Integrated Land Use and Transportation Planning based on Resource and Environmental Constraints: a Case Study on Luohe City in China

Hailong Su, Yi Wang*, Yinghui Tan and Rui Zhou

Research Center for Urban Planning and Development
Environment Science and Engineering Department, Fudan University
Shanghai, China
* Email corresponding author: evonne.w@126.com

Abstract

The importance of coordinated development between land use and transportation has been widely recognized. However, many sophisticated integration model still cannot be used in practice due to complex interactions. China's Ministry of Housing and Urban-Rural Development proposed that urban transportation masterplan should synchronize with urban masterplan in 2010, which provided policy and institutional foundation to promote integrated planning. This paper, from the perspective of planning making support, proposes the research framework of planning-process-based land use and transportation integration planning. Taking China's Luohe City as an example, the framework is divided into two stages, which are the spatial planning support and transportation planning support with optimal accessibility as a dynamic feedback between them. Meanwhile, scenario planning is introduced to deal with the uncertainty of urban development policies in the future, and index system based on resource and environmental constraints is used to evaluate different scenario planning programs.

1. Introduction

Driven by urbanization and industrialization, China's cities grow rapidly over the past three decades, but this process is based on a huge amount of cost on resources and energy consumption. This extensive economic development has been difficult to sustain in the context of scarce resources, while the smooth transformation of the economic structure will be the most important motivation for future urban development. Therefore, it requires coordinated development between land use and transportation under resources and environmental constraints to realize China's urban sustainable development transformation.

The key to achieving the coordinated development of urban land use and transportation is to think about the interaction mechanisms from the source of planning making. Limited by China's central government management system, urban masterplan and urban transportation masterplan are independently produced in China for a relatively longer time[1], which is lack of feedback and policy basis for feedback. However, this situation has been improved since China's Ministry of Housing and Urban-Rural Development proposed <Urban transportation masterplan making methods> in February 2010[2]. It states that urban transportation masterplan should synchronize with urban masterplan, which provides policy support to promote integrated land use and transportation planning.

Dating back to Lowry model [3-4] in 1960s, integrated land use and transportation planning research was established on the overall results of research in the field of urban economics, geography, transportation and urban planning by applying system science, mathematics and computer technology. Location-based land use theory laid the theoretical foundation for the integrated planning [5-9], However, due to the complex interaction between land use and transportation, many sophisticated integration model can not be used in practice [10-17]. Moreover in China, urban development policy have greatest impact on urban planning making, thus this study suggests that the main reason is that most of the simulation models are based on the principles of market economy, rather than decision making support in the planning practice, which is considered more applicable for China.

Therefore, this study, from the perspective of decision making support, proposes the framework of integrated land use and transportation planning and applies quantitative analysis and visual way of computer simulation softwares to Luohe City in China.

2. Technical Framework of Integrated Land Use and Transport Planning

2.1. Three concerns required to be addressed

The integrated planning decision support system requires not only to deal with core issues of land use and transportation respectively, but also to realize the interactive feedback between them. There are three concerns to be addressed here:

1) Resources and environmental constraints are the core issue, thus the evaluation system should based on the constraints of resources and environment.
2) Urban planning and transportation planning includes different planning levels. It should clearly clarify what should be completed in transportation planning corresponding to the level of spatial planning.
3) To achieve interaction between land use and transportation system.

2.2. Conventional Spatial Planning and Transport Planning

Figure 1 shows the spatial layout planning process that first calculates the land available for construction and demand, and distributes the demand based on possible future spatial development policies, then shapes various layouts, finally evaluates the scenario programs and recommend an optimized spatial layout.

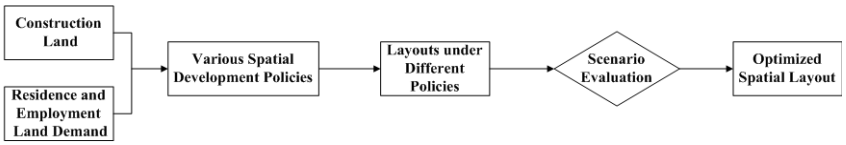


Fig.1 . Spatial planning decision-making flowchart

Figure 2 represents the transportation planning process for transportation development strategy that formulates road network layout and calculates trip demand, and distribute the demand to road network based on different transport development policies, then shapes various strategy modes, finally evaluates the scenario programs and suggests an optimized transportation development patterns.

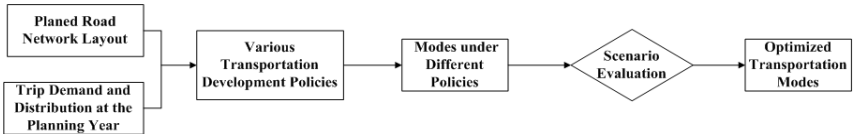


Fig. 2. Transportation planning decision-making flowchart

2.3. Framework of Integrated Land Use and Transport Planning

Overall, the technical framework is divided into two stages as shown in Figure 3, Stage 1 is mainly spatial planning by overall adjustment to achieve spatial equilibrium and optimize traffic demand and distribution; Stage 2 is mainly transportation planning by partial optimization to realize traffic equilibrium and optimize partial land use density and properties.

The first feedback from transportation to land use is achieved by evaluating whether the traffic accessibility based on traffic zones is equilibrious under different spatial development layouts. If the equilibrium is achieved, the optimized spatial layout is generated, and then planners deepen the land use layout. While the second feedback from land use to transportation is realized by accessibility evaluation based on road network. If the road network is saturate, it needs to adjust surrounding land use to optimize traffic accessibility, if not, the optimized transportation modes is attained under optimized spatial layout.

The technology platform is built up by using existing software portfolio to achieve integrated planning ideas (land modeling software WHAT IF ?[18-19] and traffic modeling software TRANSCAD[20])

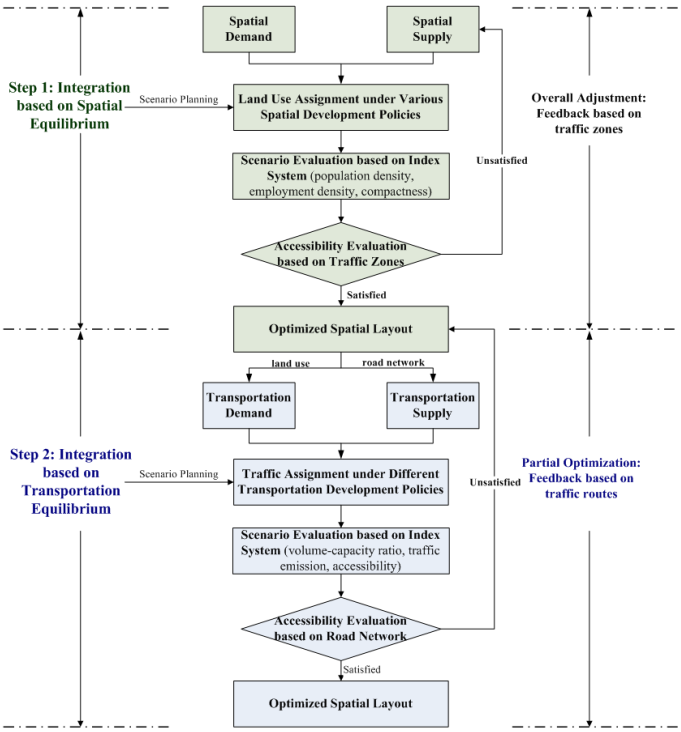


Fig. 3. Framework of integrated planning of land use and transportation

3. Case Study on Luohe City in China

3.1. Integrated Stage Based on Spatial Equilibrium

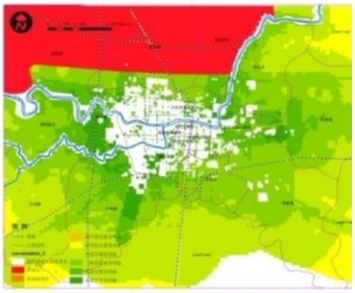
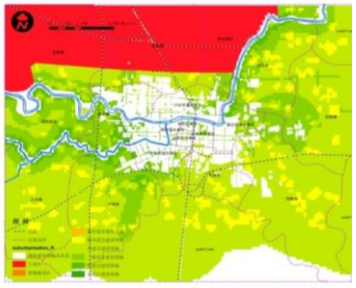
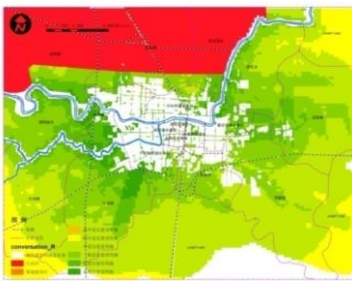
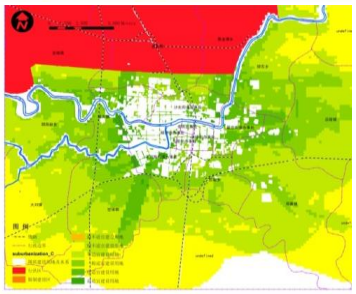
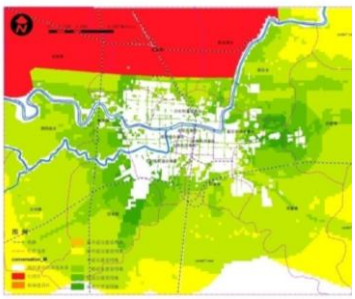
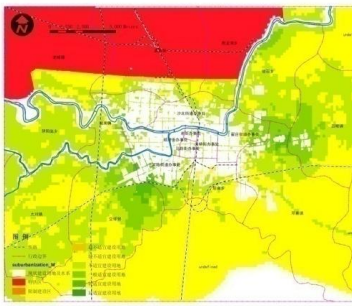
Spatial planning includes three aspects of land layout: spatial supply, spatial demand and spatial distribution. Spatial supply refers to the evaluation of the land use suitability; spatial demand mainly refers to different land demand under different growth scenarios based on uncertainties of future city development; spatial distribution talks about the spatial layouts under different policy scenarios planning programs.

3.1.1. Spatial Supply Evaluation based on Land Use Suitability

The land use suitability in this study was evaluated from four aspects, which are land location, public service facilities, environmental resources and the cost of land purchase. By calculating weights of the 4 factors

above using Analytic Hierarchy Process, a table of the results of suitability evaluation for various land uses was created below(Table 1), in which two patterns were considered including compact development pattern and extensive development pattern.

Table 1. The results of the land use suitability evaluation

Land Use	Compact Development	Extensive Development
Residence		
Public Service Facilities		
Industry		

Compact development pattern considers the development based on the existing constructed regions, including weakening to consider the cost of demolition; make sure newly developed land to be compact. Extensive development pattern do not consider the cost of infrastructure development; it mainly evaluates city's geographical conditions and the relocation cost of urbanization, which allows the city to develop with less obstacles.

3.1.2. Spatial Demand Forecast

Spatial demand mainly involves the demand for residence and employment; the core content of residence demand forecast is population estimation, which can be used to calculate residence demand based on population's residence density. Employment space prediction's core content is job estimation, which can be used to calculate land use among different industries.

1) Residence Demand Forecast

Residence forecast reflects the estimation of city scale. There are three development modes for future cities, which are rapid growth, steady growth and conservative growth. In 2008, Luohe City has a population of 740,000 in urban districts; the estimation value for three development modes are 1.4 million (rapid growth), 1.2 million (steady growth) and 1 million (conservative growth). Residence prediction includes total population, number of households, number of houses and number of dormitories.

2) **Employment Demand Forecast**

Future employment requirements are also predicted mainly from three situations: rapid growth, steady growth and conservative growth. Employment demand is mainly determined by the economic growth rate. According to the historical and current economic development trend of Luohe City, GDP per capita growth rate is 13% in the case of rapid growth, 10% for steady growth and 8% of conservative growth. The proportion of the land use in different industries from the employment data of the statistical yearbooks from 2005 to 2009 is being used to estimate future number of jobs among different industries. Employment demand includes three categories: industry classification, relationship between land use and various industries and number of jobs prediction of various industries.

3.1.3. Spatial Layouts under Different Policy Scenarios

1) Scenario 1: Non-intervention Policy

The core principle of continuing the current development policy is to allow free market to allocate spatial resources; the urban planning is to improve the layout of urban road network and configuration of public facilities. Following this policy, land use development of the villages in the city and the suburban areas cannot form the economy of scale in short time; also this rather random distribution offers great cost for providing public services and infrastructures thus interfere with the optimization of the future urban spatial structure.

2) Scenario 2: Concentrated Development Policy

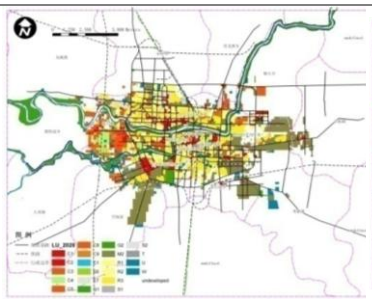
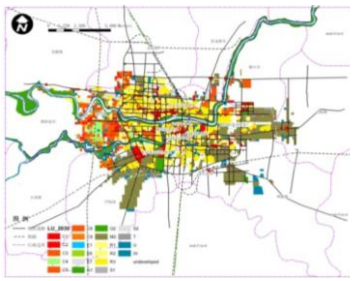
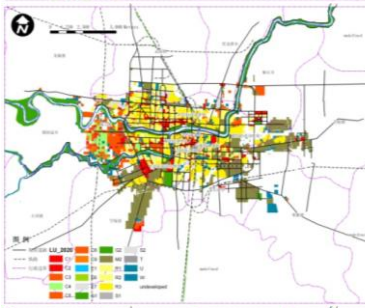
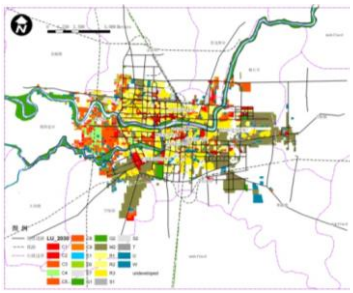
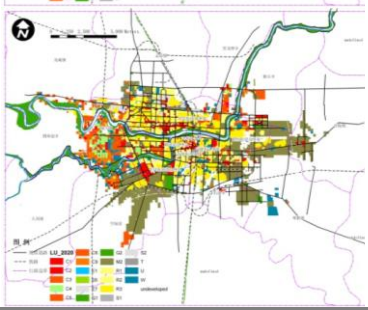
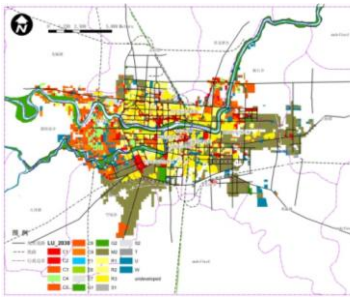
The core value of the strong-core development policy is to further agglomerate urban spatial resources, making the city shape a strong city center mode based on single market, thus boosting the development of the surrounding area. This policy makes full use of the existing urban infrastructure and transportation network; also it emphasizes the core role of city center in promoting city's economic development.

3) Scenario 3: Cluster Development Policy

The core value of the cluster development policy is to increase the effective supply of city centers based on single market by good configuration of spatial resources and new area development with low cost advantages. Cluster development means a longer commuting distance, thus city's high-end commercial activities cannot achieve economies of scale under this policy which have negative impact on city's competence. Therefore, when determining to apply cluster development policy, rapid transit network and a clear systematic development strategy need to be considered to avoid risks.

Land use spatial layouts under different policies in 2020 and 2030 of Luohe City are shown on Table 2.

Table 2. The spatial layout of 2020 and 2030 under different scenarios

Planning Year	2020	2030
Non-intervention Policy		
Concentrated Development Policy		
Cluster Development Policy		

3.1.4. Program Evaluation under Different Policy Scenarios

As shown in Figure 4, under non-intervention policy, population density and compactness are relatively significant, the old city center is crowded and overall accessibility is low, thus constraining the development of business and other service industries, which also leads to lower employment density. Under concentrated policy, there is no obvious problem and flaw compared with the other two policies, which leads to lower population density and compactness, generating a higher employment rate compared to non-intervention policy and better accessibility. Cluster development

policy provides highest employment density and accessibility, which indicates more reachable clusters near the city center, making business and industry can have very good development to provide even more employment needs.

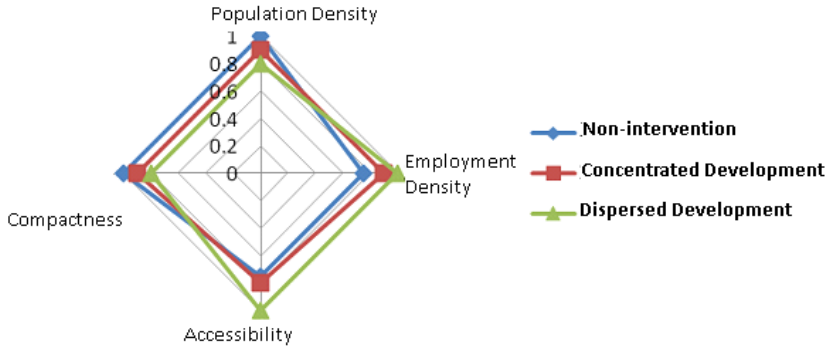


Fig. 4. The evaluation among different policy scenarios

Overall, by analyzing different policies, for Luohe, cluster development policy can provide more central location sites and balanced accessibility, which means this policy can be more conducive in nurturing Luohe's city center system and promoting Luohe's rapid development of business and other service industries.

3.1.5. Optimal Spatial Layout

Under the cluster development policy, the land use layout is further optimized in terms the following principles:

1) Balance between transportation and land use among all clusters;
2) Unique development by using natural landscape, borders, arterial in each cluster;
3) Mixed land use: the missing functions should be provided to satisfy daily demand of every cluster;
4) Preservation of the ecological space from destruction and appropriation;

Therefore, the optimal spatial layouts including the cluster system and land use can be described as Figure 5 and Figure 6 respectively.

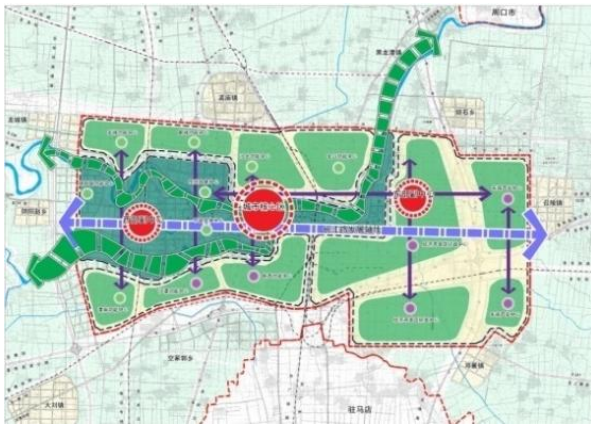


Fig.5. The spatial development pattern of cluster system

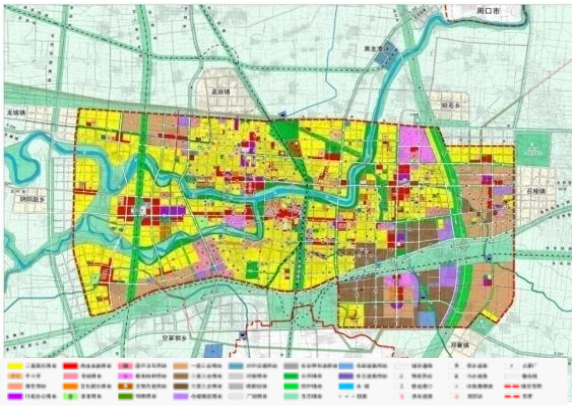


Fig. 6. Land use of 2030 under cluster development policy

In Stage 1, feedback of transport impact on land-use is mainly through the accessibility optimization based on traffic zone passed to the initial spatial supply evaluation. Since accessibility optimization brings increased traffic, and the increase in the traffic volume leads to traffic congestion thus bringing down accessibility. Therefore, the key point is to reach a stable accessibility up to spatial equilibrium. The accessibility is calculated by using TRANSCAD and feedback the data to the land use model WHAT IF?. Calculation and convergence process will not be described in detail.

3.2. Integration Stage Based on Transport Equilibrium

3.2.1. Transport Supply Analysis Based on Cluster Development Policy

Due to development uncertainties, different spatial layouts generate in terms of different policies, and then after the evaluation using related index and principles, an optimal spatial layout is obtained. Section 3.1 concludes that cluster development is the optimal spatial layout for Luohe City. Based on the cluster spatial layout, transportation planning support is mainly to analyze the supporting role of different transportation modes to spatial layout. First, it requires that within each cluster, transportation facilities can satisfy its own living and transportation needs; second, the construction of transportation corridors between clusters should meet the traffic demand among clusters.

1) Road network layout

According to the transportation master plan of Luohe City, it requires to build an efficient, fair, safe and self-grow transportation system at the end of the planning year. The road network shapes the skeleton as "6 horizontal and 11 vertical', with the integration of the current road conditions, partial broadened major roads, and optimized cross-river/railway arterials.

2) Road network characteristics

Upgrading city road patterns, hierarchy and unnecessary intersections to avoid safety hazards from the basis. Planned road area share is 19.25%, with the average road density of 5.6km/ km^2. Public transportation facility supply will not only for urban area, but also for the integration of suburban and urban areas to have a close link among public transportation terminals.

3.2.2. Transport Demand Analysis

1) Spatial Structure

The layout of urban land use affects traffic demand and distribution. Following the cluster development policy, in 2030, Luohe City's city center will be the major center for residential and commercial functions, with its eastern regions focusing on industrial land use, western and high speed train station regions for casual and business purposes and more residential areas surrounded.

2) Trip Demand Characteristics

Based on the spatial layout and land use analysis, traffic distribution characteristics of Luohe residents is generated. Generally, the need comes between east and west, then south and north directions along east and west

major lines. Suburban areas especially in the west are residential places while in the east industrial land dominates. Therefore, suburban transportation shows differences between east and west as tide effect. Public transportation facilities are planned along the banks of the river, indicating a balanced and consistent transportation need between the city center and suburban areas.

3.2.3. Traffic Assignment under Different Transportation Policies

Urban transportation structure is the ratio of different transportation modes. By guiding traffic policies, government manage and control transportation needs, transportation infrastructure construction and investment, which leads to different transportation structures in different cities. Therefore, the structure of the transportation determines the development mode of urban transportation.

1) Scenario 1: Slow Transportation Policy

From the field survey, the main transportation modes for Luohe City are walking and non-motorized vehicles. Public transportation development is slow comparing to other cities with similar scale. We suggest continue using slow traffic policy to develop transportation of Luohe City, while increasing the proportion of public transportation and adopting government policies in favor of slow traffic policy.

2) Scenario 2: Car Transportation Policy

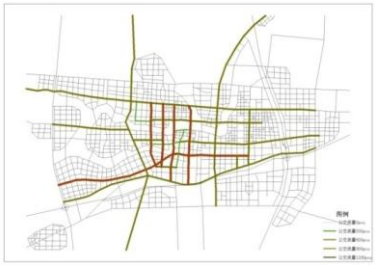
With the rapid growth of the construction land use in the city, residents have longer travel time and travel distance, which results in a transportation mode change from walking and non-motorized vehicles to private motorized vehicles between long distance areas. Residents' average salary and spending abilities increases, which also leads to a stronger need for private transportation tools like cars.

This policy needs Luohe City government to level up the construction of the highway network, increase its density, and broaden current roads. Public transportation networks should enhance the link between clusters to share part of the car transportation needs.

3) Scenario 3: Public Transportation Policy

Under public transportation policy, arterial bus lines satisfy long distance needs between clusters, normal bus lines satisfy transportation needs within clusters. This policy requires the density of the road grid and bus grid to be higher, and during the mean time increases the construction of the city bus terminals.

Table 3. Traffic assignment of different transportation policy

Planning Year	2020	2030
Slow Transportation Policy		
Public Transportation Policy		
Car Transportation Policy		

3.2.4. Evaluation on different transportation policies and optimal transportation mode

From Figure 8, car transportation approach has worst indicators while slow transportation policy has the best. In the slow transportation policy, indicators of the delay rate, density and traffic emissions are the smallest while accessibility and average travel time are on par with public transportation policy. In the car transportation approach, indicator of the delay rate, density and traffic emissions are higher than two other approaches while accessibility is lower although average travel time is similar. In the public transportation policy, all three indicators are in the middle level, and the accessibility and public transportation involvement are the best among these three policies.

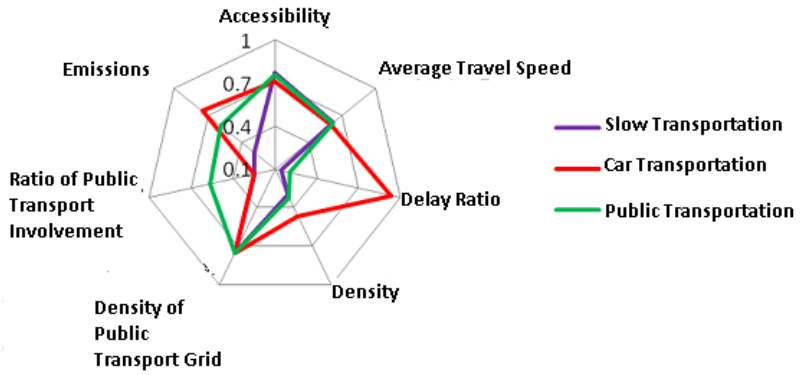


Fig. 8. The evaluation of different transportation development modes

In this stage, the feedback from transportation polices on land use is based on accessibility optimization and road saturation situation. Unreasonable land use could lead to local transportation congestion on partial roads. By optimizing accessibility, partial land use can be reconfigured to bring down the traffic volume to relieve the road saturation. Detailed calculation process will not be described in detail.

4. Discussion

1) The practice of two-stage approach in urban planning

Land use and transportation integration research has made great progress in foreign countries. However in China, due to institutional barriers in urban planning and management, the land use and transportation planning belong to different departments, and the lack of quantitative analysis tools especially in the field of spatial policies. However, with the requirements from China's Ministry of Housing and Urban-Rural Development of synchronization between departments, the integration of land use and transportation research has a bright future. This research again verifies the needs and practicality of this two-stage approach in urban planning in China.

2) Feedback from transportation on land use

Right now integrated urban planning and transportation planning synchronization has a good policy basis, but the interactive feedback and data standardization process still needs to be explored. This paper proposes accessibility as the main factor from the feedback of transportation planning, generating interactive relations between transportation and land use. With

the help of the current analytical platforms (WHAT IF? + TRANSCAD), this paper has done a preliminary research on how to integrate transportation and land use under one frame with feedbacks on both sides. Next step will be focusing on active feedback research based on UPLAN and EMME as well as data standardization.

5. Conclusion

1) Propose the framwork of integrated planning from the perspective of planning making support for the first time

Chinese scholars' research on land use and transportation integration has been there for over 30 years. Urban planning making will consider the effects of transportation policies and vice versa. However, due to institutional barriers, these two areas never integrate with each other in a constructive way. In February 2010, the Ministry of Housing and Urban-Rural Development announced the synchronization policy, setting the preliminary foundation for integration research. This paper proposed a roadmap for synchronization as well as technical support and practice on the integration, which is an innovation.

2) Propose interactive feedback approach on paths from transportation planning to land use and its technical process

In this research, the feedback from transportation planning to land use is achieved in two paths. First one is based on accessibility, which means, traffic volume resulted from types and density of land use development may create traffic congestion and lower accessibility itself, thus as one evaluation from the spatial supply and demand point of view, accessibility becomes one feedback from transportation to land use. Second one is introducing scenario planning approach, comparing spatial structure support and optimization under different transportation development policies (modes) and evaluate these different approaches, which helps selecting the suitable transportation development policy that fits the city's own spatial characteristics, and offering directions of how to optimize land use under current spatial structure and transportation modes.

Acknowledgement

This research is sponsored by the National Natural Sciences Foundation of China (Grant No: 50808048).

References

1. Ministry of Housing and Urban-Rural Development of the People's Republic of China (2005) Urban planning making methods. Beijing, China.
2. Ministry of Housing and Urban-Rural Development of the People's Republic of China (2010) transportation masterplan making methods. Beijing, China.
3. Lowry I S (1964) A model of metropolis. Santa Monica: Rand Corporation Press,
4. Peter Hall, Mark Tewdwr-Jones (2010) Urban and Regional Planning. Routledge Press.
5. He, Jia, et al. (2011) Framework for integration of urban planning, strategic environmental assessment and ecological planning for urban sustainability within the context of China. Environmental Impact Assessment Review 31(6): 549-560.
6. Durand, C. P., et al. (2011) A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning." obesity reviews 12(5):173-182.
7. LU Huapu (2006) Integrated planning of land-use and transportation systems. Journal of Tsinghua University(Science and Technology)
8. GUO Liang, HE Hui.(2009) Comparative study on the relevance of structural optimization of urban traffic and land-use patterns. Urban Planning Forum, (5)
9. Waddell, Paul. (2011) Integrated land use and transportation planning and modelling: addressing challenges in research and practice. Transport Reviews, 31(2): 209-229.
10. Cervero R. (1997) Twenty years of the Bay Area Rapid Transit system: Land use and development impacts [J]. Transportation Research Part A, (7).
11. YE Mao, GUO Xiucheng, WANG Gu. (2010) From mononuclear to group structure city:the evolution characteristics of transportation pattern in linear city——a case study of Zhenjiang. Modern Urban Research.
12. Bertolini, Luca, Frank le Clercq, and Thomas Straatemeier. (2008) Urban transportation planning in transition.Transport Policy 15(2).
13. Suzuki, Hiroaki, Robert Cervero, and Kanako Iuchi. (2013) Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development. World Bank Publications.
14. Kaiping, Li, et al. (2010) Research and Practice of Planning Collaboration in Urban Cluster Area: The Example of Guangzhou-Foshan Urban Integration Planners 9:11.
15. Ewing, Reid, et al. (2011) Transportation and Land Use. Making Healthy Places,pp.149-169.
16. WANG Jixian (2009) Method and practice of integrated planning of overseas land use and transportation. Urban Planning International.
17. WANG Shusheng (2010) Land use and transportation integrated analysis technique and its application: a case study of kunshan master plan. City Planning Review.

18. Klosterman, Richard E. (2008) A New Tool for a New Planning: The What if?™ Planning Support System in Planning Support Systems for Cities and Regions. Richard K. Brail, ed. Cambridge, MA: Lincoln Institute of Land Policy, ,pp. 85-99.
19. What If Inc.(2012) What if ? Version 2.0.
20. Caliper Corporation.(2012) Full TransCAD Version 4.5