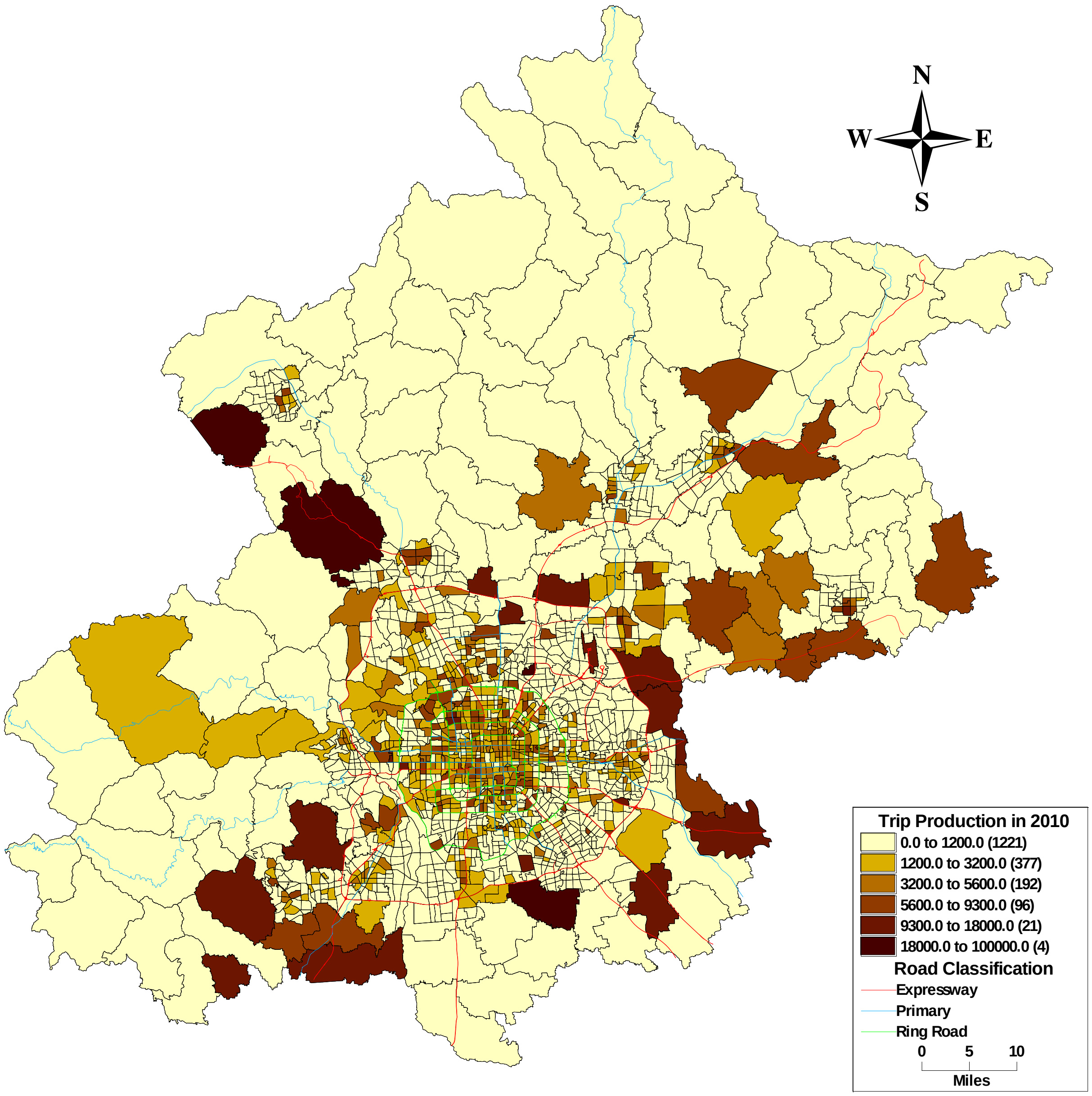


Figure 8 Trip production in Beijing in 2010

4.3.2 Trip Attraction in 2005 and 2010

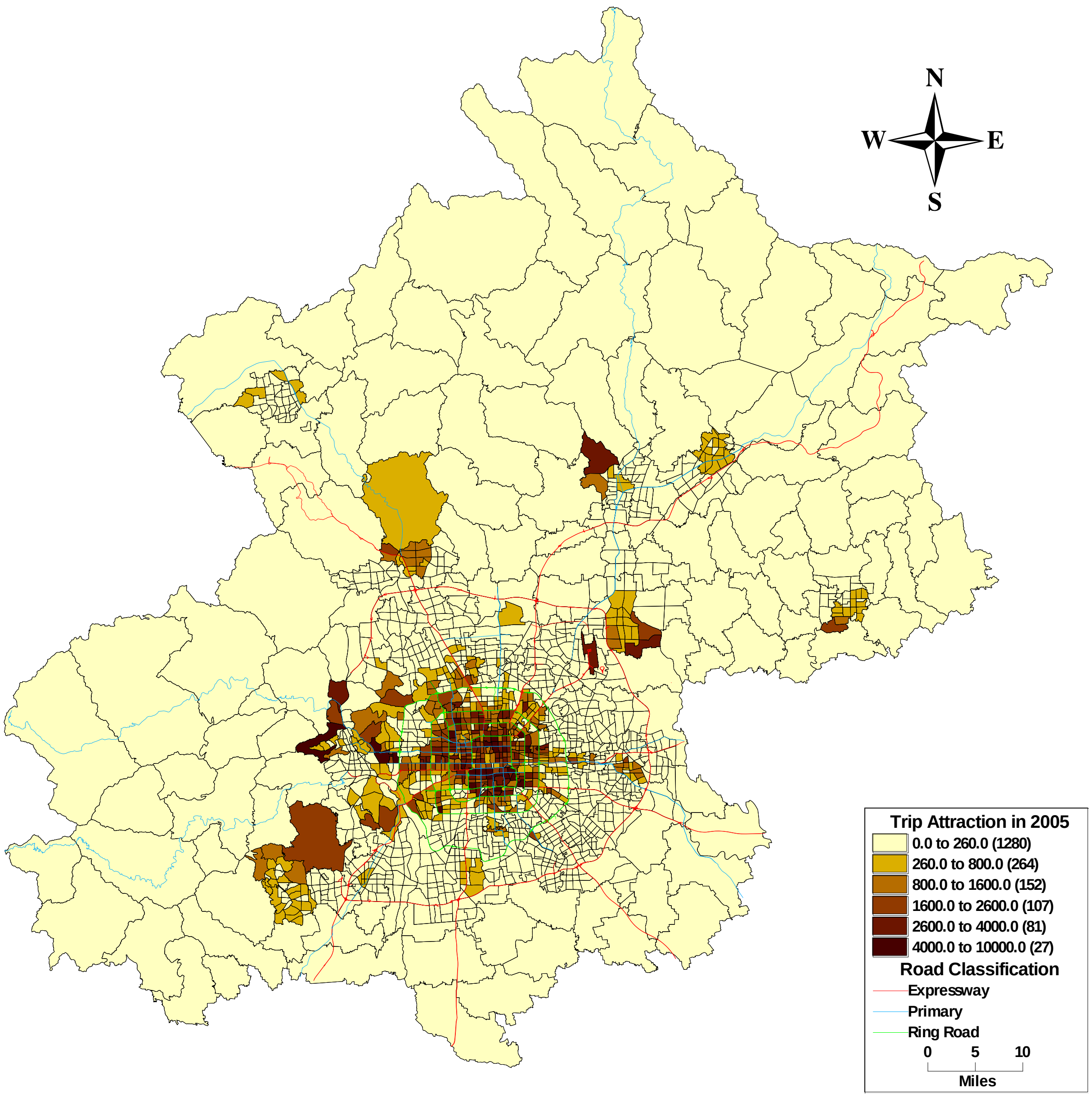


Figure 9 Trip attraction in Beijing in 2005

In 2005, the pattern of trip attraction in Beijing is very similar to the pattern of trip production that same year. The areas with high trip attraction located in the urban center, as well as some small suburb centers. There were only 27 TAZs out of 1911 that attracted more than 4000 trips, among which most of them are located within 5th ring road.

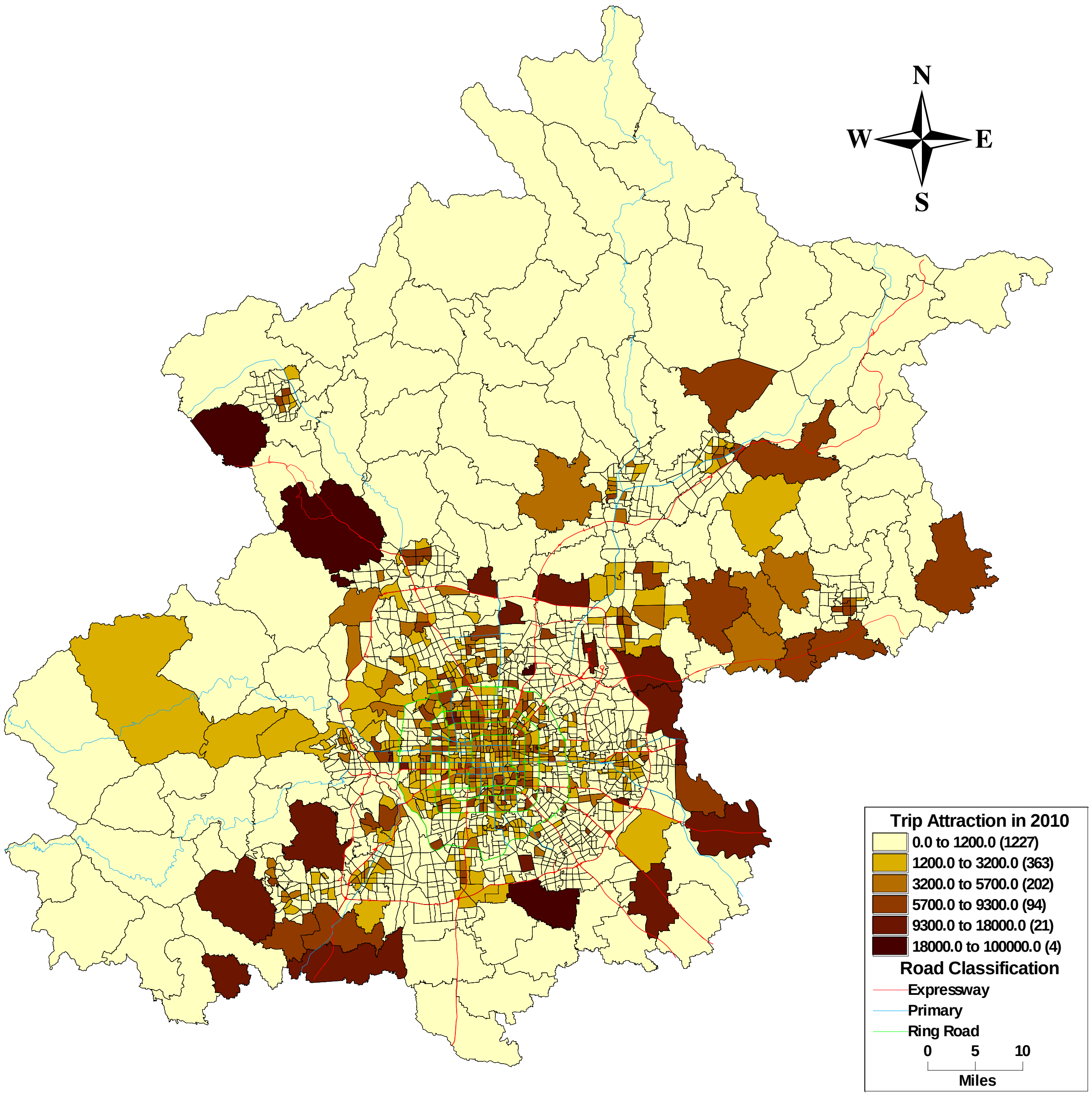


Figure 10 Trip attraction in Beijing in 2010

Similarly, the pattern of trip attraction in 2010 was similar to the pattern of trip production in the same year. Many clusters of highest trip attraction TAZ zones tended to occur in the suburb areas. Although the number of TAZs with medium trip attraction in the urban center increased greatly, the percentage of total trip attraction tended to decrease.

4.3.3 Changes in Trip Production and Trip Attraction

In the map above, the yellow color represents a decrease in trip production between 2005 and 2010, while purple refers to an increase in trip production. The darker the yellow, the greater the decrease in trip production will get, while as the purple gets darker, the larger the increase in trip production occurs. Many TAZ zones in the central area of Beijing undertook a huge decrease in trip production. Some TAZ zones in the northern areas had fewer trip productions during the 5 years as well. Meanwhile, many areas near the 6^{th} ring road had an increase in trip production. In the outward and suburb areas, the distribution of clusters of areas that experienced a growth in trip production matched the distribution of clusters of high trip production or attraction zones.

The pattern of changes in trip attraction between 2005 and 2010 is a little different from the pattern of changes in trip production. While the central areas had experienced a decrease in trip attraction, the outward zones tended to attract more trips. On the other hand, the zones that had the biggest increase in trip attraction are located on the fringe of suburbs, indicating a rapid economic development and urban growth. In the northern Beijing, most areas had only a small increase or even decrease in trip attraction, which means they had little progress in the urban development.

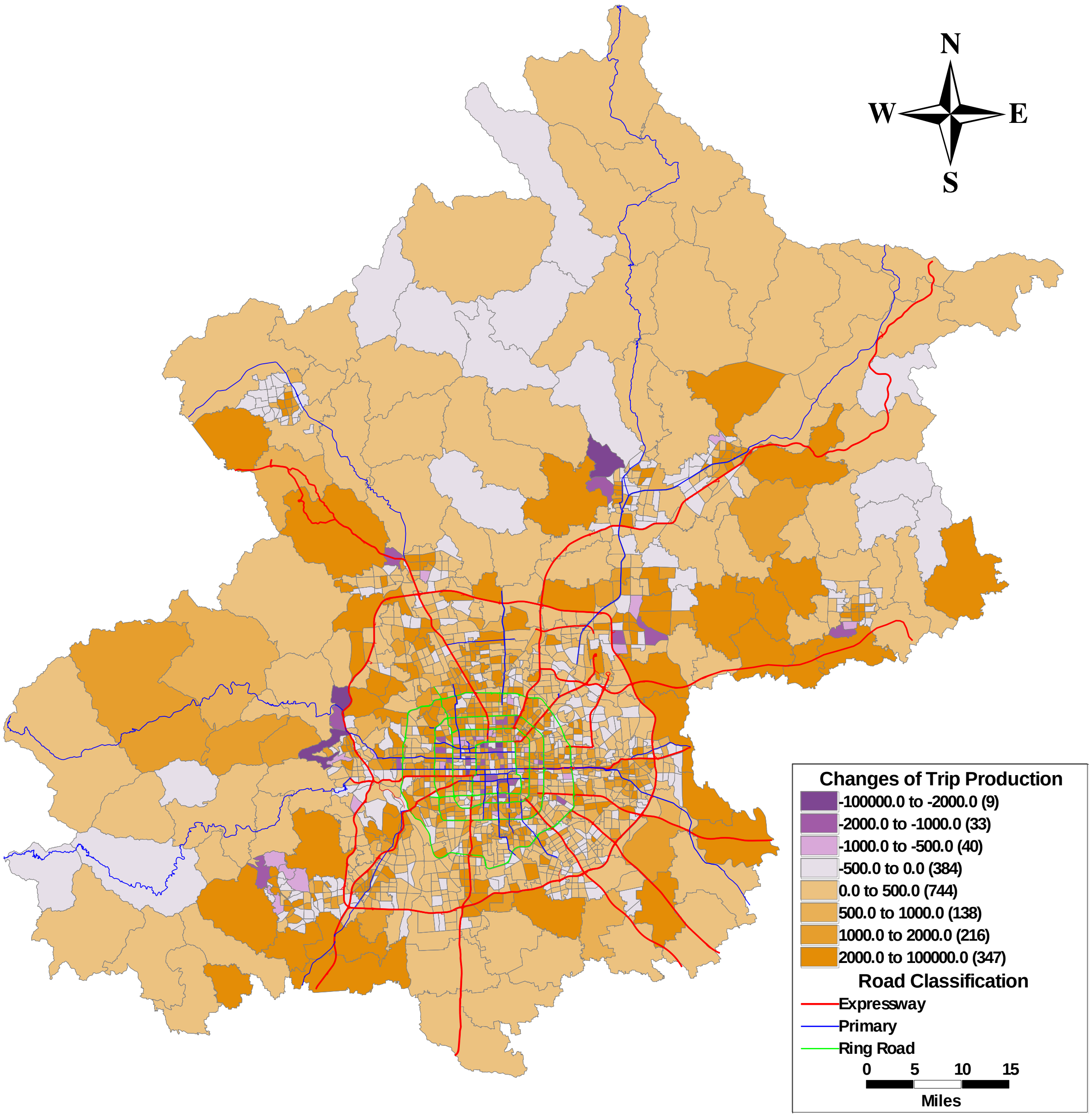


Figure 11 Changes of trip production in TAZ level in Beijing between 2005 and 2010

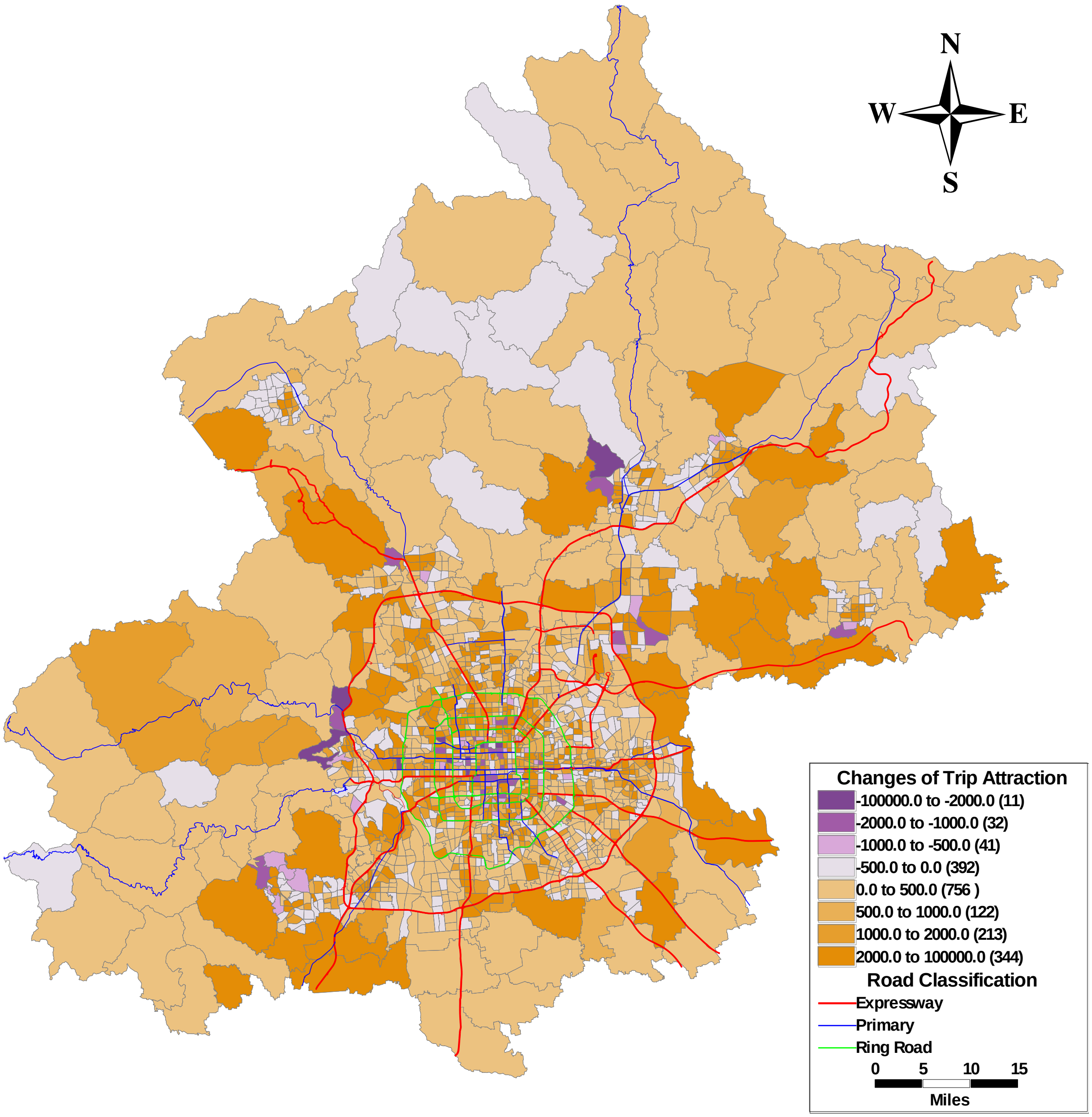


Figure 12 Changes of trip attraction in TAZ level in Beijing between 2005 and 2010

4.3.4 Changes of Travel Time in Morning Peak

With the explosive growth in the trip production and trip attraction among TAZs between 2005 and 2010, the average travel time of TAZs in Beijing in the morning peak increased from 41.5 to 57.2 minutes. In 2005, average travel time of most TAZs within the 5^{th} ring road in morning peak was less than 37 minutes, and average travel time of most TAZs within the 6^{th} ring road was less than 46 minutes.

In 2010, the TAZs that have the lowest average travel time in the morning peak are located east of the urban center because there were several new expressways constructed between 2005 and 2010. The average travel time of most TAZs within the 6^{th}ring road in morning peak was less than 60 minutes.

Between 2005 and 2010, almost all the areas had experienced increases in average travel time in the morning peak, and only 50 TAZs out of 1911 TAZs that are located east of Beijing had experienced a decrease in average travel time. The average travel time of most of the areas inside the 5^{th} ring road and the areas between the northern 5^{th} ring road and the northern 6^{th} ring road increased from 15 to 25 minutes, while the average travel time of other areas within the 6^{th} ring road increased less than 15 minutes. Only a small proportion of TAZs (9) had extremely huge increases in average travel time which were more than 60 minutes in the morning peak between 2005 and 2010, 7 of them were inside of the 6^{th} ring road, and 2 were in the peripheral areas. The distribution of areas that had huge increases in travel time also corresponded with the distribution of high trip production and attraction between the 5 years.

There is an outlier whose average travel time increased more than 130 minutes in the northwest of Beijing due to the modifiable area unit problem. The greater area will have longer centroid connector to the road network. While the TAZ in the northwest of Beijing had high trip production and attraction, the travel time will be extremely high on the long centroid connector because the traffic volume would exceed the capacity of the centroid connector tremendously

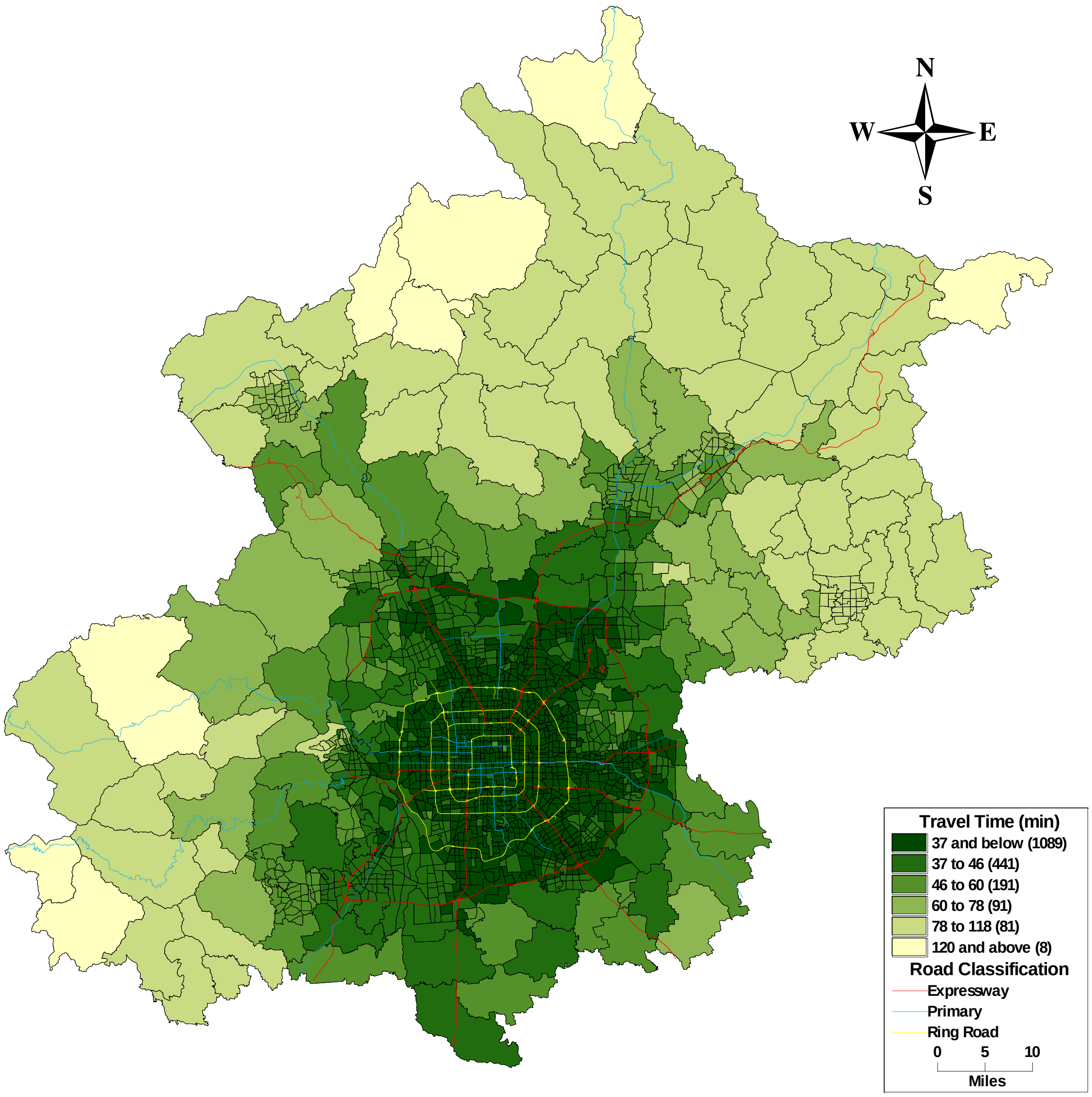


Figure 13 Average travel time in the morning peak, 2005

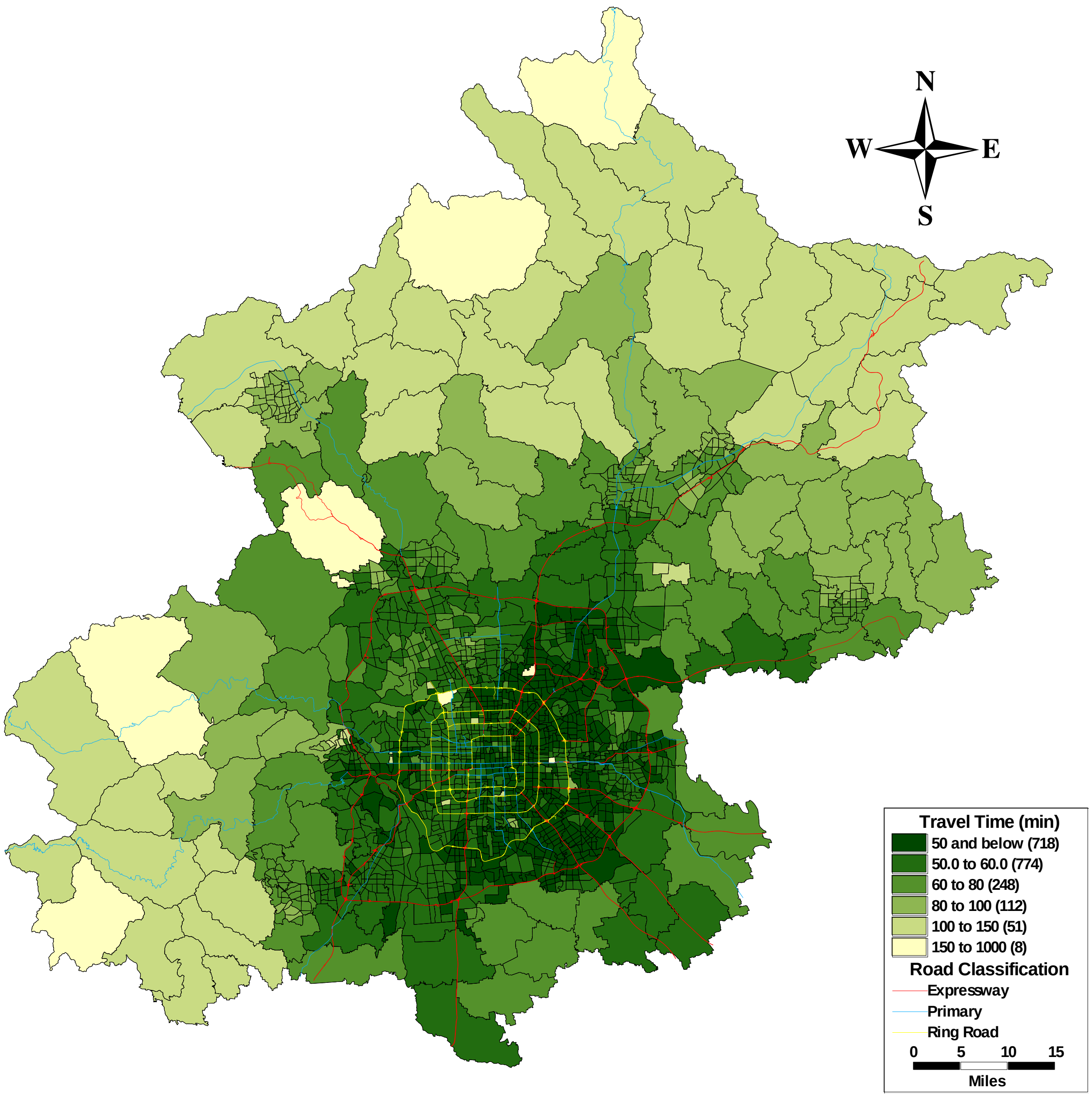


Figure 14 Average travel time in the morning peak, 2010

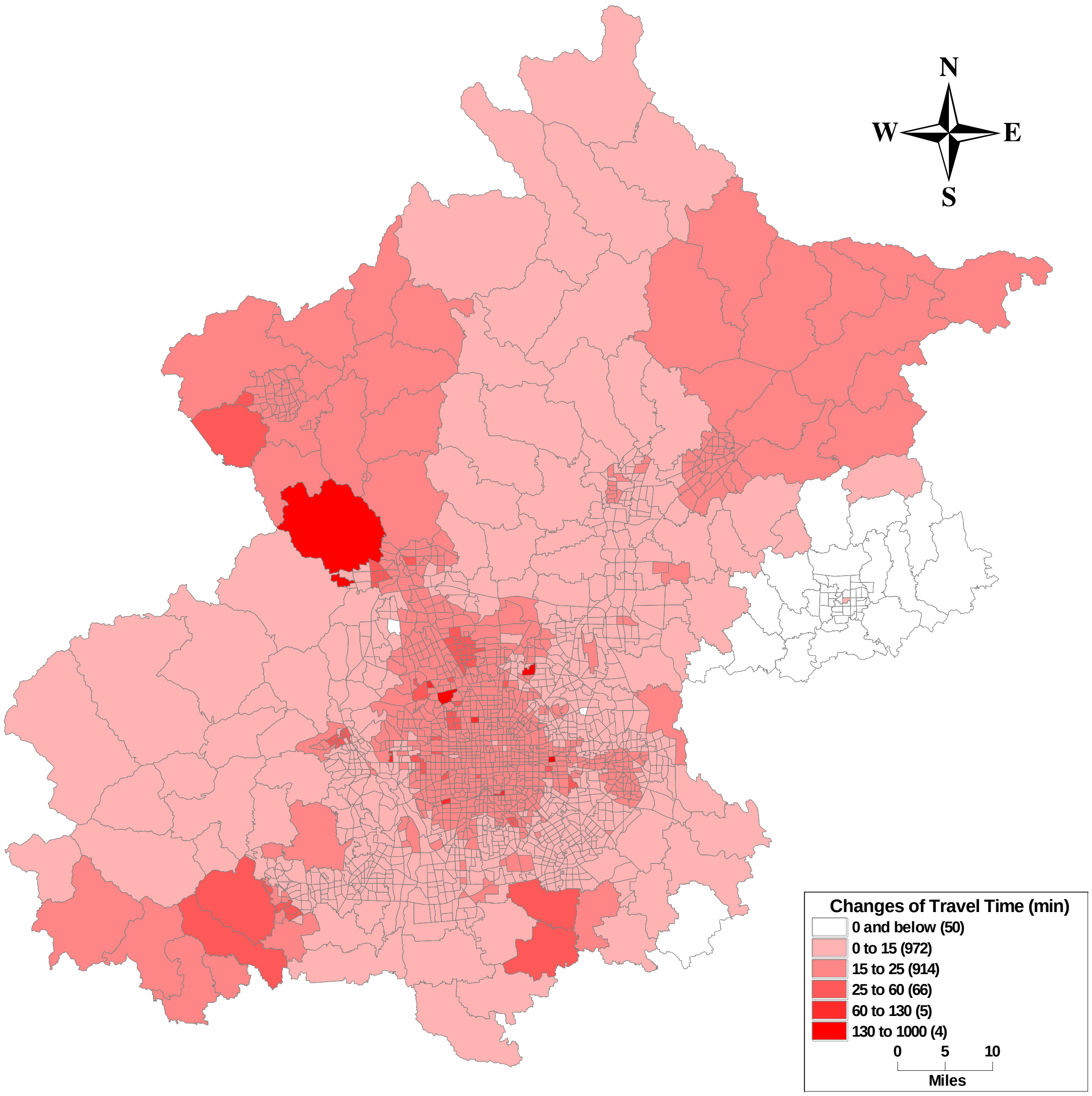


Figure 15 Changes of average travel time in the morning peak between 2005 and 2010

4.4 Traffic Assignment and Changes

In this study, since the trip data were collected by individual survey, it was difficult to determine the exact number of people on every bus trip; In addition, as the bus routes were fixed in urban areas of Beijing, bus trips were not made by the shortest path between origins and destinations, it is inappropriate to assign the trips made by bus with the user equilibrium trip assignment method. Thus, although the bus mode is one of the important travel means for citizens of Beijing, we did not take trips made by bus into account in the trip assignment. Moreover, since Beijing is the cultural, economic and political center of China, there is a large amount of visitors from other areas coming to and travelling within the city everyday by all kinds of motorized transportation means. This will greatly contributes to the traffic congestion as well. Consequently, due to the two omissions mentioned above, we considered the value of 0.75 volume/capacity ratio as a critical index which represents the traffic congestion on the road.

In the morning peak of 2005, all the traffic congestion happened on the roads in the center of the urban areas, and there was little congestion on other roads in the peripheral areas. In 2010, traffic congestion happened even on most of the segments of 6^{th} ring road. The V/C ratio on most roads within the 6^{th} ring road exceeded 1 or even 1.5, indicating the existence of heavy traffic problems in the urban core areas every morning in Beijing.

From Figure 18, it is clear that the expressways and ring roads had experienced the biggest increases in traffic flow in the morning peak. The decrease in traffic flow only happened to a small portion of the roads, most of which are tertiary roads or residential roads.

For the urban core areas, the mode shares of motorized transportation means were higher than shares in peripheral areas. Thus, the trips by cars and taxis produced in the urban core areas were calculated and assigned to the roads in the urban core areas specifically. The mode shares of both years are listed in the table below:

Table 6 Motorized Mode Shares in the Urban Core Areas in 2005 and 2010

Mode	2005 %	2010 %
Car	23.2	34.2
Taxi	8.8	6.6
Metro	3.6	11.5
Bicycle	38.5	16.4
Bus	22.9	28.2
Other	3.0	3.1
Total	100	100

It is obvious that the traffic congestion mainly happened on the primary roads, ring roads and expressways within the 4th ring road, as well as the north part of the 5th ring road in the morning peak of 2005. The worst traffic congestion occurred on the 2nd ring road, and the volume/capacity ratio on many segment of the 2nd ring road could even reach more than 2. There was little traffic congestion on the tertiary and residential roads.

In 2010, more severe traffic congestion occurred everywhere in the urban core areas within the 6th ring road compared to 2005. In the morning peak the traffic volumes exceeded the road capacities much more on the major roads, including all the primary roads, the secondary roads, the expressways, the 2nd ring road, the 3rd ring road, the 4th ring road, the 5th ring road and most of the segments of the 6th ring road. On the other hand, there was little traffic congestion on the residential roads.

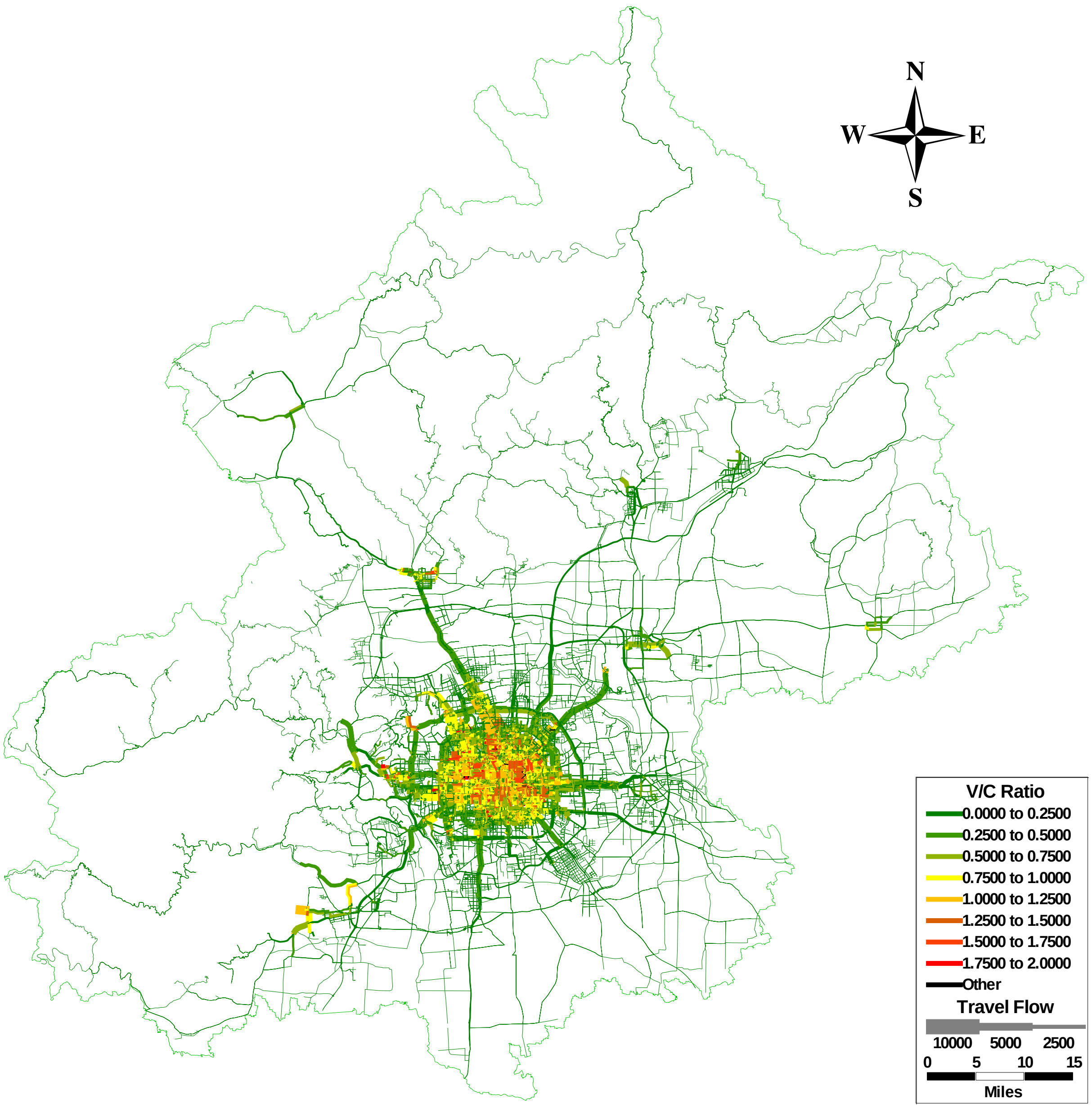


Figure 16 Distribution of traffic flow and Volume/Capacity in the morning peak, 2005

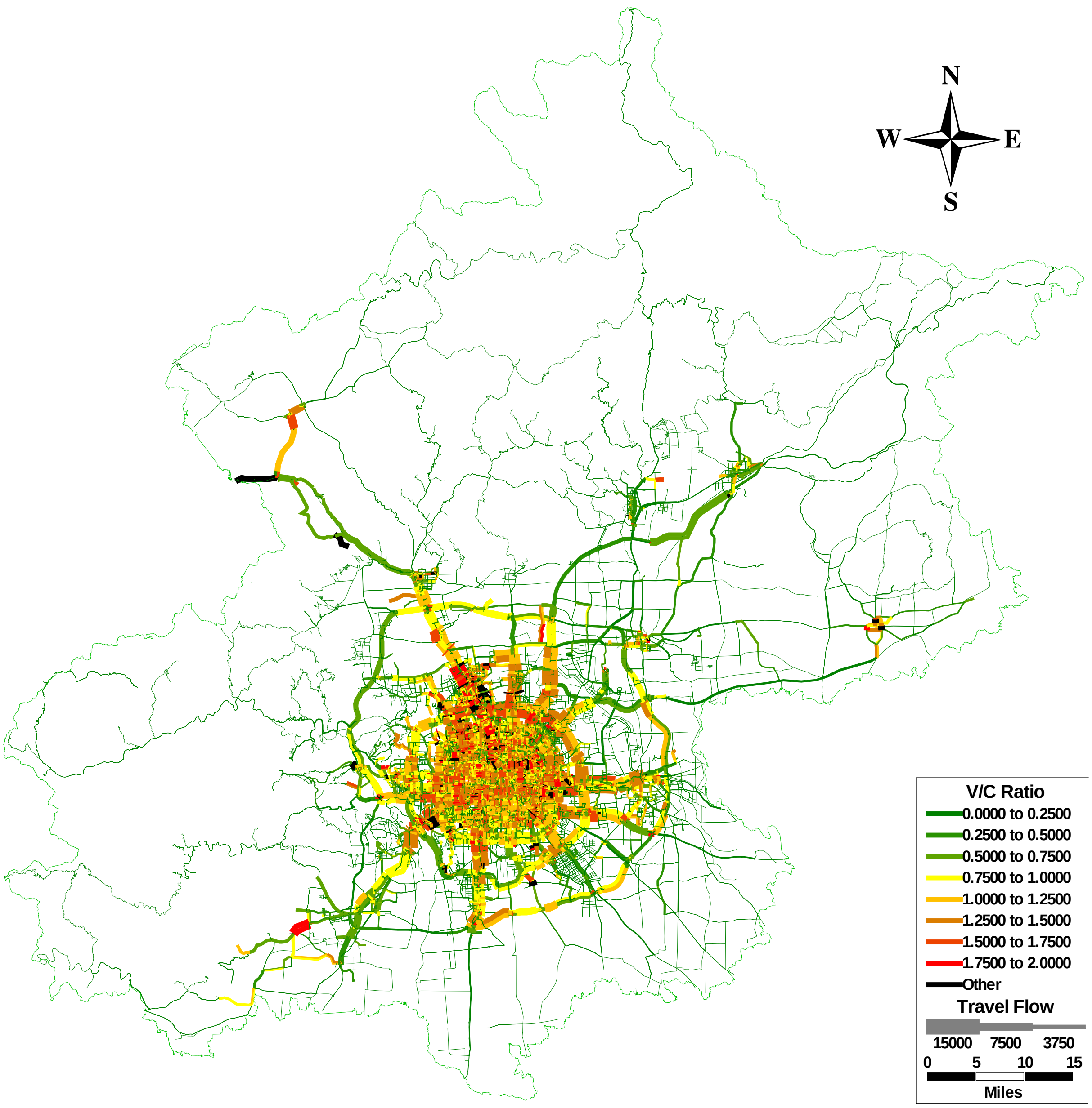


Figure 17 Distribution of traffic flow and Volume/Capacity in the morning peak, 2010

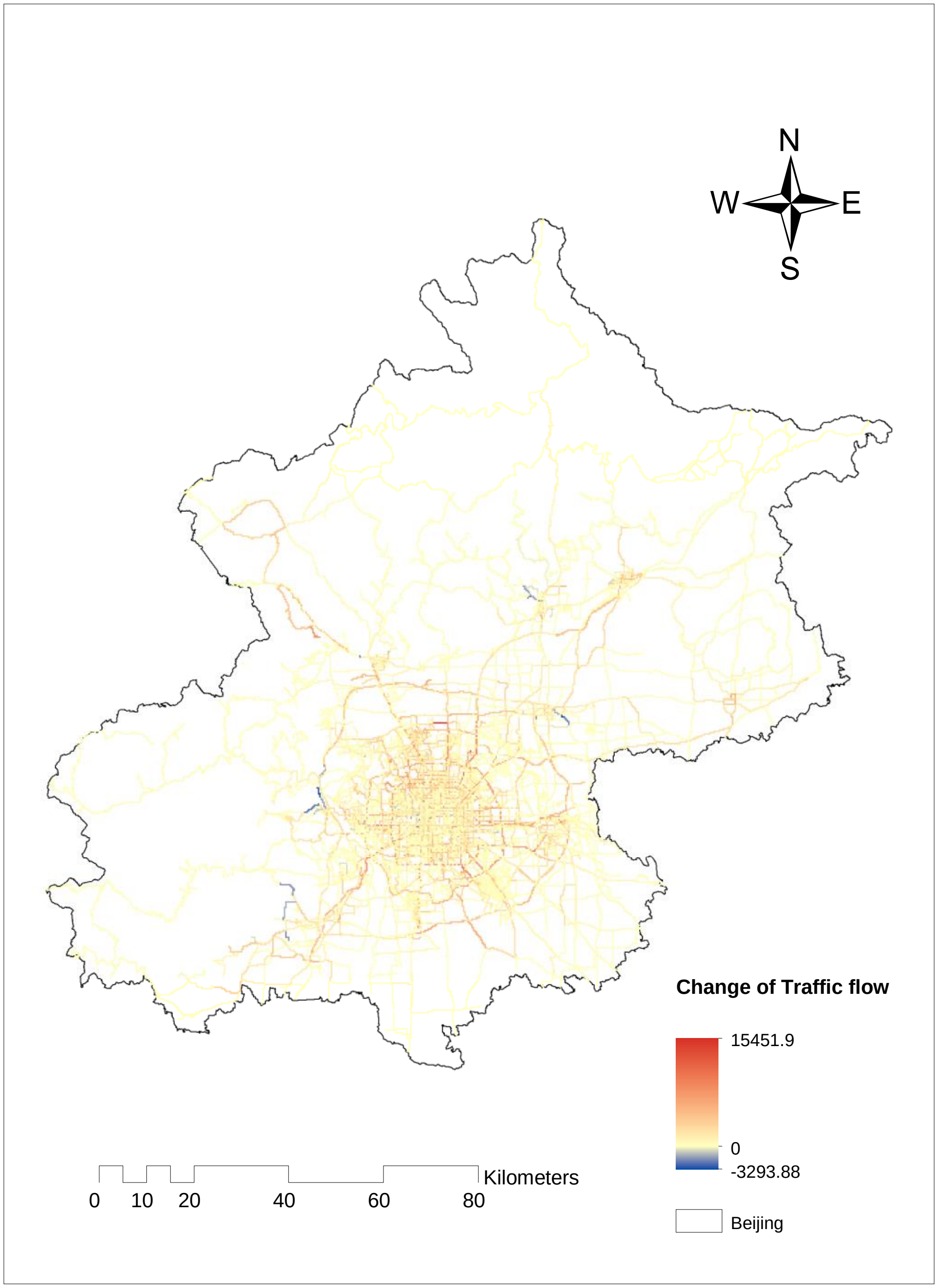


Figure 18Changes of traffic flow on roads in Beijing between 2005 and 2010

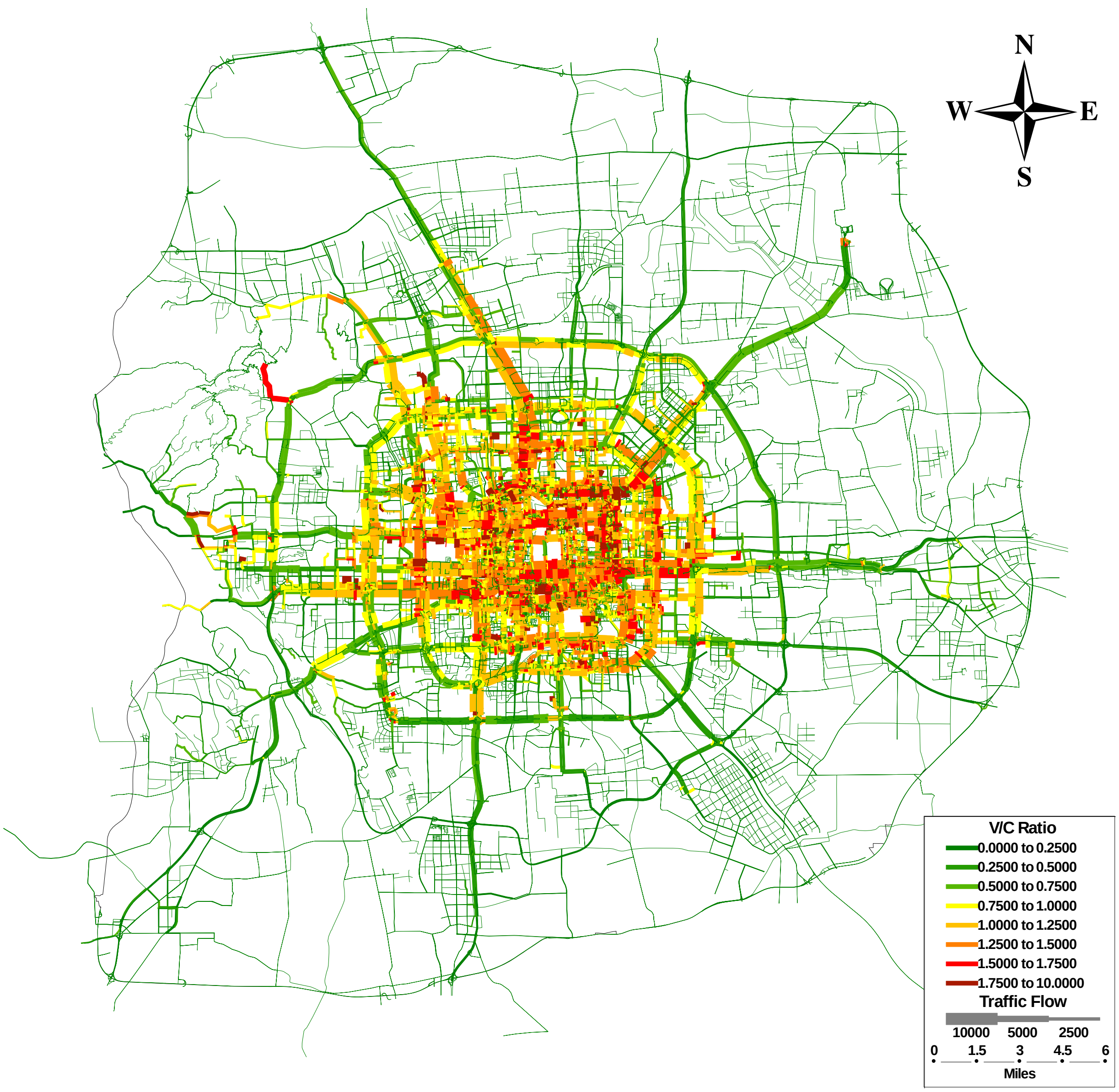


Figure 19 Distribution of traffic flow and Volume/Capacity in urban core area, 2005

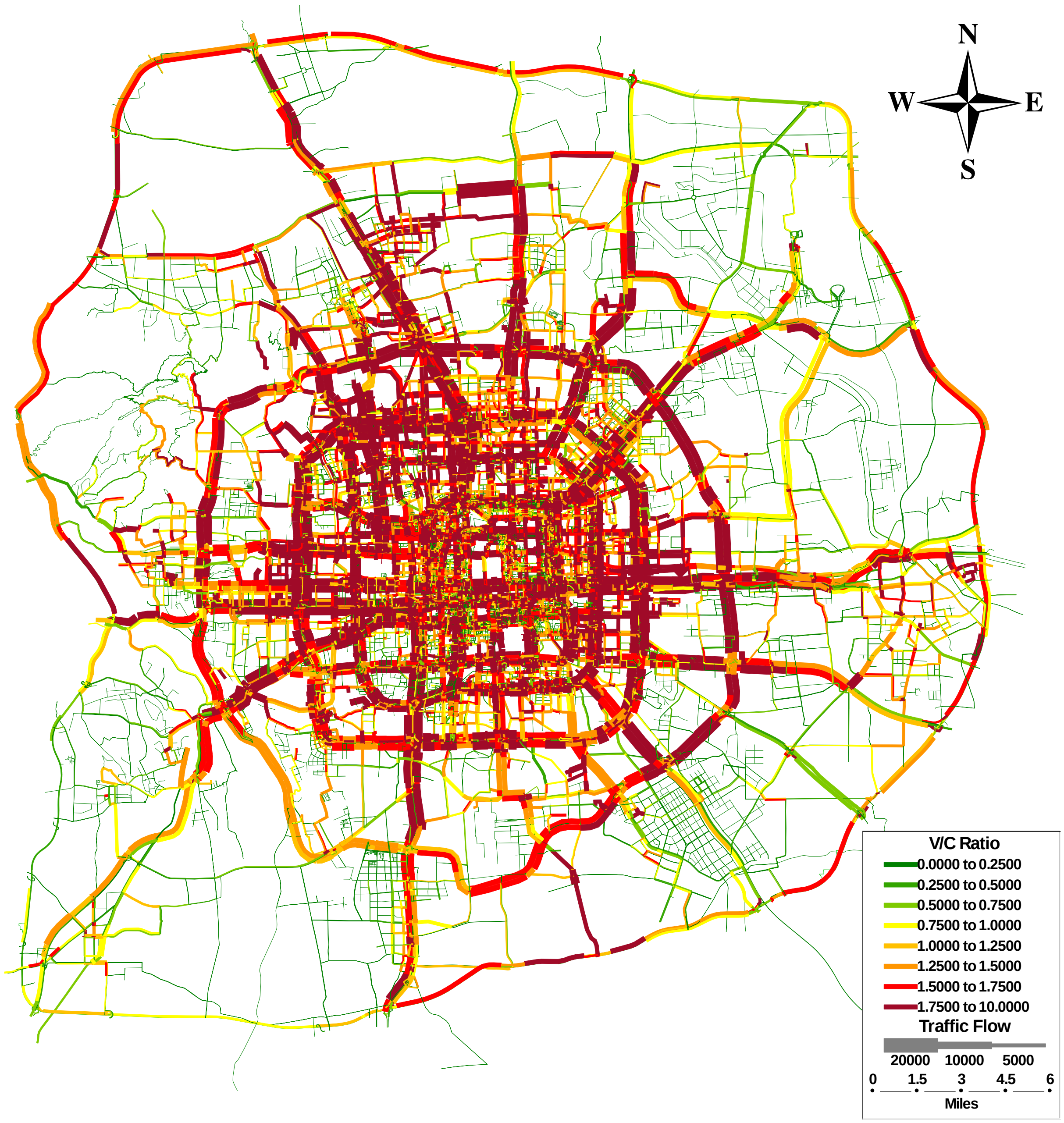


Figure 20 Distribution of traffic flow and Volume/Capacity in urban core area, 2010

In 2005, peripheral areas located outside of the 6th ring road only contributed less than 10% of the total trip production in Beijing, and most of the trip productions of peripheral areas were made to urban core destinations. From Figure 19it is clear that most of the peripheral areas around the 6th ring road had high proportion of trip production to urban core destinations. On the other hand, most of the urban areas had high proportion of trip production to urban core destinations.

In 2010, because of the urban expansion and the proliferation of suburb areas, areas that are located outside of the 6th ring road developed tremendously, contributing nearly 25% of the total trip production in Beijing. Compared to 2005, there was a decrease in areas that had high proportion of trip production to urban core destinations outside of the 6th ring road. The suburb centers in the northeast, northwest and southwest of peripheral Beijing with high trip productions had a low proportion of trip production to urban core destinations, which means most of their trips generated and ended within the same areas. Moreover, according to the Figure 20, some areas in the northeast of the urban core tended to produce more trips to peripheral destinations, indicating the high attraction from peripheral suburb centers.

The high proportion of trips to the urban core destinations to total trips in the northern and southwestern areas in 2005 and 2010 was caused by the small number problem. The trip productions in those areas were the lowest among other peripheral areas, and almost all the productions were made to the urban core destinations.

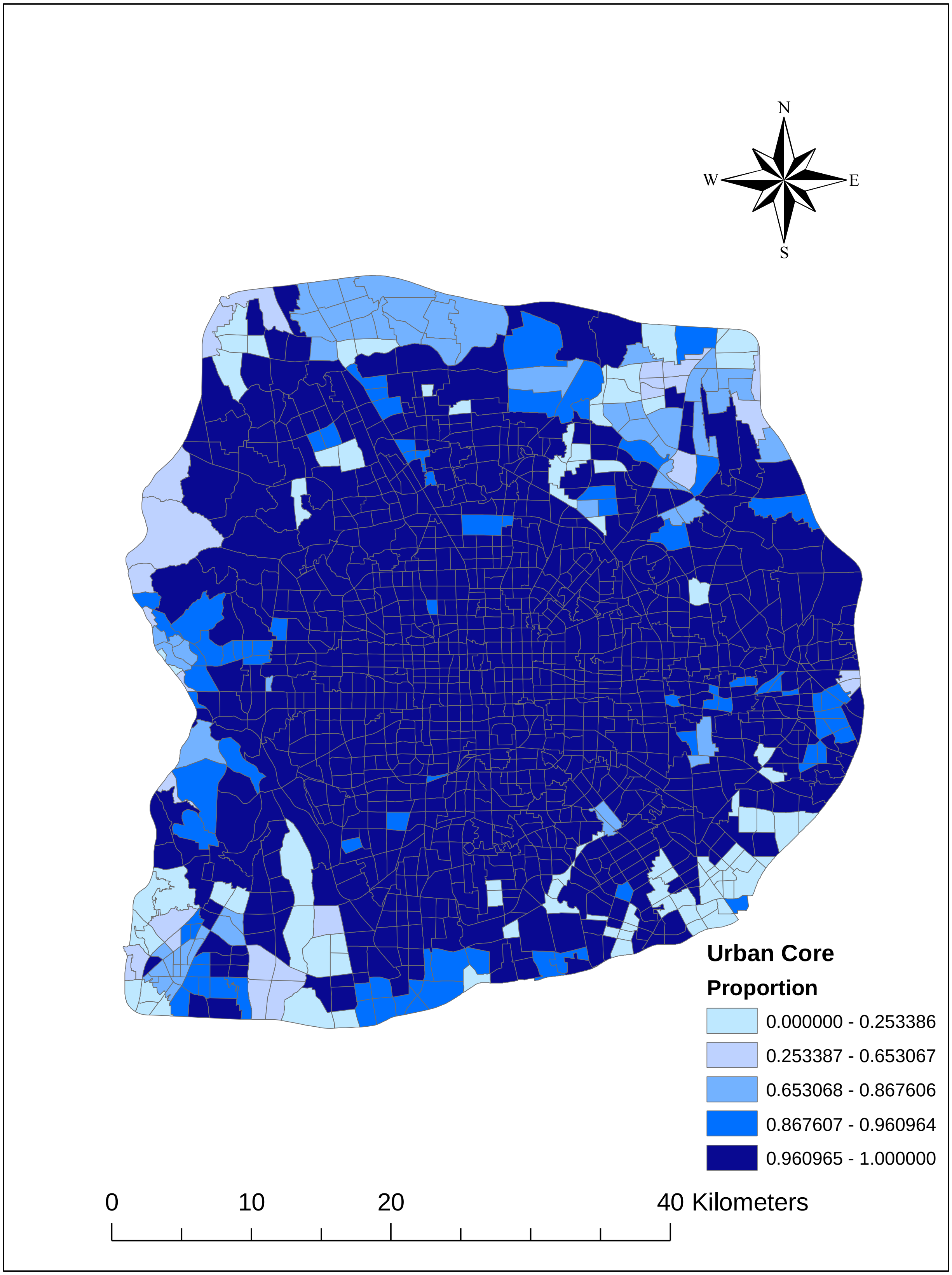


Figure 21 Proportion of trips made to urban core destinations in urban core area, 2005

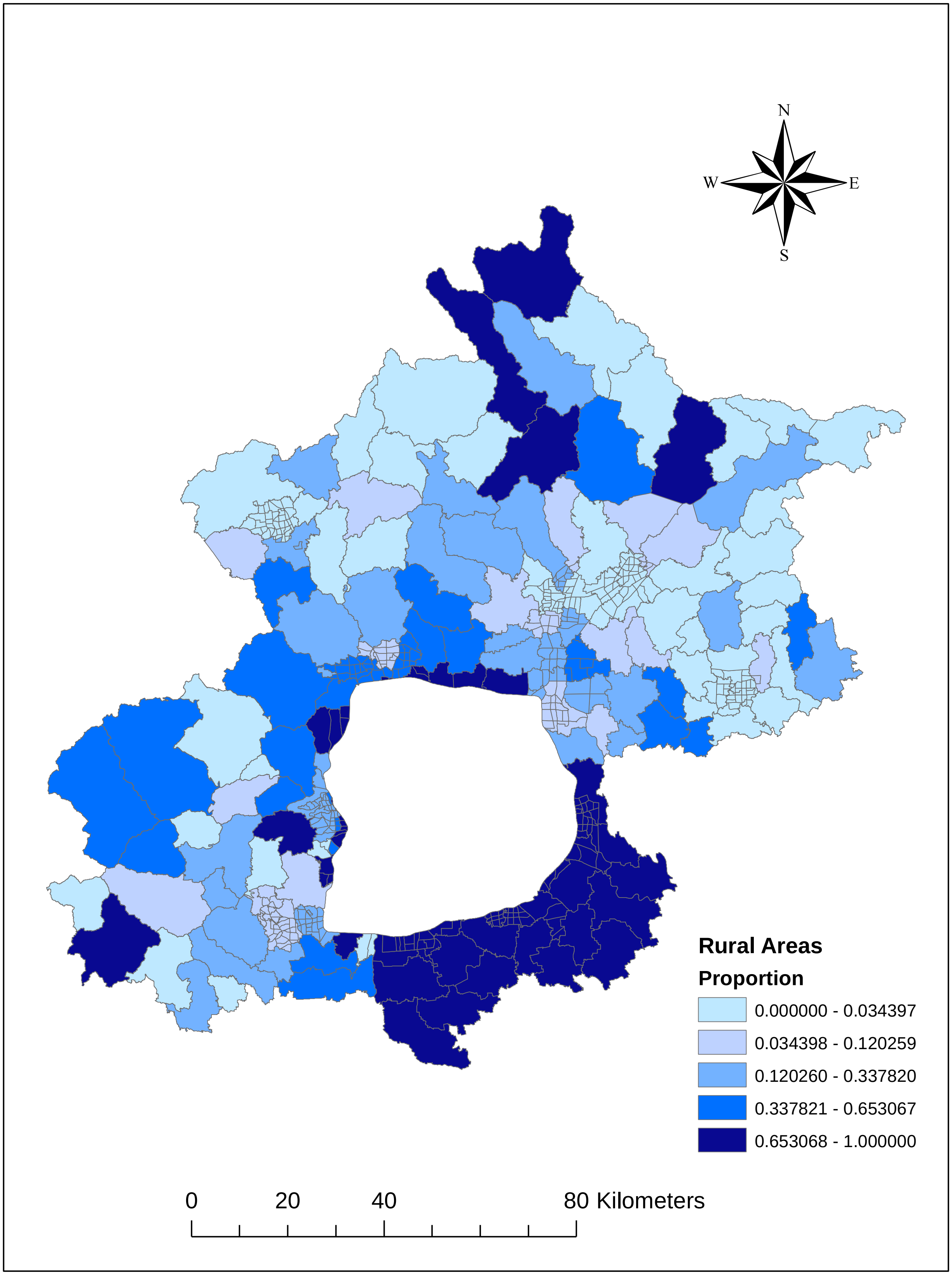


Figure 22 Proportion of trips made to urban core destinations in peripheral area, 2005

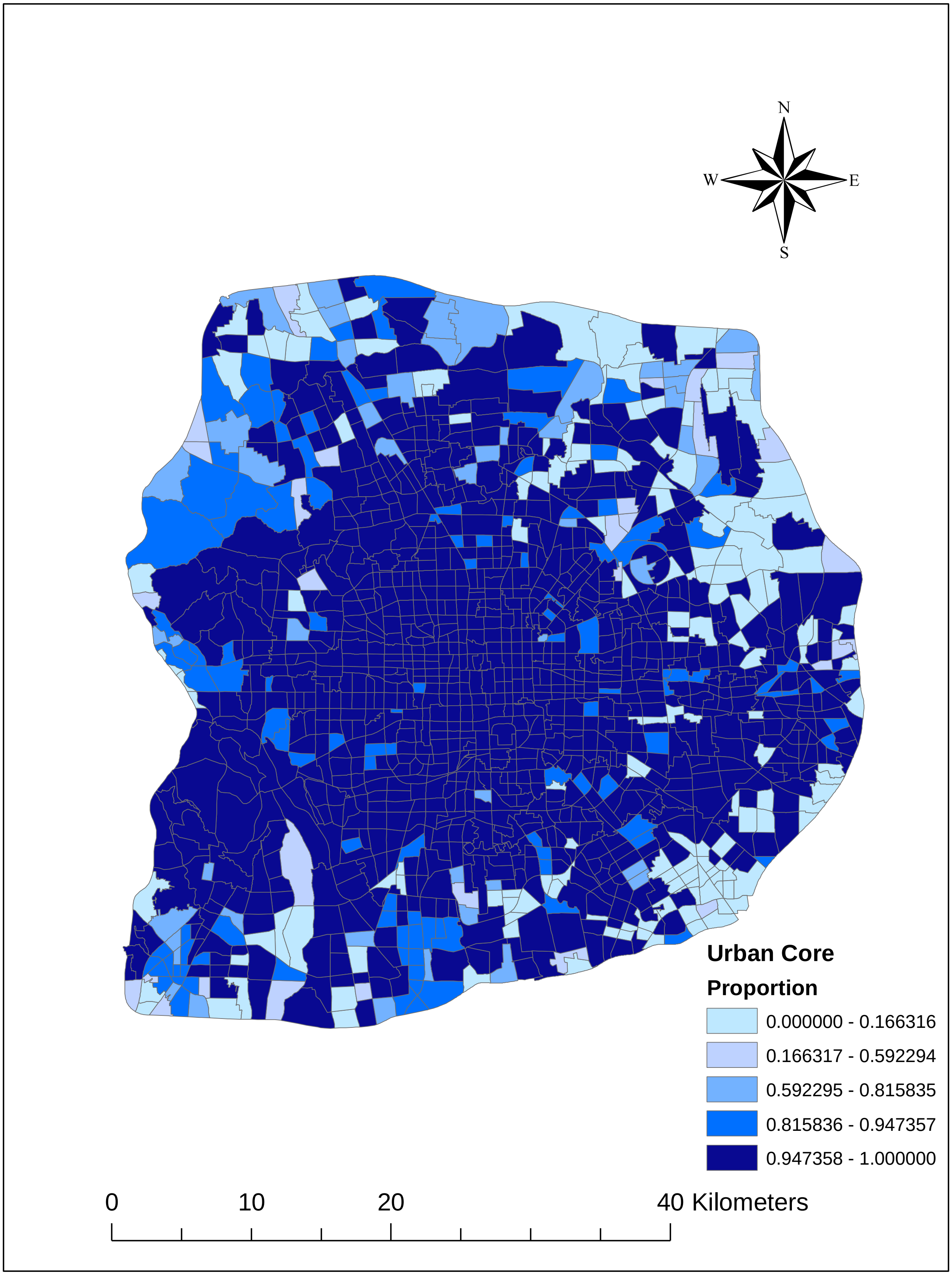


Figure 23 Proportion of trips made to urban core destinations in urban core area, 2010

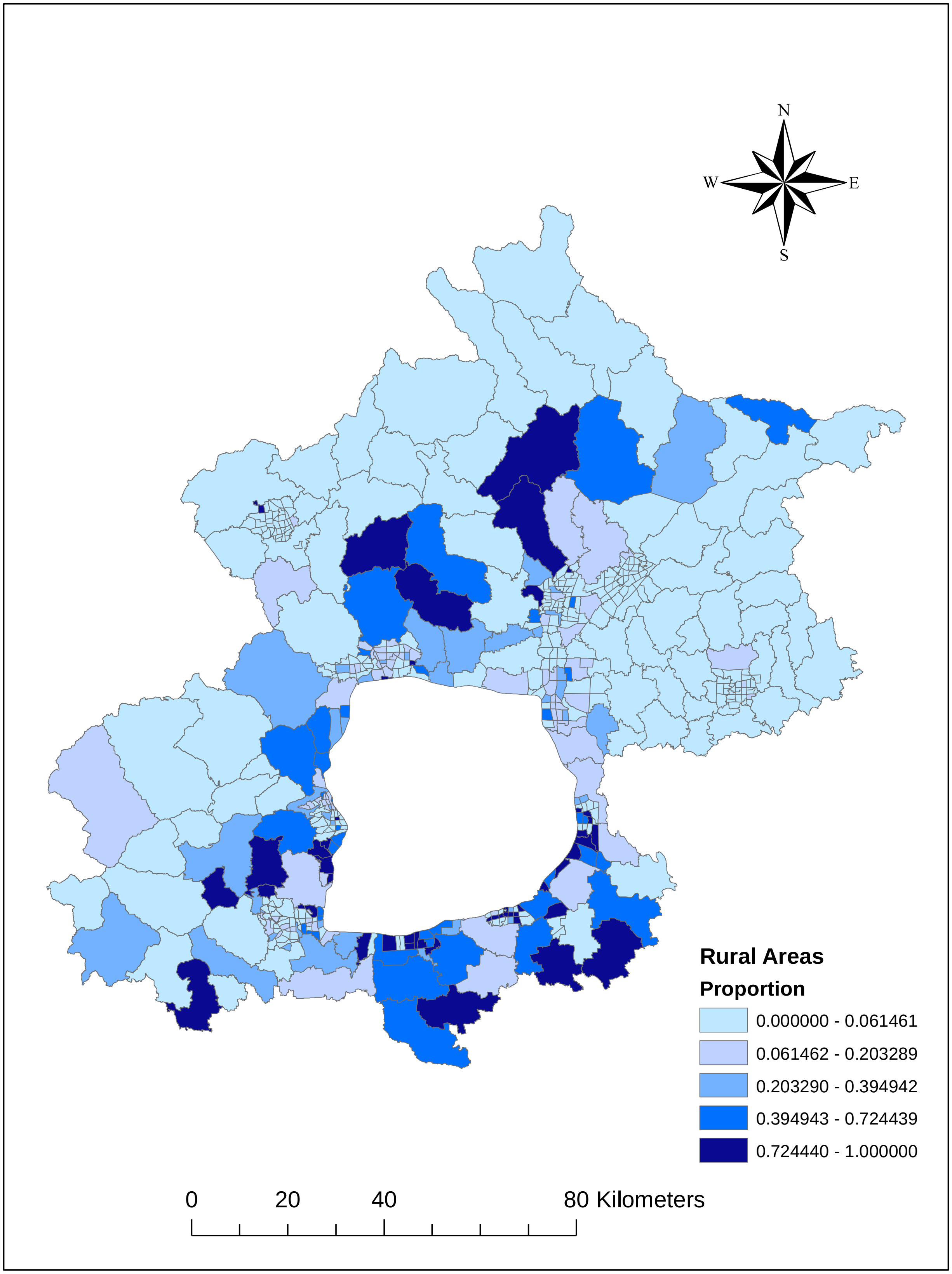


Figure 24 Proportion of trips made to urban core destinations in peripheral area, 2010

CHAPTER 5

CONCLUSION AND DISCUSSIONS

5.1 Summary of Major Findings

The study developed methods and conducted an empirical study of recent paternal changes of traffic in Beijing. In this study, three major objectives have been achieved. For the objective 1, the road dataset of Beijing in 2005 was digitized based on the remote sensing images by the government department in Beijing. The accuracy of the digitization is low as it only included the major roads in 2005, including expressways, ring roads and primary roads. However, it failed to exclude the railways in the digitization. In addition to that, besides the major roads, many residential roads and local roads were missed as well. On the other hand, the dataset in 2010 was contributed by volunteers in the online open street map. The accuracy of the road dataset in 2010 was evaluated and validated with the Google map. I used the dataset of 2005 digitized based on the remote sensing images as a reference, then created a new road dataset of 2005 by removing the roads built after 2005 in the 2010 dataset. The year of construction of the removed roads had been double checked by online source. The topology errors and the road direction for the one-way roads had also been fully checked before they can be used to perform the network analysis. The road datasets of Beijing in 2005 and 2010 were updated and validated with the information from expertise knowledge and the Code for design of urban road engineering in China, and road functional classification in Beijing. For the objective2, a spatial interpolation toolbox with user interface in ArcGIS had been developed based on python scripting in order to interpolate the traffic flow data into a common spatial zoning scheme. The spatial zoning scheme in 2010 was used as common scheme due to its consistency with the recent development in Beijing. With the road networks in 2005 and 2010 that include necessary attributes and the interpolated traffic flow data, the User Equilibrium Traffic Assignment was applied to assign traffic flow to roads, and then spatial and temporal traffic pattern were mapped and analyzed.

From 2005 to 2010, there was an explosive growth in trip generation in Beijing. In 2005, most of the trip production and trip attraction concentrated on the central areas surrounded by the 5th ring road, and the rest of them were mainly generated in the suburb centers in the west and north of the 6th ring road. This centralized trip distribution revealed the concentrated urban form of Beijing in 2005.

In 2010, the trip distribution became more dispersed than it was in 2005. The areas that had high trip production and attraction extended from central areas and suburb centers to the outside areas. In the meantime, the highest trip production and attraction occurred in the peripheral areas of the suburb centers in the southwest, northwest and northeast of Beijing instead of the central areas. These procedures indicated both rapid urban expansion and suburbanization over the 5 years in Beijing.

Most of the decline in trip production and attraction over the 5 years occurs on the central areas inside of the 3rdring road and suburb centers. The areas that were along with the 3rd, 4th and 5th ring roads, expressways and primary roads, and areas around the suburb centers had experienced the biggest increases in trip production and trip attraction.

The average travel time in the morning peak increased from 41.5 to 57.2 minutes during the 5 years. Most areas inside of the 5th ring road had experienced increases from 15 to 25 minutes in the average peak travel time. Due to the construction of the expressway from urban core areas to the eastern suburb areas, the average travel time in the eastern suburb areas decreased.

In 2005, more than 90% of the trip productions and attractions were made within the central areas of Beijing, and most of the trip productions in the peripheral areas were made to urban core destinations. In 2010, the peripheral areas contributed to more trip productions and attractions. Instead of the urban core destinations, most of the trips generated in the peripheral areas were made to peripheral destinations. Many areas in the northeast and southeast urban core areas had low proportion of trip productions to urban core destinations, indicating that most of their trips were attracted by the peripheral urban centers. All of these trends imply the rapid urban growth from areas circled by the 5^{th} ring road to the peripheral areas outside the 6^{th} ring road, as well as the suburbanization in the northeast, northwest and southwest of peripheral Beijing.

In 2005, the traffic flow in the morning peak on most of the major roads within the 4^{th} ring road had exceeded the road capacity, resulting in mediate traffic congestion in central urban areas. There was not too much excess traffic flow on other types of roads, such as tertiary roads and residential roads in peripheral areas. In 2010, as the trip generation increased greatly, there was an explosive growth in traffic flow on the roads within the 6^{th} ring road, which caused a much broader area where traffic congestion occurred. In the urban core areas within the 6^{th} ring road, traffic congestion mainly happened to ring roads, expressways, primary roads and secondary roads. During the 5 years, the traffic flow on most of the roads, particularly the major roads, had increased greatly, while the residential roads in the central areas tended to receive fewer flows.

Changes of travel patterns over the 5 years between 2005 and 2010 provided views of urban development, urban lifestyle, and traffic problems in Beijing. With more and more trips produced and attracted in Beijing, the size of urban and suburb areas in Beijing had largely expanded. Meanwhile new suburb centers had greatly developed. The new urban structure and the increasing trips resulted in more complicated traffic patterns on roads. Severe traffic congestion which mainly occurred on major roads radiated from the 4th ring road to the 6th ring road. Consequently the average travel time in peak hours increased greatly.

Overall, by examining the spatial distribution of trip production and trip attraction in 2005 and 2010, as well as the their changes over the 5 years, it is easy to find out that most travel activities in Beijing occurred and ended within the urban core areas, particularly inside of the 4th ring road areas in 2005, and the travel activities became more dispersed by spreading out towards the eastern and the western areas either near the 6th ring road or in suburbs in 2010. The change patterns of trip production and trip attraction and the between 2005 and 2010 also show us the spatial variation trend of travel activities. The exploration of traffic flow distributions for both years was achieved with the User Equilibrium assignment method, suggesting that the traffic congestion occurred and increased explosively on the major roads over the 5 years. Based on the spatial interpolation, the trip flow data were successfully interpolated to a common aggregated zoning scheme (scheme of 2010), which makes the analysis of changes in traffic flow distribution available. As a result, only a few local roads received reduce in the traffic flow, while most of the high class roads experienced increases.

During the past decade, motor vehicles have become an increasingly important contributor to air pollution in major Chinese cities. Walsh (2000) estimates that motor source are contributing approximately 45-60% of the NO_x emissions and about 85% of the CO emissions in typical Chinese cities. The rapid increase of vehicular emission is especially obvious in Beijing as the number of vehicles and trips boomed. Panis et al. (2006) found that the frequent acceleration and deceleration movements of motor vehicles would significantly increase the pollutant emissions. As a result, the densities of air pollutant emitted by motor vehicles tended to be extremely high in areas where severe traffic congestion happened because of the frequent acceleration and deceleration movements in the slow speed. One of the effective methods to alleviate the traffic congestion and reduce the air pollution is to encourage the turnover rate of high-use public fleets (taxis and buses) (Oliver et al. 2009).

The traffic distribution in peak hours is also useful when the government needs to respond to accidents or emergencies. Based on the information about the average speed, average travel time and V/C ratio of road segments under both normal and congested condition the government could set up the emergency response sites which could effectively cover certain service areas and access accidents in the shortest time. Moreover, the government could also build special passes which are limited to emergency-responding use in areas where the severe traffic congestions are likely to occur.

The major cause of the congestion in Beijing is the rapid increase in the number of motor vehicles in recent years. However, other factors, such as parking on roads, improper driving behaviors, frequent infrastructure construction and road maintenance also make a contribution to the traffic congestion. The tourism will also aggravate the traffic congestion in Beijing as well. Beijing attracts more and more tourists year by year, though a large proportion of the tourists prefer to travel by subway within the city, others will contribute to the tremendous increase in the traffic volume on the roads connecting the famous tourism sites. The potential way to alleviate this negative impact is to encourage people use their bikes instead of cars and buses, and update or build bike routes, as well as increase the amount of bike parking available. It is also important for the government to strengthen the transportation management and improve the traffic law enforcement.

Although the trip production and trip attraction tended to be more dispersed in 2010 than it was in 2005, the urban core areas still produced and attracted most of the trips, making the traffic congestion concentrate on the major roads in the central areas. If the reconstruction and redevelopment in the urban core areas can be strictly controlled with a certain scale, the radiating increasing trend of daily travel demand through the major roads will be reduced. Since the urban sprawl between 2005 and 2010 can cause trip length to increase, obviously, it is very important to develop new urban areas or suburb centers multi-functionally in order to reduce the average travel time. For example, the distribution of housing and work place should be balanced, and the service infrastructure and necessary facilities should be well-planned.

The spatial interpolation tool provides an effective way to analyze the changes of traffic flow distribution as well as the travel patterns between 2005 and 2010. As the road network grows, it is difficult to directly obtain the changes of traffic flow on the road segments because of the difference between datasets from different years. By interpolating the spatial flows based on the same spatial zoning scheme the changes of flows can be easily computed, and the changes of traffic flow can be assigned to roads. Moreover, the spatial interpolation will be useful in examining the relationship between travel patterns and the socio-economic or demographic characteristics of traveler and predicting the travel demand in the future, or the relationship with variables, such as air pollution or land use. Sometimes, data by different socio-economic categories in some areas are available only at a certain level which represents the finest spatial aggregation, this interpolation tool will be able to convert flow data to different levels of spatial aggregation, which will make the investigation of the relationship between travel patterns and socio-economic characteristics possible.

5.2 Limitations and Future Research Avenue

There are several limitations in this study. Since the flow data were collected by each geographic unit (TAZ), the mode share and time share were obtained for the whole city and the whole urban core area. It is inevitable that the accuracy will be decreased when the broad scale mode shares and time shares are applied to every geographic unit. The spatial flow data and mode share should be gathered specifically by each geographic unit so that the results of trip generation and traffic assignment can be improved.

The important attributes of roads in Beijing were obtained and assigned by their classification only, which brought much uncertainty to the road capacity. As a result, the volume/capacity in peak hours might be somewhat underestimated or overestimated. In order to improve the accuracy of the traffic assignment and the reliability of the analysis, it is essential to validate the information of each road in Beijing. In this case, much manual work is needed to fill the gaps of road information. The number of lanes, speed limit and road capacity should be checked by field investigation.

The road network dataset for 2005 needs to be refined as it was derived directly from removing the major roads constructed between 2005 and 2010. However, because of the Olympic Games held in 2008, Beijing government not only built several expressways and primary roads, the city also built or reconstructed many secondary, tertiary and residential roads after 2005. In order to improve the accuracy of traffic distribution in 2005, the differences of roads by all categories should be taken into consideration based on ground truth data.

The parameters in the travel cost function used in this study were obtained from the US highway network. New parameters which are suitable for the road network of Beijing should be calibrated by field data.

In addition, due to the aggregation of trips into traffic analysis zones and the loading of the trips at centroids, the discontinuity in road volume near the centroid connector and unrealistic assignments in the neighborhood of the centroid connectors will be resulted in inevitably. Consequently the modifiable area unit problem occurred when calculating the average time of spatial units (TAZ) in the morning peak based by adding the travel time on the road segments connecting TAZs under congestion. The broader of the level of aggregation will result in the greater the sizes of the zones. Thus, the centroid connectors of the zones with greater sizes will be longer as well. In such case, the calculation of the average travel time in zones with greater sizes will be less inaccurate. The metropolitan Beijing has large differences in TAZ sizes in the urban core and suburban areas, and the average travel time in the urban core areas would be much more reliable due to the MAUP.

Another limitation of the trip assignment is that the intrazonal trips did not enter the transportation system. Normally larger zones produce more intrazonal trips and thus less trips on the network. The smaller zones with fewer roads coded in the network and fewer intrazonal trips will result in over assignment while the larger zones with more roads coded and intrazonal trips will result in under assignment.

If the socio-economic data aggregated in certain spatial level for Beijing were available for 2005 and 2010, the traffic flow data could be interpolated to the corresponding spatial zoning scheme of socio-economic data with the spatial interpolation tool. In the next step the relationship between travel patterns and socio-economic development will be fully examined by certain statistic regression analysis so that we could obtain a better understanding of that how the travel patterns will be affected by the economic or social development between these 5 years in Beijing, which will help us to predict the travel patterns and travel demand in the future years. Based on the previous findings from the analysis for 2005 and 2010, and new findings for future years, planners and decision makers will be able to improve or develop a more effective transportation system that will provide high quality transportation services at a reasonable cost with minimal environment impact in the future. This is quite important for Beijing which is undergoing severe traffic problems (congestion and highest travel cost), air pollution and even land use imbalance. It is meaningful to carry out such analysis on travel patterns in order to develop information to help make decisions on the future development and management of transportation systems in urban areas.

REFERENCES

Acker, V. and F. Witlox (2010). "Commuting trips within tours: how is commuting related to land use?" Transportation 38(3): 465-486.

Almaani M S S. Network trip assignment and aggregation procedures in urban transportation planning and design [J]. 1988.

Alpkokin, P., C. Cheung, J. Black and Y. Hayashi (2008)."Dynamics of clustered employment growth and its impacts on commuting patterns in rapidly developing cities."Transportation Research Part A: Policy and Practice 42(3): 427-444.

Antipova, A., F. Wang and C. Wilmot (2011). "Urban land uses, socio-demographic attributes and commuting: A multilevel modeling approach." Applied Geography 31(3): 1010-1018.

Anselin L. Local indicators of spatial association—LISA [J]. Geographical analysis, 1995, 27(2): 93-115.

Baum-Snow, N. (2010). "Changes in Transportation Infrastructure and Commuting Patterns in US Metropolitan Areas, 1960–2000."American Economic Review 100(2): 378-382.

Beckmann M, McGuire C B, Winsten C B. Studies in the Economics of Transportation [R]. 1956.

Borrestad, L. A., L. B. Andersen and E. Bere (2011)."Seasonal and socio-demographic determinants of school commuting."PrevMed 52(2): 133-135.

Boussauw, K., T. Neutens and F. Witlox (2011). "Minimum commuting distance as a spatial characteristic in a non-monocentric urban system: The case of Flanders." Papers in Regional Science 90(1): 47-65.

Buchin, K., M. Buchin, J. Gudmundsson, M. LÖFfler and J. U. N. Luo (2011)."Detecting Commuting Patterns by Clustering Subtrajectories."International Journal of Computational Geometry &Applications 21(03): 253-282.

Burrough, P. (1986). Principles of GIS for Land Resources Assessment. Clarendon, Oxford.

Cervero R. Jobs-housing balance revisited: trends and impacts in the San Francisco Bay Area [J]. Journal of the American Planning Association, 1996, 62(4): 492-511.

Chen X, Zhan F B, Wu G. A spatial and temporal analysis of commute pattern changes in Central Texas [J]. Annals of GIS, 2010, 16(4): 255-267.

Christian, T. J. (2012). "Automobile commuting duration and the quantity of time spent with spouse, children, and friends." PrevMed 55(3): 215-218.

Congdon, P. and C. D. Lloyd (2012). "A spatial random-effects model for interzone flows: commuting in Northern Ireland." Journal of Applied Statistics 39(1): 199-213.

Dieleman, F., M. Dijst and G. Burghouwt (2002). "Urban Form and Travel Behaviour: Micro-level Household Attributes and Residential Context." Urban Studies 39(3): 507-527.

Fisher P F, Langford M. Modeling Sensitivity to Accuracy in Classified Imagery: A Study of Areal Interpolation by Dasymetric Mapping [J]. The Professional Geographer, 1996, 48(3): 299-309.

Florian M, Nguyen S. An application and validation of equilibrium trip assignment methods [J]. Transportation Science, 1976, 10(4): 374-390.

Flowerdew, R. and Green, M. (1992).Developments in areal interpolation methods in GIS. The Annals of Regional Science, 26:67-78.

Flowerdew R, Green M. Areal interpolation and types of data [J]. Spatial analysis and GIS, 1994,

Frost M, Linneker B, Spence N. Excess or wasteful commuting in a selection of British cities [J]. Transportation Research Part A: Policy and Practice, 1998, 32(7): 529-538.

Gaubatz P. China's urban transformation: patterns and processes of morphological change in Beijing, Shanghai and Guangzhou [J]. Urban Studies, 1999, 36(9): 1495-1521.

Giuliano, G. and K. Small (1993). "Is the Journey to Work Explained by Urban Structure?" Urban Studies 30(9): 1485-1500.

Giuliano G, Narayan D. Another look at travel patterns and urban form: the US and Great Britain [J]. Urban studies, 2003, 40(11): 2295-2312.

Giuliano, G., Narayan, D., 2004. A Comparison of work and non-work travel: The US and Great Britain, In: Rietveld, P., Stough, R., (Eds.), Barriers to Sustainable Transport. London, E.T. Spon., forthcoming.

Giuliano G, Dargay J. Car ownership, travel and land use: a comparison of the US and Great Britain [J]. Transportation Research Part A: Policy and Practice, 2006, 40(2): 106-124.

Goodchild, Michael F., ed. "Environmental modeling with GIS." (1993).

Gordon, P., H. W. Richardson and M.-J.Jun (1991)."The Commuting Paradox Evidence from the Top Twenty."Journal of the American Planning Association 57(4): 416-420.

Guell, C., J. Panter, N. R. Jones and D. Ogilvie (2012). "Towards a differentiated understanding of active travel behaviour: using social theory to explore everyday commuting." SocSciMed 75(1): 233-239.

Haixiao, P., S. Qing and Z. Ming (2009)."Influence of Urban Form on Travel Behaviour in Four Neighbourhoods of Shanghai."UrbanStudies 46(2): 275-294.

Hamilton B W, Röell A. Wasteful commuting [J]. The Journal of Political Economy, 1982: 1035-1053.

Hamilton B W. Wasteful commuting again [J]. The journal of political economy, 1989, 97(6): 1497-1504.

Holzer, H. (1991). "The Spatial Mismatch Hypothesis: What Has the Evidence Shown?" Urban Studies 28(1): 105-122.

Horner, M. W. (2006)."A multi-scale analysis of urban form and commuting change in a small metropolitan area (1990–2000)."The Annals of Regional Science 41(2): 315-332.

Huang, J., 2009. Beijing will levy emissions fee for motorized vehicles (in Chinese: Beijing jidongchezhengpaiwufeichengweijinianzhongdian). Beijing Youth Daily (in Chinese: Beijing qingnianbao), 31 January, p. A2.

Huber M J, Boutwell H B, Witheford D K. Comparative analysis of traffic assignment techniques with actual highway use [J]. NCHRP Report, 1968 (58).

Hughes, M. A. (1987). "Moving Up and Moving Out: Confusing Ends and Means about Ghetto Dispersal." Urban Studies 24(6): 503-517.

IntPanis L, Broekx S, Liu R. Modelling instantaneous traffic emission and the influence of traffic speed limits [J]. Science of the Total Environment, 2006, 371(1): 270-285.

Jang W, Yao X. Interpolating Spatial Interaction Data1[J]. Transactions in GIS, 2011, 15(4): 541-555.

Jones, C. H. and D. Ogilvie (2012). "Motivations for active commuting: a qualitative investigation of the period of home or work relocation." Int J BehavNutrPhysAct9: 109.

Kain J F. Housing segregation, negro employment, and metropolitan decentralization [J]. The Quarterly Journal of Economics, 1968, 82(2): 175-197.

Killer, V. and K. W. Axhausen (2010)."Mapping Overlapping Commuting-to-Work Areas."Journal of Maps 6(1): 147-159.

Kim, C., S. Sang, Y. Chun and W. Lee (2012). "Exploring urban commuting imbalance by jobs and gender."AppliedGeography 32(2): 532-545.

Kwasniewska, M., K. Kaczmarczyk-Chalas, M. Pikala, Broda, K. Kozakiewicz, A. Pajak, A. Tykarski, T. Zdrojewski and W. Drygas (2010)."Socio-demographic and lifestyle correlates of commuting activity in Poland."PrevMed 50(5-6): 257-261.

Lam, N. (1983). Spatial Interpolation Methods: A Review. The American Cartographer, 10(2): 129 -149.

Lau, J. C.-Y. (2013). "Sustainable urban transport planning and the commuting patterns of poor workers in a historic inner city in Guangzhou, China."Habitat International 39: 119-127.

Li, S. m. (2010). "Evolving Residential and Employment Locations and Patterns of Commuting under Hyper Growth: The Case of Guangzhou, China." Urban Studies 47(8): 1643-1661.

Li T, Corcoran J, Burke M. Disaggregate GIS modelling to track spatial change: exploring a decade of commuting in South East Queensland, Australia [J]. Journal of Transport Geography, 2012, 24: 306-314.

Limtanakool, N., M. Dijst and T. Schwanen (2006). "The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips." Journal of Transport Geography 14(5): 327-341.

Ling, X., W. Bingsong and Y. Kaizhong (2010). "Study on the Temporal and Spatial Features of Changes with Commuting, Employment and Residence in Beijing." Procedia - Social and Behavioral Sciences 2(5): 7056-7070.

Lukić, V. and B. Tosić (2011). "Daily commuting – similarities and differences between Serbia and Slovenia." ActageographicaSlovenica 51(2): 319-336.

Ma L J C. Economic reforms, urban spatial restructuring, and planning in China [J]. Progress in Planning, 2004, 61(3): 237-260.

Marique, A.-F., S. Dujardin, J. Teller and S. Reiter (2013). "School commuting: the relationship between energy consumption and urban form." Journal of Transport Geography 26: 1-11.

McArthur, D. P., G. Kleppe, I. Thorsen and J. Ubøe (2011). "The spatial transferability of parameters in a gravity model of commuting flows." Journal of Transport Geography 19(4): 596-605.

Modarres, A. L. I. (2011). "Polycentricity, Commuting Pattern, Urban Form: The Case of Southern California." International Journal of Urban and Regional Research 35(6): 1193-1211.

Murphy E. Excess commuting and modal choice [J]. Transportation Research Part A: Policy and Practice, 2009, 43(8): 735-743.

Newman P W G, Kenworthy J R. Gasoline consumption and cities: a comparison of US cities with a global survey [J]. Journal of the American Planning Association, 1989, 55(1): 24-37.

Nesterov Y, de Palma A. Stationary dynamic solutions in congested transportation networks: summary and perspectives [J]. Networks and spatial economics, 2003, 3(3): 371-395.

Nowlan, David M. and Stewart, Greg. 1991. Downtown Population Growth and Commuting Trips: Recent Experience in Toronto. Journal of the American Planning Association 57 (2), 165-182

O'Kelly, M. D. and Lee, W. (2005) Disaggregate journey-to-work data: implications for excess commuting and jobs–housing balance, Environment and Planning A, 37(12), pp. 2233–2252.

Pendyala R M, Goulias K G, Kitamura R. Impact of telecommuting on spatial and temporal patterns of household travel [J]. Transportation, 1991, 18(4): 383-409.

Qian, Z. and H. M. Zhang (2012). "On centroid connectors in static traffic assignment: Their effects on flow patterns and how to optimize their selections." Transportation Research Part B: Methodological 46(10): 1489-1503.

Reggiani, A., P. Bucci and G. Russo (2010)."Accessibility and Network Structures in the German Commuting."Networks and Spatial Economics 11(4): 621-641.

Reimers, A. K., D. Jekauc, E. Peterhans, M. O. Wagner and A. Woll (2013)."Prevalence and socio-demographic correlates of active commuting to school in a nationwide representative sample of German adolescents."PrevMed 56(1): 64-69.

Sandow E. Commuting behaviour in sparsely populated areas: evidence from northern Sweden [J]. Journal of Transport Geography, 2008, 16(1): 14-27.

Sang S, O'Kelly M, Kwan M P. Examining Commuting Patterns Results from a Journey-to-work Model Disaggregated by Gender and Occupation [J]. Urban studies, 2011, 48(5): 891-909.

Scheiner, J. and C. Holz-Rau (2007). "Travel mode choice: affected by objective or subjective determinants?" Transportation 34(4): 487-511.

Schwanen, T. and P. L. Mokhtarian (2005). "What affects commute mode choice: neighborhood physical structure or preferences toward neighborhoods?" Journal of Transport Geography 13(1): 83-99.

Scott D M, Kanaroglou P S, Anderson W P. Impacts of commuting efficiency on congestion and emissions: case of the Hamilton CMA, Canada [J]. Transportation Research Part D: Transport and Environment, 1997, 2(4): 245-257.

Sheffi Y. Urban transportation networks: equilibrium analysis with mathematical programming methods [J]. 1985.

Shen, Q. (2000). "Spatial and Social Dimensions of Commuting."Journal of the American Planning Association 66(1): 68-82.

Signorino, G., R. Pasetto, E. Gatto, M. Mucciardi, M. La Rocca and P. Mudu (2011). "Gravity models to classify commuting vs. resident workers. An application to the analysis of residential risk in a contaminated area."Int J Health Geogr 10: 11.

SImSgallagHEr K E, QIn K I, KEBIn H E. In-use vehicle emissions in China: Beijing study [J]. 2009.

Sohn, J. (2005). "Are commuting patterns a good indicator of urban spatial structure?" Journal of Transport Geography 13(4): 306-317.

Stead D, 2001, "Relationships between land use, socioeconomic factors, and travel patterns in Britain" *Environment and Planning B: Planning and Design* 28(4) 499 – 528

Sultana S. Job/housing imbalance and commuting time in the Atlanta metropolitan area: Exploration of causes of longer commuting time [J]. Urban Geography, 2002, 23(8): 728-749.

Taylor B D, Ong P M. Spatial mismatch or automobile mismatch? An examination of race, residence and commuting in US metropolitan areas [J]. Urban Studies, 1995, 32(9): 1453-1473.

Tkocz Z, Kristensen G. Commuting distances and gender: a spatial urban model [J]. Geographical Analysis, 1994, 26(1): 1-14.

Timmermans H, van der Waerden P, Alves M, et al. Spatial context and the complexity of daily travel patterns: an international comparison [J]. Journal of Transport Geography, 2003, 11(1): 37-46.

Walsh, M.P., 2000. Transportation and the environment in China. China Environment Series, Washington, DC

Wang D, Chai Y. The jobs–housing relationship and commuting in Beijing, China: the legacy of<i>Danwei</i> [J]. Journal of Transport Geography, 2009, 17(1): 30-38.

Wardrop J G. ROAD PAPER. SOME THEORETICAL ASPECTS OF ROAD TRAFFIC RESEARCH[C]//ICE Proceedings: Engineering Divisions. Ice Virtual Library, 1952, 1(3): 325-362.

Watling, D. (2006). "User equilibrium traffic network assignment with stochastic travel times and late arrival penalty."European Journal of Operational Research 175(3): 1539-1556.

Weber J, Sultana S. Journey-to-Work Patterns in the Age of Sprawl: Evidence from Two

White M J. Urban commuting journeys are not" wasteful"[J]. The journal of political economy, 1988, 96(5): 1097-1110.

Midsize Southern Metropolitan Areas [J]. The Professional Geographer, 2007, 59(2): 193-208.

Wei, Y. D. (2001). "Decentralization, Marketization, and Globalization: The Triple Processes Underlying Regional Development in China." Asian Geographer 20(1-2): 7-23.

Zhang H M. On centroid connectors in static traffic assignment: Their effects on flow patterns and how to optimize their selections [J]. Transportation Research Part B: Methodological, 2012, 46(10): 1489-1503.

Zhang,W., Yi, W., 2006. A Study of Livable Cities in China:Beijing (zhongguoyijuchengshiyanjiubaogao: Beijing Pian). Social Sciences Literature Press (She huiwenxianchu ban she), Beijing.

Zhao, P. (2010). "Sustainable urban expansion and transportation in a growing megacity: Consequences of urban sprawl for mobility on the urban fringe of Beijing." Habitat International 34(2): 236-243.

Zhao, P. (2011). "Car use, commuting and urban form in a rapidly growing city: evidence from Beijing." Transportation Planning and Technology 34(6): 509-527.

Zhao, P. and B. Lu (2010)."Exploring job accessibility in the transformation context: an institutionalist approach and its application in Beijing."Journal of Transport Geography 18(3): 393-401.

Zhao, P., B. Lu and G. de Roo (2011). "The impact of urban growth on commuting patterns in a restructuring city: Evidence from Beijing." Papers in Regional Science 90(4): 735-754.

Zhao, P., B. Lu and G. J. J. Linden (2009). "The Effects of Transport Accessibility and Jobs–Housing Balance on Commuting Time: Evidence from Beijing." International Planning Studies 14(1): 65-83.

Zhao, P., B. Lü and G. d. Roo (2011)."Impact of the jobs-housing balance on urban commuting in Beijing in the transformation era."Journal of Transport Geography 19(1): 59-69.

Zhao, P., B. Lü and J. Woltjer (2009). "Conflicts in urban fringe in the transformation era: An examination of performance of the metropolitan growth management in Beijing." Habitat International 33(4): 347-356.

Zheng S, Fu Y, Liu H (2005) Anemperical study on the willingness to pay for residential location and location choice of urban residents in China.*Economic Geography* 25: 2–13 (in Chinese)

Zhou Y, Ma L J C. Economic restructuring and suburbanization in China [J]. Urban Geography, 2000, 21(3): 205-236.

Zhou Y (1997) On the suburbanization of Beijing. *Chinese Geographical Science* 7: 208–219