Integrated Land Use and Transport Modeling with Computable Urban Economic Model: A Case of Changzhou, China

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by

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Abstract

Rapid urbanization and industrialization are causing many problems including urban sprawl, traffic congestion and environmental contamination in China, which are considered urban malaise that causes harm to urban health. However, the planning, policymaking, governance and management of urban infrastructure, land use, transport, and environment in China are separated from each other. Along with the economic growth and urban land expansion in China, urban land use and transport are virtually involved in a complex process in which they interact with each other. Hence, interrelationship between land use and transport became a mutually concerned issue with the rapid economic growth and urbanization in China. Therefore it is urgent to investigate the interactive mechanism among urban land use, and transport to propose a sustainable spatial planning strategy for integrated urban planning and policymaking.

As one of the core cities of the Yangtze River Delta in China, Changzhou City is one of most urbanized and industrialized regions in Jiangsu Province and in all of China; thus it can be seen as a typical case study for developed urban area. By using a traffic assignment results based on Origin-Destination person trip data in Changzhou, China, we investigated the spatial gradient of traffic congestion at the level of road link, and correlation between congestion and land use. Our study shows that congestion tends to be located close to the urban geometric center, as well as residential land and commercial land, implying that they are correlated positively with each other. However, land use diversity and intensity do not show absolute positive or negative interrelationship with congestion. We found a spatial mismatch between traffic congestion and land use diversity and intensity, indicating that most road congestion do not occur in the high-intensity mixed-use areas.

Spatial interrelationship between land use and transport by using geospatial analysis is inadequate because the agents' behaviors and microeconomic theory are not taken into account. Thus, we developed a computable integrated model of land use and transport in the tradition of the Computable Urban Economic (CUE) model which is consistent with urban microeconomic theory. The model explicitly takes into account the interaction between behaviors of households and firms, and different markets. All these behaviors and location decisions are determined endogenously, and thus this model implicitly determines land use pattern, travel patterns including commuting and shopping trip, and travel mode choice as well. The system of equilibrium conditions

expressed as a complicated set of homogeneous equations is non-linear and cannot be solved analytically, thus we have to rely on numerical simulations. We employed the Newton-Raphson algorithm and UE (user equilibrium) method based on GAMS and JICA-STRADA platform to obtain the equilibrium solutions. Via iterative procedures, we simultaneously calculated population/employment distribution and land use pattern in each zone, and also traffic volumes in each road link.

By using the approach according to New Economic Geography, the integrated land use and transport model in the tradition of CUE model has been extended with economies of scale, for the sake of urban agglomeration simulation. It is assumed that each firm produces a product variant in a monopolistic competition market, and the number of firms is explicit and determined endogenously. The Dixit-stigliz type utility function with product variety is adopted into the model structure to reflect consumers' love for variety. Also, the internal increasing returns of scale and fixed cost are introduced in firm behavior to extend the model with economies of scale.

Parameter estimation and model calibration for a 'Benchmark' city was conducted on the basis of empirical data from several approved sources for Changzhou in 2008. Parameters for 'Benchmark' simulation were estimated from Person Trip Survey (2008), statistical data and empirical data. Also, numerical computations were implemented by employing both the model with and without economies of scale to examine the urban agglomeration effect. Clearly, simulation results show that the extended model incorporated with economies of scale can represent the urban agglomeration effect commendably.

Based on the 'Benchmark' simulation in 2008, taking land use policy as an important measure for urban sprawl and compact city, two different land use planning scenarios were set up to evaluate the population/employment distribution, travel behaviors and also carbon emissions generated by exogenous policy shock. Scenario simulation results exhibit a low-carbon roadmap for urban development. Compact city scenario that improves land use efficiency in central zones is effective for carbon reduction, but excessive urban sprawl and rapid land conversion in suburbs result in higher carbon emissions that cause harm to the urban environment. This result is consistent with the viewpoint and empirical results that suggests a compact city is good for energy conservation because urban activities could be located closer together to reduce long-distance travel and usage rates of automobiles. Nonetheless, external diseconomies of urban agglomeration such as excessive population concentration and traffic congestion likewise need to draw urban planners’ attentions.

In a word, the integrated land use and transport model in the tradition of CUE model that accommodates carbon emission evaluation and describes the interactive mechanism among urban land use and transport, is an effective tool for analyzing and evaluating urban planning and infrastructure policies. In the Changzhou case study, compact city produces less carbon emissions than urban sprawl, indicating that compactness, namely a high-density mixed-use and intensified land use pattern and urban form, can be accepted as a promising solution for achieving the goal of low-carbon development.

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1 Introduction

1.1 Background

Since the 21st century, urbanization has been the major characteristic of socioeconomic development of human beings and global landscape change. More people live in urban areas than in rural areas, with 54% of the world's population residing in urban areas in 2014, but just 30% of population was urban in 1950. Moreover, 66% of the world's population is projected to the urban. Tokyo is the world's largest city with an agglomeration of 38 million inhabitants, followed by Delhi with 25 million, Shanghai with 2 million, and Mexico City, Mumbai and Sao Paulo, each with around 21 million inhabitants (United Nations, 2014). Urbanization is not only relevant to the physical construction, but a range of disciplines, including urban planning, geography, economics, sociology, and public health. As the world continues to urbanize, a series of challenges will be increasingly concentrated in cities, particularly in the lower-middle-income countries where the pace of urbanization is the fastest. Sustainable urban policies to improve the life quality, economic growth and environmental conservation are needed.

During China's socioeconomic transition and rapid industrialization with the government's new policy of opening and reform established in 1978, urbanization has been accelerated by China's social and economic development. By the end of 2013, 53.7% of the total population lived in urban areas, a rate that rose from 26% in 1990, and the urbanization rate according to official forecast will reach 60% by 2020. Meanwhile, rapid urbanization and urban land expansion are also causing many problems including urban sprawl, traffic congestion and environmental contamination in China. These are considered urban malaise that cause harm to urban health. In fact, an upward trend in population explosion, traffic congestion, land use conversion and air pollution, which is drawing worldwide attention from not only scientists, but also from politicians and the public, becomes an important concern as well.

Taking traffic congestion as an example, since traffic congestion is reaching intolerable levels in many cities in China, it becomes one of the serious urban problems with the rapid economic development, urbanization and motorization over the past two decades. As the bottleneck of urban development in China, traffic congestion has not only damaged urban economic efficiency and life quality, but also given rising to environmental pressure especially urban atmospheric contamination (Shen, 1997). Traffic congestion costs about 58 billion Yuan RMB (4.22% of GDP) in Beijing in 2010, including time delay cost, extra oil combustion, traffic accident direct economic loss, vehicle loss cost, environment pollutants (Mao et al., 2012). Moreover, it is likely that congestion problem will worsen owing to the accelerated urbanization and car ownership ratio within the near future. A considerable amount of research has been carried out to investigate why traffic congestion occurs and accordingly put forward countermeasures such as increasing road supply, public transit priority, congestion pricing, three-dimensional transport network, odd-even rationing policy, etc. (Verhoef, 2002; Arentze et al., 2007; Currie et al., 2007; Zhu et al., 2007; Zhou et al., 2010). However, it seems that traffic congestion cannot be reduced or eliminated completely; instead, a vicious cycle between transport governance and congestion has begun to form. The major reason why transport policies for congestion mitigation often cease to be effective is the ignored origin of how traffic comes about, and the interaction between land use and transport.

1.2 Problem statement

From the viewpoint of microcosmic agents' behaviors, a city is the place where residential, production, and transport behaviors cluster together, as well as the concentration of population and employment. Urban space also can be seen as a composition of static land use pattern and mobile traffic flow. Thus, along with the economic growth and urban land expansion in China, urban land use and transport are involved in a complex process in which they interact with each other. However, the planning, policymaking, governance and management of urban infrastructure, land use, transport and environment in China are separated from each other. Specifically, urban infrastructure planning and housing are managed by Ministry of Housing and Urban-rural Development, while land use and transport are planned by Ministry of Land and Resources, and Ministry of Transport, respectively. To some extent, integrated land use and transport planning is usually ignored by government and scholars in China.

Therefore it is urgent to investigate the interactive mechanism between urban land use and transport to propose a sustainable spatial planning strategy for China's urban development. That is to say, we need to establish an integrated model to illustrate how land use and transport interact with each other, test how infrastructure planning and urban policies would influence land use pattern and travel behavior, and also provide a computable assessment tool for urban planners and policymakers. Such an integrated land use and transport modeling can reflect relevance and coupling of urban subsystems which are interacted by each other, avoiding being isolated, static and one sided policymaking. Integrated planning and modeling will be conducive to infrastructure policy coordination and systematic decision making, offering technical supports to evaluate impacts of infrastructure policies on every urban sub-systems.

1.3 Objectives of research

The main objective of this study is to better understand the interactive mechanism between land use and transport by employing Computable Urban Economic (CUE) model, and to provide an operable analytical tool for China's urban planning and infrastructure policymaking. More precisely, the study intends to investigate how urban land use and transport pattern would influence each other, as well as the forming process of urban spatial morphology and agglomerations. They can be grouped into three concrete items as follows:

(1) Developing a land use and transport interactive model in the tradition of CUE model. Particularly, economies of scale and urban agglomeration mechanism are considered into the land use and transport modeling.

(2) Numerical computation for real case in Changzhou City, China.

(3) Urban planning and infrastructure policy evaluation.

1.4 Scope of research

The scope of research in this thesis is documented as follows:

Chapter 2 is to review the existing land use and transport models and their features, advantages and shortcomings.

Chapter 3 is to introduce the land use and traffic pattern in Changzhou city. Firstly, the geography, history and socioeconomic development in Changzhou are described. Secondly, land use structure and pattern are analyzed based on land use database. Thirdly, travel demand and spatial distribution are depicted by using Person Trip (PT) survey data conducted in 2008. Then, we discuss the spatial gradient and interrelationship of land use pattern and travel behavior especially traffic congestion.

Chapter 4 is to build a land use and transport interactive model in the tradition of CUE model. In the first section, we formulate the model structure including households' behavior, firms' behavior, transport behavior, and general equilibrium. Second section is to design an algorithm based on GAMS and JICA STRADA for solving the general equilibrium equations. Then, we estimate the parameters for the "Benchmark" case study in Changzhou on the basis of economic, land use, and person trip data in Changzhou, 2008.

Chapter 5 is to extend the model with economies of scale. The assumptions of product varieties and increasing return to scale are introduced to formulate the model structure consistent with the monopolistic competition market. Secondly, numerical computation is also conducted based on the empirical data in Changzhou City in order to detect the urban agglomeration effect.

In chapter 6, we apply this model to land use policy assessment. Different land use planning scenarios are set to describe distinct spatial planning orientations and land use modes. The simulation results are analyzed in search of the most appropriate land use strategies. Another point is to compare the results simulated by the model incorporated with and without economies of scale.

Chapter 7 is the conclusions and the roadmap for future works.

The research process and framework of this thesis is shown as Figure 1.1.

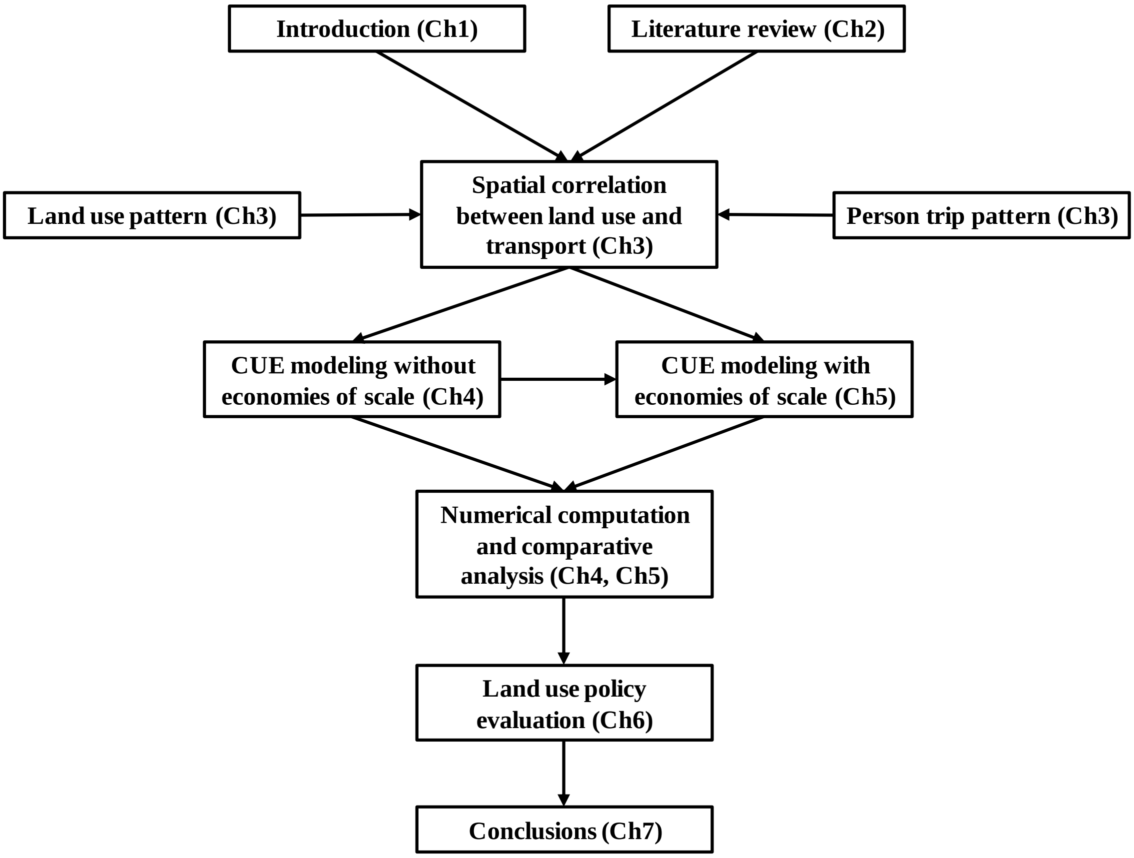


Figure 1.1: Research process and framework

1.5 Research methods

Methods used for this study can be stated as follows. Firstly, based on land use and person trip database, we investigate the spatial interrelationship between land use and transport by employing GIS analysis methods such as buffer zone and gradient analysis. Secondly, we integrate methodologies of computable general equilibrium model and "Four-Step" transport modeling in sake of a computable integrated modeling to depict the interaction between land use and transport, and then incorporate this model with economies of scale for detecting urban agglomeration effects. At the end, scenario analysis method is applied to policy assessment in search of the optimum urban planning and infrastructure policy.

1.6 Expected contribution

The research attempts to be one contribution to land use and transport interactive modeling by using the framework and theory of computable urban economic (CUE) model. Our motivation of this research is to better understand the interaction between land use and transport for urban planning and infrastructure policymaking in China. Specifically, it is expected that the model structure, numerical computation, data analysis and policy implication in this paper will contribute to four points as follows.

(1) Chapter 3 investigates the land use and travel pattern in Changzhou, especially spatial gradient of traffic congestion at the level of road link, and correlation between congestion and land use, by using traffic assignment results based on Origin-Destination person trip data. Our study is helpful to detect the spatial distribution and interrelationship of land use and transport in a typical city in Eastern China.

(2) The land use and transport model in the tradition of CUE model presented in Chapter 4 provides a workable analytical tool for simulating location choices, land use pattern, and travel behaviors as well. One of important points in the research is to integrate the computable general equilibrium model with traffic assignment to develop a practical methodology for China's urban planning.

(3) Another academic contribution is to extend the CUE model with economies of scale to simulate the urban agglomeration effect. Product varieties and internal increasing to scale are set to develop a land use and transport interactive model in the tradition of CUE under the assumptions of monopolistic competition. The extended model can explain why households tend to reside, work and shop in some zones where urban agglomerations occur.

(4) Chapter 6 offers an approach for policy evaluation by using CUE model. To answer the question of optimum land use planning in Changzhou, we analyze how land use layout and pattern would modify population/employment distribution, person trips, traffic volume, congestion, environment impacts and urban agglomeration effect as well, and then policy implications are discussed for land use strategies with the

purpose of benign urban development and environment conservation in Changzhou.

2 Literature review

2.1 General introduction

As this is a central issue concerning to urban planners and policymakers, there have been considerable research into integrated land use and transport modeling. Especially in developing countries such as China, the interaction between land use and transport becomes the key problem of urban governance and management with the accelerating urbanization and economic growth. Starting from the conceptual model of interactive land use-transport system and their casual loop, urban economic theories represented by computable general equilibrium (CGE) model and computable urban economic (CUE) model are employed to simulate how urban land use pattern affects travel behavior and transport system and vice versa. This chapter is to review the methodologies of integrated land use and transport modeling.

2.2 Land use and transport interaction

The connection between land use and transport is a fundamental concept in urban modeling, because they are inexorably connected. Figure 2.1 exhibits the causal loop between land use and transport. First of all, land use pattern, which affects urban form and configuration, decides the spatial distribution and intensities of residential, industrial activities, etc. and generates the traffic demand including commuting trips, shopping trips and other trips. Transport infrastructure and traffic demand determine together the accessibility and mobility which is a measure of the ability to move efficiently between origins and these destinations. Land price and location choice will be affected by the accessibility and mobility, as well as land use pattern. Thus, studies on land use and transport interaction have drawn urban planners and scholars' attentions in recent years (Atash, 1993), and the question of whether and how transport influences land use change or how land use dictates transportation has been a matter of ongoing concern among urban planning and transport professionals.

Several studies have found that transport infrastructure contributes to land use change, urban sprawl and farmland conversion (Handy, 2005; Hawbaker, et al., 2006; Zhang et al., 2013). Specifically, transport infrastructure investment and improvement accelerates regional economic growth and urban land expansion due to the enhancing accessibility and easiness of freight and logistics. On the other hand, land use pattern exerts an influence on travel behaviors as well (Krizek, 2003a, 2003b; Khattak, et al., 2005; Paez, 2006; Soltani, et al., 2006). Spatial distributions of residential land, central business district and shopping center structure the origins and destinations of travel trips for commuting and shopping. Therefore, urban and transport planners have gradually shifted their emphasis to the interrelationship between land use pattern and transport for integrated urban land use-transport planning.

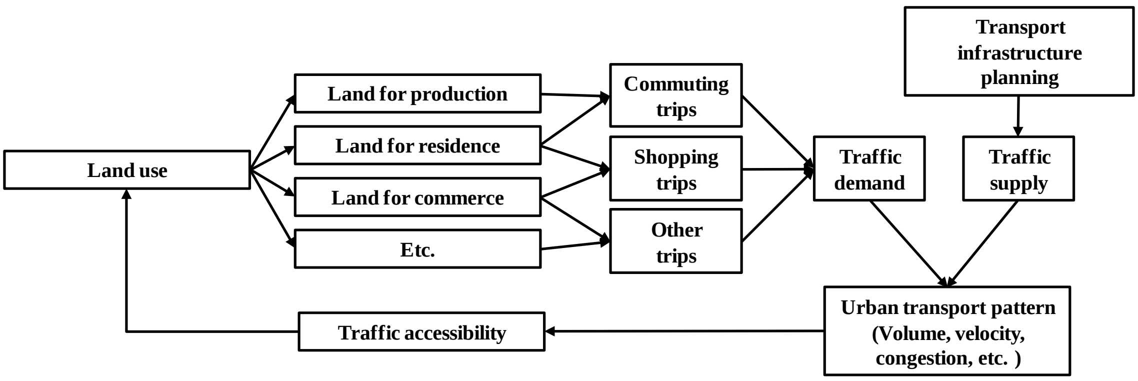


Figure 2.1: Interactive loop between land use and transport

Conventional wisdom asserts that there exists a connection between travel behavior and land use pattern in urban areas. It is argued that more compact land use pattern characterized by high-density mixed-use development and traditionally designed neighborhood can reduce travel time and congestion because urban activities are located closer thus travel distances can be shortened and households tend to substitute driving trips with walking trips (Cervero, et al., 1996; McCormack, et al., 2001; Kuzmyak, et al., 2006), while sprawling pattern, namely highly dispersed and low-density single-use development is likely to increase long-distance trips requiring motorized vehicles which lead to more traffic congestion (Downs, 1992; Gillham, 2002; Kii, et al., 2005). However, some studies maintained that the correlation between land use and travel behavior was complex and not completely understood (Handy, et al., 2005; Handy, 2006; Shay, et al., 2005), and contended that dispersed pattern and suburbanization do not produce more long-distance trips and congestion (Gordon, et al., 1991). Despite being debated widely by urban and transport planners, the interrelationship between transport and land use pattern remains unclear in details.

Generally speaking, a number of studies have explored the land use and transport interaction by using comparative data across distinct urban areas (Sarzynski, et al., 2006). A variety of overall indicators such as average commuting time and average daily traffic volume, etc. have been used to denote the integral transport condition or travel behavior in a whole city (Boarnet et al., 1998; Sarzynski, et al., 2006). These studies investigated the correlation between land use and transport by using descriptive and statistical methods like a "black box", which may be the major reason why contrary and conflicting results have arisen regarding the positive or negative correlation between land use and transport due to lack of detailed information and behavior mechanism behind.

2.3 Land use and transport modeling

In order to put forward a powerful tool for spatial planning and infrastructure policymaking, a variety of land use and transport models have been developed already. On one hand, land use modeling characterized mainly by land use change simulation has been achieved with the matured knowledge and technologies in geography and urban landscape. Land use modeling emphasizes the driving forces and spatial evolution related to land use changes. Especially with the advent of Geographic Information System (GIS), Remote Sensing (RS), Cellular Automata (CA), and Multi-Agent System (MAS), a number of land use models have arisen, such as CLUES (Veldkamp, et al., 1996; Verburg et al., 2002), GEOMOD (Pontius, et al., 2001), GeoCA (Li, 2011), etc. However, these land use models rarely take into account transport issues and urban economic theories.

On the other hand, urban transport forecasting and modeling have traditionally followed the sequential four-step model (FSM) or urban transportation planning (UTP) procedure, first implemented on mainframe computers in the 1950s at the Detroit Metropolitan Area Traffic Study and Chicago Area Transportation Study (CATS). In the late 1960s, Hiroshima Metropolitan Transportation Plan was first conducted in consideration of different travel modes. Since then, FSM came into being, including trip generation (step 1), trip distribution (step 2), modal split (step 3), and traffic assignment (step 4). Trip generation determines the frequency of origins or destinations of trips in each traffic analysis zones (TAZs) by trip purpose, and then trip distribution matches origins with destinations, often using a gravity model function. Mode split computes the proportion of trips between each origin and destination that often use a logit form model. Traffic assignment allocates trips between an origin and destination by a particular mode to a route, and Wardrop's principle of user equilibrium is usually employed under the assumption that each driver chooses the shortest path or travel time, subject to every other driver doing the same.

With the development and widespread application of FSM, it has been criticized because the land use pattern is fixed as a constant and interactive mechanism between land use and transport is ignored. Thus, integrated land use and transport modeling was advocated to overcome the disadvantages of traditional separate land use model and transport model. Since the Lowry model developed by Ira S. Lowry when he was working for the Pittsburgh Regional Economic Study (Lowry, 1964; Garin, 1966; Gross, 1982), there has been a new generation of land use-transport models developed since the 1990s that departs from traditional aggregate models, and incorporate innovations in discrete choice modeling, microsimulation, dynamics, and geographic information systems. These common integrated land use and transport models include Integrated Transportation and Land Use Package (ITLUP) by Putman (1983, 1991, 1998), MEPLAN by Echenique (1990), TRNUS by De La Barra (1984), and UrbanSim by Waddell (2002). Despite various land use models emerge in large numbers and have been applied widely, conventional land use and transport interactive models often lack the consideration of complete microeconomic foundation, thus there is still behavior and systemic inconsistency resulting in distorted and invalid urban simulation (Anas, 1982, 1987).

2.4 Computable urban economic model

Since urban economics forms its normative theory and framework from Alonso (1964), microeconomic foundation has been integrated gradually into operational urban modeling. Computable General Equilibrium (CGE) model, has been applied to urban land use and transport modeling through a series of market equilibrium conditions under which economic entities' behaviors are also defined explicitly by utility maximization or profit maximization (Anas, et al., 1996; Anas, et al., 1999; Anas, et al., 2007). Each economic agent demands or supplies land, goods, and transport service, and selects the location where the utility or profit is the highest among all alternative locations in an urban system. This model takes into account land, labor, and commodity markets, so it is better to explicitly describe interactive mechanisms between urban economy, land use and transport. The rent, wage and commodity price at each zone that attain demand-supply equilibria are determined simultaneously, therefore the completeness of urban spatial CGE model can contribute to urban simulation and policy evaluation. However, due to the fact that traffic sector is endogenously incorporated into the general equilibrium, urban spatial CGE model is hardly incorporated with sophisticated traffic network or zoning owing to complicated numerical simulation and model calibration. For just this reason, it is relatively tough to apply the urban spatial CGE model for practical urban planning and infrastructure policy evaluation.

Computable Urban Economic (CUE) model, which is also based on standard theories in the tradition of urban economics, addressed a typical framework of partial market equilibrium model (Takagi, et al., 1999; Ueda, et al., 1993; Yamasaki, et al., 2007; Ueda, et al., 2013). Compared with CGE models, the CUE model is simplified in market sector to improve the implementability for complicated traffic network and city zoning, hence existing CUE models were able to be applied to transport planning, land use planning, and urban policymaking easier (Ueda, et al., 1993; Takagi, et al., 1999; Yamasaki, et al., 2007). However, existing CUE models only emphasize land market equilibrium, and do not include equilibrium of labor and commodity market; that is to say, Walras' law holds closely in the CGE model, while it does not in CUE model due to partial market equilibrium feature of CUE model. It is the shortcoming that conventional CUE model cannot reflect the complete economic behaviors of whole urban system.

Although CGE/CUE models provide for a promising class of land use-transport models that can describe interaction mechanism in urban system better, existing models still have various limitations. Some studies examined whether the income share spent on a shopping destination is determined by its relative size such as production scale, employment scale and land area for firms. The results show that consumers' preferences for shopping depend not only on their disposable incomes and the full prices of shopping trips but also on the relative size of shopping centers, which means that households spend more disposable income at lager shopping destinations (Mun, et al., 1989; Anas, et al., 1996). Generally speaking, an inherent zonal attractiveness is defined exogenously to define the location choice probabilities for residence, working and shopping, especially for reflecting the urban agglomeration effects (Muto, et al., 2000; Muto, et al., 2001; Suzuki, et al., 2002). However, economies of scale are not considered in CGE/CUE modeling. Despite the fact that urban land use pattern and travel behaviors can be simulated through employing such plausible exogenous variables, the urban agglomeration mechanism cannot be simulated, which does harm to the model effectiveness in policy evaluation.

2.5 Summary

This chapter reviewed the methodologies of existing integrated land use and transport modeling and pointed out their characteristics and shortcomings both in theory and practice. Traditional land use-transport modeling tends to build the interactive mechanism by using descriptive statistical methods or geographical technologies such as CA, gravity model, etc., but neglects the microeconomic basis and behaviors of agents, leading to invalid urban planning and infrastructure policies. CGE/CUE models, which are consistent with the microeconomic theory, can depict the location choice and travel behaviors of agents commendably. Although CUE model has been applied widely in many fields of urban planning and policymaking, it is still new in China's urban planning, and needs to be developed for China's urban planning and infrastructure policymaking.

However, conventional CGE/CUE models do not consider the economies of scale and urban agglomeration effect. With the economic development and urbanization in developing countries such as China, population concentration, industry cluster and urban agglomeration phenomenon are becoming more evident. How to depict and simulate the urban agglomeration in China as well as the interrelationship between urban policies and agglomeration effects have drawn little attention from scholars and urban scientists. Therefore, it is necessary to take into account the economies of scale for an integrated land use and transport modeling which can reflect the microeconomic mechanism of urban agglomeration.

3 Land use and traffic pattern in Changzhou City

3.1 General introduction

This chapter describes the overview of Changzhou City including geography, history, population, economic development, etc. In particular, urbanization and land use pattern are analyzed according to the land use database in Changzhou. Also, travel behaviors and person trips are described by using the Person Trip (PT) survey data of Changzhou conducted in 2008.

The final section of this chapter discusses the spatial pattern and interrelationship of land use and transport. Specifically, since correlation between land use and congestion is becoming a mutually concerned issue with the rapid population explosion and urbanization in China, we investigate the spatial gradient of traffic congestion at the level of road link and land use patterns as well, and also correlation between congestion and land use, by using a traffic assignment results based on Origin-Destination person trip data. In consideration of these findings, policy implications for mitigating traffic congestion are discussed to answer China's land use strategies.

3.2 Overview of Changzhou City

Changzhou (Chinese: 常州) is a prefecture-level city located in the Taihu plain of the lower reaches of the Yangtze River, and has a subtropical monsoon climate, with annual average temperature of 15 °C. Changzhou City is situated in the southeastern part of Jiangsu Province, which has a surface area of 1,864 km^2 (CSB, 2009). Changzhou borders the provincial capital of Nanjing to the west, Zhenjiang to the northwest, Wuxi to the east, and the province of Zhejiang to the south. The prefecture-level city of Changzhou administers seven county-level divisions, including five districts: Zhonglou District, Tianning District, Qishuyan District, Xinbei District, Wujin District, and two county-level cities (satellite cities) including Jintan and Liyang (Figure 3.1). Our research only considers the traditional city area i.e. five city administrative districts, but excludes two satellite cities. Changzhou's total population is 4,592,431 inhabitants at the 2010 census whom 3,290,918 lived in the built-up area made up of five urban districts.

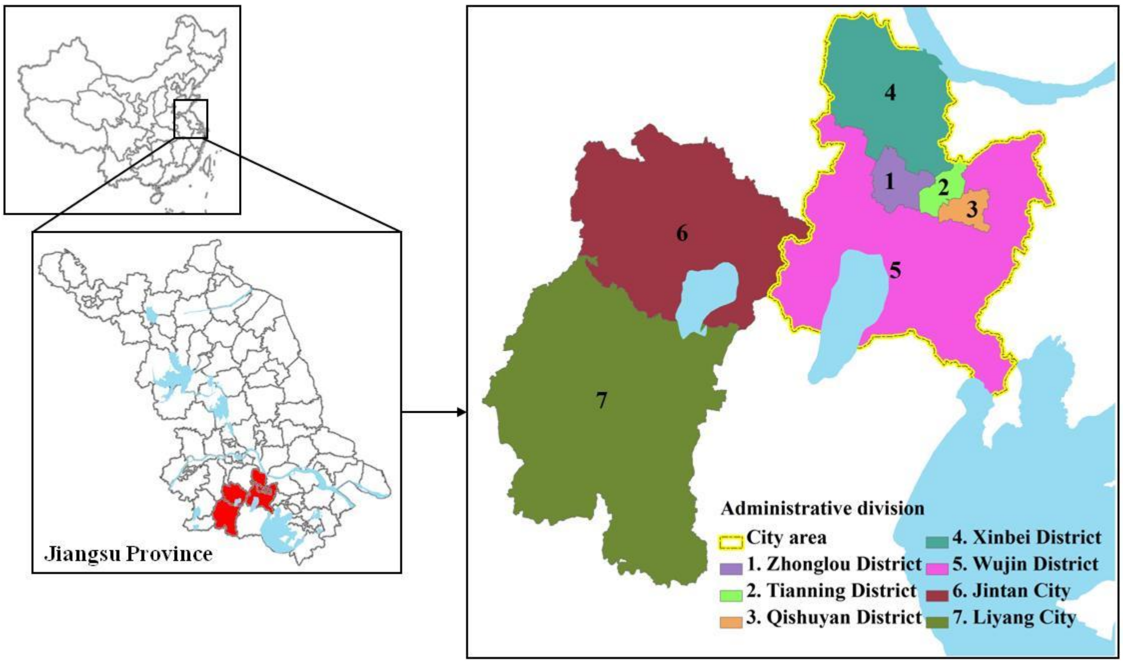


Figure 3.1: Location of study area

Changzhou, which was previously known as Yanling (延陵), Piling (毘陵), Jinling (晋陵), and Wujin (武進), has a long history more than 3,200 years. "The Ruins of Yancheng" (淹城遺址), comprises the remains of a walled city located in the Wujin district of Changzhou that was founded over 3000 years ago at the beginning of the Western Zhou (周) dynasty. The earliest record of a settlement on the site of modern Changzhou is as a commandery founded in 221 B.C. at the beginning of the Qin (秦) Dynasty. During the interregnum between the Sui (隋) and Tang (唐) dynasty, the city of Piling was the capital of Kingdom of Liang (梁) (A.D. 619 to 620). Following construction of the Grand Canal in 609, Changzhou became a canal port and transshipment point for locally-grown grain, and has maintained these roles ever since. The rural counties surrounding Changzhou are noted for the production of rice, fish, tea, silk, bamboo, and fruit.

Changzhou’s traditional role has been that of a commercial center and in particular a distribution center for agricultural produce, which was shipped by Grand Canal to the north and later, to Shanghai. Since 1908, Changzhou has been linked by rail with Shanghai and Nanjing, and Changzhou started to set up cotton mills in the 1920s, and the cotton industry got a boost in the late 1930s when businesses began relocating outside of Shanghai. Nowadays, Changzhou has remained a textile center and the most important location in Jiangsu Province for weaving. It also has large food-processing plants as well as flour-milling, rice-polishing, and oil-pressing industries. After 1949 it also developed as a centre of the engineering industry (diesel engines, generators, transformers and other machinery), and high technology.

Situated on the main Beijing-Shanghai rail line, and also on the busy Shanghai-Nanjing route, Changzhou has remained one of the most developed cities in Jiangsu Province, even in Yangtze River Delta and eastern China, ranked third after Suzhou and Wuxi. The agglomeration is now part of Shanghai Metropolitan Area which has now more than 36,000,000 inhabitants, only second in China after Pearl River Metropolitan Area. Changzhou’s GDP is 396.98 billion CNY in total and 85,464 CNY per capita in 2012, less than that of Suzhou and Wuxi but more than the capital city Nanjing, ranked the city third in Jiangsu Province. Changzhou is also one of the top business cities in China. According to Forbes ranking, Changzhou was the 9th best business city in mainland China in 2008.

3.3 Urbanization and land use pattern

As one of the cities of which urbanization and industrialization develop rapidly, Changzhou’s urban land expansion is extremely intensive so that land use pattern in Changzhou has been changing quickly with the acceleration in the growth of social economy and urbanization. Urban expansion can be detected by using remote sensing images from 1985 to 2005 (Figure 3.2). They show urban built areas expanded pretty acutely during these 20 years in this rapid urbanized region. In terms of the index of urban land area, it increased from 95.25 km^2 in 1985 to 224.80 km^2 in 2005, with an annual expansion of 6.48 km^2. According to land use database in 2008 obtained by land use map from Changzhou Planning Bureau (CPB, 2008), land use was classified as residential land, industrial land, commercial land, and green space (Figure 3.3), and they account for 7.50%, 8.19%, 1.84% and 82.47%, respectively (Table 3.1).

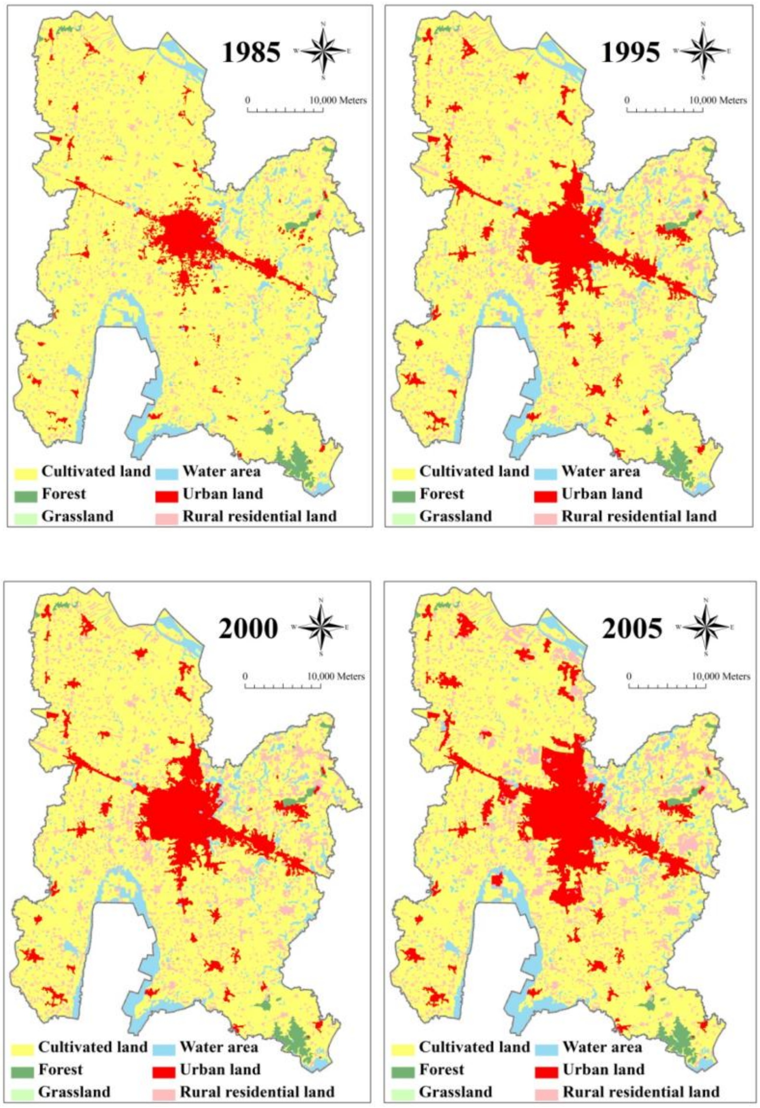


Figure 3.2: Urban land expansion from 1985 to 2005

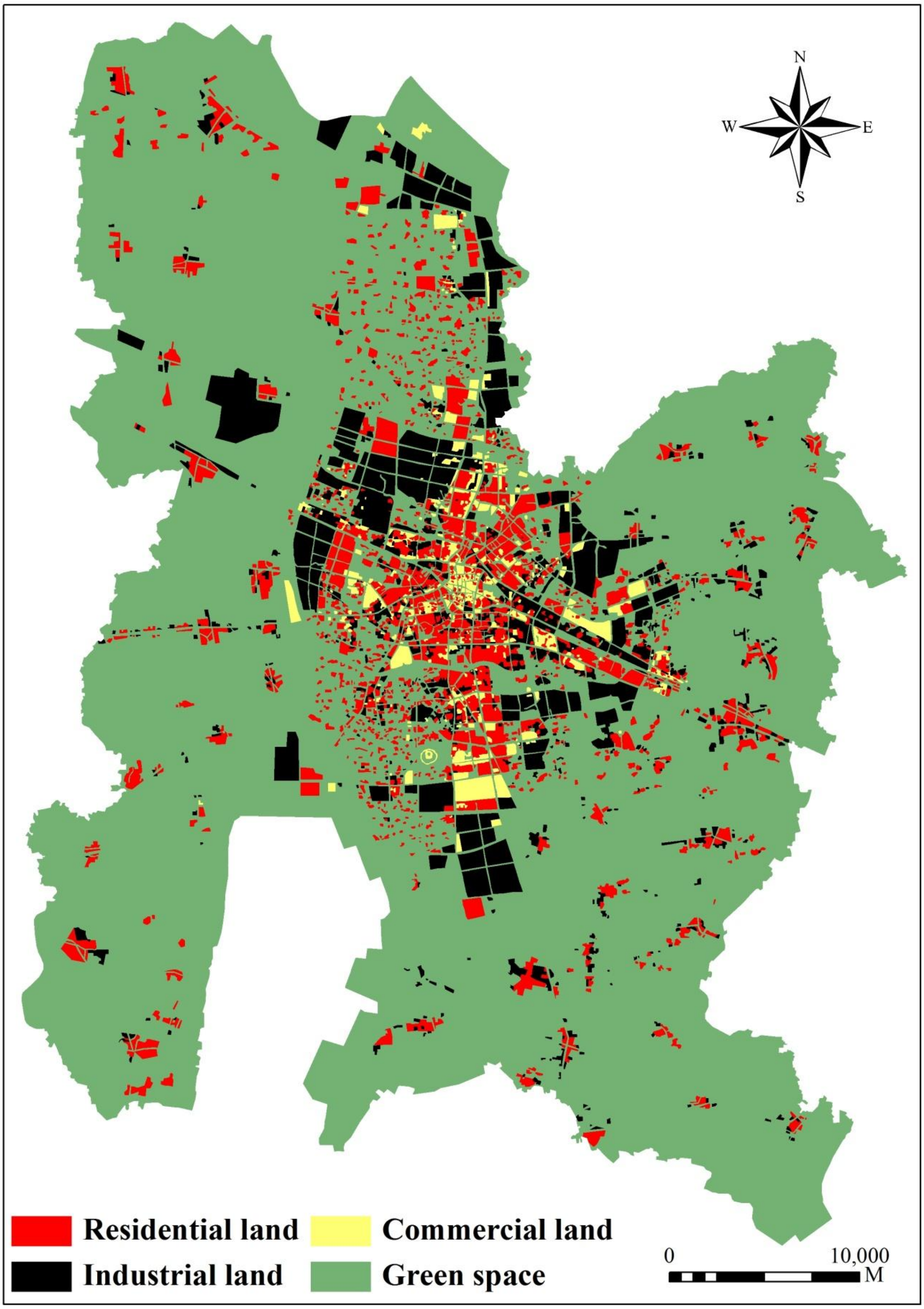


Figure 3.3: Land use pattern in Changzhou (2008)

Table 3.1: Land use pattern

Land use type	Area (km^2)	Percentage (%)
Residential land	127.71	7.50
Industrial land	139.46	8.19
Commercial land	31.35	1.84
Green space	1,404.38	82.47
Total	1,702.90	100.00

3.4 Person trip analysis

Travel data is acquired based on Changzhou Person Trip Survey (CPB, 2008). In the survey, five city districts in Changzhou City were divided into 6 traffic areas (Figure 3.4), 40 medium traffic regions and 438 traffic analysis zones (TAZs) (Figure 3.5). In PT survey, the sample size is 10,238 households and 29,589 citizens, with the sample rate of 2% in central zones, and 0.5% in suburban and peripheral zones. As shown in Table 3.2, total trips per day generated by sample household are 75,587 (7.38 per household and 2.55 per capita). Person trips includes 18,887 trips of “To work”, 4,159 trips of “To school”, 3,154 trips of “To business”, 7,022 trips of “To shopping”, 2,014 trips of “To entertainment”, 1,367 trips of “To visit friend”, 33,859 trips of “To home”, and 5,125 trips of “Others”. The trip to work accounting for 24.99% plays a significant role except the trips to home, indicating that commuting is the major travel purpose in Changzhou.

Table 3.3 exhibits the modal split of different trip purposes. In total, walking, bicycle, public transport, and automobile account for 21.37%, 34.08%, 11.92%, and 32.63%, respectively. The bicycle is the dominant travel modes in most of trip purposes, especially for “To school”, “To work” and “To home”, which is consistent with the main trip characteristics in China where bicycles are mostly used. The usage ratio of public transport is low, indicating that public transport is not a popular travel mode in Changzhou.

Three-dimensional surface diagrams of Origin-Destination (OD) matrix of 15 traffic regions reveal that high values of commuting, shopping and other trips appear at the diagonal lines, implying that households prefer intrazonal trips for commuting, shopping and other purposes (Figure 3.6, 3.7, 3.8). The reason might be that they tend to find a job and go shopping inside their residential region to lower traffic costs.

On the other hand, it could be detected that a significant urban agglomeration occurs in the urban geometric center from the Origin-Destination data. According to the traffic generation and attraction densities (trips per hectare) in all 438 TAZs (Figure 3.9 and 3.10) computed based on Origin-Destination (OD) matrix, the closer to the city geometric center the higher the traffic generation and attraction densities, indicating that the urban center has more driving and attractive force to person trips than suburban and peripheral areas.

Table 3.2: Person trip by purposes

Trip purpose	The number of trips	Percentage (%)
To work	18,887	24.99
To school	4,159	5.50
To business	3,154	4.17
To shopping	7,022	9.29
To entertainment	2,014	2.66
To visit friend	1,367	1.81
To home	33,859	44.79
Others	5,125	6.78
Total	75,587	100.00

Table 3.3: Model split by purposes (%)

Trip purpose	Walking	Bicycle	Public Transport	Automobile	Total
To work	5.65	47.92	7.32	39.11	100
To school	31.80	45.16	10.75	12.29	100
To business	4.82	20.26	2.89	72.03	100
To shopping	43.08	28.62	11.79	16.51	100
To entertainment	67.90	16.29	5.81	10.00	100
To visit friend	10.85	34.50	37.91	16.74	100
To home	22.30	39.76	9.15	28.79	100
Others	24.81	37.34	8.70	29.15	100
All trips	21.37	34.08	11.92	32.63	100

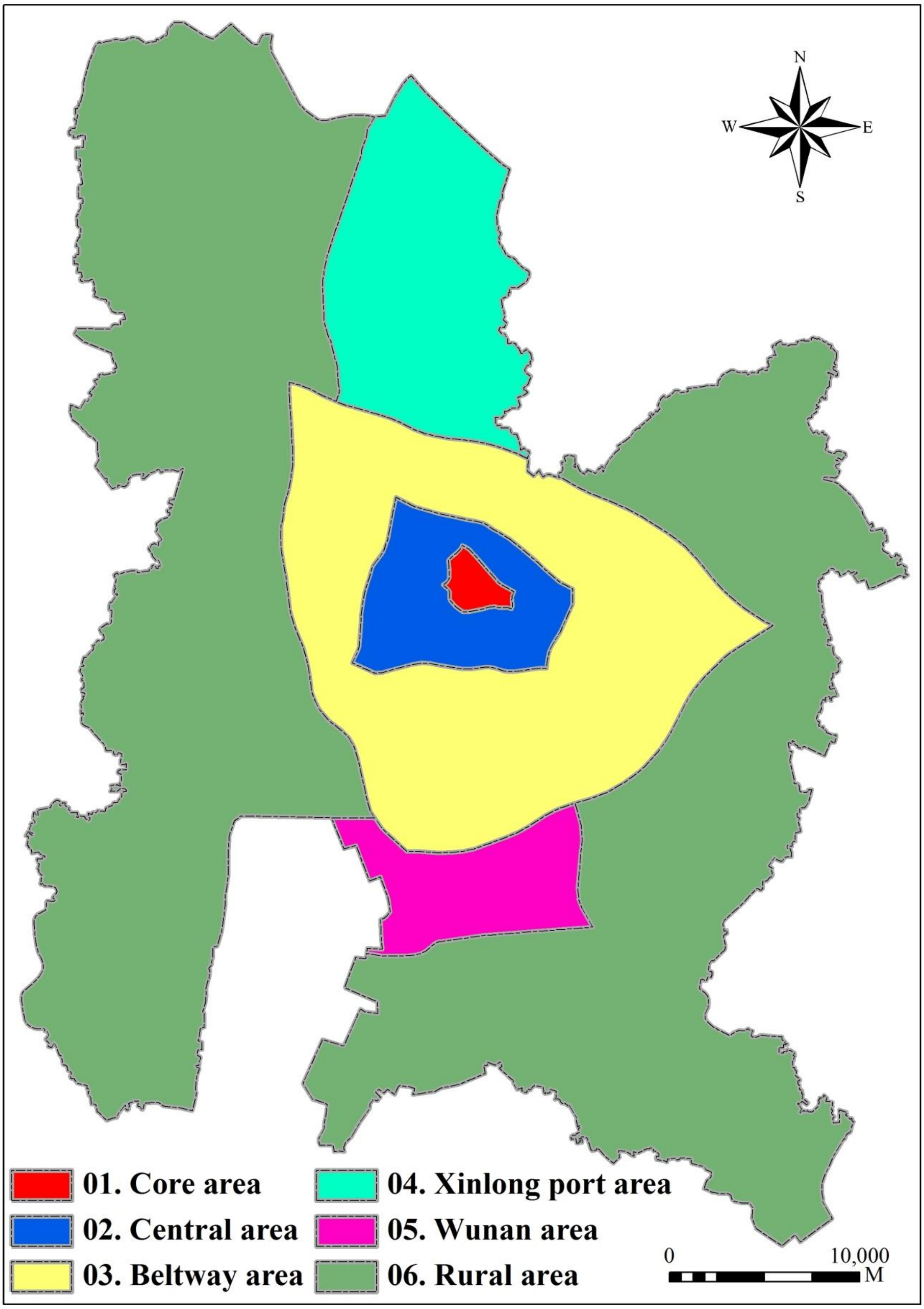


Figure 3.4: Traffic areas

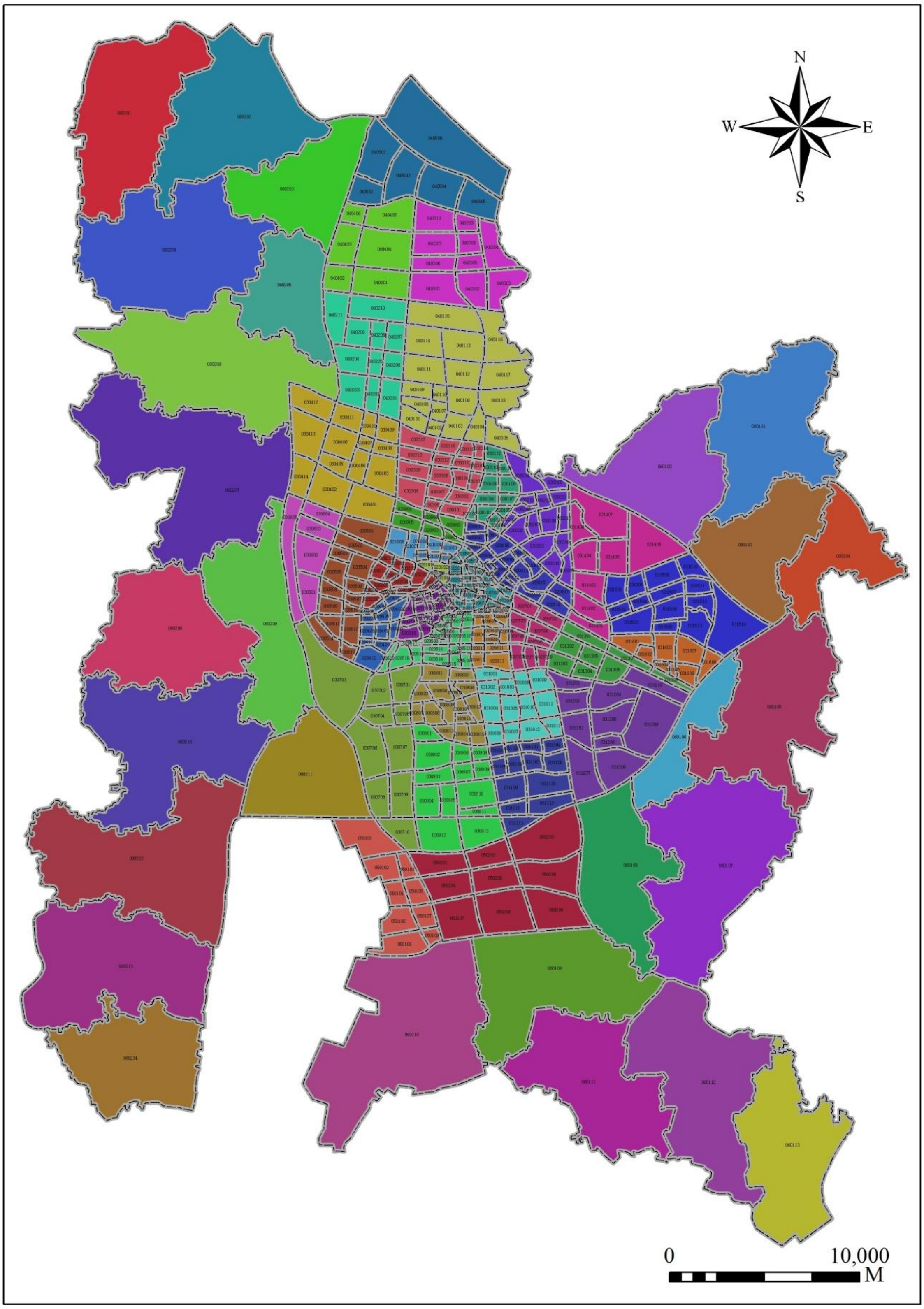


Figure 3.5: Traffic analysis zones

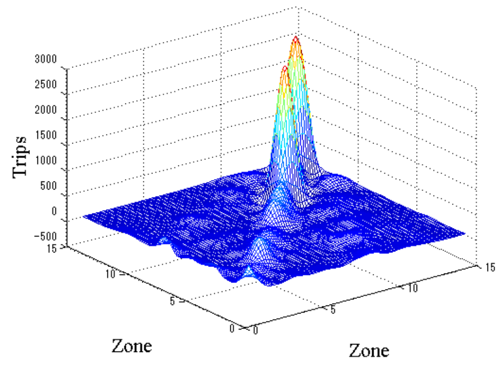


Figure 3.6: Trips for commuting

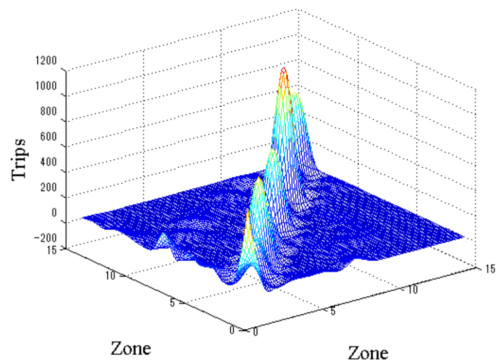


Figure 3.7: Trips for shopping

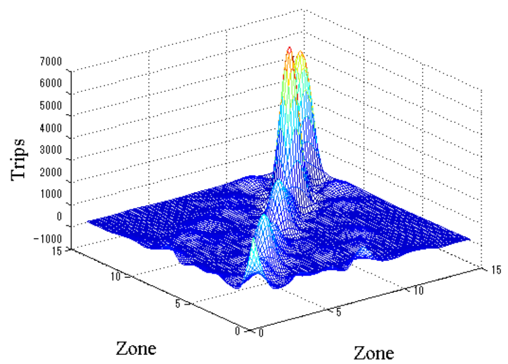


Figure 3.8: Trips for other purposes

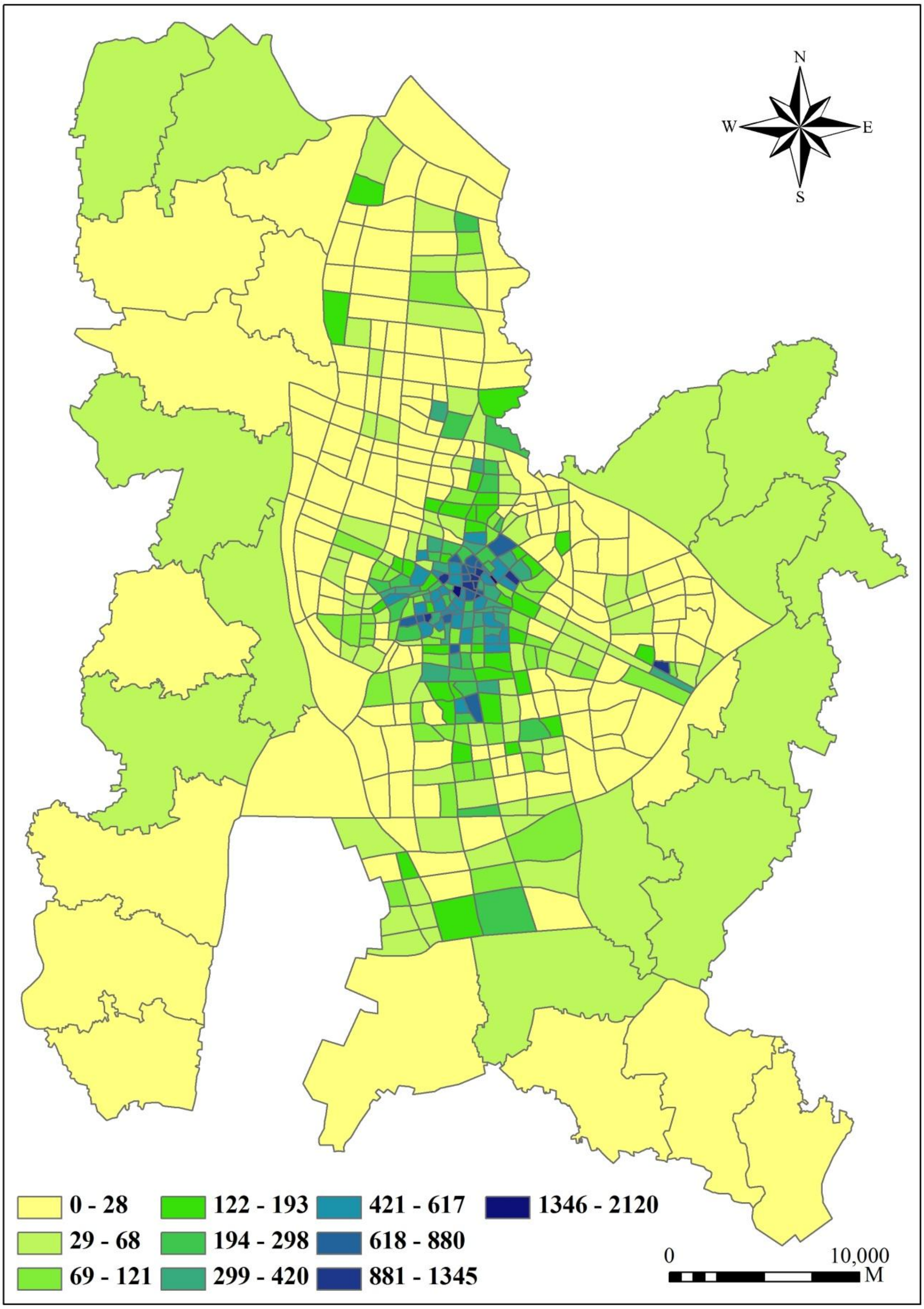


Figure 3.9: Traffic generation density

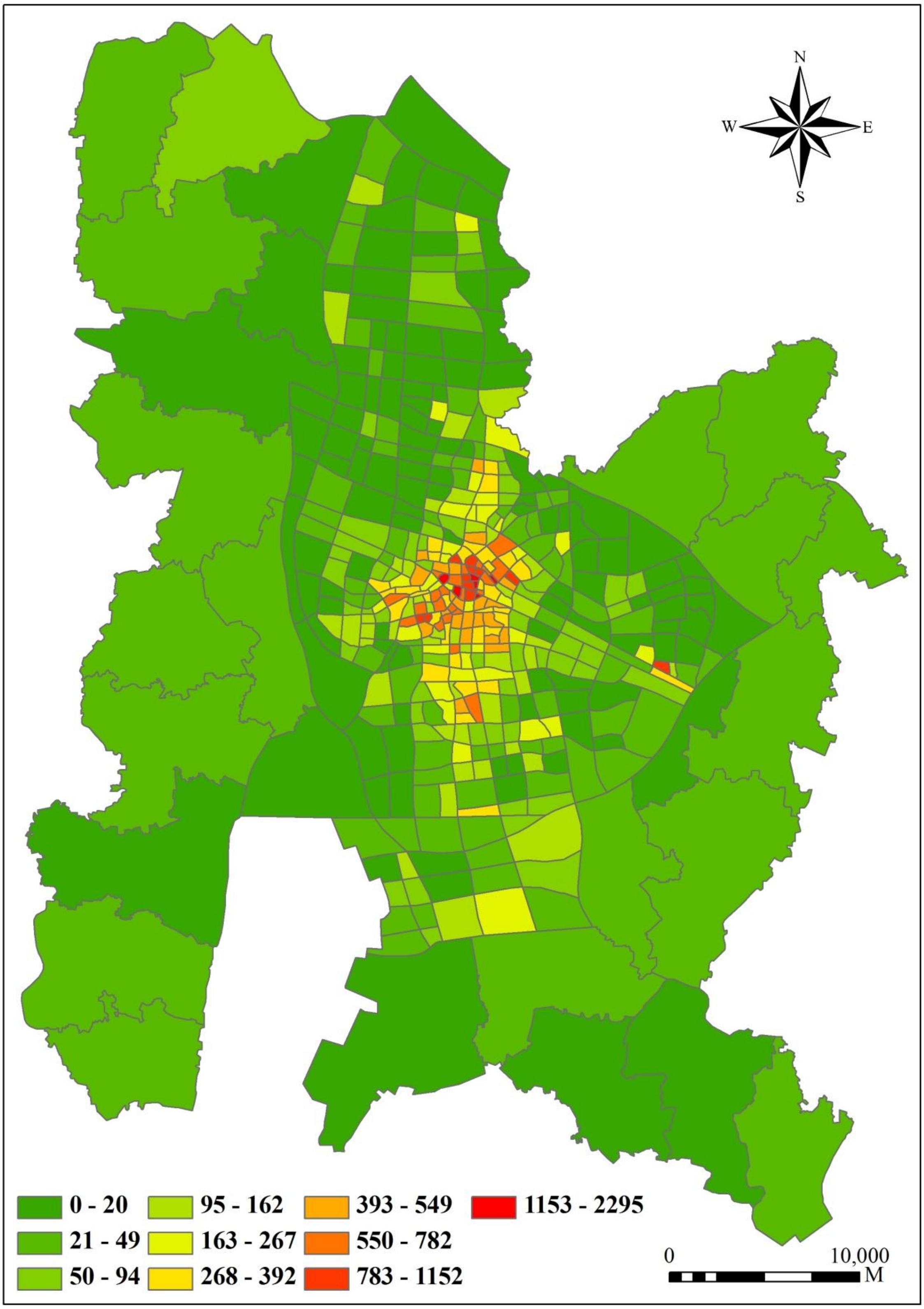


Figure 3.10: Traffic attraction density

3.5 Spatial pattern and correlation between land use and transport

3.5.1 Methods

In order to detect the spatial pattern and correlation between land use and transport, taking traffic congestion as a representative measure of transport condition, our research methods are divided into three main steps: (1) traffic assignment; (2) buffer zone and gradient analysis; (3) correlation analysis.

We refer to traffic assignment model for detecting traffic volume and congestion on each road link employing User Equilibrium (UE) in the JICA-STRADA 35 platform based on Origin-Destination (OD) data provided by Person Trip Survey in Changzhou City (2008). The traffic network of 5 types: collector street, arterial street, major road, highway, and expressway consists of 1,744 road links and 1,011 nodes, and it also contains road characteristics including road type, length, maximum allowable velocity, and capacity, etc. (Table 3.4 and Figure 3.11). All-day driving trips from Origin-Destination (OD) data were extracted and then changed to peak-hour vehicle OD matrix based on PCU and peak-hour coefficient. The simulated traffic was assigned to the road network by using UE method, and simulation results contain traffic volume per link, and Volume-Demand-to-Capacity Ratio (VCR) per link.

Table 3.4: Road capacity and Maximum allowable velocity

Road type	Collector street	Arterial street	Major road	Highway	Expressway
Road capacity (Vehicles per hour per lane)	600	900	1000	1200	1400
Maximum allowable velocity (kilometers per hour)	40	60	80	80	100

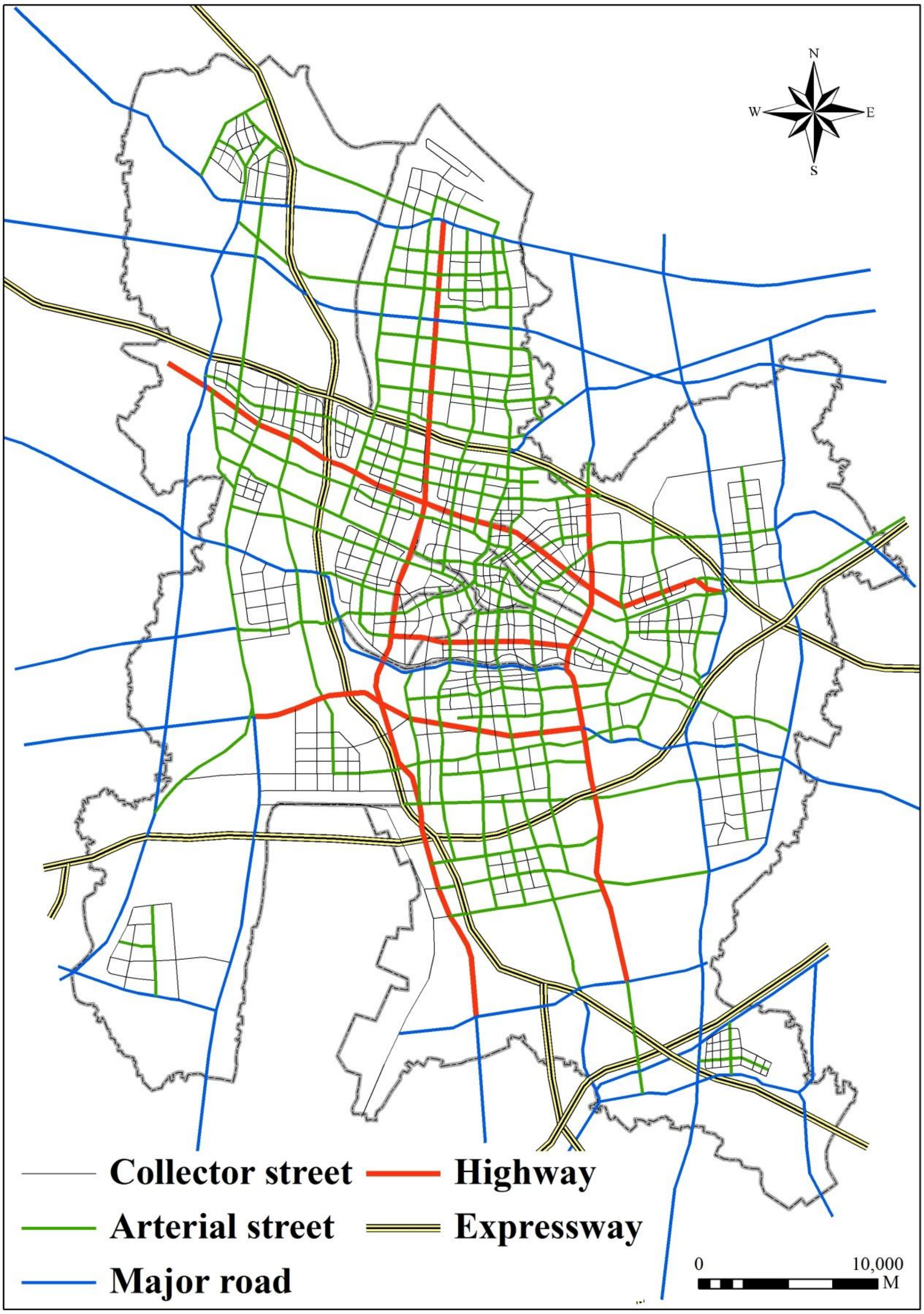


Figure 3.11: Road network

Buffer zone and gradient analysis are powerful analytic tools for detecting spatial pattern and distribution of geographic elements. In order to analyze the spatial pattern and correlation between traffic congestion and land use, buffers of 30 km at one-km intervals were constructed surrounding the urban geometric center of Changzhou. Next, it becomes possible to investigate the traffic congestion and land use pattern at different distances from city center by overlaying buffers with traffic network and land use map.

Land use indices including land use diversity (*LUD*) and land use intensity (*LUI*) were built to measure the spatial structure, pattern and impact degree of human activities on land use. Land use diversity (*LUD*) is a quantitative measure that reflects how many different land use types there are in a certain area. *LUD* can be expressed by Shannon's diversity index (Shannon, 1948), which is most often calculated as follows:

$$LUD = -\sum_{\forall i} a_i \ln a_i \tag{3.1}$$

Where a_i is the area proportion of the ith type of land use. *LUI* is a measure that indicates the intensity of economic activities and aitificialization degree, which also can be seen as the human-induced amplification of economic yields and productivity (Dietrich, et al., 2012), so we refer to land economic output to reflect the land use intensity of different land use types.

$$LUI = \sum_{\forall i} a_i R_i \tag{3.2}$$

Where R_i is the economic output of ith land use type, and we set 199.04, 3,257.01 and 1,876.70 CNY per square meter per year for R_i of residential land, industrial land, and commercial land, based on related research in China's land economic density (Feng, et al., 2008; Wu, et al., 2013), GDP and land use data in Changzhou City (CSB, 2008).

3.5.2 Spatial distribution of traffic congestion

Figure 3.12 exhibits the simulation results of traffic assignment. To a large extent, traffic congestion occurred in the city geometric center as well as the southern part of Changzhou City. Although the southern suburban zones are far away from the city center, South Changzhou New Town developed recently where there are also relatively high residential densities and population concentrations leads to significant traffic congestion. Figure 3.13 shows the average VCR of different road types. Generally speaking, VCR of collector street and arterial street are higher than those of major road, highway and expressway, implying that traffic congestion in Changzhou tended to occur in the local streets which have lower capacity and maximum allowable velocity.

Buffer analysis presents the spatial gradient of traffic congestion that shows a declining trend with increasing the distance to the city center (Figure 3.14). The peak value of VCR is located at the 2 km to the city center, indicating that geometric center is the most congested area. Then, VCR decreased sharply from 3 km to 16 km, and displayed a relatively flat but fluctuating tendency from 17 km to 30 km. In particular, there exist two peak values at 17 km and 24 km, the reason of which is also the South Changzhou New Town where traffic congestion occurred.

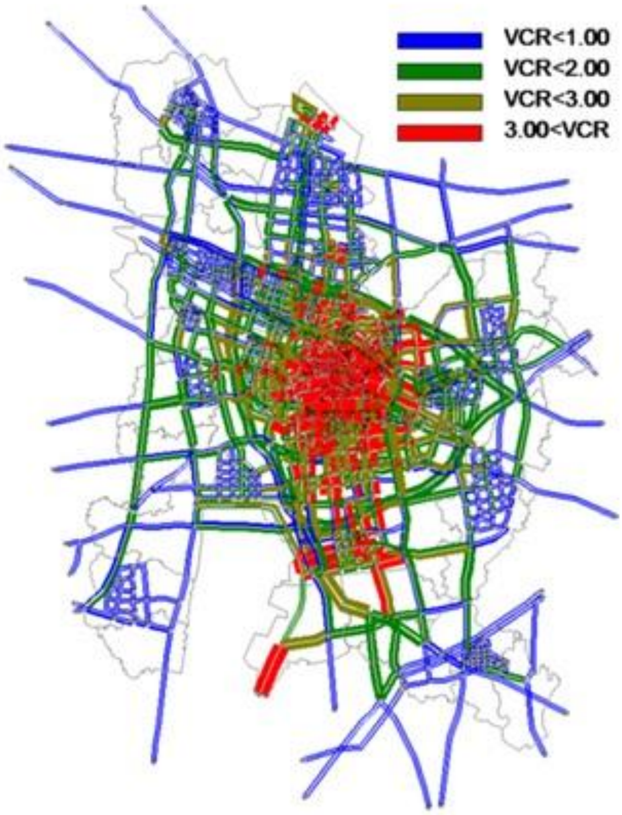


Figure 3.12: Traffic assignment result

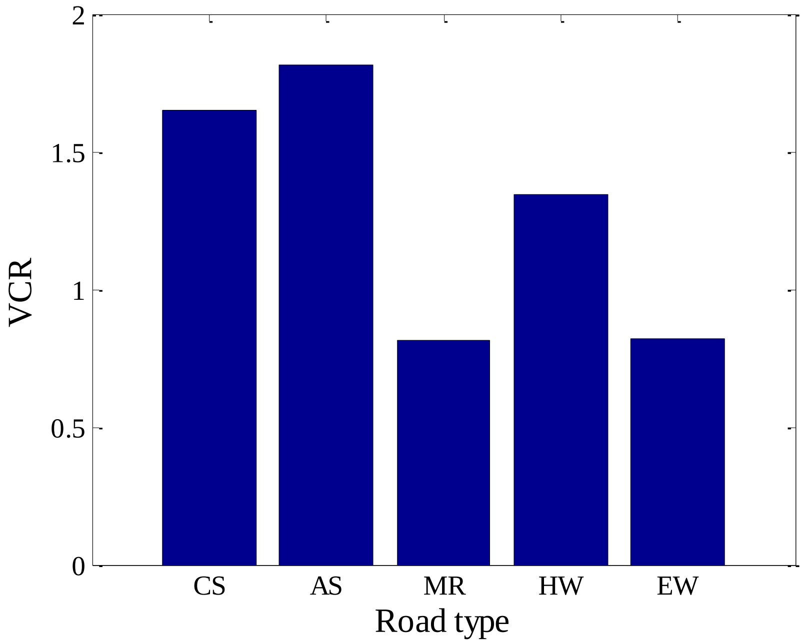


Figure 3.13: Traffic congestion level (VCR) of different road types

Note: CS, collector street; AS, arterial street; MR, major road; HW, highway; EW, expressway

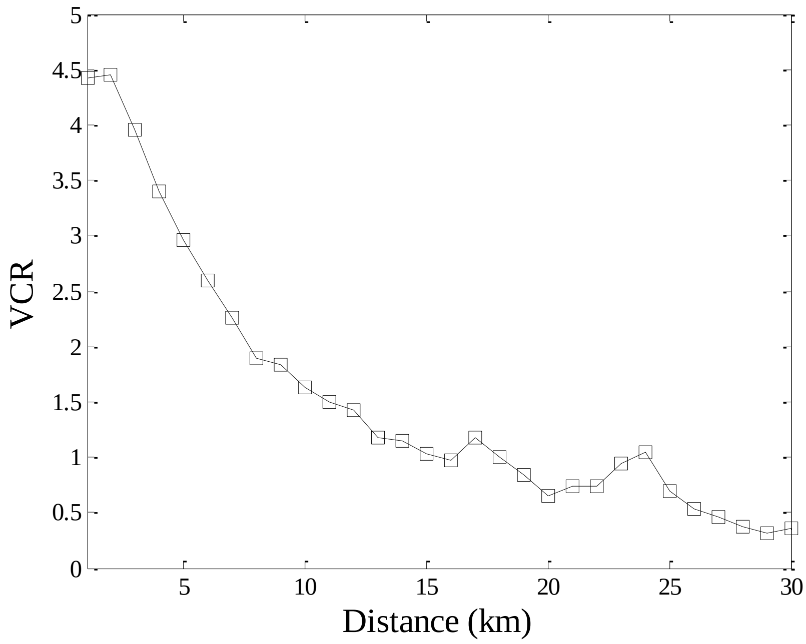


Figure 3.14: Spatial gradient of traffic congestion level (VCR)

3.5.3 Spatial distribution of land use pattern

Besides the spatial distribution of traffic congestion, the spatial gradient of land use pattern also can be detected by employing buffer analysis. As shown in Figure 3.15, The proportion of residential land increased from 29.72% at 1 km to a peak of 44.33% at 3 km, and then decreased sharply to 7.40% at 11 km, which is followed by a relatively flat trend from 11 km to 30 km. Industrial land exhibits an inverted ‘V’ shape: its proportion increased from a 3.28% at 1 km to a peak of 37.07% at 8 km, and then gradually decreased to a minimum value of 0.79% at 29 km. Spatial pattern of industrial land shows that industrial activities tend to be gathered in the intermediate area near the city center. Commercial land is widely distributed near the city center, which presents a declining tendency of land area proportion with increasing distance to the city center. Green space has a clear spatial tendency: the proportion rose with increasing distance to city center and peaked at 94.13% at 29 km. In summary, residential land and commercial land are distributed near city center or intermediate area near city center, while green space is distributed in suburban and peripheral zones.

Next, spatial gradient analysis of land use diversity index and land use intensity index can be used to investigate the spatial distribution of land use pattern as a whole. As displayed in Figure 3.16, *LUD* tended to decline as distance from city center increased on the whole, and another peak of 0.54 is observed at 22 km. It is clear that *LUD* peaked in the city center due to the distribution of a variety of land use types there, but urban expansion and new town development in Changzhou also led to an increasing land use diversity in the suburban zone. A spatial gradient similar to that seen in *LUD* is observed for *LUI*, which shows a fluctuating but decreasing tendency with its maximum value of 1,332.03 occurring at 8 km and its minimum value of 32.08 at 29 km. Compared with what is observed in *LUD*, *LUI* exhibits a same spatial trend that the value decreased intensely from 8 km to 13 km.

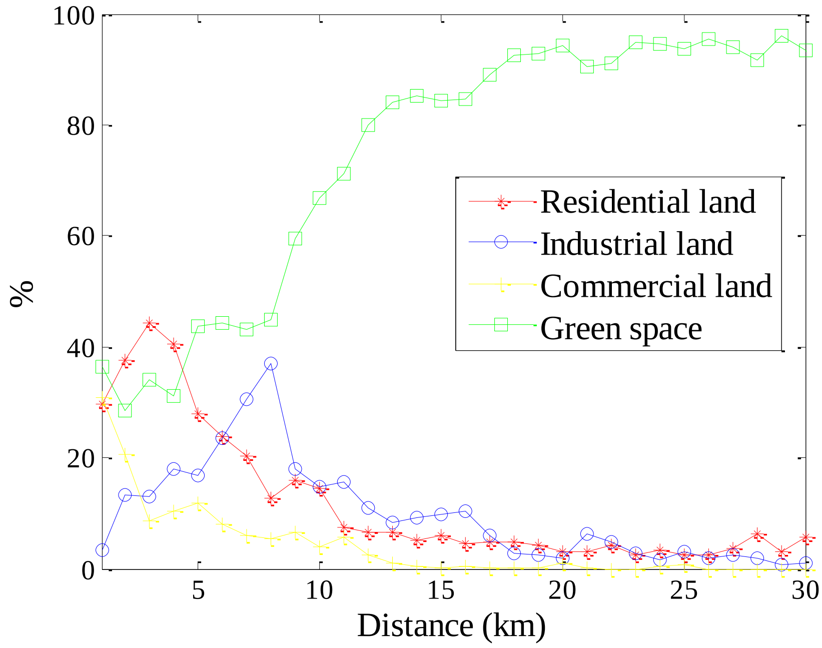


Figure 3.15: Spatial gradient of land use pattern

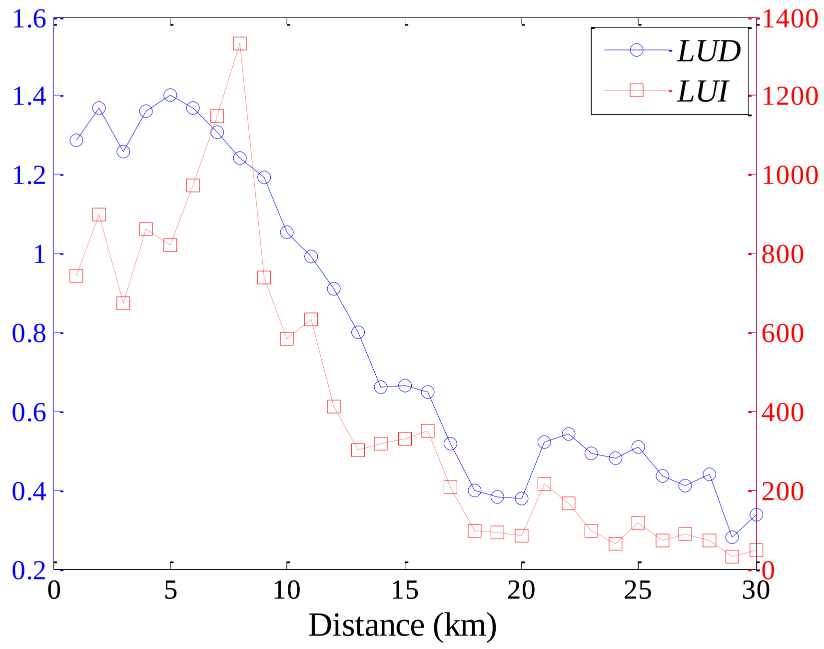
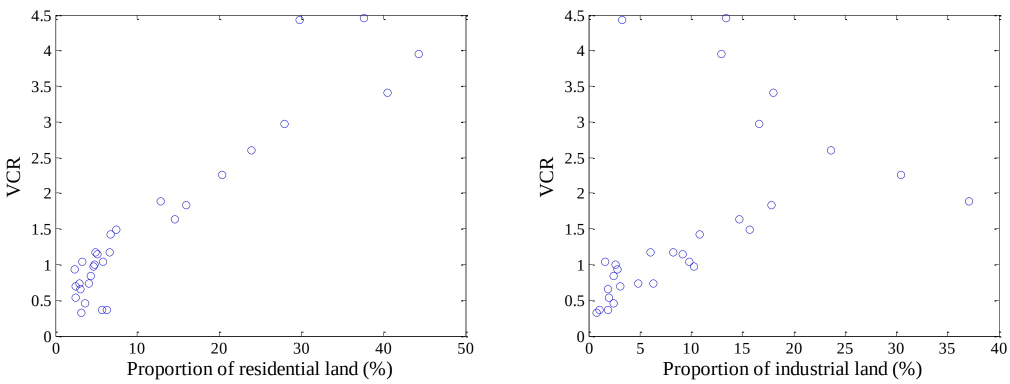


Figure 3.16: Spatial gradient of *LUD* and *LUI*

3.5.4 Correlation between traffic congestion and land use pattern

Figure 3.17 clearly indicates that land use pattern does correlate to the traffic congestion. The proportions of residential land and commercial land present positive correlations with VCR, while those seen in green space show a negative correlation with VCR. Industrial land distinguishingly correlates with VCR shows both positive and negative correlation partially, implying that industrial land can generate and inhibit traffic congestion for different cases. The key finding here is that traffic congestion occurs in the area where the proportions of residential and commercial land are high, while the industrial regions were not congested significantly.

The correlations between *LUD*, *LUI* and VCR present 'S' shape and inverted 'V' shape, respectively (Figure 3.17). Maximum VCR does not occur in the region where land use diversity and intensity are high. In the areas where the *LUD* and *LUI* are relatively low, they are positively correlated with traffic congestion, but they show negative correlations when the *LUD* and *LUI* are high. This phenomenon also could be detected in the spatial gradient analysis above: there exists a spatial inconsistency that traffic congestion occurred at 1 km, while *LUD* and *LUI* peaked from 6 km to 8 km.



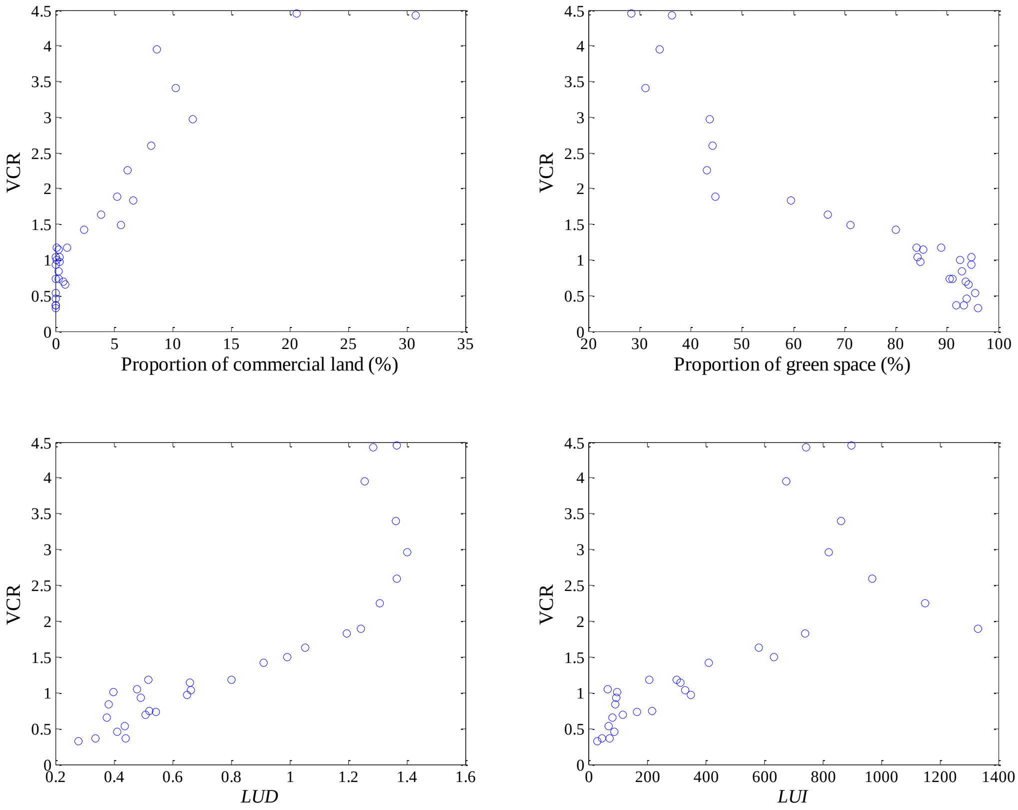


Figure 3.17: Correlations between traffic congestion and land use

3.5.5 Discussions

Existing research has found clear correlations between land use factors and traffic congestion by comparing empirical evidences of different cities. This correlation also could be found in the analysis on road scale within urban area, thus we can answer the question of whether traffic congestion is correlated to land use pattern within urban areas. Traffic congestion tends to be located near the city geometric center, as well as the spatial distribution of residential land, and commercial land. This suggests that residential and commercial activities indeed have significant driving forces for urban traffic congestion, but industrial and manufacturing activities do not markedly give rise to traffic congestion. The spatial distribution of single land use type is not sufficient to clarify the interaction of land use pattern and traffic congestion, so we turn now to a discussion of the spatial correlation between comprehensive land use index and traffic congestion.

Past studies declared that mixed and high-density land use mode plays a critical role in mitigating traffic congestion. However, there is no typical significant positive or negative correlation between land use diversity, intensity, and traffic congestion within urban areas, which is not consistent with the conclusions in past studies. An interesting finding is the spatial mismatch of the core region congested with traffic flows, and the region with high land use diversity and intensity. In general, our analysis indicates that, on one hand, in the areas where *LUD* and *LUI* are relatively low e.g. suburban and peripheral zones, to some extent, land use diversity and intensity exert a positive influence on traffic congestion; on the other hand, land use diversity and intensity have a inhibition effect on traffic congestion in central zones with high *LUD* and *LUI*.

The analysis of spatial gradients and their correlations of land use and traffic congestion at urban scale are easily affected by physical geography, local geomorphology, land use planning, population, transport policy, and other factors of the case city itself. A more generalized conclusion needs further research based on different urban types to summarize the homogeneous feature of the interaction between land use and transport. Nevertheless, there is no doubt that we can put forward concrete urban policy recommendations for eastern Chinese cities represented by Changzhou. Nowadays, urban polices in Changzhou tend to construct new housing quarters and industrial parks in suburban zones, in order to transfer the residential and manufacturing functions from central zones to suburbs. This is because the central business district (CBD), characterized by its high land value and attractiveness to consumers, is inclined to be used more for commercial purpose due to the high comparative returns. However, our studies showed highest land use diversity and intensity will not lead to extra traffic congestion, we thus can obtain urban planning guidelines for Changzhou: central built up area should conserve land use diversity and intensity and improve the efficiency by reuse of current land resources, land replotting and urban renewal. This planning philosophy is accordance with the viewpoints of compact city.

Another policy implication is about the new town planning. East China has witnessed a dramatic urban sprawl for decades. Several new dwelling zones, and recreational business district (RBD) are under planning and consideration in Changzhou City. The key point that needs to be paid special attention here is that new town development is bound to create new growth points of traffic congestion in suburban and peripheral areas inevitably. And the congestion level will increase gradually with the size of new towns growing, because land use and traffic congestion are at a stage of positive correlation. Therefore, dwelling zone development requires business zone, shopping districts and other supporting facilities to improve the land use diversity and intensity. If doing so, the correlation between land use and traffic congestion can enter the negative part of the ‘S’ shape and invert ’V’ shape curves.

Traffic congestion level embodies the spatial distribution of traffic flows but cannot reflect the trip purposes that are closely related to land use types. Hence, travel patterns for various trip purposes such as commuting, shopping, leisure, etc. should be taken into account to examine the interaction of traffic congestion and land use, especially the response of different trip purposes to land use pattern. In addition, land use pattern still can be subdivided into more detailed types for sake of investigating the inherent mechanism how land use generate traffic congestion. For instance, traffic generation, attraction and congestion caused by commuting to school are affected by spatial distribution of land for education facilities. And other land use features such as building floor area ratio (FAR), and landscape indices like fragmentation, isolation, evenness, etc. also need to be analyzed with traffic behaviors if data could be available.

3.6 Summary

This chapter presented the geography, history, population, industry, economic development, urbanization, and land use and travel pattern in Changzhou. In particular, we evaluated traffic congestion at road scale by using a traffic assignment model and person trip data, and then analyzed the spatial distribution and correlations between land use and traffic congestion. We have demonstrated that spatial distribution of different land use types, land use diversity and intensity are significantly correlated with traffic congestion. The key point is to shift the focus only on transport to the interaction between land use and transport, in doing so to provide reference for the urban planning. Therefore, our aim was not only to identify the influences of land use pattern to traffic congestion, but also to put forward planning recommendations and urban development strategies for mitigating traffic congestion in the process of China’s rapid urbanization. Our findings indicated that land use intensity and diversity conservation in built up area, namely a high-density mixed-use and compact urban form could be accepted as a promising solution for traffic decongestion.

There is still a range of limitations needed to be solved in the future works. Given the lack of logistics data, we just focused on the private vehicle trips but did not consider the business trips in the traffic assignment modeling. Besides, as discussed above, the nearest future extensions for this research are spatial correlations between land use and traffic congestion in the consideration of more detailed analytical factors such as FAR, building densities, trip purpose, etc. Moreover, buffer and spatial gradient analysis is used to only reveal the geographical correlation between land use pattern and traffic congestion, but cannot interpret the microscopic behaviors of land users and traffic entities clearly. It is necessary to develop a computable land use and transport interactive model, which is able to depict explicitly the behavior mechanism of microscopic agents like consumers, producers, travelers, and government within urban areas, to facilitate harmonious and sustainable urban and transport development in China's rapid urbanization area.

4 CUE modeling for land use and transport interaction

4.1 General introduction

Our focus in this chapter is to develop an integrated model of land use and transport in the combination of each advantage of existing CGE/CUE models that can reflect general market equilibrium including land, labor and commodity markets, and transport assignment for sophisticated traffic network respectively, in order to be used practically in China's urban planning and infrastructure policymaking. This chapter puts forward the model structure including behaviors of household, firm, transport, as well as the general equilibrium and programming algorithm. Then the parameter estimation and modal calibration are conducted based on the land use, PT survey and economic data in Changzhou. The final section is the numerical computation to propose a benchmark model for policy evaluation in Changzhou.

4.2 Model structure

4.2.1 Model settings

We developed a computable integrated model of land use and transport in the tradition of the CGE/CUE model (Anas, et al., 1996; Anas, et al., 1999; Anas, et al., 2007; Ueda, et al., 2013). In this model, the city encompasses i zones, and in each zone i homogenous land area A_i is given which is available for residences and retail firms. Households decide where to reside, where to work, where and how much to shop, how much labor to supply, while retail firms in each zone i produce a zone-specific commodity according to a Cobb-Douglas technology that combines land and labor supplied by households. There is no predetermined employment and shopping center, but all location decisions of households are determined endogenously by the equilibrium of land, labor and commodity markets in each zone. That is to say, households who reside and work in this closed city choose their residential, employment and shopping zones based on utility maximization and profit maximization. Due to the lack of logistics data, we only consider retail market, commuting and shopping trips in the model. Travel mode choice concerns walk, bicycle, public transport and automobile. Traffic assignment can be carried out by using an User Equilibrium (UE) method based on an OD matrix and road network. In brief, all these behaviors and location decisions are determined endogenously, and thus this model implicitly determines location choices, land use pattern, traffic volume including commuting and shopping trips, and travel mode choices as well.

4.2.2 Households' behavior

A Household resides in some zone *i* and works in some zone *j*, that is to say, household will choose the "residence-job pair (*i*,*j*)". They value locational variety in shopping and their preference for variety is specified, so that they want to shop everywhere. The preference for locational variety is equivalent to assuming that goods produced and sold in different zones are viewed as product variants by virtue of their location. Household residing at zone *i* and working at zone *j* travels from zone *i* to every zone *k* where production occurs to purchase the unique goods produced there. We assume that separate trips are made to each production zone *k*, purchasing a unit quantity of commodity per trip. The households' utility function is: (Cobb-Douglas utility function)

$$\underset{Z_{ij},q_{ij},L_{ij}}{MAX} \quad U_{ij} = \alpha \ln\left(\sum_{k=1}^{I} \iota_{ijk} Z_{ijk}^{\eta}\right)^{1/\eta} + \beta \ln q_{ij} + \gamma \ln L_{ij} + u_{ij} \tag{4.1}$$

subject to:

$$\sum_{k=1}^{I} Z_{ijk}\left(p_k + 2c_{ik}\right) + r_i q_{ij} + 2d\rho c_{ij} = w_j\left(H - TT_{ij} - L_{ij}\right) + D \tag{4.2}$$

Where α, β, γ are preference coefficients, and it is assumed that they are identical across households and have a sum total of one. Z_{ijk} is the number of shopping trips made by a household, employed at zone *j*, from the home zone *i* to zone *k* to purchase commodity, and it is also the quantity of the commodity purchased at zone k by household residing at zone i and working at zone j. q_{ij} is the lot size of household at home zone i. L_{ij} is the leisure time of the household. u_{ij} are idiosyncratic utility constants. p_k is the commodity price at zone k. r_i is the rent for land at zone i, and w_j is the wage rate at zone j. c_{ik} is the money cost of one-way travel from zone i to zone k. d is number of work days in a period (year). ρ is the parameter given exogenously for adjusting the number of commuting trips per day. ι_{ijk} is the coefficient for measuring the inherent shopping preference to zone k for a household residing at zone i and working at zone j. $1/(1-\eta)$ is the elasticity of substitution taking Dixit-Stiglitz form by assuming $0<\eta<1$. H is the time endowment available for work, leisure and travel per period. TT_{ij} is the total travel time per period including commuting and shopping, and let t_{ik} be the one-way travel time from zone i to zone k, it is calculated as:

$$TT_{ij} = 2d\rho t_{ij} + \sum_{k=1}^{I} 2t_{ik} Z_{ijk} \tag{4.3}$$

It is assumed that there are no specific land owners and traffic agencies, thus households are equal owners of all the land and transport revenue in the economy. Hence, aggregate land rents and transport tolling are redistributed as dividend, D, paid to each household reflecting their shares of land and transport revenue. Letting N be the exogenous number of households, and F_{ij} total trips from zone i to zone j per day, the dividend is:

$$D = \frac{1}{N}\left(\sum_{i=1}^{I} A_i r_i + 2d \sum_{i=1}^{I}\sum_{j=1}^{I} F_{ij} c_{ij} \right) \tag{4.4}$$

The budget constraint may be rearranged to express the expenditure of full economic income:

$$\sum_{k=1}^{I} Z_{ijk}\left(p_k + 2c_{ik} + 2w_j t_{ik}\right) + r_i q_{ij} + w_j L_{ij} = w_j H + D - 2d\rho\left(c_{ij} + w_j t_{ij}\right) \tag{4.5}$$

Hence, Marshallian demand can be calculated as:

$$Z_{ijk} = \frac{\iota_{ijk}^{\frac{1}{1-\eta}} \left(p_k + 2c_{ik} + 2w_j t_{ik}\right)^{\frac{1}{\eta\text{-}1}}}{\sum_{k=1}^{I} \iota_{ijk}^{\frac{1}{1-\eta}} \left(p_k + 2c_{ik} + 2w_j t_{ik}\right)^{\frac{\eta}{\eta\text{-}1}}} \alpha\left[w_j H + D - 2d\rho\left(c_{ij} + w_j t_{ij}\right)\right] \tag{4.6}$$

$$q_{ij} = \beta \frac{w_j H + D - 2d\rho\left(c_{ij} + w_j t_{ij}\right)}{r_i} \tag{4.7}$$

$$L_{ij} = \gamma \frac{w_j H + D - 2d\rho\left(c_{ij} + w_j t_{ij}\right)}{w_j} \tag{4.8}$$

Then indirect utility function is:

$$^{*}U_{ij} = V_{ij} + u_{ij} = \ln\left[w_j H + D - 2d\rho\left(c_{ij} + w_j t_{ij}\right)\right] - \frac{\alpha(\eta\text{-}1)}{\eta} \ln\left(\sum_{k=1}^{I} \iota_{ijk}^{\frac{1}{1-\eta}} \left(p_k + 2c_{ik} + 2w_j t_{ik}\right)^{\frac{\eta}{\eta\text{-}1}}\right)$$
$$- \beta \ln r_i - \gamma \ln w_j + u_{ij} \tag{4.9}$$

The best residence-job location pair is found in the outer stage maximization by comparing the indirect utility of all (i, j) pairs. Households choose the most preferred pairs differently because the idiosyncratic taste constants for residence-job location pairs differ among households and distributed randomly among them. Therefore location choices of "residence-job pair (i,j)"can be described by choice probability in the form of a discrete choice model:

$$\Psi_{ij} = \frac{e^{\lambda V_{ij}}}{\sum_{s=1}^{I}\sum_{m=1}^{I} e^{\lambda V_{sm}}}; \quad \sum_{i}^{I}\sum_{j}^{I} \Psi_{ij} = 1 \tag{4.10}$$

Where Ψ_{ij} is the joint probability that the household chooses a home at zone i and a job at zone j.

4.2.3 Firms' behavior

Retail firms producing at the same zone are identical and competitive in the output and input markets, and the number of firms in a zone is indeterminate. The unique goods are sold at the zone where they are produced, implying logistics will not be considered in this model. The firm's technology is Cobb-Douglas and constant returns to scale, with labor and land the only two inputs. Let X_i be the aggregate output produced at zone *i*, *B* be the scale parameter; and let M_i and Q_i be the aggregate labor and land inputs utilized at zone *i*. The production function is:

$$X_i = BM_i^{\delta} Q_i^{\mu}; \qquad \delta + \mu = 1 \tag{4.11}$$

Then the conditional input demand functions are derived based on profit maximization:

$$M_i = \delta p_i \frac{X_i}{w_i} \tag{4.12}$$

$$Q_i = \mu p_i \frac{X_i}{r_i} \tag{4.13}$$

Because free entry in each zone insures that profit maximizing firms make zero economic profit, the price of output can be expressed as a function:

$$p_i = \frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta} \mu^{\mu}} \tag{4.14}$$

4.2.4 Transport behavior

There are two kinds of daily traffic flows originating at a zone *i* and terminating at the same or another zone *j*. Let ${}^{c}F_{ij}$ be the expected commutes from zone *i* to zone *j* per day, and ${}^{s}F_{ij}$ be the expected shopping trips from zone *i* to zone *j* per day. Total trips from zone *i* to zone *j* per day are then F_{ij}:

$$^{c}F_{ij} = \rho N \Psi_{ij} \tag{4.15}$$

$$^{s}F_{ij} = \frac{N \sum_{s=1}^{I} \Psi_{is} Z_{isj}}{d} \tag{4.16}$$

$$F_{ij} = {}^{c}F_{ij} + {}^{s}F_{ij} \tag{4.17}$$

Individual expected travel costs and travel times for all residents in the urban area depend on the travel mode. Let $^{tm}c_{ij}$ be the travel mode-specific travel cost; $^{tm}c^{fix}$ be the travel mode-specific fixed costs, i.e. costs not depending on the travel time and distance; $^{tm}c^{time}$ be the travel mode-specific variable time dependent costs per km; $^{tm}t_{ij}$ be the one-way travel mode-specific travel time from zone *i* to zone *j* with travel mode *tm.* Then aggregate monetary one-way travel costs from zone *i* to zone *j* with travel mode *tm* are:

$$^{tm}c_{ij} = {}^{tm}c^{fix} + {}^{tm}c^{time} \cdot {}^{tm}t_{ij} \tag{4.18}$$

Every household is assumed to own a car, and public transport is available for any person trip from zone *i* to zone *j*. There is endogenous congestion only for automobile, and the travel time of automobile could be calculated based on UE method. Congested time for each road link *a*, t_a, can be calculated by BPR function:

$$t_a = t_{a0} \left[1 + \varepsilon \left(\frac{F_a}{K_a} \right)^{\sigma} \right] \tag{4.19}$$

Where t_{a0} is the minimum (zero-flow) travel time per unit distance; F_a is the traffic volume of link *a*; K_a is the road capacity of link *a*; ε and σ are parameters given exogenously.

The travel times of other travel modes without endogenous congestion such as walk, bicycle and public transport from zone *i* to zone *j* are given by assuming exogenous given specific average speed of travel mode *tm*, ^{tm}v, and shortest travel distance. Therefore, these travel mode-specific one-way travel costs and travel times can be transformed into traveler specific generalized travel costs c_{ij} and travel times t_{ij} which enter the budget and time constraint of all households.

$$c_{ij} = \sum_{\forall tm} {}^{tm}\pi_{ij} \, {}^{tm}c_{ij} \tag{4.20}$$

$$t_{ij} = \sum_{\forall tm} {}^{tm}\pi_{ij} \, {}^{tm}t_{ij} \tag{4.21}$$

Where ${}^{tm}\pi_{ij}$ is the probability that a traveler chooses travel mode tm for a trip from zone i to zone j. A traveler will choose the available travel mode tm with some probability depending on utility associated with travel cost and time of mode tm. This probability ${}^{tm}\pi_{ij}$ can be computed by using a mode choice model in multinomial logit form:

$${}^{tm}\pi_{ij} = \frac{e^{{}^{tm}TV_{ij}}}{\sum_{\forall tm} e^{{}^{tm}TV_{ij}}} \tag{4.22}$$

$${}^{tm}TV_{ij} = \omega_1 \, {}^{tm}c_{ij} + \omega_2 \, {}^{tm}t_{ij} \tag{4.23}$$

Where ${}^{tm}TV_{ij}$ is the utility with travel mode tm from zone i to zone j, and ω_1, ω_2 are parameters given exogenously.

4.2.5 General equilibrium

Now the behaviors of households, firms and transport are combined into a general equilibrium model to simultaneously clear the market for land, labor and the locally produced commodity in each zone. In each zone i, the land, labor and commodity markets clear by:

$$N \sum_{j=1}^{I} \Psi_{ij} q_{ij} + Q_i = A_i \tag{4.24}$$

$$N\sum_{s=1}^{I}\Psi_{si}\left(H - TT_{si} - L_{si}\right) = M_i \tag{4.25}$$

$$N\sum_{n=1}^{I}\sum_{s=1}^{I}\Psi_{ns}Z_{nsi} = X_i \tag{4.26}$$

These excess demand equations (4.24), (4.25), (4.26), plus the zero-profit conditions given by (4.14), are to be solved for the vectors ***r***, ***w***, ***p***, ***X***.

4.2.6 Programming algorithm

The system of equilibrium conditions expressed as a complicated set of homogeneous equations is non-linear and cannot be solved analytically, thus we have to rely on numerical simulations. The Newton-Raphson algorithm and UE method based on GAMS and JICA-STRADA platform were employed to obtain the equilibrium solutions. This full closed general equilibrium system is homogenous of degree zero in rent ***r***, wage ***w***, and commodity price ***p***. Thereby Walras' law holds and one price in ***r***, ***w***, ***p*** is arbitrary. These equilibrium prices can be normalized and demands can be expressed in terms of relative price. We adopt the convention that the arbitrary price which is chosen as numeraire is the land rent of the central zone, which implies that the rent for land at the central zone is fixed, and thus we discard the land market condition for the central zone. Then integrating general equilibrium computation and traffic assignment, an iterative procedure must be employed to get the equilibrium ***r***, ***w***, ***p***, ***X*** and congested travel time ***t***. We simultaneously calculated the land use pattern, population and employment distribution in each zone, and traffic volumes in each road link as well. The cyclical linking of the algorithm is shown in Figure 4.1.

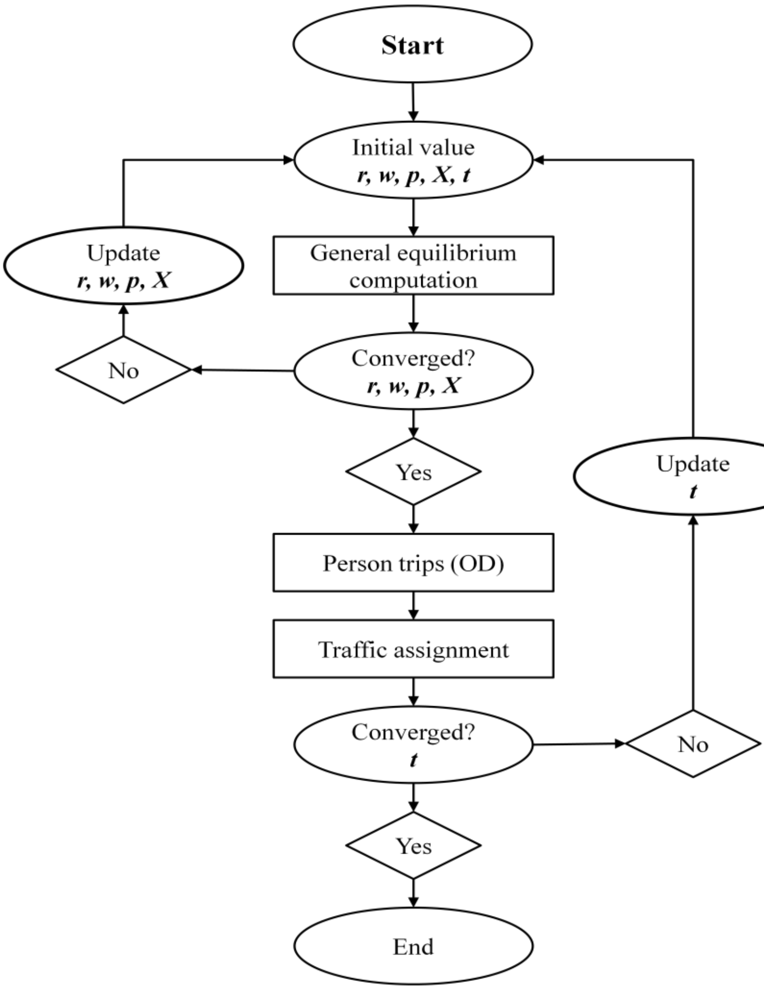


Figure 4.1: Cyclical linking of the algorithm

4.3 Parameter estimation and modal calibration

For numerical computation, Changzhou City is divided into 15 zones, as a benchmark model, including 8 central zones (1-8), 5 suburban zones (9-13) and 2 peripheral zones (14-15) that could reflect the feature that land supply increase with distance from the city center (Figure 4.2). Road network of Changzhou City includes 5 types: collector street, arterial street, major road, highway and expressway, as same as the settings in chapter 3.

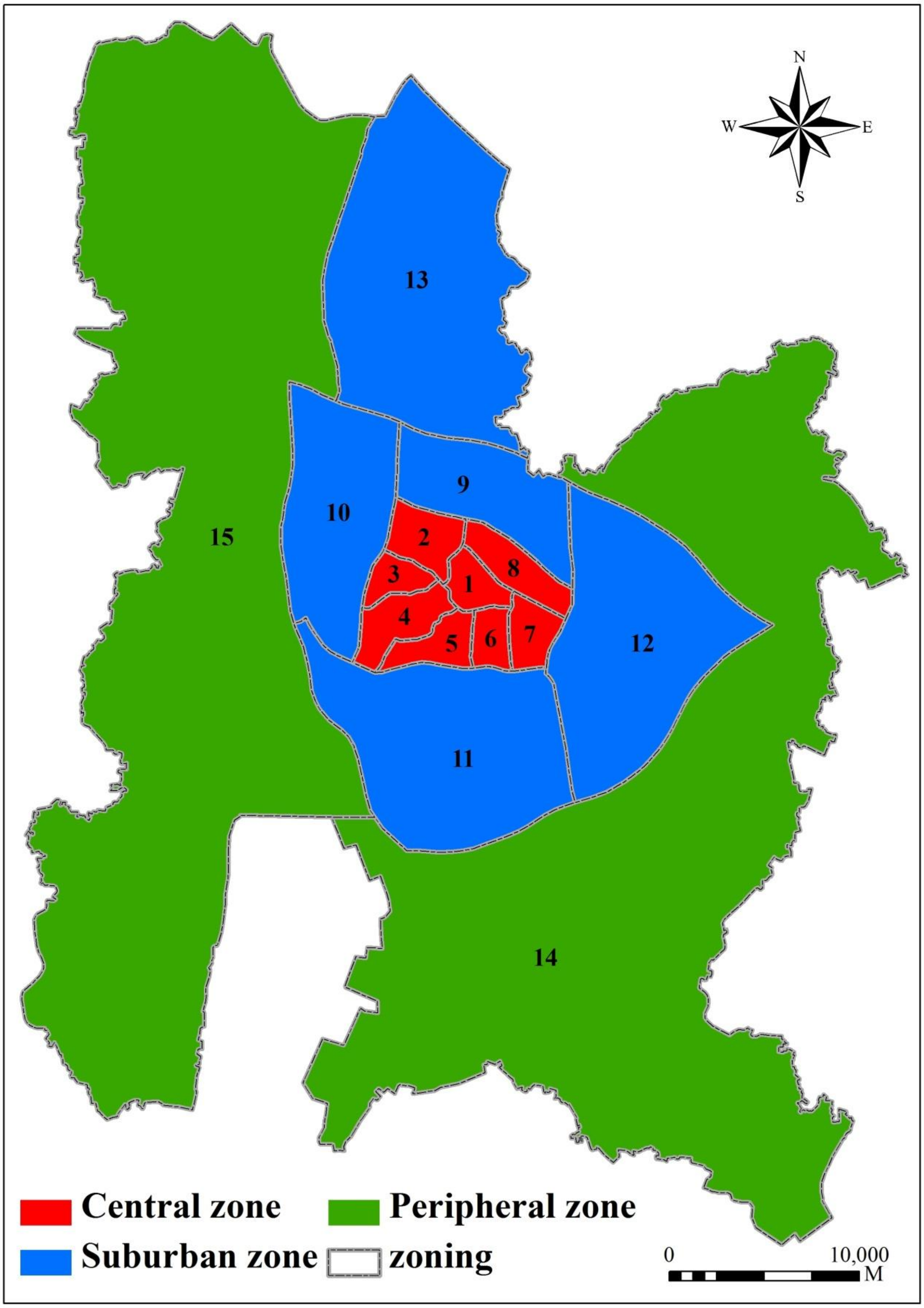


Figure 4.2: Zoning

We describe below the parameter estimation and model calibration for a benchmark city on the basis of empirical data from several approved sources of Changzhou in 2008. Parameters for benchmark simulation are estimated from Person Travel Survey (CPB, 2008), statistical data and empirical data. The calibration ensures that the benchmark model simulation exhibits spatial economic figures such as rent and wage, land use figures such as land use area for firms and for residences, and traffic figures such as traffic flows and modal split which approximate real evidences of Changzhou City.

According to the Statistical Yearbook of Changzhou (CSB, 2009), the number of households of Changzhou in 2008 is 757,277, assuming one worker per household. Preferences are set so that 73% of full economic income goes to shopping, 10% to land, 17% to leisure, in order to fit the actual situation of relative expenditure shares for goods consumption, housing and leisure time (CSB, 2009). The total time endowment H is taken to be 6,000 hours per year and work days is 250 days per year. Person survey data shows that daily commuting in Changzhou is not only one time per day, so we used ρ which equals to 2.37 to calibrate total commuting trips. The dispersion parameter λ used in location decision, the elasticity of substitution η, and production parameters are set based on relevant research results (Anas, et al., 1996; Anas, et al., 1999). λ, η, scale parameter B, cost shares of labor and land input in production function δ, μ, are set at 12, 0.6, 0.25, 0.65 and 0.35 respectively.

Person Trip Survey (CPB, 2008) shows households tend to shop in their residential zone, that is to say, intrazonal shopping is more frequent than interzonal shopping, implying that consumers consider their residential zone has the highest inherent zonal attractiveness for shopping. The reason might be that they can save time by shopping at the zone where they reside. Thus, it is assumed that household's shopping preferences are affected endogenously by the economic value of travel time which they need to travel from shopping zone i to residential zone k. The inherent shopping preference ι_{ijk}, can be described by choice probability in the form of a discrete choice model, and we estimated ξ=-0.05 based upon shopping OD matrix from person survey data (CPB, 2008).

$$\iota_{ijk} = \frac{e^{\xi w_j t_{ik}}}{\sum_{s=1}^{I} e^{\xi w_j t_{is}}}; \quad \sum_{k}^{I} \iota_{ijk} = 1 \tag{4.27}$$

Urban travel speed is taken to be 4 km/h for walking, 8km/h for bicycle, 18km/h for public transportation and 50 km/h for automobile respectively. According to the traffic tariff system in Changzhou City, fixed monetary travel costs of walking, bicycle, public transport and automobile are fixed at 0, 0, 5, 0 CNY respectively, and the variable time dependent costs are assumed to be 0, 0, 0, 25 CNY per hour. ω_1, ω_2 are set at -0.43 and -2.04 estimated based on person survey data in 2008 by using Maximum Likelihood Method (CPB, 2008). ε and σ are set at 0.15 and 4 according to the default value of BPR function. Rent in zone 1, as a numeraire for benchmark simulation, is set at 340 CNY per square meters which is cited from benchmark land price in Changzhou (CBLR, 2008). Parameter settings are shown in Table 4.1.

Table 4.1: Parameters for benchmark model

Households' behavior						
α=0.73	β=0.10	γ=0.17				
N=757,277	H=6,000	d=250	ρ=2.37	η=0.6	ξ=-0.05	λ=12
Firm' behavior						
B=0.25	δ=0.65	μ=0.35				
Transport behavior						
${}^{walk}c^{fix}$ =0	${}^{bicycle}c^{fix}$ =0	${}^{public}c^{fix}$ =5	${}^{auto}c^{fix}$ =0 (CNY)			
${}^{walk}c^{time}$ =0	${}^{bicycle}c^{time}$ =0	${}^{public}c^{time}$ =0	${}^{auto}c^{time}$ =25 (CNY/h)			
${}^{walk}v$=4	${}^{bicycle}v$=8	${}^{public}v$=18	${}^{auto}v$=50 (km/h)			
ω_1=-0.43	ω_2=-2.04	ε=0.15	σ=4			
Numeraire						
r_1=340 (CNY/square meters)						

4.4 Numerical computation

Benchmark simulation results exhibit the rent, product density, population and employment densities, and land use pattern. Figure 4.3 and 4.4 shows that the rent and product density in central zones (zone 1-8) are far more than those in suburban zones and peripheral zones (zone 9-15). Households tend to work in central zones and reside in suburban zones and peripheral zones, as a result of employment densities in zone 1-8 more than residential densities but less than in zone 9-15 (Figure 4.5). Compared with population densities, employment densities decline steeply with distance from the urban center, because the central location is relatively attractive for firms due to its high accessibility. In the whole city, 33.84% of the land is used by residences, and 66.16% is occupied by firms. 84.14% of the land is required for firms in the central zone (zone 3), but this percentage falls to 58.87% in the suburban zone (zone 11), owing to the attraction to workers and firms of central zone as well (Figure 4.6).

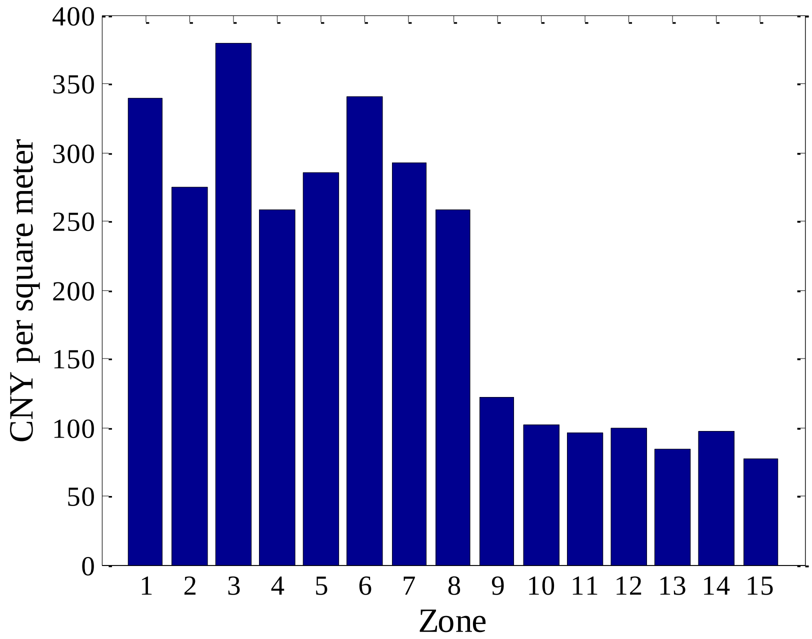


Figure 4.3: Rent

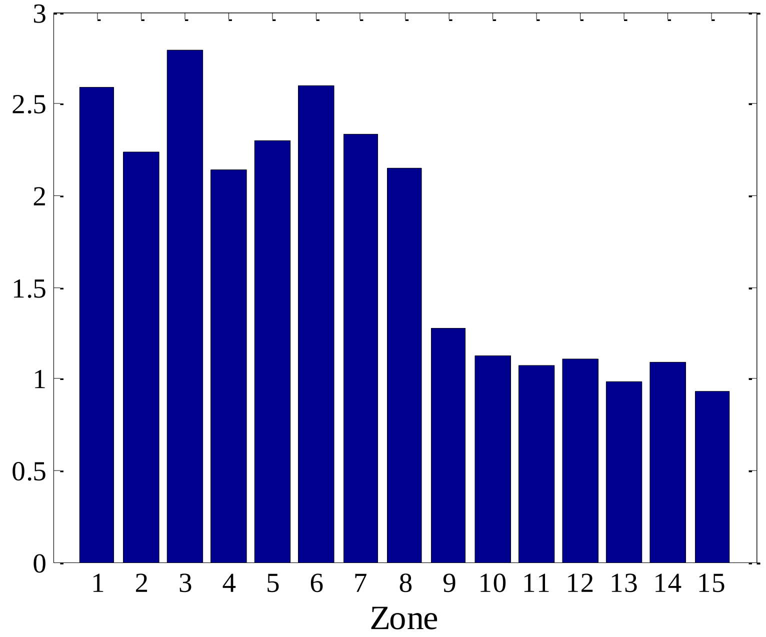


Figure 4.4: Production density

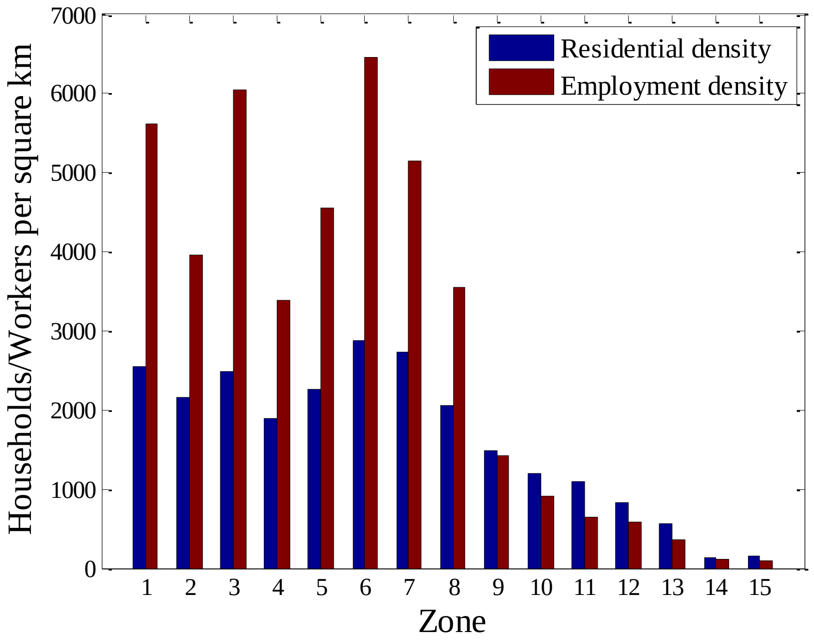


Figure 4.5: Population and employment densities

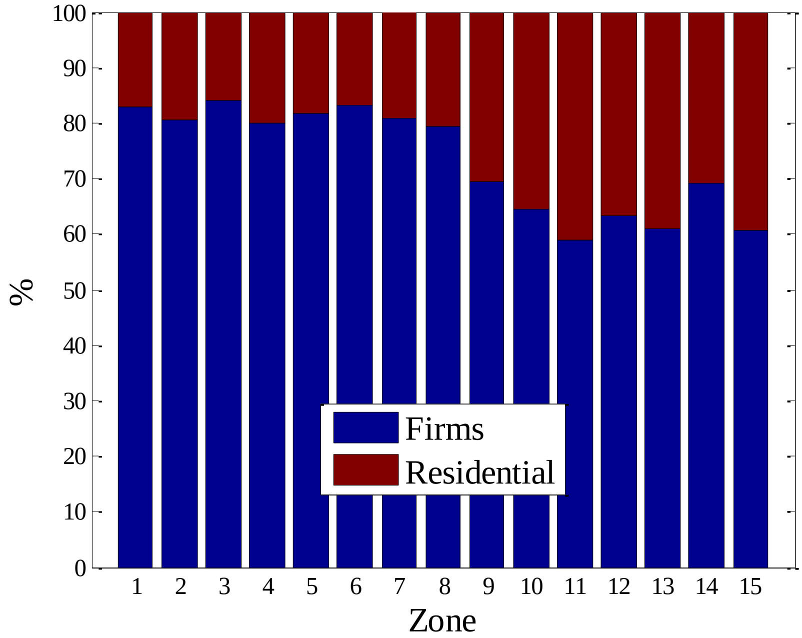


Figure 4.6: Land use pattern

The total daily traffic volume per day is 2,838,671 trips and 3.75 trips per household. Daily commuting trips and shopping trips are 1,794,747 trips and 1,043,925 trips, respectively, in total and 2.37, 1.38 trips, respectively, per household. In total traffic flows, 8.49% and 33.87% are taken by walking and bicycle, respectively; 14.29% and 43.35% use public transport and automobile respectively. As shown in Figure 4.7, there exists a concentration of traffic generation and attraction as same as the distribution of population and employment in central zones. Figure 4.8 exhibits the simulation results of modal split in different distances. Usage percentages of walking and public transport display significant positive and negative correlations to trip distance, respectively. The relation between the usage percentages of bicycle and trip distances shows an inverted U-shaped curve. To some extent, usage percentages of automobile are also correlated positively to trip distances. In summary, households are inclined to choose walking and bicycle as travel modes for short-distance trips especially when the distances are shorter than 5 km, while they prefer motor vehicles for long-distance trips.

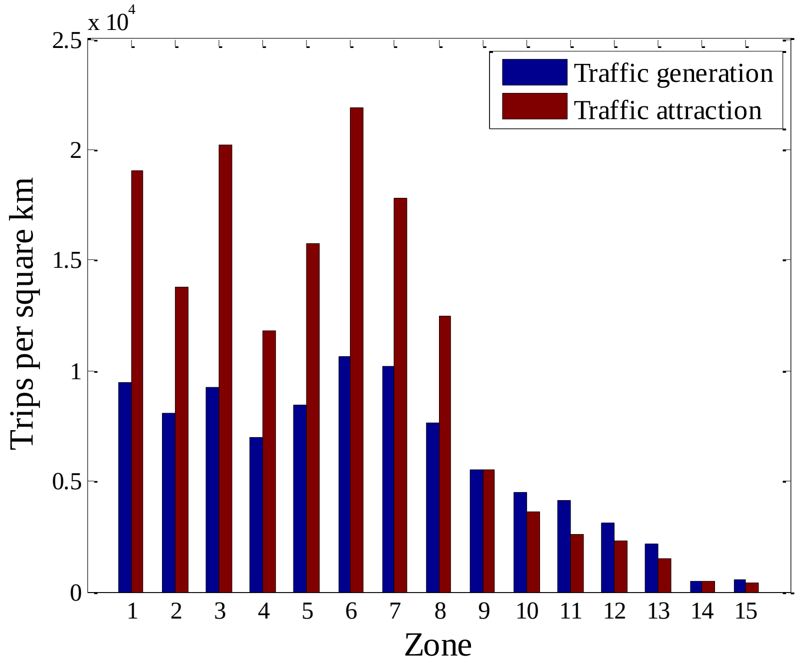


Figure 4.7: Traffic generation and attraction densities

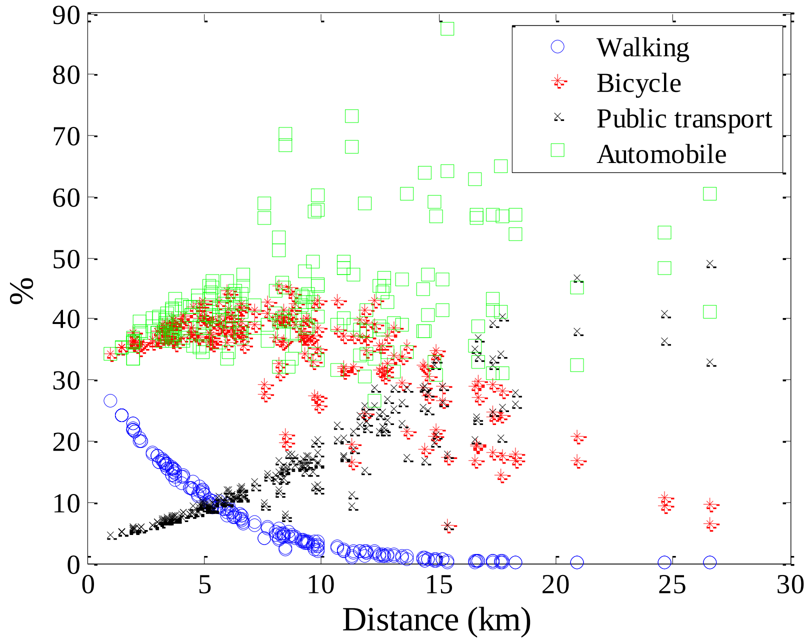
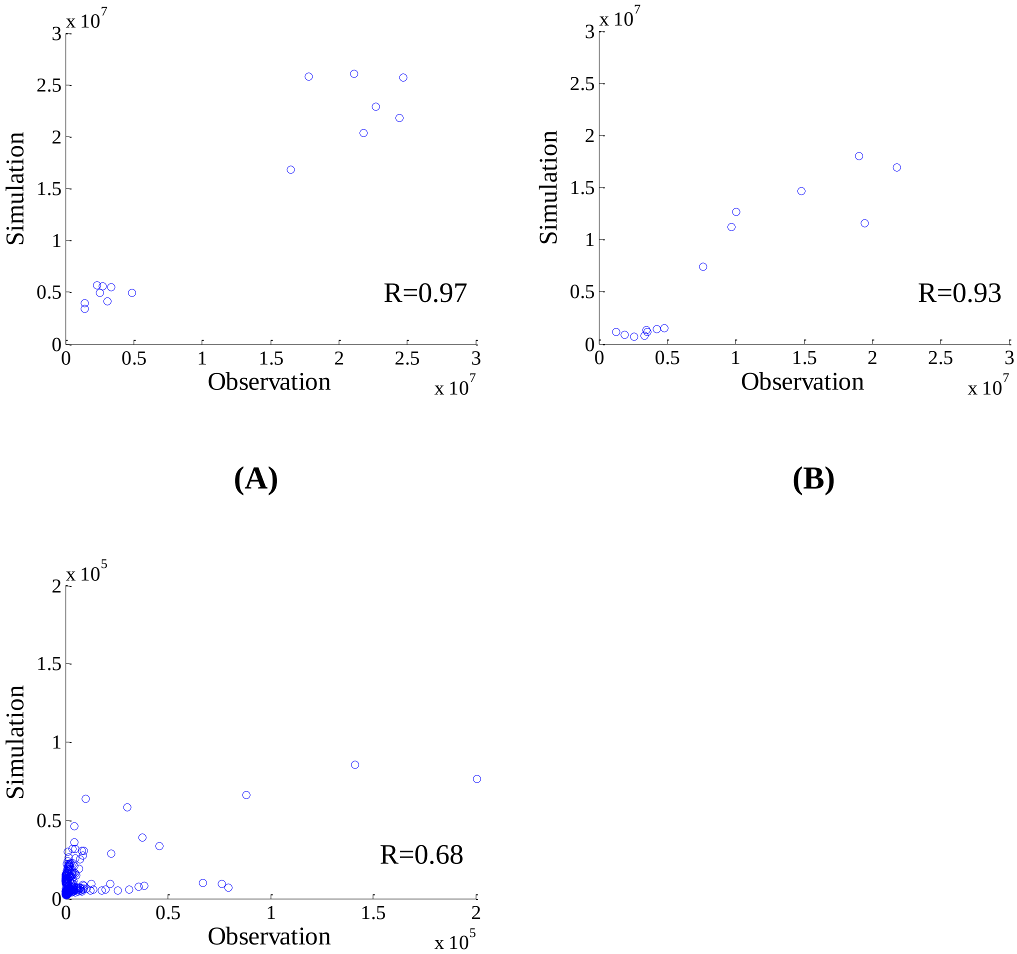


Figure 4.8: Modal split

Figure 4.9 shows the correlation between observed data and simulations, verifying that this model could be accepted as a policy evaluation tool. In a word, this model can provide detailed information on land use and travel patterns, by simulating residential and working location and transport behavior.



(A) **(B)**

(C)

Figure 4.9: Comparison between model output and observation. (A) Land for firms. (B) Land for residences. (C) Person trips

4.5 Summary

This chapter formulated the mathematic form of an integrated land use and transport model in the tradition of CUE model, which is consistent with urban microeconomic theory. The location choice and travel behaviors of microeconomic agents can be described by households' utility maximization and firms' profit maximization. In mathematics, this model is a system of nonlinear equations needed to be solved to get the equilibrium values of a set of endogenous variables. The land use pattern, traffic volume and congestion, modal split, and population/employment distribution also can be determined endogenously and simultaneously.

In addition, parameters were estimated to calibrate the benchmark model for Changzhou in 2008, based on the land use, PT survey, and economic data. Then, a numerical computation was conducted, the results of which indicate that employment and production activities tend to be located in the central zones, and households prefer walking and bicycle for short-distance trips while motor vehicles for long-distance trips. Although the model presented in this chapter integrated the general equilibrium model with the traffic assignment, economies of scale have not been considered so that the urban agglomeration effect cannot be simulated reasonably. In the next chapter, the CUE model incorporated with economies of scale will be proposed to depict how urban agglomeration occurs.

5 CUE model incorporated with economies of scale

5.1 General introduction

Undoubtedly, CUE model used to simulate the urban land use and transport interaction, which is consistent with the microeconomic theory, can be seen as a powerful analytical tool for urban planning and infrastructure policy evaluation. However, economies of scale, which are the primary cause of urban agglomeration namely population/employment concentration and clustered industries, have not been considered in the integrated land use and transport modeling. The existence of scale economies, in fact, has been proved in a variety of empirical studies (Quigley, 1998). Urban modeling and simulation without regard to economies of scale might draw an evaluation result quiet different from the reality where agglomeration effects exist.

In recent years, with the development of New Economic Geography that provides a practical methodology to model the mechanism of urban agglomeration (Dixit, et al., 1977; Fujita, 1988; Tabuchi, 1998; Glazer, et al., 2003), economies of scale have been gradually considered in the urban economic modeling and general equilibrium modeling. Hence, it is also conceivable to introduce economies of scale and agglomeration effects to the integrated land use and transport modeling. In this chapter, an integrated land use and transport model in the tradition of CUE model will be extended with economies of scale.

5.2 Model structure

5.2.1 Model settings

To explain the urban agglomeration, this model is incorporated with economies of scale by the approach according to New Economic Geography (Krugman, 1991). Specifically, the Dixit-Stiglitz type utility function with product variety, and the production behavior equipped with increasing return technology are adopted into the model structure. The key point here is the product differentiation and the approach is characterized by the integration of both supply and demand side approaches to agglomeration (Abdel-Rahman, 1988). For the demand side, product variety is presented as a key factor in consumer agglomeration, because households derive higher utility with the increasing supply of differentiated commodities or services because of their taste for product variety. The supply side is characterized by monopolistic competition and decreasing average cost at the firm level, indicating the internal increasing returns to scale.

In this model, the city encompasses *i* zones, and in each zone *i* there exsit l_i producers or firms which are monopolists in the production of a single variety. A homogenous land area A_i is given which is available for residences and production. Households who live in this city also need to decide the residential, working and shopping location and the amount of commodity consumption based on utility maximization. It indicates that there are no predetermined working and shopping center in the city but they are determined endogenously by the equilibrium of land, labor and commodity markets in each zone. Traffic assignment also can be carried out by using an User Equilibrium (UE) method based on an OD matrix and road network. Like chapter 4, travel mode choice concerns walk, bicycle, public transport and automobile.

5.2.2 Households' behavior

The utility of a household who resides in zone *i* and works in zone *j* also includes consumptions of commodities, residential land, and leisure time. Let α, β, γ be preference coefficients which are identical across households and have a sum total of one; the utility function of a household residing in zone *i* and working in zone *j*, U_{ij}, could be expressed in Cobb-Douglas utility function:

$$\underset{Z_{ij},q_{ij},L_{ij}}{MAX} \quad U_{ij} = \alpha \ln\left(\sum_{k=1}^{I}\sum_{\forall l_k} \iota_{ijk} {Z_{ijk}^{l_k}}^{\eta}\right)^{1/\eta} + \beta \ln q_{ij} + \gamma \ln L_{ij} + u_{ij} \tag{5.1}$$

subject to:

$$\sum_{k=1}^{I}\sum_{\forall l_k} Z_{ijk}^{l_k}\left(p_k^{l_k} + 2c_{ik}\right) + r_i q_{ij} + 2d\rho c_{ij} = w_j\left(H - TT_{ij} - L_{ij}\right) + D \tag{5.2}$$

In the equation (5.1), $Z_{ijk}^{l_k}$ is the number of the commodity l_k purchased in zone k by household residing in zone i and working in zone j, and it is also the shopping trips made by a household, employed at zone j, from the home zone i to shopping zone k to purchase commodity, because we assume that separate trips are made to each production zone k, purchasing a unit quantity of commodity per trip. There are l_k differentiated products in each zone k, thus specifying the CES function implies the love for variety. $1/(1-\eta)$ is the elasticity of substitution taking Dixit-Stiglitz form by assuming $0<\eta<1$. q_{ij} is the lot size of household at home zone i. L_{ij} is the leisure time of the household. The coefficient ι_{ijk} is for measuring the inherent shopping preference to zone k for a household residing in zone i and working in zone j. u_{ij} are idiosyncratic utility constants.

In the budget constraint equation (5.2), $p_k^{l_k}$ is the commodity price of product l_k at zone k. r_i is the rent for land at zone i, and w_j is the wage rate at zone j. c_{ik} is the money cost of one-way travel from zone i to zone k. d is number of work days in a period (year). ρ is the parameter given exogenously for adjusting the number of commuting trips per day. H is the time endowment available for work, leisure and travel per period. TT_{ij} is the total travel time per period including commuting and shopping, and let t_{ik} be the one-way travel time from zone i to zone k, it is calculated as

$$TT_{ij} = 2d\rho t_{ij} + \sum_{k=1}^{I}\sum_{\forall l_k} 2t_{ik} Z_{ijk}^{l_k} \tag{5.3}$$

It is also assumed that there do not exist specific land owners and traffic agencies, thus households are equal owners of all the land and transport revenue in the economy. Hence, non-wage income, D, can be expressed as:

$$D = \frac{1}{N}\left(\sum_{i=1}^{I} A_i r_i + 2d\sum_{i=1}^{I}\sum_{j=1}^{I} F_{ij} c_{ij}\right) \tag{5.4}$$

The budget constraint may be rearranged to express the expenditure of full economic income:

$$\sum_{k=1}^{I}\sum_{\forall l_k} Z_{ijk}^{l_k}\left(p_k^{l_k}+2c_{ik}+2w_j t_{ik}\right)+r_i q_{ij}+w_j L_{ij}=w_j H+D-2d\rho\left(c_{ij}+w_j t_{ij}\right) \qquad (5.5)$$

Hence, Marshallian demand can be calculated as:

$$Z_{ijk}^{l_k}=\frac{\iota_{ijk}^{\frac{1}{1-\eta}}\left(p_k^{l_k}+2c_{ik}+2w_j t_{ik}\right)^{\frac{1}{\eta-1}}}{\sum_{k=1}^{I}\sum_{\forall l_k}\iota_{ijk}^{\frac{1}{1-\eta}}\left(p_k^{l_k}+2c_{ik}+2w_j t_{ik}\right)^{\frac{\eta}{\eta-1}}}\alpha\left[w_j H+D-2d\rho\left(c_{ij}+w_j t_{ij}\right)\right] \qquad (5.6)$$

$$q_{ij}=\beta\frac{w_j H+D-2d\rho\left(c_{ij}+w_j t_{ij}\right)}{r_i} \qquad (5.7)$$

$$L_{ij}=\gamma\frac{w_j H+D-2d\rho\left(c_{ij}+w_j t_{ij}\right)}{w_j} \qquad (5.8)$$

Then indirect utility function is related to the number of product varieties:

$$^{*}U_{ij}=V_{ij}+u_{ij}=\ln\left[w_j H+D-2d\rho\left(c_{ij}+w_j t_{ij}\right)\right]-\frac{\alpha(\eta-1)}{\eta}\ln\left(\sum_{k=1}^{I}\sum_{\forall l_k}\iota_{ijk}^{\frac{1}{1-\eta}}\left(p_k^{l_k}+2c_{ik}+2w_j t_{ik}\right)^{\frac{\eta}{\eta-1}}\right)$$

$$-\beta\ln r_i-\gamma\ln w_j+u_{ij} \qquad (5.9)$$

Therefore location choices of "residence-job pair (*i*,*j*)" also can be described by choice probability in the form of a discrete choice model like chapter 4:

$$\Psi_{ij}=\frac{e^{\lambda V_{ij}}}{\sum_{s=1}^{I}\sum_{m=1}^{I}e^{\lambda V_{sm}}};\quad \sum_{i}^{I}\sum_{j}^{I}\Psi_{ij}=1 \qquad (5.10)$$

Where Ψ_{ij} is the joint probability that the household chooses a home at zone *i* and a job at zone *j*.

5.2.3 Firms' behavior

There are l_i retail producers of varieties in zone *i*, and each of them is a monopolist in the production of a single variety. In the monopolistically competitive market, the production of an individual differentiated good l_i in zone *i* involves labor and land two inputs, and a fixed cost assumed as a part of land for production, which represents increasing returns to scale in production. Let $X_i^{l_i}$ be the aggregate output of variety l_i produced in zone *i*; B be the scale parameter; $M_i^{l_i}$ and $Q_i^{l_i}$ be the aggregate labor and land inputs utilized in the zone *i* for producer l_i; FIX_i be the fixed cost in zone *i*. The production function is:

$$X_i^{l_i} = BM_i^{l_i\,\delta} Q_i^{l_i\,\mu}; \qquad \delta + \mu = 1 \tag{5.11}$$

And the cost function is:

$$COST_i^{l_i} = M_i^{l_i} w_i + Q_i^{l_i} r_i + FIX_i r_i \tag{5.12}$$

The explicit solutions of factor input function can be derived by cost-minimization problem. The cost-minimization problem is the same regardless of whether the market is competitive, the firm is a monopolist or if there is some intermediate situation with imperfect competition. The cost-minimization problem is to find the cheapest way to produce a given level of output for a firm that takes factor prices as given. The cost-minimization problem of the firm l_i is

$$\underset{M_i^{l_i}, Q_i^{l_i}}{MIN} \quad COST_i^{l_i} = M_i^{l_i} w_i + Q_i^{l_i} r_i + FIX_i r_i \tag{5.13}$$

$$s.t. \quad X_i^{l_i} = BM_i^{l_i\,\delta} Q_i^{l_i\,\mu} \tag{5.14}$$

The Lagrangian problem is set as:

$$L = M_i^{l_i} w_i + Q_i^{l_i} r_i + FIX_i r_i - \lambda\left(BM_i^{l_i\,\delta} Q_i^{l_i\,\mu} - X_i^{l_i}\right) \tag{5.15}$$

and then differentiate with respect to $M_i^{l_i}$, $Q_i^{l_i}$ and λ. This gives us the three first-order conditions:

$$w_i - \lambda\delta BM_i^{l_i\,\delta-1} Q_i^{l_i\,\mu} = 0 \tag{5.16}$$

$$r_i - \lambda\mu BM_i^{l_i\,\delta} Q_i^{l_i\,\mu-1} = 0 \tag{5.17}$$

$$BM_i^{l_i\,\delta} Q_i^{l_i\,\mu} - X_i^{l_i} = 0 \tag{5.18}$$

We can arrange the first two equations (5.16), (5.17), and divided the first equation (5.16) by the second equation (5.17) to get

$$\frac{w_i}{r_i} = \frac{\lambda\delta BM_i^{l_i\,\delta-1} Q_i^{l_i\,\mu}}{\lambda\delta BM_i^{l_i\,\delta} Q_i^{l_i\,\mu\text{-}1}} = \frac{\delta Q_i}{\mu M_i} \tag{5.19}$$

Note that the technical rate of substitution must equal the factor price ratio.

Multiply the equation (5.16) by $M_i^{l_i}$ and equation (5.17) by $Q_i^{l_i}$ to get

$$w_i M_i^{l_i} = \lambda\delta BM_i^{l_i\,\delta} Q_i^{l_i\,\mu} = \lambda\delta X_i^{l_i} \tag{5.20}$$

$$r_i Q_i^{l_i} = \lambda\mu BM_i^{l_i\,\delta} Q_i^{l_i\,\mu-1} = \lambda\mu X_i^{l_i} \tag{5.21}$$

so that

$$M_i^{l_i} = \frac{\lambda\delta X_i^{l_i}}{w_i} \tag{5.22}$$

$$Q_i^{l_i} = \frac{\lambda \mu X_i^{l_i}}{r_i} \tag{5.23}$$

Now the equation (5.18) can be used to solve λ. Substituting the solutions for $M_i^{l_i}$ and $Q_i^{l_i}$ in equation (5.22) and (5.23) into the third first order equation (5.18):

$$B\left(\frac{\lambda \delta X_i^{l_i}}{w_i}\right)^{\delta}\left(\frac{\lambda \mu X_i^{l_i}}{r_i}\right)^{\mu} = X_i^{l_i} \tag{5.24}$$

We can solve this equation for λ:

$$\lambda = \frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}} \tag{5.25}$$

Along with equations (5.22) and (5.23), final solutions for $M_i^{l_i}$ and $Q_I^{l_i}$ can be derived. These factor demand functions will take the form

$$M_i^{l_i} = \delta \frac{X_i^{l_i}}{w_i}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) \tag{5.26}$$

$$Q_i^{l_i} = \mu \frac{X_i^{l_i}}{r_i}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) \tag{5.27}$$

The profit function for monopolist l_i in zone i is:

$$\pi_i^{l_i} = p_i^{l_i} X_i^{l_i} - COST_i^{l_i} \tag{5.28}$$

$$\Leftrightarrow \pi_i^{l_i} = p_i^{l_i} X_i^{l_i} - M_i^{l_i} w_i - Q_i^{l_i} r_i - FIX_i r_i \tag{5.29}$$

The price, $p_i^{l_i}$, should be derived by profit maximization subject to consumers' demand, because in monopolistic competitive market, each firm will set up the price taking into account consumers' demand. As discussed in the consumers' behavior, the demand for commodity l_i in zone i equals to the sum of the consumption from consumers living in all zones in the city:

$$X_i^{l_i} = \alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns} \tag{5.30}$$

Where N is the exogenous number of consumers, I_{ns} is the income of a consumer residing in zone n and working in zone s; α is the expenditure share of commodities; Ψ_{ns} is the location choice probability of "residence-job pair (n,s)"; P is the price index; σ is the elasticity of substitution. The interzonal transport cost for shopping takes the iceberg form: specifically, a consumer residing in zone n has to pay $\tau_{ni}p_i^{l_i}$ (τ_{ni}>1) for purchasing a good l_i in zone i.

Thus, the profit-maximization problem is

$$\underset{p_i^{l_i},M_i^{l_i},Q_i^{l_i}}{MAX} \quad \pi_i^{l_i} = p_i^{l_i} X_i^{l_i} - COST_i^{l_i} = p_i^{l_i} X_i^{l_i} - M_i^{l_i} w_i - Q_i^{l_i} r_i - FIX_i r_i \tag{5.31}$$

$$s.t \quad X_i^{l_i} = \alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns} \tag{5.32}$$

$$\Leftrightarrow \underset{p_i^{l_i},M_i^{l_i},Q_i^{l_i}}{MAX} \quad \pi_i^{l_i} = p_i^{l_i} X_i^{l_i} - X_i^{l_i}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) - FIX_i r_i \tag{5.33}$$

$$\Leftrightarrow \underset{p_i^{l_i},M_i^{l_i},Q_i^{l_i}}{MAX} \quad \pi_i^{l_i} = p_i^{l_i}\left(\alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns}\right) - \left(\alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns}\right)\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) - FIX_i r_i \tag{5.34}$$

We differentiate with respect to p to get the three first-order condition:

$$\frac{\partial \pi_i^{l_i}}{\partial p_i^{l_i}} = (1-\sigma)\left(\alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns}\right) + \sigma\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)\left(\alpha N \sum_{n=1}^{I}\sum_{s=1}^{I} \Psi_{ns} \frac{\tau_{ni} p_i^{l_i\,-\sigma}}{P^{1-\sigma}} I_{ns}\right)\frac{1}{p_i^{l_i}} = 0 \tag{5.35}$$

$$\Leftrightarrow (1-\sigma)+\sigma\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)\frac{1}{p_i^{l_i}}=0 \tag{5.36}$$

$$p_i^{l_i} = \frac{\sigma}{\sigma-1}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) \tag{5.37}$$

Equation (5.37) reveals that each monopolist l_i in zone i charges the same price: $p_i^{l_i}=p_i$ for all l_i. The markup is lower the higher the elasticity of substitution σ.

The profit function (5.28) can be rewritten by using the price policy (5.37):

$$\pi_i^{l_i} = \frac{\sigma}{\sigma-1}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)X_i^{l_i} - X_i^{l_i}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) - FIX_i r_i \tag{5.38}$$

Due to the free entry (FE), each firm will then make zero pure profits:

$$\pi_i^{l_i} = 0 \tag{5.39}$$

$$\Leftrightarrow \frac{\sigma}{\sigma-1}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)X_i^{l_i} - X_i^{l_i}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) - FIX_i r_i = 0 \tag{5.40}$$

$$\Leftrightarrow \frac{1}{\sigma-1}\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)X_i^{l_i} = FIX_i r_i \tag{5.41}$$

$$\Leftrightarrow X_i^{l_i} = \frac{FIX_i r_i(\sigma-1)}{\left(\frac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right)} \tag{5.42}$$

Equation (5.42) also shows that output is the same for all firms. Then, input demand $M_i^{l_i}$ and $Q_i^{l_i}$ can be rewritten by using the solution of equilibrium $X_i^{l_i}$ (5.42):

$$M_i^{l_i} = \delta\frac{FIX_i r_i(\sigma-1)}{w_i} \tag{5.43}$$

$$Q_i^{l_i} = \mu\frac{FIX_i r_i(\sigma-1)}{r_i} \tag{5.44}$$

In summary, $M_i^{l_i}$, $Q_i^{l_i}$, and $p_i^{l_i}$ can be formulated as:

$$\begin{cases} M_i^{l_i} = \delta \dfrac{FIX_i r_i(\sigma - 1)}{w_i} \\ Q_i^{l_i} = \mu \dfrac{FIX_i r_i(\sigma - 1)}{r_i} \\ p_i^{l_i} = \dfrac{\sigma}{\sigma - 1}\left(\dfrac{w_i^{\delta} r_i^{\mu}}{B\delta^{\delta}\mu^{\mu}}\right) \end{cases} \tag{5.45}$$

5.2.4 Transport behavior

There are still two kinds of daily traffic flows originating at a zone i and terminating at the same or another zone j. Let ${}^{c}F_{ij}$ be the expected commutes from zone i to zone j per day, and ${}^{s}F_{ij}$ be the expected shopping trips from zone i to zone j per day. Total trips from zone i to zone j per day are then F_{ij} as follows. Modal split and traffic assignment can be computed as same as chapter 4.

$${}^{c}F_{ij} = \rho N \Psi_{ij} \tag{5.46}$$

$${}^{s}F_{ij} = \frac{N\sum_{s=1}^{I}\sum_{\forall l_j}\Psi_{is} Z_{isj}^{l_j}}{d} \tag{5.47}$$

$$F_{ij} = {}^{c}F_{ij} + {}^{s}F_{ij} \tag{5.48}$$

5.2.5 General equilibrium

To close the model, the land equilibrium conditions need to be modified to make sure that land supplies equal to the sum of demands of residential land q_i, land for production Q_i, and fixed cost FIX_i in each zone. The land, labor and commodity markets in each zone i clear by:

$$N\sum_{j=1}^{I}\Psi_{ij}q_{ij}+\sum_{\forall l_i}Q_i^{l_i}+\sum_{\forall l_i}FIX_i = A_i \tag{5.49}$$

$$N\sum_{s=1}^{I}\Psi_{si}\left(H-TT_{si}-L_{si}\right)=\sum_{\forall l_i}M_i^{l_i} \tag{5.50}$$

$$N\sum_{n=1}^{I}\sum_{s=1}^{I}\sum_{\forall l_i}\Psi_{ns}Z_{nsi}^{l_i}=\sum_{\forall l_i}X_i^{l_i} \tag{5.51}$$

5.2.6 Simplification of formula

According to behavior of production side, it can be clarified that price and output are the same for all producers in each zone i, thus l_k for all p, X and other related variables can be omitted. Commodity consumption for each product variety l_k, $Z_{ijk}^{l_k}$, is also same for all varieties in zone k, so it can be denoted as Z_{ijk}^{*}. Let n_i be the number of product varieties or firms in zone i, which can be decided by the market equilibria as well, and then equations for numerical computation are simplified as follows. Clearly, equation (5.54) implies that the higher the number of varieties n_i, the higher the level of utility U_{ij} that reflects love for variety.

$$Z_{ijk}^{*}=\frac{\iota_{ijk}^{\frac{1}{1-\eta}}\left(p_k+2c_{ik}+2w_jt_{ik}\right)^{\frac{1}{\eta\text{-}1}}}{\sum_{k=1}^{I}\iota_{ijk}^{\frac{1}{1-\eta}}n_k\left(p_k+2c_{ik}+2w_jt_{ik}\right)^{\frac{\eta}{\eta\text{-}1}}}\alpha\left[w_jH+D-2d\rho\left(c_{ij}+w_jt_{ij}\right)\right] \tag{5.52}$$

$$TT_{ij}=2d\rho t_{ij}+\sum_{k=1}^{I}2t_{ik}n_kZ_{ijk}^{*} \tag{5.53}$$

$$^{*}U_{ij}=V_{ij}+u_{ij}=\ln\left[w_jH+D-2d\rho\left(c_{ij}+w_jt_{ij}\right)\right]-\frac{\alpha(\eta\text{-}1)}{\eta}\ln\left(\sum_{k=1}^{I}\iota_{ijk}^{\frac{1}{1-\eta}}n_k\left(p_k+2c_{ik}+2w_jt_{ik}\right)^{\frac{\eta}{\eta\text{-}1}}\right)$$

$$-\beta\ln r_i-\gamma\ln w_j+u_{ij} \tag{5.54}$$

$$M_i = \delta \frac{FIX_i r_i (\sigma - 1)}{w_i} \tag{5.55}$$

$$Q_i = \mu \frac{FIX_i r_i (\sigma - 1)}{r_i} \tag{5.56}$$

$$p_i = \frac{\sigma}{\sigma - 1} \left(\frac{w_i^\delta r_i^\mu}{B \delta^\delta \mu^\mu} \right) \tag{5.57}$$

$$X_i = \frac{FIX_i r_i (\sigma - 1)}{\left(\frac{w_i^\delta r_i^\mu}{B \delta^\delta \mu^\mu} \right)} \tag{5.58}$$

$$F_{ij} = \rho N \Psi_{ij} + \frac{N \sum_{s=1}^{I} \Psi_{is} n_j Z_{isj}^*}{d} \tag{5.59}$$

$$N \sum_{j=1}^{I} \Psi_{ij} q_{ij} + n_i Q_i + n_i FIX_i = A_i \tag{5.60}$$

$$N \sum_{s=1}^{I} \Psi_{si} \left(H - TT_{si} - L_{si} \right) = n_i M_i \tag{5.61}$$

$$N \sum_{n=1}^{I} \sum_{s=1}^{I} \Psi_{ns} n_i Z_{nsi}^* = n_i X_i \tag{5.62}$$

5.3 Numerical computation and comparative analysis

Parameters are set as same as those in Chapter 4, including households' behavior, firms' production behavior, transport behavior, and numeraire. Fixed cost, FIX_i, which is assumed as a fixed part of land in zone i, equals to 10% of production land for each firm in zone i. Table 5.1 shows the fixed cost in each zone estimated by the practical data including land area for production and the number of firms in

Changzhou. By running the programming, simulation results of this model extended with economies of scale can be compared to them without urban agglomeration computed in chapter 4.

Figure 5.1 and 5.2 displays the number of product variety, n_i, and the product variety density in each zone. Clearly, both of them are higher in central zones than in suburban and peripheral zones, leading to urban agglomerations in the city center. The agglomeration effects can be detected by the comparative analysis between the simulation results calculated from the model with and without economies of scale. As shown in Figure 5.3 and 5.4, land rents and product density in central zones calculated by model incorporated with economies of scale are higher than those without economies of scale, while they are lower in suburban and peripheral zones with economies of scale. Population and employment densities, traffic generation and attraction contribution rates exhibit same characteristics that more significant concentrations of population and employment, and travel behaviors occur in city center (Figure 5.5, 5.6, 5.7, 5.8).

Besides, model with economies of scale generates shorter travel distance (20,960,871 km per day) than that without economies of scale (23,557,465 km per day). The reason might be the more household tend to reside, work and shop in central zones for the higher number of product varieties, implying that economies of scale and urban agglomeration effect can reduce travel distances.

In a word, the extended model with economies of scale can reflect the mechanism of urban agglomeration. These output variables also can be used to represent the equilibrium state of urban land use-transport interactive system what we call “Benchmark case” in consideration of economies of scale. Then, policy assessment becomes feasible by comparing the output variables of “Benchmark case” with those simulated under any exogenous policy scenario settings. The key point here is that the distorted results simulated by conventional model without economies of scale can be overcome because it is able to consider urban agglomeration effects into the urban policy evaluation by using the extended CUE model incorporated with economies of scale.

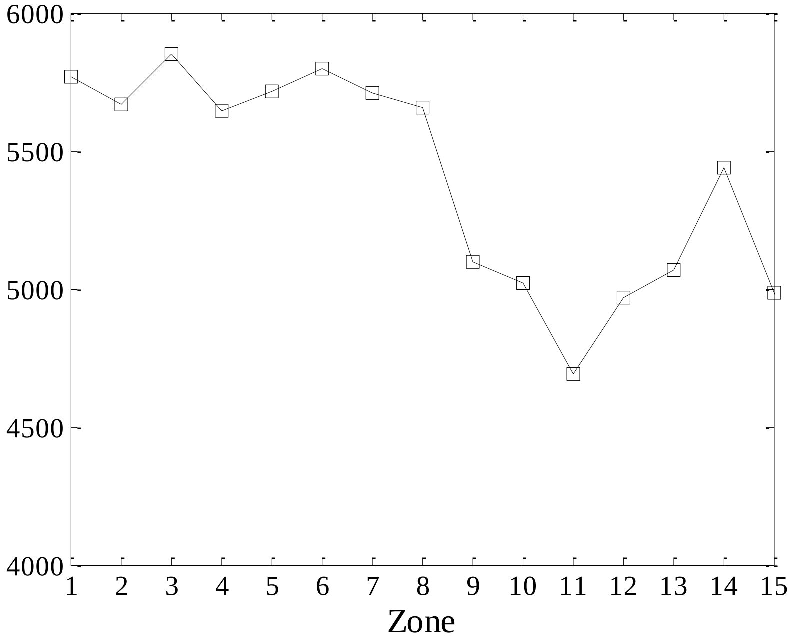


Figure 5.1: Product variety

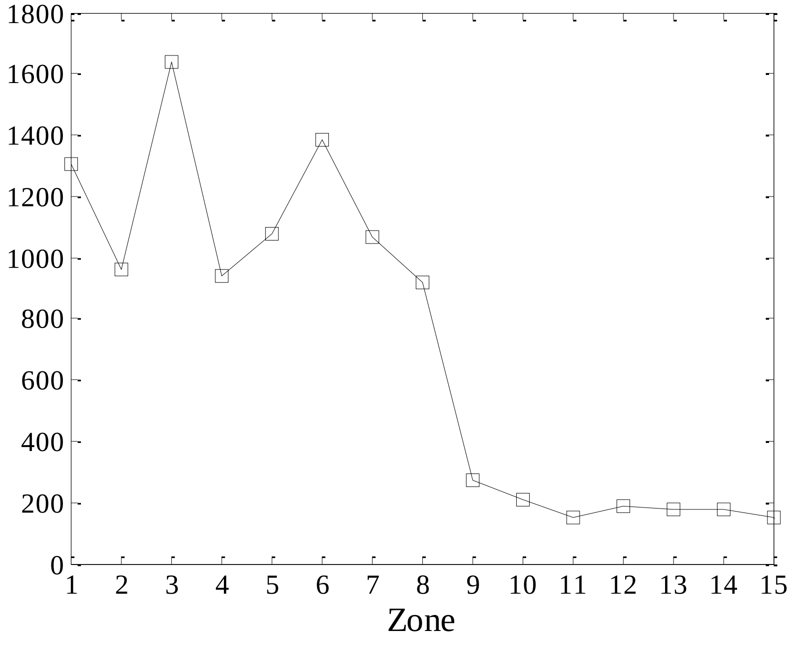


Figure 5.2: Product variety density

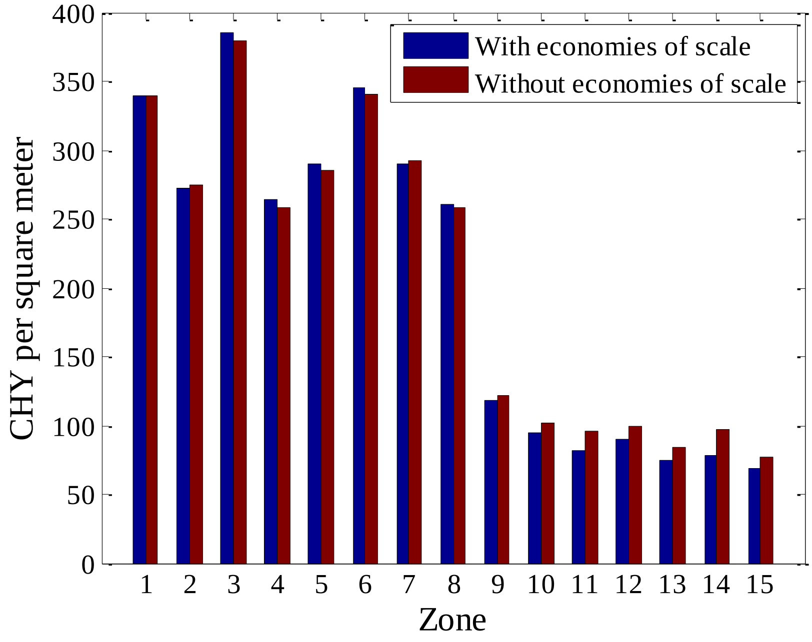


Figure 5.3: Rent

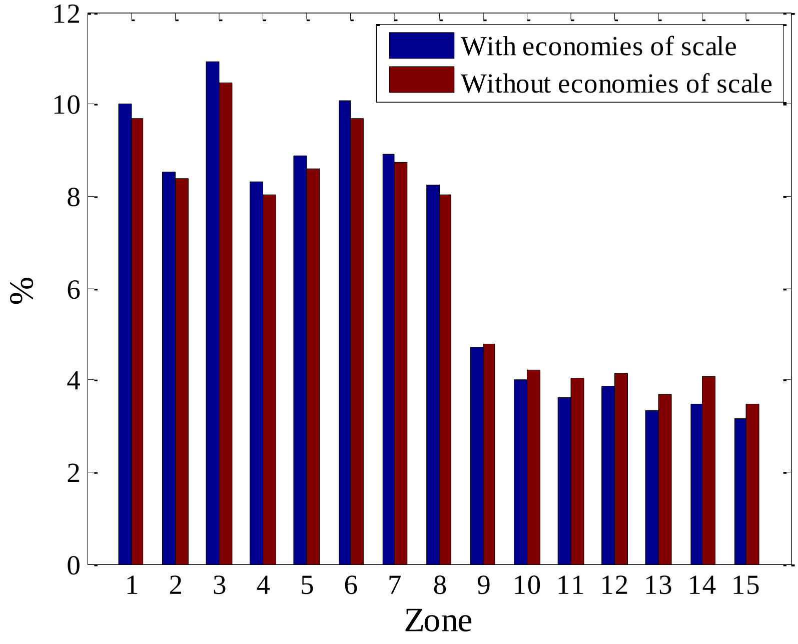


Figure 5.4: Contribution rate of production density

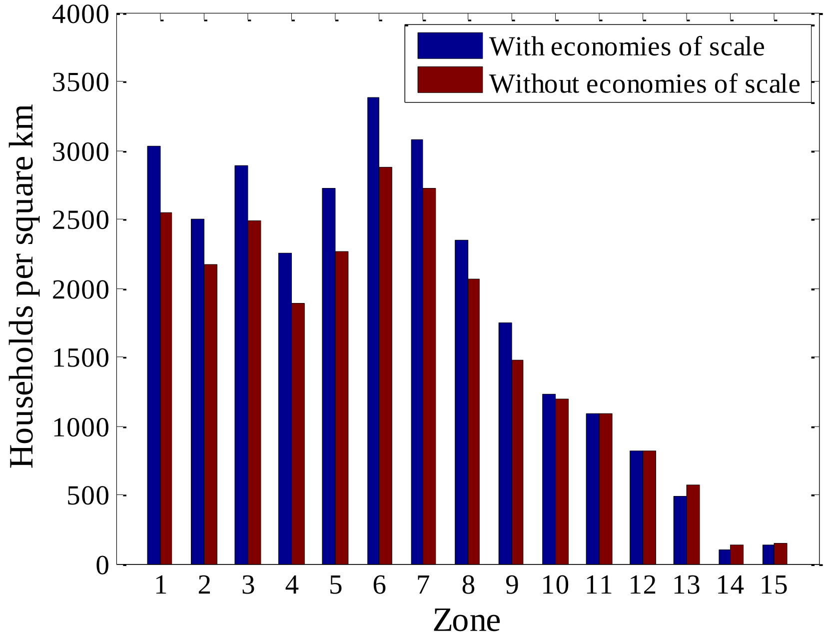


Figure 5.5: Population density

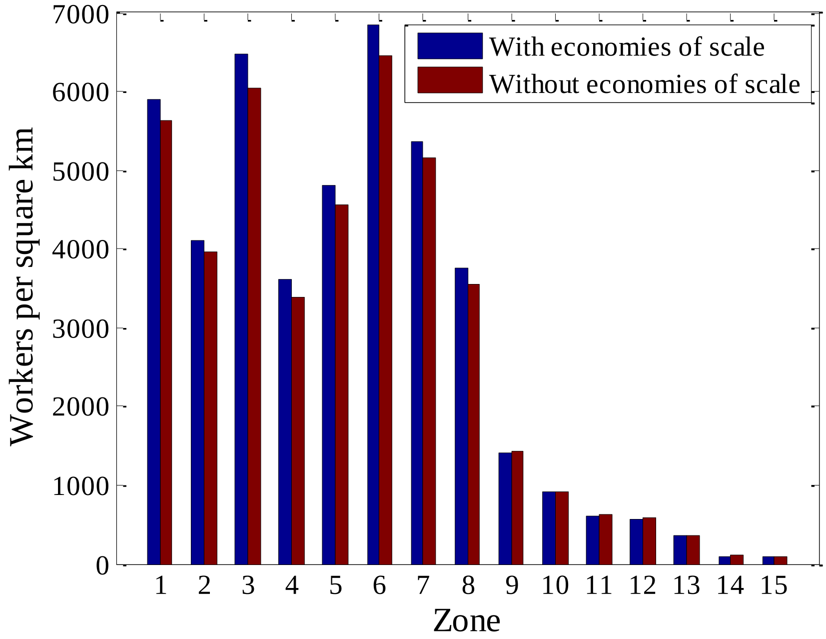


Figure 5.6: Employment density

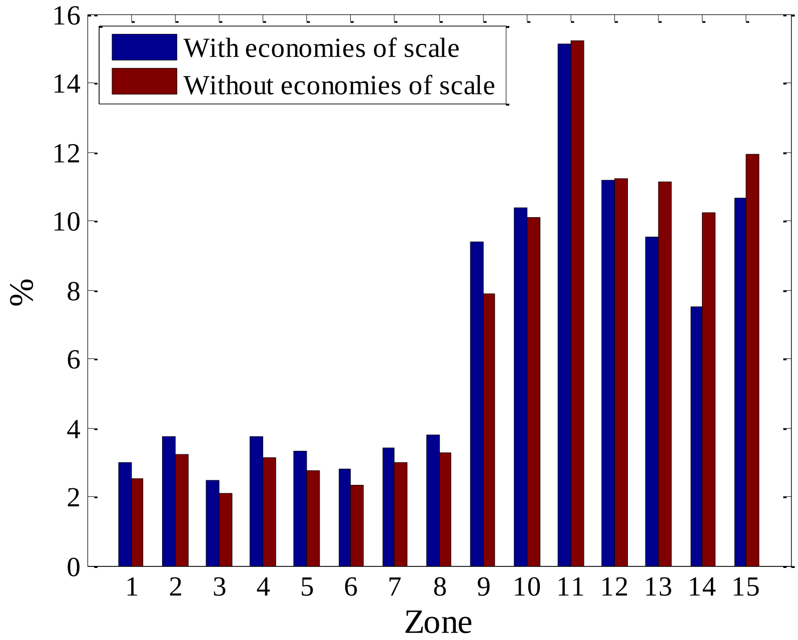


Figure 5.7: Contribution rate of traffic generation

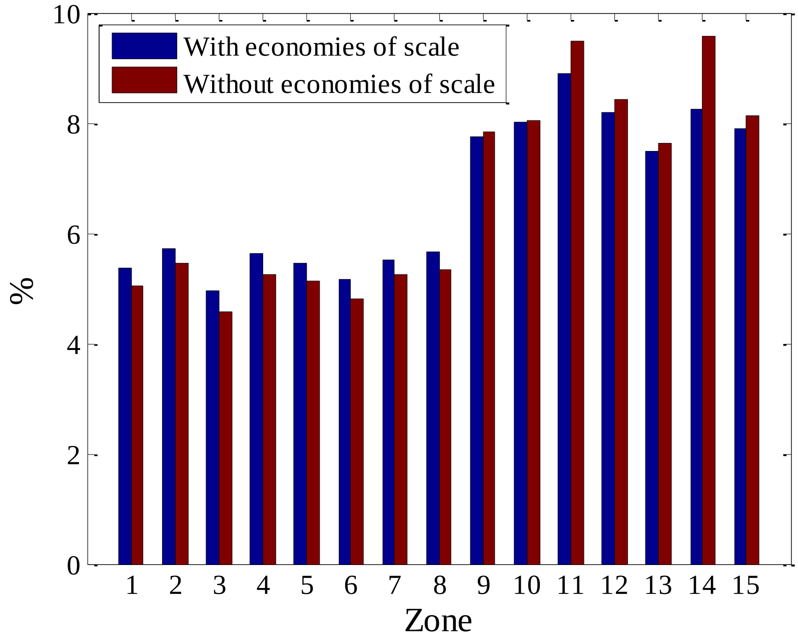


Figure 5.8: Contribution rate of traffic attraction

Table 5.1: Fixed cost setting

Zone	1	2	3	4	5
Fixed cost (m^2)	501.83	682.92	400.04	696.40	608.52
Zone	6	7	8	9	10
Fixed cost (m^2)	474.48	616.05	714.09	2,413.33	3,156.15
Zone	11	12	13	14	15
Fixed cost (m^2)	4,370.16	3,447.24	3,750.29	3,728.53	4,292.28

5.4 Summary

This chapter demonstrated the model extension based on the standard model structure presented in chapter 4, in order to introduce the economies of scale into the land use and transport interactive modeling. It is assumed that not only locations are differentiated, but also commodities produced in same zone are differentiated by each other. That is to say, each firm produces a product variant in a monopolistic competition market, and the number of firms is explicit and determined endogenously. Through this assumption, thus, the internal increasing returns of scale and fixed cost were introduced in firm behavior to extend the model with economies of scale.

Then, a numerical computation has been also implemented to verify whether the extended model can simulate the urban agglomeration effects commendably. By comparing the simulation outputs, it is clear that the model incorporated with economies of scale can represent the urban agglomeration effect, indicating that more households tend to reside, work and also shop in the central zones rather than suburban or peripheral zones, due to the love for varieties.

6 Land use policy evaluation with CUE model

6.1 General introduction

Conventional spatial planning and land use strategies in China overlook the interaction between land use and transport, leading to the one-sided policymaking which cannot reflect the interactive systematicness of a city. Therefore, it is necessary to evaluate the impact on travel behavior, population and employment distribution of land use policies, by employing the CUE model. On the other hand, existing models are rarely applied to environmental impact assessment, which is becoming increasingly important in the field of urban studies, especially in developing countries such as China. Of particular interest is also the ability to accommodate the environment evaluation to the CUE model for optimum land use planning.

With regard to the environmental problem, an upward trend in carbon emission is drawing worldwide attention from not only scientists, but also from statesman and the public, and is becoming an important environmental concern as well (Houghton, et al., 1999; Caspersen, et al., 2000). From the viewpoint of the carbon source, a city is the place where populations, architecture, transport, and industries cluster together, as well as the concentration of high-energy expenditure and environment emissions. In the progress of urban social economic growth and land expansion in China, carbon emissions, urban land use and transport are involved in a complex process in which these different elements interact with each other. Therefore, it is meaningful to investigate the impact on carbon emissions of land use policies to propose a sustainable spatial planning strategy for carbon reduction. This is to fight against global climate change; that is to say, it is meaningful to test how land use planning and policies would modify carbon emissions, and to provide a computable assessment tool for carbon reduction policy from the perspective of spatial planning.

In addition, it is practicable to compare the different simulation results of model incorporated with economies of scale to those without urban agglomeration effects. Land use pattern, population and employment distribution and even environment impact are associated with the agglomeration mechanism. Thus, in this chapter, besides land use scenarios will be set to simulate how different land use layout will modify the travel behaviors and carbon emissions, urban agglomeration effects will also be underlined to identify their effects on travel behaviors and carbon emissions.

6.2 Land use planning in Changzhou

Along with the population explosion and economic development, extensive utilization of land resources is leading to massive farmland conversion and urban sprawl, which creates serious resource deterioration and eco-environmental problems. According to Changzhou General Land Use Planning (2006-2020) (CBLR, 2011), three land use strategies are presented for keeping a balance between economic development, urban construction, natural resource conservation and environmental protection: (1) Urban Growth Boundary (UGB) management. Built-up area expansion boundary should be controlled to restrict the urban sprawl and farmland conversion in suburbs. (2) Compact and mixed-use urban form. Industrial land should be distributed in clustered mode for concentrated and intensive scale management. High-rise housing, second utilization and exploitation of idle land, and three-dimensional land use development in built-up area are encouraged. (3) Sustainable and optimum land use layout. Land use zoning will be conducted according to regional natural and socioeconomic conditions. The key point is to deal with the relation between land resource conservation and utilization, especially farmland and ecological land preservation in suburbs.

In consideration of current land use pattern, development strategies in the future, ecological conservation, and coordination with other related spatial planning, the guideline for land use layout is to promote land use efficiency in central zones, improve the new town in the southern and northern Changzhou, and protect the rural landscape in eastern and western Changzhou. (1) Central zone. Urban central zone will turn into modern CBD and new administration center. Urban landscape belt will be constructed along with the Grand Canal. In this region, it is needful to focus on the conservation of historic sites, protection of local landscape, and commercial development. (2) New town layout. North new town highlights the industrial development and the role of transportation junction due to the Changzhou high-speed rail station located in the north. South new town will be built as a sub CBD where the functions of residence, business, recreation and technical research and development are underlined. (3) Rural area. Construction of industrial zones is the focus in eastern rural area, especially the manufacturing base for cars which is the characteristic industry in Changzhou. Transport infrastructure will be emphasized in western rural area to develop a logistics center and agricultural products base there.

6.3 Scenario settings

In this context, taking land use control and layout as an important measure for compact city development and urban land expansion, two different spatial planning scenarios are set up to evaluate environmental emissions generated by exogenous policy shock based on benchmark simulation in 2008. It is supposed that change in land use pattern would affect travel pattern and resulting carbon emissions. According to Changzhou General Land Use Planning, available land area will increase by 46.63 km^2 for residential and industrial use in ten years from 2010 to 2020 (CBLR, 2011). Here we take an interest in how the spatial allocation of increasing available land area would affect carbon emissions, and which scenario is the most appropriate for carbon reduction, in order to provide an assessment tool that can be used to detect the interaction between land use allocation and environment impacts for low-carbon city planning.

Two scenarios I and II are set to reflect compact city scenario and urban sprawl scenario respectively, with same increasing available land area. For scenario I, available land area will increase in eight central zones (1 - 8) by 46.63 km^2 in total to improve land use density, exploit resource potentialities in the urban central zone, and for ecological and agricultural land protection. For scenario II, available land area will increase in the peripheral zone (15) also by 46.63 km^2 for accelerating urbanization and non-agriculturization in the suburbs, and for underlining the guarantee of land resources for economic growth.

6.4 Carbon emission evaluation method

As this is a central issue of concern to urban planners and environmental policymakers, there has been considerable research into carbon emission evaluation and carbon reduction. The input-output model and computable general equilibrium model could be integrated to evaluate the carbon emissions induced by production (Kainuma, et al., 2000; Druckman, et al., 2009; Tscharaktschiew, et al., 2010; Zhang, 2013). Consumer Lifecycle Approach (CLA) provides a carbon emission evaluating methodology from the viewpoint of consumers and households (Weber, et al., 2000; Bin, et al., 2005). However, conventional carbon evaluation systems often resort to carbon list, index system, and econometric or statistical methods, but lack the consideration of microscopic behavior, and interaction among urban spatial elements such as location choice, land use pattern and transport. Thus, low-carbon urban planning and infrastructure policies usually become ineffective due to the fact that existing carbon evaluation methods and carbon reduction policies cannot explain the interactive mechanism between individual behaviors and urban environment.

Therefore, we need to employ a carbon evaluation method which can be introduced into the land use-transport interactive model to calculate the carbon emitted by land use scenarios. Carbon emitted in transport sector interacts closely with urban form and land use patterns, so it is assumed that transport section is the only carbon source, namely, carbon emissions produced by daily life and industrial manufacture are excluded. A few of studies on carbon evaluation consider carbon emissions as a linear function of traffic volume and travel distance (IPCC, 2006; Grazi, et al., 2008), but neglect the endogenous traffic congestion which actually plays an important role in carbon emissions. Since longer congested time generates more carbon emissions in same travel distance, it is assumed that each commuting and shopping trip induces carbon emissions, CE, which is mainly endogenously determined by traffic volume F and congested travel time t rather than travel distance.

$$CE = f(F, t) \tag{6.1}$$

We use a gasoline consumption function developed by German Road and Transportation Research Association (FGSV, 2002) to evaluate carbon emissions.

$$^{tm}GC_{ij} = {}^{tm}e\left[e_1 + e_2\left(\frac{1}{t_{ij}}\right)^2 + e_3 t_{ij}\right] \tag{6.2}$$

Where $^{tm}GC_{ij}$ is the individual gaslion consumption from zone i to zone j with travel mode tm; ^{tm}e is an exogenously given efficiency parameter used to obtain the gaslion consumption induced by different travel modes. It is assumed that gaslion only consumed by public transport and automobile, thus ^{walk}e and $^{bicycle}e$ equal to zero. And $^{public}e$ is fixed to 0.09, while ^{auto}e, 0.65 estimated based on the actual gaslion consumption data in China. e_1=17.7766, e_2=0.0023606, e_3=1461.87 are positive and exogenously given constant parameters. Then carbon emissions from zone i to zone j with travel mode tm, $^{tm}CE_{ij}$, are then given by the function:

$$^{tm}CE_{ij} = \frac{ef}{740}\,{}^{tm}GC_{ij} \tag{6.3}$$

Where 1/740 is the inverse of the assumed gasoline density in grams per liter used to convert gasoline consumption in gram into liter; ef=2925 gCO_2/liter is used to convert gasoline consumption in liters into carbon emissions in grams (Tscharaktschiew, et al., 2010). Therefore total carbon emissions produced by transport sector, TCE, are:

$$TCE = 2\sum_{\forall tm}\sum_{i=1}^{I}\sum_{j=1}^{I} {}^{tm}CE_{ij} F_{ij} {}^{tm}\pi_{ij} \tag{6.4}$$

6.5 Numerical simulation

6.5.1 Simulation results without economies of scale

We now turn to the simulation results of land use planning and policies for carbon reduction. As exhibited from Figure 6.1 to Figure 6.6, Population/employment distribution, and traffic behaviors changed due to land use scenarios. Population and employment densities increased in central zones in scenario I, but decreased in Scenario II. Also, traffic generation and attraction increased in central zones in scenario I, but rose up in the suburban and peripheral zones in scenario II (Figure 6.3

and 6.4). Simulation results imply that more households chose the central zones as the residential and working places in scenario I for more available land, while households decided to reside in peripheral zone as result of the increasing land supply there in scenario II. Figure 6.5 shows that short-distance trips (<5km) in scenario I increased, while scenario II produced more long-distance trips. As mentioned in Figure 4.6 of chapter 4, households preferred walking and bicycle for short-distance trip, leading to higher choice probability of walking and bicycle in scenario I due to increasing short-distance trips. On the contrary, scenario II gave rise to high usage rates of motor vehicles including automobile and public transport owing to increasing long-distance trips (Figure 6.6).

Table 6.1 compares the total travel distances and carbon emissions of benchmark and two land use scenarios. Total carbon emissions per year in benchmark case are 1,361.11 kilotons, and public transport and automobile produce 74.64 and 1,286.48 kilotons of carbon emissions, respectively. Obviously, automobile is a major carbon source compared to public transport. Travel distances in scenario II are more than those in scenario I as well as carbon emitted in the transport sector.

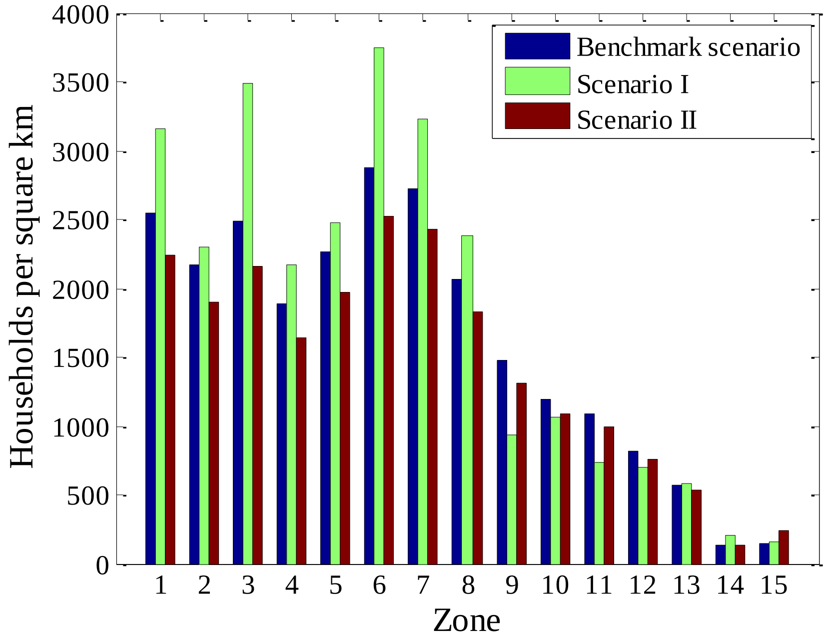


Figure 6.1: Population density computed by model without economies of scale

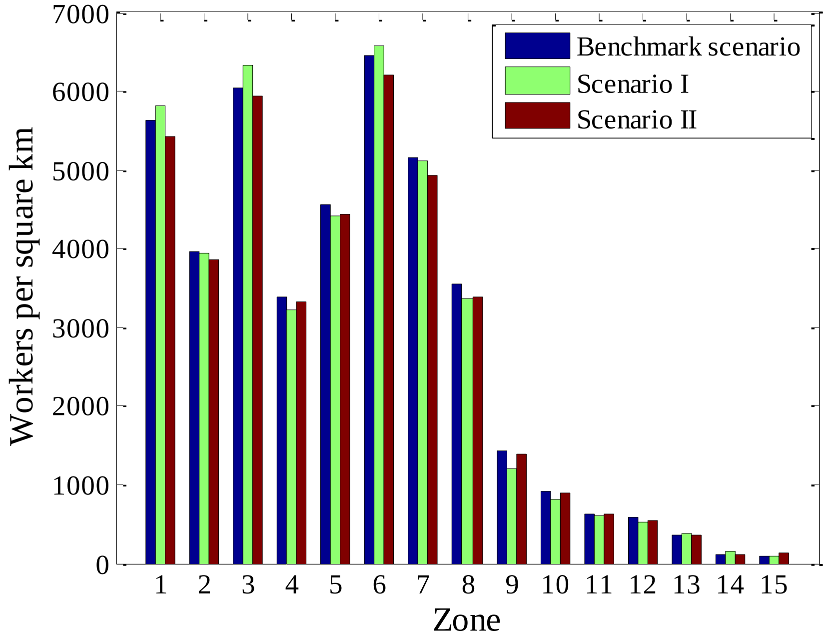


Figure 6.2: Employment density computed by model without economies of scale

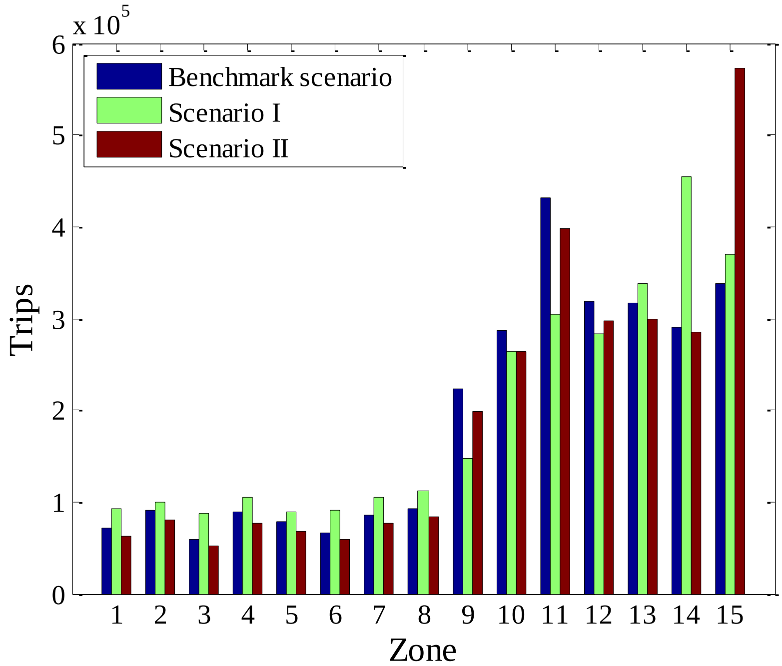


Figure 6.3: Traffic generation computed by model without economies of scale

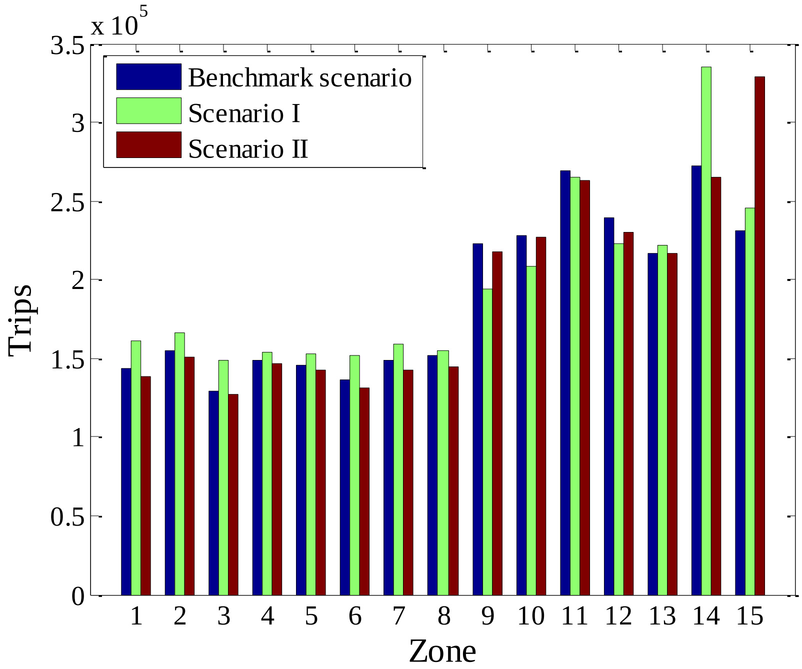


Figure 6.4: Traffic attraction computed by model without economies of scale

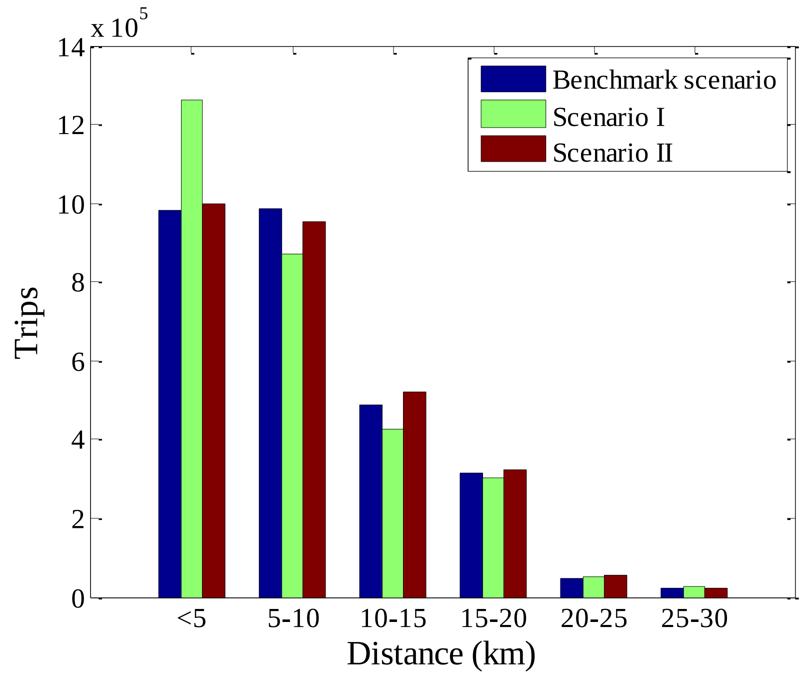


Figure 6.5: Travel distance computed by model without economies of scale

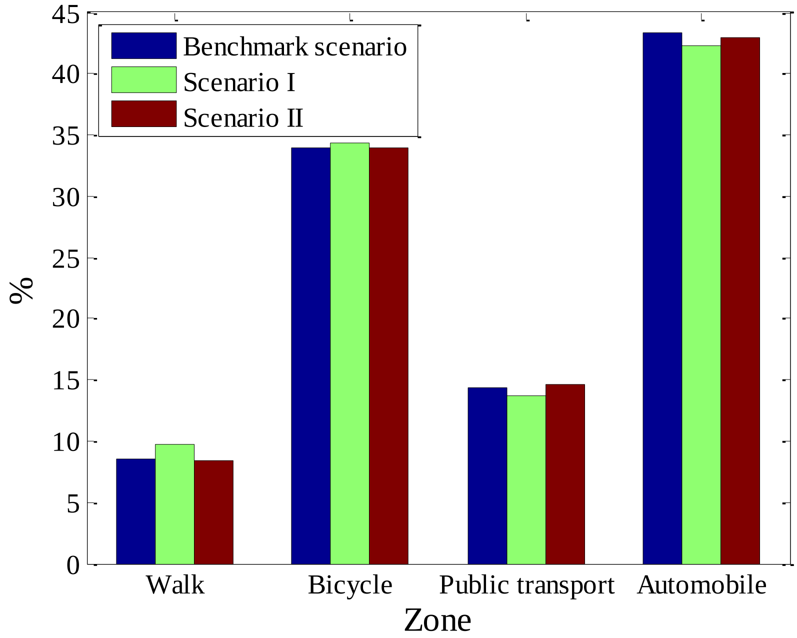


Figure 6.6: Modal split computed by model without economies of scale

Table 6.1: Travel distances (km per day) and carbon emissions (kiloton per year) computed by model without economies of scale

Scenario	TTD	PC	AC	TC
Benchmark	23,557,465	74.64	1,286.48	1,361.11
I	22,804,311	73.45	1,257.65	1,331.10
II	24,208,584	78.86	1,312.76	1,391.61

Note: TTD, total travel distances; PC, carbon emitted by public transport; AC, carbon emitted by automobile; TC, total carbon emissions

6.5.2 Simulation results with economies of scale

Also of interest is the simulation by employing the model incorporate with economies of scale. Land use scenarios updated the population/employment distribution, travel patterns including generation and attraction, travel distance and modal split as well (Figure 6.7, 6.8, 6.9, 6.10, 6.11, 6.12). Simulation results show that, in scenario I, more household preferred central zones for residence, working and shopping because of the love for variety, leading to long-distance trip reduction and increasing usage rate of walking and bicycle. Additionally, population/employment concentration, and traffic generation/attraction are more significant than those computed by the model without economies of scale.

As exhibited in Table 6.2, travel distances in scenario I were cut down from benchmark scenario, but increased in scenario II. Carbon emitted in scenario I (1,220.13 kilotons per year) is more than that in benchmark scenario (1,217.01 kilotons per year) but less than that in scenario II (1,246.41 kilotons per year). It is clear that scenario I produced less carbon emissions than scenario II because of decreasing long-distance trips, which also has been proved in the simulation without economies of scale. The interesting point here is the reason why scenario I generates more carbon than benchmark scenario. Then it can be asked if the reason is that scenario I with agglomeration effects in central zones generates more traffic volume and congestion as the carbon source.

Traffic assignment results show the changes in traffic volume of two land use scenarios. There is a tendency that traffic volume in scenario I increased mostly in road links located in the central zones, while that in scenario II increased in road links located in the suburban and peripheral zones (Figure 6.13 and 6.14). The reason why scenario I produces more carbon than benchmark scenario might be more significant urban agglomeration producing rising traffic volume in central zones, which correspondingly resulted in increasing travel time i.e. traffic congestion in city center beyond all doubt. Nonetheless, compared with scenario II, scenario I still can be considered as a low-carbon land use layout, owing to the relatively less carbon emissions. In spite of a more congested city center with increasing traffic volume in scenario I shown in Figure 6.13, reduction on long-distance travel and motor vehicle usage can eliminate carbon emitted by increasing traffic volume in the city center.

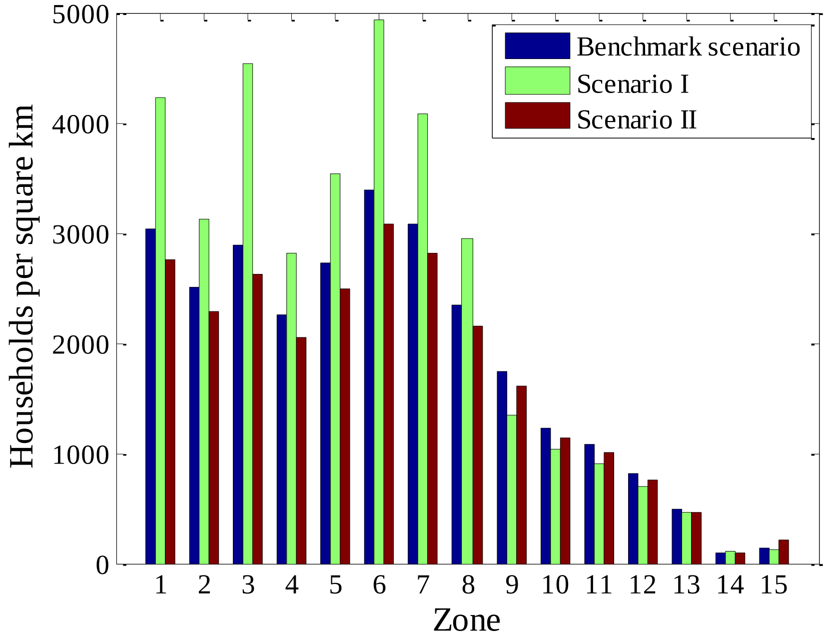


Figure 6.7: Population density computed by model with economies of scale

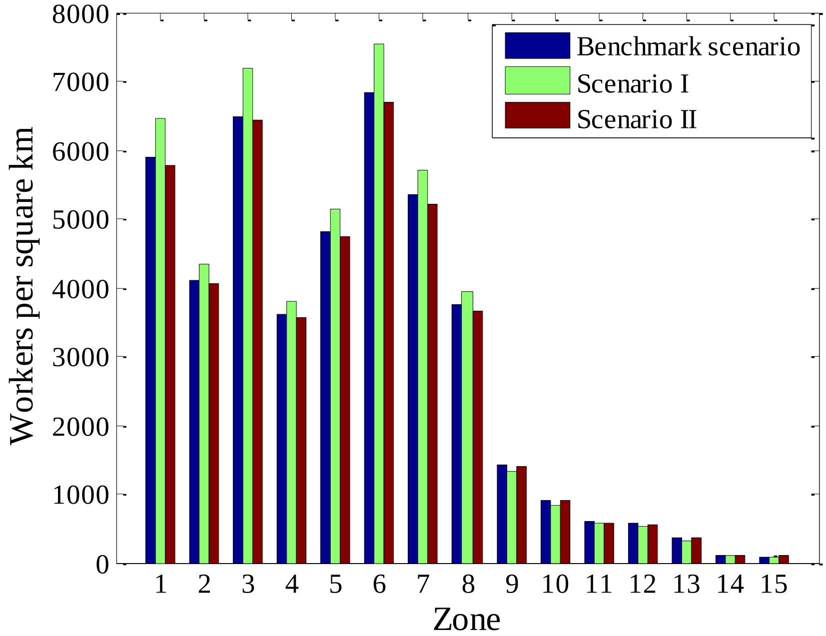


Figure 6.8: Employment density computed by model with economies of scale

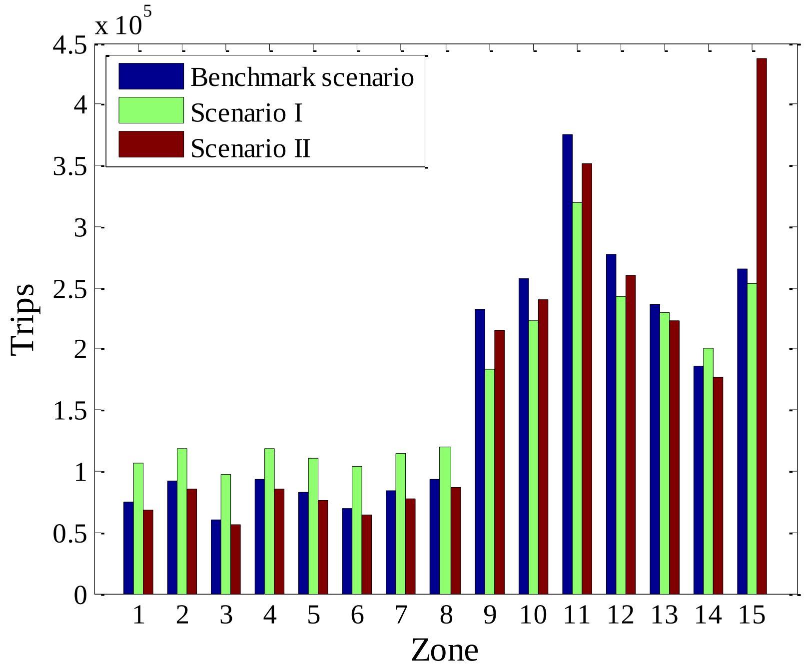


Figure 6.9: Traffic generation computed by model with economies of scale

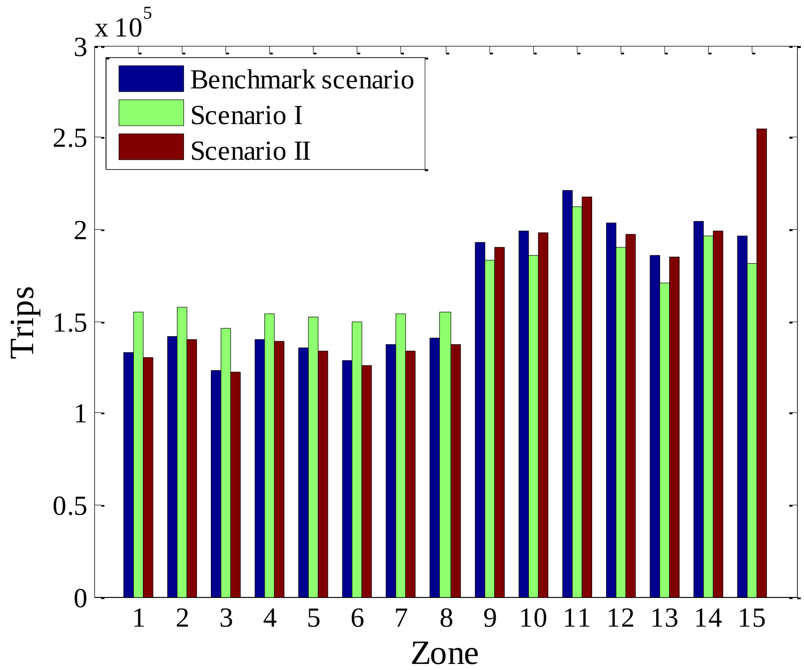


Figure 6.10: Traffic attraction computed by model with economies of scale

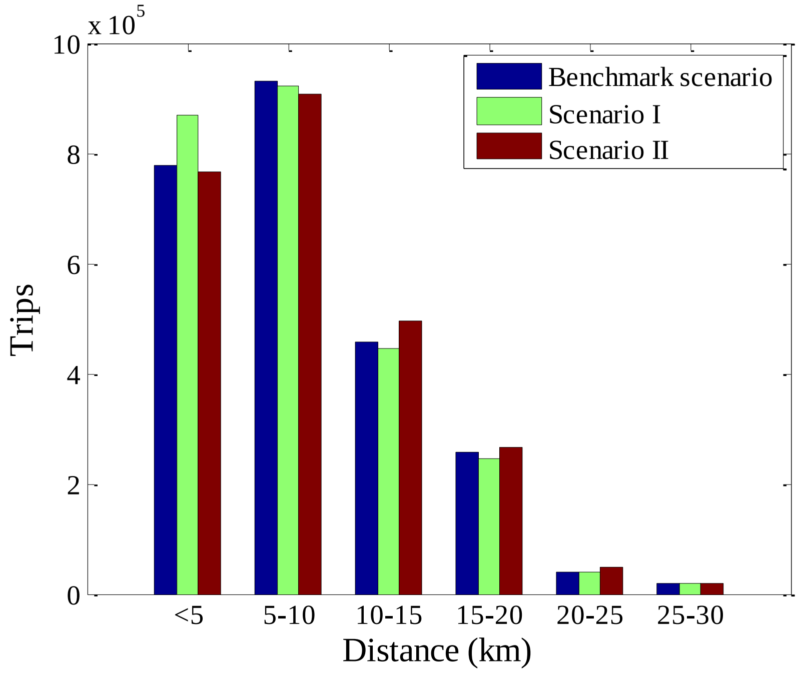


Figure 6.11: Travel distance computed by model with economies of scale

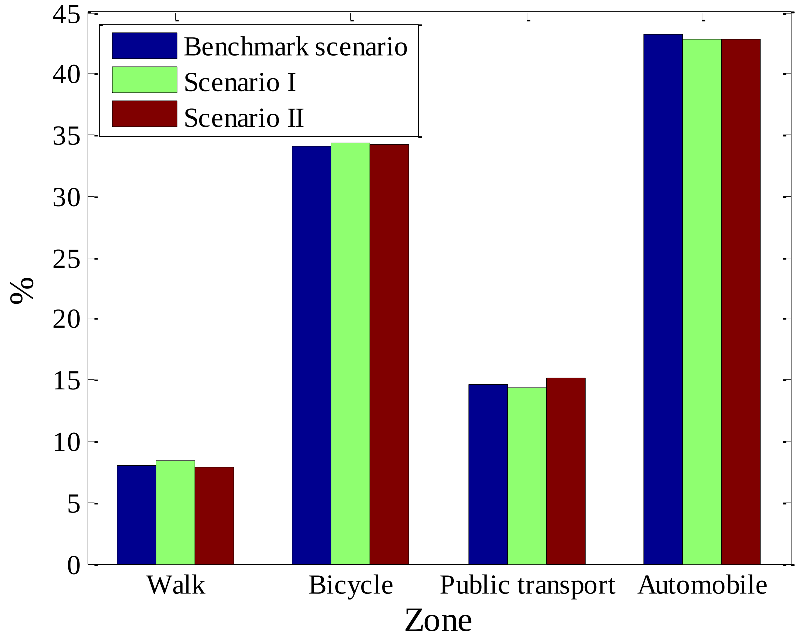


Figure 6.12: Modal split computed by model with economies of scale

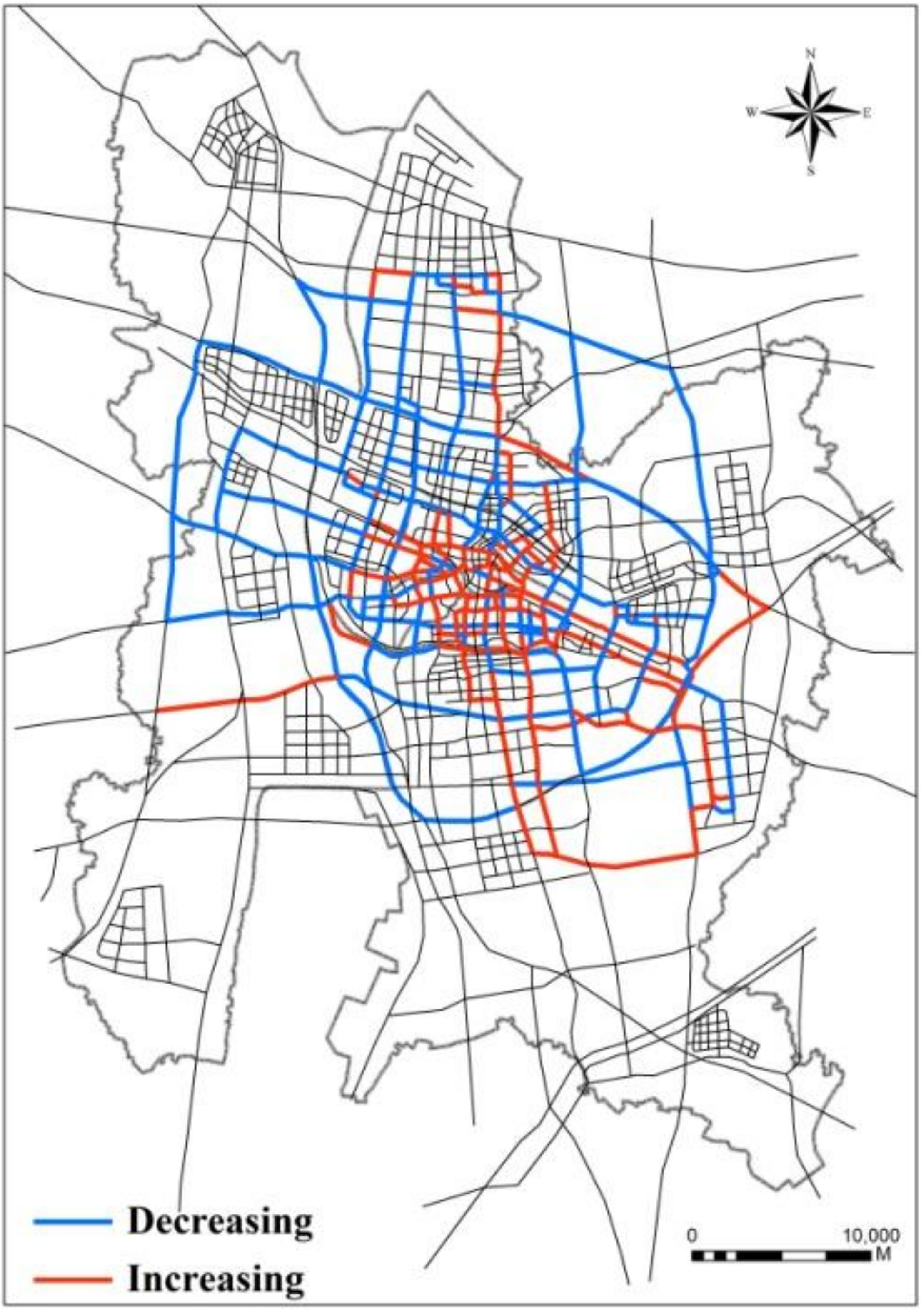


Figure 6.13: Changes in traffic volume: Scenario I

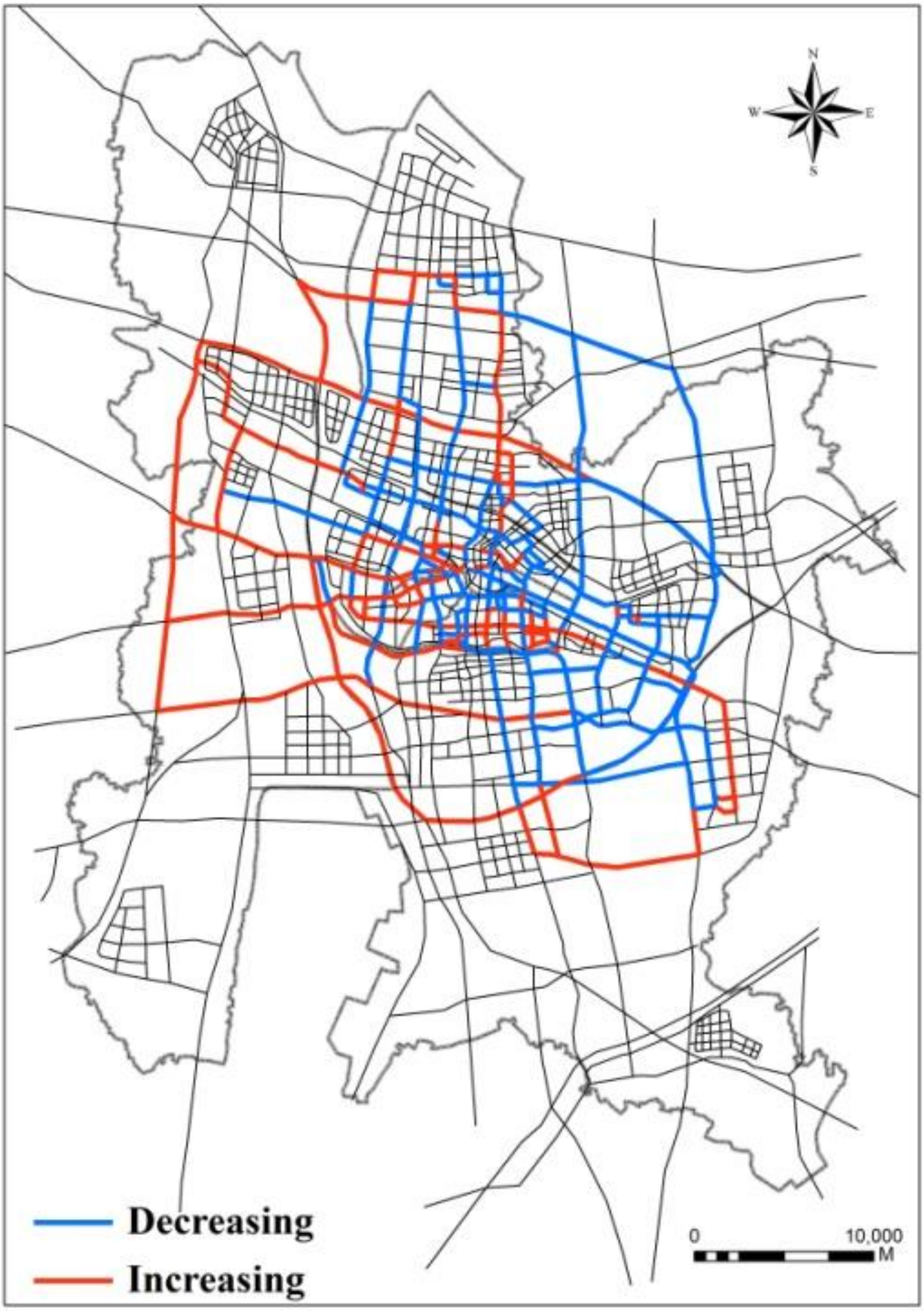


Figure 6.14: Changes in traffic volume: Scenario II

Table 6.2: Travel distances (km per day) and carbon emissions (kiloton per year) computed by model with economies of scale

Scenario	TTD	PC	AC	TC
Benchmark	20,960,871	67.42	1149.60	1217.01
I	20,858,679	67.36	1152.77	1220.13
II	21,611,857	71.49	1174.92	1246.41

Note: TTD, total travel distances; PC, carbon emitted by public transport; AC, carbon emitted by automobile; TC, total carbon emissions

6.6 Policy implication

Land use scenario simulations present a low-carbon roadmap for urban development. Compact city scenario that improves land use density in central zones is effective for carbon reduction, but urban sprawl scenario that land expands rapidly to peripheral zone results in higher carbon emissions that cause harm to the urban environment. The reason that compact city scenario produces less transport-related carbon emissions than urban sprawl scenario is because increasing land use density in central built up area shortens travel distances, and also motor vehicle usage which is the major carbon source. This result is consistent with the viewpoint and empirical results that suggests a compact city is good for energy conservation because urban activities could be located closer together to reduce long-distance travel and usage rates of automobiles (Kii, et al., 2005; Shim, et al., 2006).

Our research focuses how land use patterns will modify the travel behaviors and resulting carbon emissions, and indeed compact city can contribute to low-carbon urban development. However, there is no doubt that inordinate growth in land use density in central built up area will generate excessive population agglomerations and traffic congestions which are definitely harmful to the healthy city system. Excessive urban agglomeration indeed gives birth to more carbon emissions, which has been proved in the simulation results by the model incorporated with economies of scale. The negative externalities of urban agglomeration effect also need to be noticed in policymaking, particularly for developing countries such as China where the excessive urban agglomeration will cause many urban problems that cannot be neglected with the accelerated urbanization and economic growth.

Nonetheless, the key policy implication here is that a moderate increase in land use density in city center will play an active role in carbon reduction, in spite of the external diseconomies of urban agglomerations. In addition, though we come to the conclusion that an appropriate land use pattern and layout is beneficial to carbon reduction, land development expenses were not considered in scenario simulations. Generally, land development in built up area is more costly than land expansion in suburbs; hence it is necessary to explore how to keep balance between economic cost and environmental impacts of urban development in the future.

6.7 Summary

In this chapter, land use policy has been evaluated by using the CUE model with and without economies of scale. Two land use scenarios produced different population/employment distribution, travel pattern and resulting carbon emissions. In summary, compact city scenario generates less carbon emissions than urban sprawl scenario, indicating that compactness, namely a high-density mixed-use and intensified urban form, can be accepted as a promising solution for achieving the goal of low-carbon development. Another policy implication is that carbon emission might be cut down by means of improving public transport usage rates because automobiles overwhelmingly contribute to carbon emissions.

Furthermore, the outcomes of the model which takes into account economies of scale show more significant urban agglomerations represented by high population/employment concentration, and traffic generation/attraction as well. Meanwhile, the external diseconomies of urban agglomeration have been detected in the scenario simulation. To be concluded, land use patterns, which determine the spatial urban structure and configuration, can affect travel behaviors and carbon emissions. Therefore, the integrated land use and transport planning deserves more attention for low-carbon urban development, as it can contribute to carbon reduction by urban spatial organization.

7 Conclusions and future research

7.1 Brief summary

This chapter attempts to summarize the research conclusions, put forward to the corresponding suggestions and policy implications. Moreover, the limitations of this research and recommendations for future research are also provided.

The purpose of this research is to develop an integrated land use and transport model in the tradition of CUE model for urban planning and infrastructure policy evaluation, the core mission of which is to introduce the economies of scale to the land use and transport modeling for urban agglomeration simulation. The brief summary of the study demonstrated in this thesis are highlighted as follows:

(1) Chapter 1 introduces the background of rapid urbanization and urban problems in China, posed a problem statement that it is necessary to establish an integrated land use and transport model for urban planning and policymaking, and then put forward the research objective, scope, methods, and excepted contributions.

(2) Chapter 2 reviews the land use and transport interaction, and methodologies of integrated land use and transport modeling including their features and shortcomings. Then, a roadmap for developing an appropriate integrated modeling of land use and transport interaction with CUE model was pointed out.

(3) Chapter 3 provides the current situation of land use and traffic pattern in Changzhou City as a case study. Particularly, by using buffer zone and gradient analysis method based on geographical information system, the spatial distribution and interrelationship of land use pattern and traffic congestion was analyzed to investigate the geographic correlations between land use and transport.

(4) Chapter 4 is to formulate a CUE model, which is consistent with microeconomic theory, in order to describe the interaction between land use and transport from the perspective of microcosmic agents’ behaviors. An empirical

simulation based on the land use and person trip database of Changzhou was also conducted in this chapter.

(5) Chapter 5 is to extend the CUE model proposed in chapter 4 in consideration of economies of scale, for the sake of urban agglomeration simulation. Also, a numerical simulation was implemented by employing the extended model for detecting the urban agglomeration effect.

(6) Chapter 6 is to apply the CUE model to land use planning evaluation on the basis of benchmark model of Changzhou. Two scenarios were set for compact city and urban sprawl scenarios. The impacts on population and employment distribution, travel behaviors and resulting carbon emissions of two land use scenarios were simulated to propose policy implications for sustainable urban development in Changzhou.

7.2 Conclusions

Main conclusive points of this study are as follows.

(1) The integrated land use and transport model in the tradition of CUE model, which depicts the interactive mechanism among urban land use and transport by describing microeconomic behaviors of agents, is an effective tool for analyzing and evaluating urban planning and infrastructure policies.

(2) Economies of scale can be incorporated in the land use and transport modeling by adopting product differentiation and production behavior equipped with increasing return technology. Numerical computation shows that extended model with economies of scale is able to simulate the urban agglomeration effects in Changzhou.

(3) Land use scenario simulation reveals that compact city scenario generates less carbon emissions than urban sprawl scenario. A high-density mixed-used compact land use layout and urban configuration is supposed to be a correct and effective approach for low-carbon city planning.

(4) Immoderate urban agglomeration effects might cause the external diseconomies such as high population concentration in city center and resulting traffic

congestion, etc., which are ought to come into notice of both academia and practical interests of urban planners, with the rapid urbanization and economic development in China particularly.

7.3 Recommendations for future works

This research intends to examine how to formulate the interaction between land use and transport and urban agglomeration as well, by using the framework of CUE model. It is positively that, the modeling, numerical computation and policy evaluation provided a new viewpoint and analytical tool which contributes to China's urban planning and policymaking. Still, there remain considerable limitations to be solved in the future.

(1) Only the retail market was considered in this study but freight was suppressed for model simplification. It is better to incorporate freight and logistics into the model in the future if the logistic data could be available.

(2) Besides economies of scale proposed in this study, shopping behavior also can be extended to introduce economies of scale in shopping which stem from multipurpose trips that means consumers can buy more than one commodity during each shopping trip.

(3) Carbon emitted in daily life and industrial manufacture sectors need to be taken into consideration to build a complete city-level carbon emission evaluation system for low-carbon urban planning and policy analysis. Other environmental influences such as PM2.5 produced by trips, urban landscape change caused by transport infrastructure construction also can be considered in this model for environmental impact assessment of urban planning.

(4) Another task to be challenged in the future is the high efficient algorithm and programming for identifying equilibrium solutions. Integrated land use and transport modeling in the tradition of CUE model is defined as a large system of equations to be solved, thus the numerical computation to obtain equilibrium solutions is unwieldy due to a large number of variables and equations.

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