LUTIPSS: A ArcGIS Engine Based Planning Support System for Land Use and Transportation Integration

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Abstract

To meet practical needs of urban planning in China, we developed the Planning Support System for Land Use and Transportation Integration (LUTIPSS). This system is ArcGIS Engine based, and consists of three modules: Mapping Operation Module (MOM); Spatial Planning Module (SPM), which includes space demand, space supply, space allocation and land use program evaluation in order to generate optimal land use plan with all factors considered up to date; Transportation Planning Module (TPM) which functions as a conventional four-step travel model. LUTIPSS was successfully applied to the master plan of Luohe City and Nanyang City – two medium-size cities in China to portrait future urban forms and travel demand. LUTIPSS is a tool for quantifying the impacts of land use on transportation at the level of master plan and testing whether the planning ideas, policies and scenarios comply with the goals of smart city.

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1 Introduction

Land use and its synchronized development with transportation system have always been the popular topics in the fields of urban planning, transportation and urban geography studies. Coordinated development between land use and transportation plays a key role towards optimizing urban spatial structure, improving efficiency of urban transportation system, and realizing sustainable development of a city.

Dating back to Lowry model (Lowry, 1967) in the late 1960's, 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. Waddell (2002,2011) introduced UrbanSim, a new land use model system responding to the problems resulting from land use, transportation and environmental planning, and presented a case study on Eugene-Springfield, Oregon, and later has been adopted by many cities and metropolitan planning organizations as a tool in sustainable land use and transportation planning. Johnston et al.(2004) developed GIS based UPlan land use allocation model to forecast future land use. Ferreira et al. (2010) developed a framework that links the transportation model and land use model. Gao et al. (2010), reported multi-year efforts of developing the California PECAS statewide integrated land use/transportation model and preliminary results of a sensitivity test. Miller et al. (2011) discussed the land use model validation based on the ILUTE (Integrated Land Use, Transportation, Environment) model system, which is an agent-based micro-simulation model for the Greater Toronto-Hamilton Area (GTHA).

Based on geographic information technology, the Planning Support System (PSS) is a powerful tool to assist planners to analyze spatial data with its core algorithms. PSS was first proposed by Harris (1989), and gained a lot of attention since early 1990's (Harris, 1993; Klosterman 1997, 1999; Brail & Klosterman, 2001; Geertman & Stillwell, 2003, 2009; Brail, 2008; Klosterman, 2008; Placeways LCC, 2015) .Compared with general GIS, PSS is a more professional platform that focuses on specific planning tasks and supports strategic decisions throughout the entire process of urban planning.

In China, the local government instead of market controls urban development. Land use planning and transportation planning belong to different administrative departments, and are conducted with little coordination. Unfortunately, the two departments usually have different visions about city

development, and the land use planning department has more power in practice. This explains why the two processes are out of tune in almost all cities in China. In 2010, China Ministry of Housing and Urban Rural Development (2010) published a new regulation for urban planning in which the urban master planning and transportation planning are required to be conducted with the same timelines. The new regulation provides policy foundation for making the two efforts in concord.

Driven by urbanization and industrialization, China's cities grow rapidly over the past three decades. However, this process is based on huge amount of resources and energy consumption and environment deterioration as the costs. Obviously, this type of economic development will not be sustainable in the context of scarce resources. Chinese governments have been aware of the consequences of this development model and have been pushing a transformation of the economy from pursuing the growth of gross domestic production to smart growth.

In the United States, smart growth focuses on the urban form, function and infrastructure that will support economic and social development in a sustainable way. Thus the spatial planning of smart city orients to addressing urban issues, such as urban sprawl, traffic congestion, air quality deterioration, and noise etc.,. In other words, the purpose of smart planning is to reduce urban sprawl and dependence on auto. Smart urban planning should improve people's access to opportunities and services, promote land use density and mixed uses, enhance public transit system, and reduce vehicle miles traveled which implies less emissions of pollutants and CO_2.

In China, the challenges in smart urban planning are different due to urban population and existing urban form. According to administrative structure, China has 4 central government directly managed cities, 28 provincial-level cities, 2 special administrative region (Hong Kong and Macau), 285 prefecture-level or above cities, and 368 county-level cities at the end of 2013 （China Economic Development Committee of Small and Medium-size Cities, 2014）. In urban planning, cities are usually classified by population size. A city with less than one million people is classified as medium-small size city (China State Council, 2014). Thus, 162 prefecture-level and almost all county-level cities are middle-small cities. In terms of existing urban form, the majorities of the cities have only one urban center. During the process of fast expansion, most of cities still keep their one center urban structure. The urban center functions as the center of politics, economy, and culture, and therefore as the employment center. High housing costs force people to live far from where they work (usually the urban center) and thus longer commute. The latest survey shows that the average commute time (one way) in Beijing is 97 minutes (Labor Market Research

Center of Beijing Normal University, 2014). For large cities, the existing land use pattern can only be changed through redevelopment. While in medium-small cities, there are a lot of opportunities to create new sub-centers in long range land use master plan.

Besides the political challenges, Chinese local governments are also facing technical challenges in applying modeling tools in planning practice. A lot of demonstrated integrated landuse and transportation models in the U.S. are hard to be applied in China cities due to their complex structures and heavy dependence on data for calibration and validation. We find PSS is of more interest than large urban models among Chinese urban planners, and is more appropriate to Chinese professional given the current policy context. For this reason, we have been developing a planning support system that incorporates both land use and transportation components, and that supports Chinese font. The paper reports the structure and functions of LUTIPSS, and its application in Luohe, China.

2 LUTIPSS Components

The main development tools of LUTIPSS are Visual Studio 2010 with .NET and ArcGIS Engine 10.0 coding environment. All the menus and icons of the system are shown in Chinese font. It is compiled and run as an application. The system includes three modules: Mapping Operation Module (MOM), Spatial Planning Module (SPM) and Transportation Planning Module (TPM). The inputs and outputs of the three modules are stored in geodatabase, and data exchanges of the three modules are done within the geodatabase.
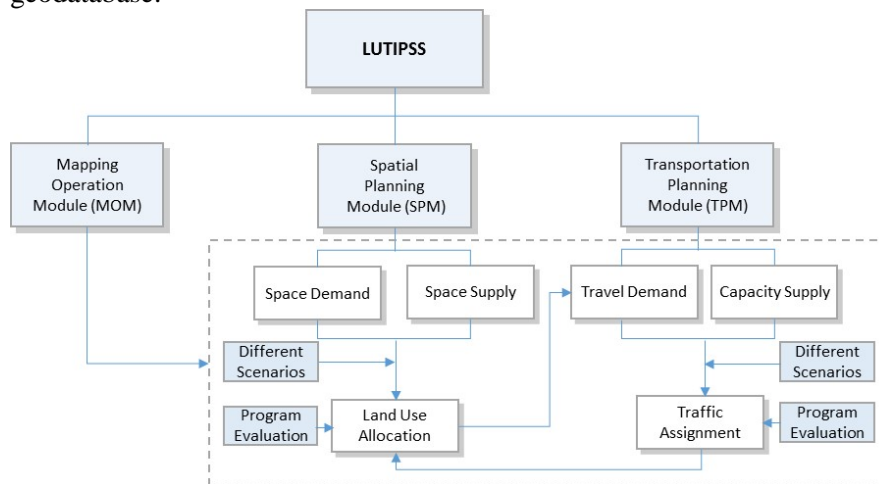
Figure 1 The Framework of LUTIPSS

2.1 Mapping Operation Module (MOM)

Map operation module provides file operations, basic map tools, query tools, layer operations and other functionalities which ArcGIS has.

File operations can load files that ArcGIS supports like shapefile, grid, images, etc. The project document is saved as project document (.mxd). Basic map tools provide common GIS navigation tools such as pan, zoom, previous view, the latter view, the full extent map, and measuring tools (distance, area). Query tools support map query (point, polygon and circle selection), also support advanced queries. Users can set up complex combination of conditions to query eligible objects, such as a query of contours with height from 100 m to 120 m in the contour layer. Layer operations can view all the attribute information in the way of list , and provides symbolic tools of layers. Current version supports two rendering types(single symbol and graduated colors). Graduated colors rendering can choose classification fields, methods (Equal Interval, Geometrical Interval, Natural Breaks, Quantile) and ribbons.

2.2 Spatial Planning Module (SPM)

Spatial Planning Module provides creating grid, grid adjustment, space supply, space demand, space allocation, program evaluation, and other functionalities.

Creating grid tool can create the basic unit for spatial analysis. The user can define the size of the grid cell. The system now provides the four options, 200m, 500m, 1000m and 1500m. The grid cell can be edited to put a constraint where an allocation is not allowed by the grid adjustment tool, i.e. the ecological land which is forbidden to be constructed on.
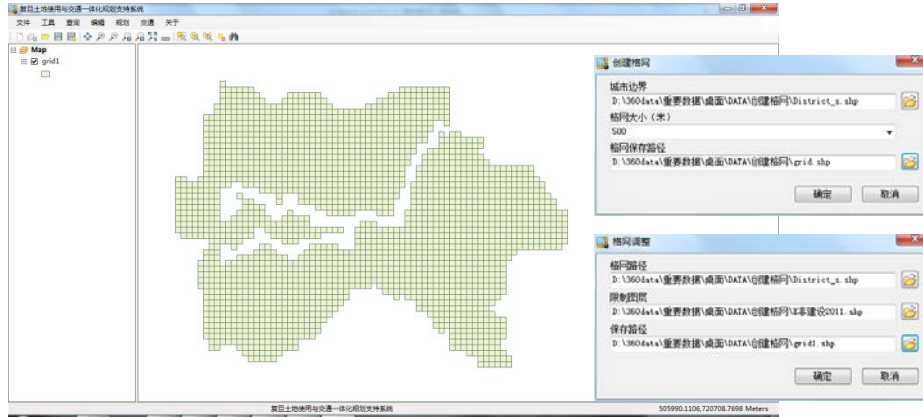
Figure 2 The User Interface of Creating Grid and Grid Adjustment Function

Space demand involves computing area of land consumed for each land use type based on forecasted population in the planning year by inputting the unit land consumption per household and worker. Calculated results can be saved as an XML configuration file and will be used as the inputs of space allocation.
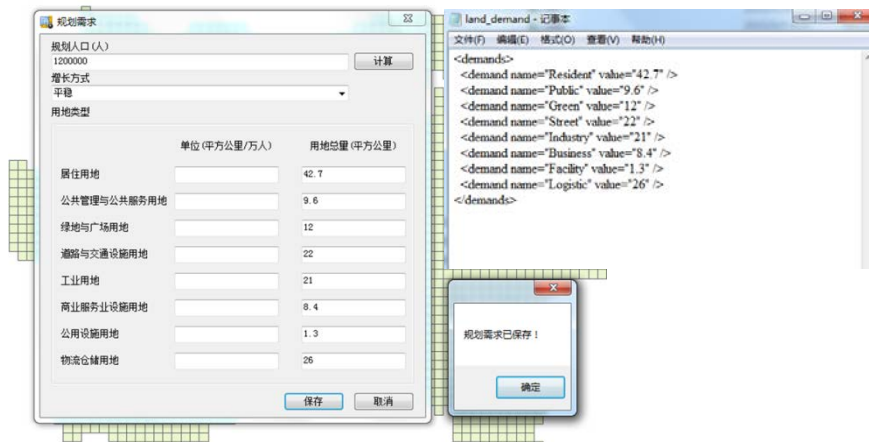

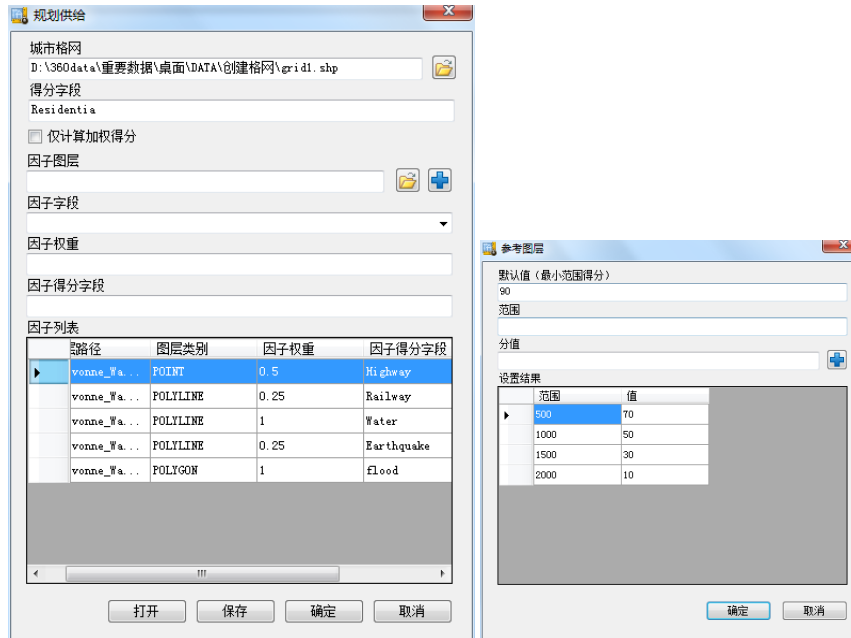**Figure 3 The User Interface and XML file of Space Demand Function**

Figure 4 The User Interface of Space Supply

Space supply refers to land suitability evaluation based on those positive and negative factors that affect land use. The system provides a flexible way to support multiple factor data, and to set weights of different factors for different land uses. For a point or line layer, suitability score is determined by the distance from the centroid of the grid to the point or the nearest section of the line; for polygon layer, if the grid cell is out of the polygon, the score is the nearest distance to the polygon; if the grid cell is within the polygon, the score can be set directly. The system calculates the suitability score for each grid cell and each factor layer first and then sum all scores as a final suitability score for each grid cell. The final score is used as the base of space allocation. The factor data, weight and scores can be saved as XML configuration files.

Space allocation involves assigning grid cells with different land use types based on the outputs of space demand and supply. The weighted score computed in space supply of each grid cell is sorted in descending order, combined with the settings of allocation sequence of different land use types (the system can adjust the allocation sequence), the grid cell is allocated to different land use types sequentially based on the final suitability score. A proportion factor is designed to allocate the growth to new growth area.

Figure 5 The User Interface of Space allocation

A visualization tool is designed to present the results of the land use al-location. The results can be viewed in tables and charts for one scenario or multiple scenarios.

2.3 Transportation Planning Module (TPM)

Transportation Planning Module functions as a traditional four-step model. It includes trip generation, mode split, trip distribution, and trip assign-ment. Also it incorporates the transfer function from grids to TAZs, and OD desire line.

The module can draw and load road networks (intersection, line seg-ments), Traffic Analysis Zone (TAZ) etc., and set the attributes by adding the fields, like the zone no, zone name, road name etc., (Figure 6). The function of girds to TAZs automatically aggregate the total trip produc-tions and attractions based on the land use allocation in grid cells obtained from SPM to TAZs, if the centroid of grid cell is located in the TAZ.
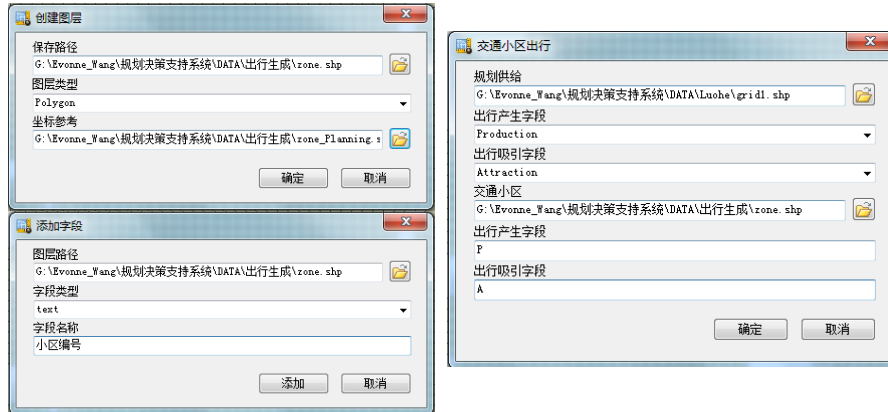
Figure 6 The User Interface of Creating Layers (road,TAZ) and Grids to TAZs

The module computes travel impedances, uses a gravity model, and then converts person trips by mode into vehicle trips to get OD matrix. Mode split is considered simply by setting different mode share according to different policy scenarios. The computation results of travel impedances and vehicle trips for each OD pair are saved as CSV files. Traffic assignment tool assigns vehicle trips to road networks based on road link congestion level (volume/capacity ratio). The user can set either maximum number of iterations or a gap between the two iterations as the convergence criteria. The assignment results can be viewed as shape files, tables, and charts.
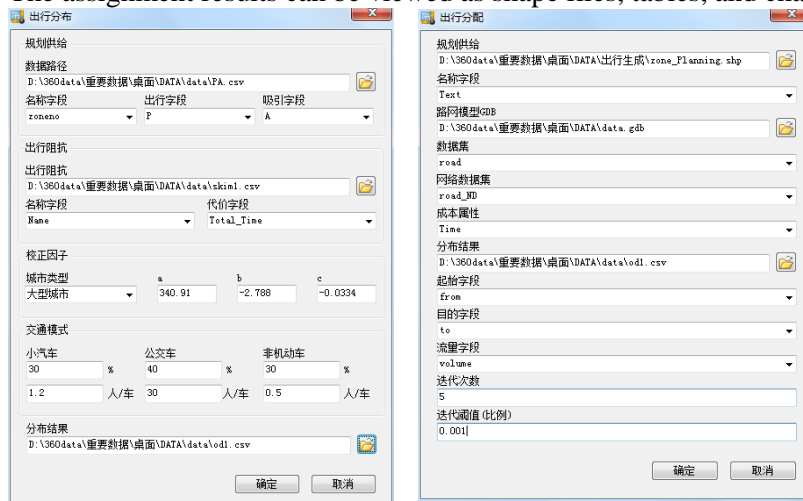

Figure 7 The User Interface of Trip Distribution and Trip Assignment

3 System Implementation and Application

LUTIPSS were applied to the master plan practice of Luohe City and Nan-yang City, two medium-size cities in Henan Province, China, with a popu-lation around 1 million. Given the similarities, only the application to Luohe Master Plan is presented in this paper.

3.1 Land Use Sketch Planning

Luohe City is a city in Henan Province. Its population is 740,000 in the base year (2011) and larger than 1,000,000 in the planning year (2030) un-der different scenario. The purpose of this study was to develop a master plan for this fast growing city. LUTIPSS was developed to meet the need for a useful modeling tool. The grid cell size was set as 200m*200m. Three scenarios were tested: status quo (LU1), one-center scenario (LU2), and multi-center scenario (LU3):

- LU2: one-center scenario. This scenario boosted the development in the urban core area to create agglomeration effects in the urban core area.

- LU3: multi-center scenario. This scenario was designed to pursue a better job housing fit by reforming the current highway system and creating several sub-centers.

3.1.1 Space Supply based on Land Use Suitability Evaluation

Land use suitability in this study was evaluated from four aspects: land lo-cation, public service facilities, environmental resources, and costs of land purchase. Eleven factors were considered and evaluated separately (see Table 1). The nine layers were spatially overlapped and weighted to get the total scores which represented the suitability of a piece of land for a specif-ic land use type (see Table 2). The results of suitability evaluation for vari-ous land uses were presented in Figure 8.

Table 1 Land Use Factors

Factors	Criteria	Value	Factors	Criteria	Value
Distance	<500m	90	Distance to High-speed Rail	< 1000m	90
to	500~1000m	70		1000~2000m	70
Ramps	1000~1500m	50		2000~3000m	50
of	1500~2000m	30		>3000m	10
Highway	>2000m	10	Waterfront	<400m	90
Eleva-	<62m	10		400~800m	70

tion	62~64m	30		800~1200m	50
	64~66m	50		1200~1600m	30
	66~68m	70		>1600m	10
	> 68m	90		>90%	90
	Freeway < 500m	90		75%~90%	70
	Arterial < 500m	70	Existing Village	50%~75%	50
Existing Road	Sub-arterial <500m	50		<50%	30
	Minor Road <500m	30		0	10
	Others	10	Earth-quake Belt	<4000m	90
	Inside	90		4000~100000m	50
Existing Built-up Area	< 2000m	70		>10000m	10
	2000~4000m	50	Flood Area	Inside	0
	4000~6000m	30		Outside	90
	>6000m	10			

Table 2 Weights of Land Use Factor In Different Scenarios

| Factors | Weights (Residential/Commercial/Industrial Area) | | |
	LU1	LU2	LU3
Elevation	0.25/0.25/0.25	0.25/0.25/0.25	0.25/0.25/0.25
Earthquake	0.25/0.25/0.25	0.25/0.25/0.25	0.25/0.25/0.25
Existing Road	0.75/1/1	0.75/1/1	0.5/0.5/0.5
Built-up Area	1/1/0.75	1/1/0.75	0/0/0
High-speed Rail	0.5/1/0.5	0.5/1/0.5	0.25/1/0
Village	0.25/0.25/0.25	0.25/0.25/0.25	1/1/0.75
Waterfront	1/0.75/0.25	1/0.75/0.25	1/0.75/0.25
Highway	0.5/0.5/1	0.5/0.5/1	0.5/0.25/1
Flood Area	1/1/1	1/1/1	1/1/1
Accessibility	0.5/0.5/0.5	0.5/0.5/0.5	0.5/0.5/0.5
Policy		0.25/0.25/0.25	0.25/0.25/0.25

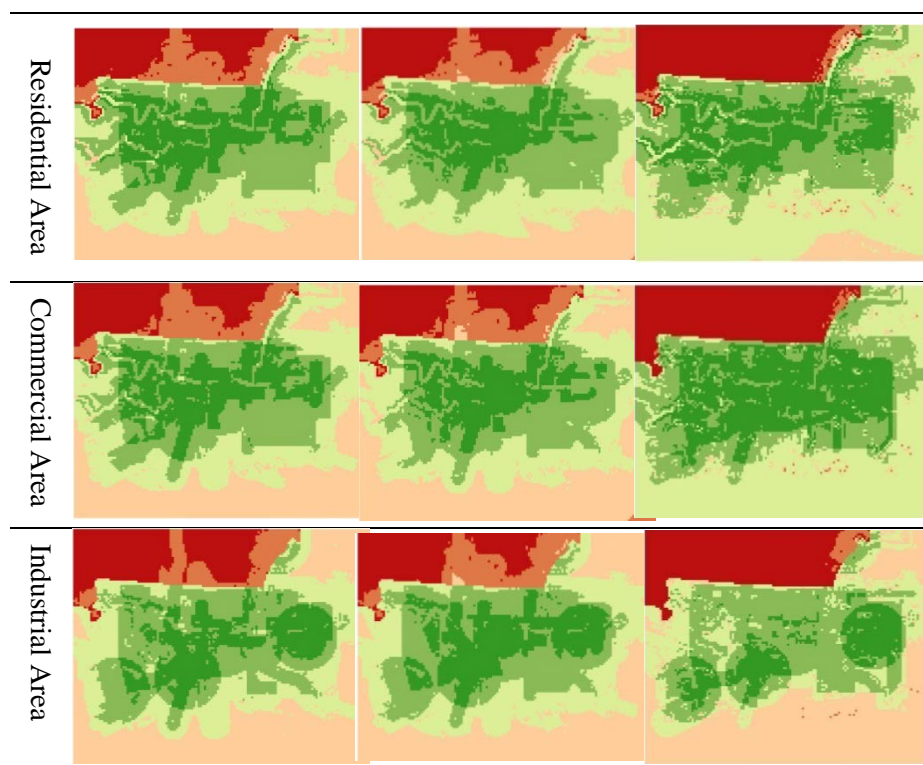| LU1: Status quo | LU2: One-center | LU3:Multi-center |

Figure 8 The Results of Land Use Suitability Evaluation

3.1.2 Space Demand Forecast

Space demand was estimated based on the forecast of population and employment. A multiplier (dwellings per households by income type or square meters per employee by industry) was applied to obtain the total demand for residence and employment.

Residence forecast reflects the estimation of city scale. Luohe City has a population of 740,000 in urban districts in the base year. The forecast of population was 1.4 million (rapid growth), 1.2 million (steady growth), and 1 million (conservative growth), respectively. Residence forecast took into account total population, number of households, number of dormitories, and vacancy rate.

Accordingly, the employment was forecasted at different growth rate. Employment demand was mainly determined by economic growth rate. According to historical and current economic development trend of Luohe

City, GDP per capita growth rate was 13% in the case of rapid growth, 10% of steady growth, and 8% of conservative growth. The proportion of the land use in different industries from the employment data of the statistical yearbooks in the past 10 years was used to estimate future number of jobs among different industries.

3.1.3 Space Allocation under Different Policy Scenarios

Figure 9 showed the allocation results. From the figure 8,we can see that, compared with the status, the one center scenario had more commercial land use and less residential land use in urban center, and the multi-center scenario had more commercial land use and public facilities out of urban core.
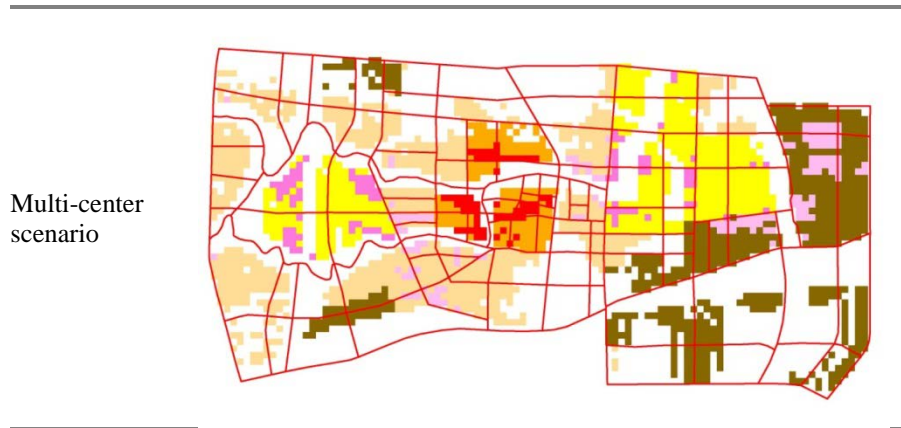
Planning Year	2030

Status quo

One center scenario

Multi-center scenario
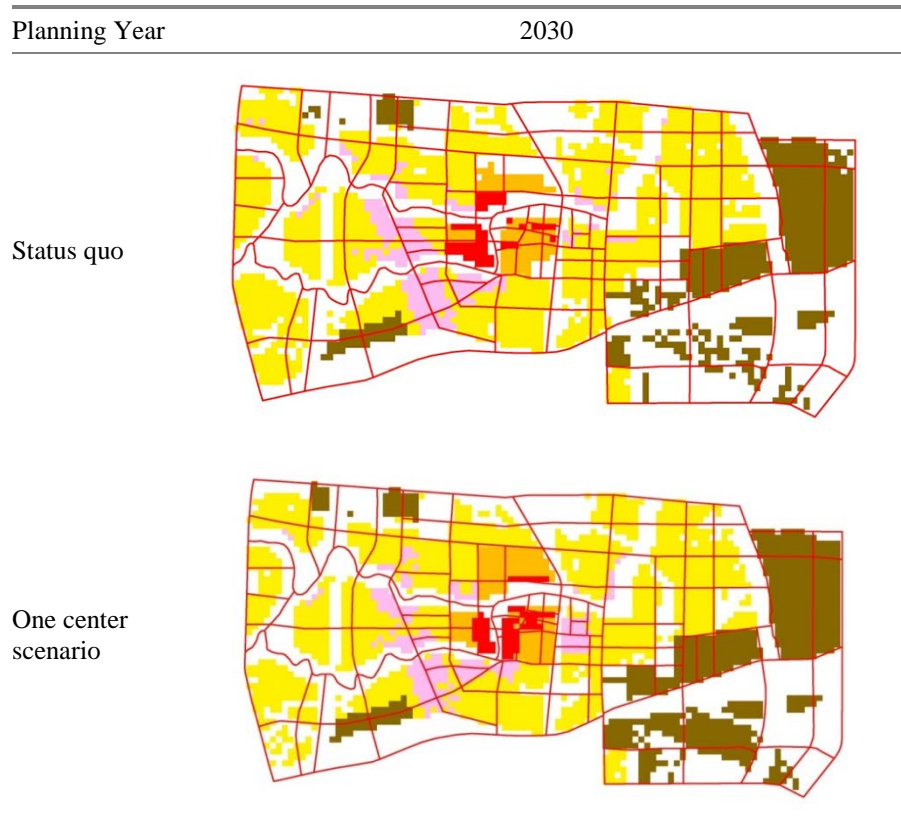
Figure 9 Land Use in 2030 under Different Scenarios

3.2 Transportation Demand Forecasting

The travel demand was based on the land use forecast. The trip production and attraction were calculated at the grid cell level with the trip generation rates from a survey and then were aggregated to traffic analysis zone (TAZ) level. Luohe City was classified into 121 TAZs.

Figure 10 shows the population and employment distribution under 3 scenarios. For status-quo, the population and employment is relatively concentrated; for one-center scenario, it's most concentrated; while the multi-center scenario presents two development trends from central area to the east and the west separately.

Scenario	Population	Employment
Status quo		

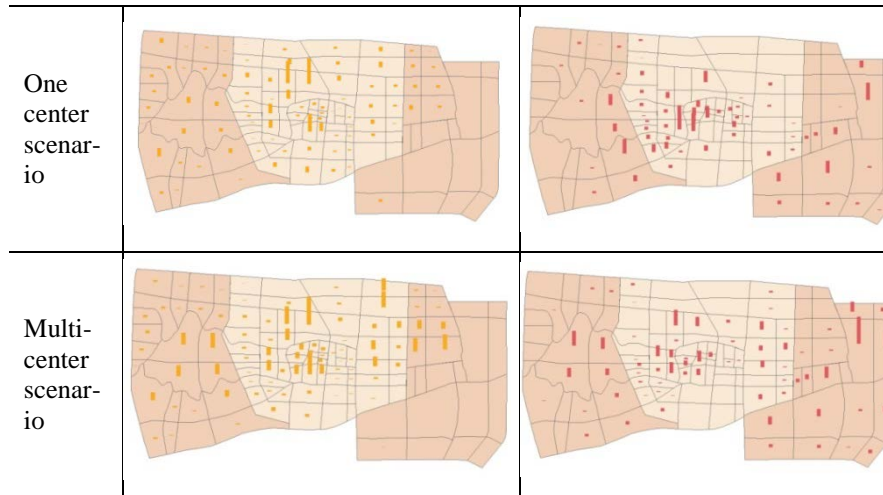|		
One center scenario		
Multi-center scenario		

Figure 10 Population and employment distribution based on TAZ in 2030 under Different Scenarios

3.3 Land Use Refinement

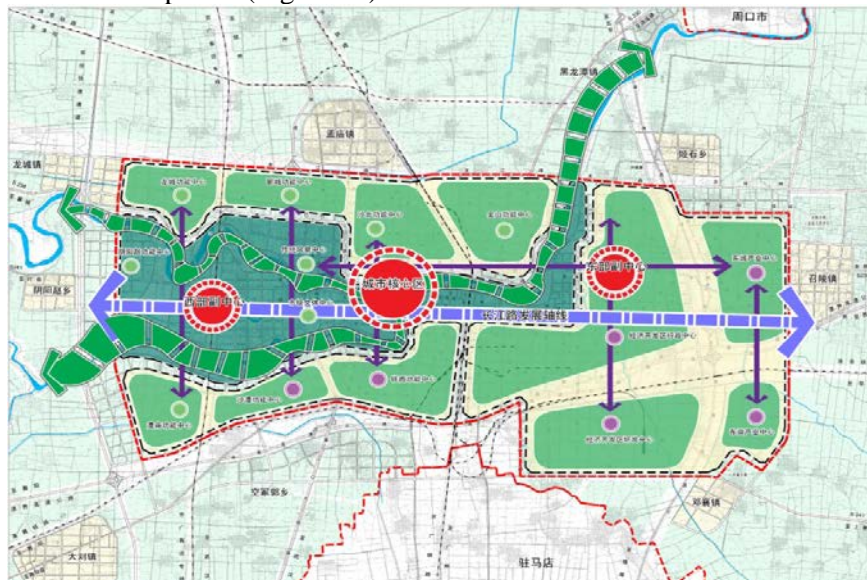From the perspective of spatial structure, the optimal land use option is cluster development (Figure 11).

Figure 11. Spatial structure of clusters

Under the cluster pattern, the adjustments were made to the land use allocations at a more detailed level by urban planners(Figure 12).
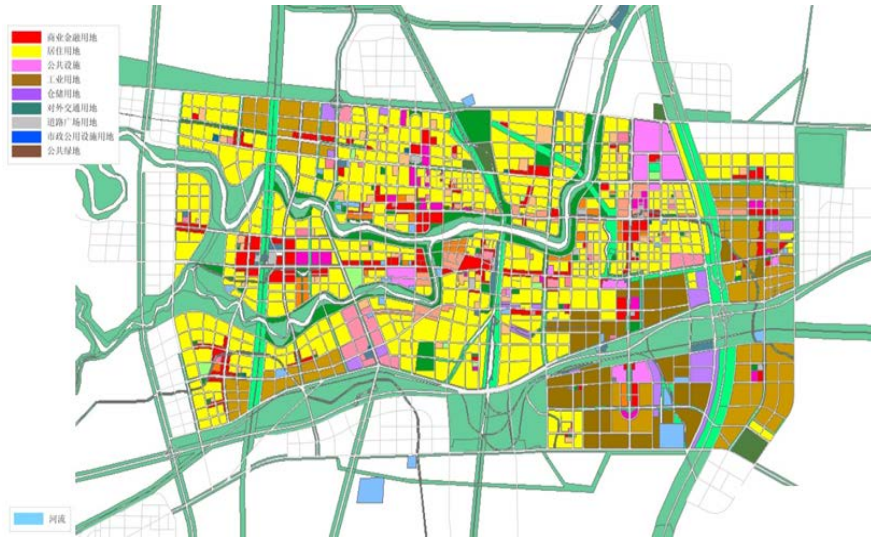

Figure 12. Land Use of Multi-center Scenario

3.4 Transportation Planning

Based on the refined land use from the multi-center scenario, three transportation policies were tested for year 2030 by giving different mode split:

- TP1: Slow Transportation Policy (Car 8%, Bus 15%)
- TP 2: Public Transportation Policy (Car 15%, Bus 30%)
- TP 3: Car Transportation Policy(Car 30%, Bus 15%)

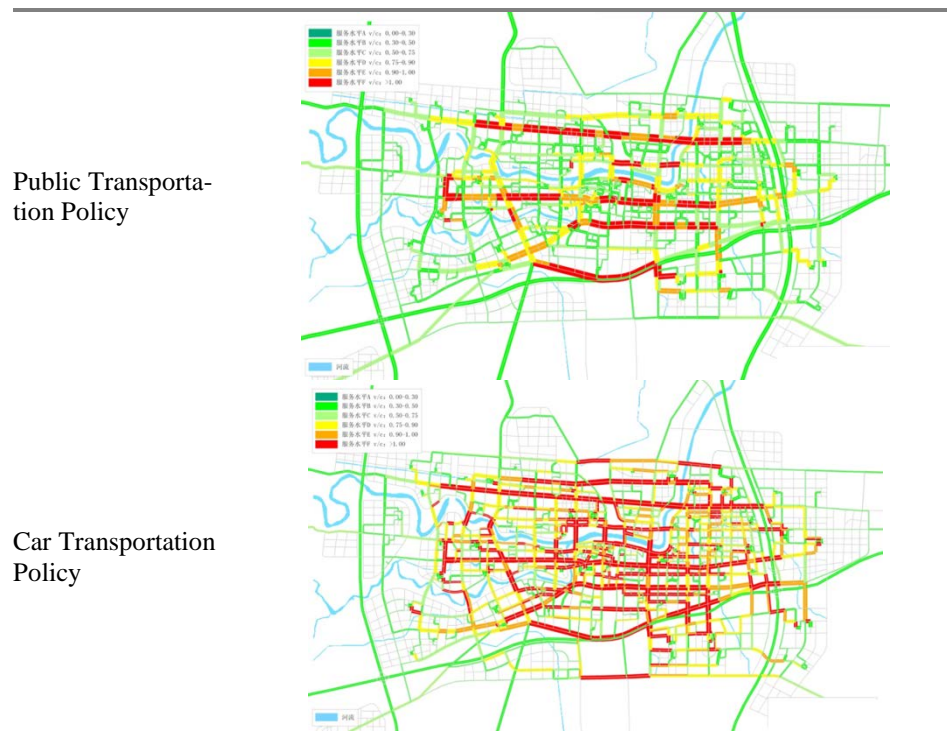Implement the traffic assignment, the results are shown in Figure 13.

Planning Year	2030
Slow Transportation Policy	

Figure 13. Traffic Assignment of Different Transportation Policy

Conclusions

LUTIPSS is a GIS based planning support system. It includes both land use planning and transportation planning. The concept of land use forecast in it is similar to that used in UPlan (Johnston et al, 2003) and is in line with the traditional land use planning procedures. It only requires the minimum data inputs and forecast the land use and travel demand caused by growth. It provides Chinese user interface, and thus can be learnt quickly by Chinese users. The biggest contribution of LUTIPSS to the modeling art is probably the transportation planning tools. To our best knowledge, LUTIPSS is the first PSS that provides network coding, four-step travel demand forecasting, and visualization. Its successful application in two cities demonstrates that it is a valuable planning tool in forecasting land use and its impacts on transportation.

Like UPlan, the weights LUTIPSS land use planning part heavily relies on experts' knowledge on the relative importance of the factors and the ranges of their impacts. It can be calibrated but at present works as a generalized tool. When it is customized to a specific city, a calibration is

strongly recommended. Similarly, the travel demand forecasting needs to be recalibrated. We understand that, compared with the functionalities provided by Cube, Emme, and TransCAD, TPM in LUTIPSS is very basic and coarse.

LUTIPSS is a very flexible framework. Both land use and transportation planning parts can be easily customized to meet special need for different cities. Our next step is to refine the two modules and build a feedback loop so that it can be used to evaluate the impacts of land use on transportation , and vice versa. We are also planning to do more sensitivity tests and develop a semi-automatic calibration procedure.

Acknowledgement

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