Traffic modeling in urban system based on RS improved Four-Step Model

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Abstract: the traffic modeling is very critical for traffic control/ management and urban planning. Numerous methods are proposed for traffic modeling, in which the four-step model developed well and applied widely to analysis the interaction between land use and transportation system. Four-step model comprised of four parts: trip generation, trip distribution, mode assignment and route assignment. And the first step, determination of the traffic demand, is very important to the accuracy of the prediction. Conventional method defined generation rate (GR) of traffic zones to measure the traffic demand, and they are usually determined according to the land usage of traffic zones by which the zones with the same land usage maintained the same and generation rate. It's reasonable and has been widely used due to the fact the land usage reflect the intensity of human activities. However, in urban system due to the complex activities in land use zones, the zones with the same land use status are possible to suffer different intensities of human activities. As the date limitation, the problem of how to measure the traffic demand in urban system is still unaddressed. Towards this problem, this paper proposed a remote sensing (RS) based four-step model to assist the production of generation rate. In particular, the RS indexes NDVI, MNDWI and NDBI were employed to identify the GR and AR. First, by statistic analysis the NDVI and MNDWI were used to extract the areas where there were no traffic demand, for example the water body and the land covered by plants. Second, the NDBI index was analyzed to reflect the degree of building density by the membership function. The membership of belonging to built-up area was then used to assist the determination of GR and AR. By comparing conventional GR and the GR of proposed method, we found the proposed model reflected the land use intensities and the outcome was finer than that of conventional method. The integration of RS and traditional traffic modeling can improve the accuracy and address the problem of data limitation in traffic modeling which would be meaningful.

INTRODUCTION

The traffic modeling is critical in the urban system recently. As the increase of car ownership and the frequency of travel, the transportation problems, including congestion, excessive emission of pollution airs, emerged especially in urban areas where the human activities are intensive. To predict the traffic flow and find out the road network with excessive traffic flow or evaluate how much traffic the new road will carry, the traffic modeling is necessary for the urban planning, amelioration of traffic conditions, promotion of living condition of the urban areas.
So far, numerous models are proposed for the traffic modeling, for example, FSM, Activity-based Model, Fratar Model and so on (McNally and Rindt, 2008; McNally, 2000; Levinson and Kumar, 1996). Among all these models the FSM is the most famous model that has been put into practice well and fully (Balling et al., 2004; Greenwald, 2006). Currently, the transport modeling practice is dominated by the FSM (Davidson, 2011). FSM was first developed in the 1950's (Patterson and Bierlaire, 2007), notable in the Detroit Transport Study in 1953 and the Chicago Area Transport Study in 1955 (Weiner 1984). It has been integrated with land use planning due to the fact that the first step of transportation generation is determined by the land usage. Balling (2004) used it in the process of land use and transportation optimization as the tool to evaluate/predict the condition of planned transportation system in the background of a certain land use planning. Greenwald (2006) addressed the relationship between land use, destination selection and travel mode choice by using the FSM.

However, there still are some limitations in FSM. For example, the demand of transportation for a certain transportation analysis zone (TAZ), which is not defined by consistent geographic scales but zones borders often correspond to major streets in a particular region under analysis (Greenwald, 2006), is conventionally measured by the land usage and the zones with the same land usage were assumed to maintain the same traffic demand in FSM. To some extent, it's reasonable and meaningful due to the fact the land usage reflect the intensity of human activities and been widely used. However, in urban system as the complex activities in land use zones, the zones with the same land use status are possible to suffer different intensity of human activities. For example, the residential land with different volume fraction will provide much various capacities of housing and the demand for travelling; the industrial land with different companies and factories will also provide different number of employment and travelling demand. However, as the date limitation it's hard to survey the actual capacity of each TAZ in urban areas. Therefore, the problem of how to measure the traffic demand in urban system is still unaddressed and the method of referring to land usage is existed and applied widely.

As the development of the remote sensing technique, the land use information in a large extent with accuracy can be captured. Without doubt, the spectral information can reflect the intensity of the human activities in some extent and the accuracy would be guaranteed. Since Rouse (1973) proposed the NDVI, numerous normalized difference indexes emerged in the RS studies due to the fact that they are easy to be used and calculated. The main principle of these indexes is maximizing the difference of the strongest reflection band and lowest reflection band of the certain land usage, and then the interested land usage can be enhanced while the others are restrained. Therefore, this paper proposed a remote sensing (RS) based four-step model to assist the first step in FSM where the generation rates of TAZs are determined. In particular, the RS indexes normalized difference vegetation index (NDVI), modified normalized difference water index (MNDWI) (Xu, 2006), and normalized difference built-up index (NDBI) (Lee et al, 2009) were employed. The NDVI and WNDWI were used to extract the area where there are no traffic demand, for example water body and vegetation. Then, the fuzzy membership function of NDBI was established to describe the degree of building density, with which and land usage the generation rates of TAZs can be determined. The fuzzy membership function is defined according to the analysis of NDBI and the suggestions of experts. By the fuzzy membership, the TAZs with the same land usage but different building densities would maintain different generation rates which would be more reasonable.

The rest of the paper is organized as follows. In the second part the improvement of generation rates by RS indexes is proposed where the definitions and the functions of the indexes were stated; and then the process of extraction of areas with no traffic demand and calculation of membership of building density from NDBI are proposed. In the third part, the Futian district in Shenzhen, center of Pearl River Delta, south China, was selected as case study area to conduct the traffic modeling by FSM, and the results of conventional FSM and RS-improved FSM were compared according to the traffic surveyed points. The last part discussed the proposed method, and the potential applications in future are discussed.

METHODS

Four-step model

FSM consists of separate models which calculate and distribute travel behaviors by transportation analysis zone and the process of FSM can be expressed as follows.

(1) Trip generation determines the frequency of origin or destination of trips in each zone which is usually identified as a function of land use, household demographic, or other socio-economic factors.

To implement this step, the study area is divided into geographic units, TAZ, by road lines. Information on land use, population, and economic forecasts is used to estimate how many trips will be made from each zone. According to Balling (2004) the model of trip production of zone i,P_i, is written as Equation 1.

$$P_i = f(x^i) \quad (1)$$

where x^i is a vector of characteristics for segmentation i. In our work, land use type and area of segmentation comprises vector x^i. By conventional model, Equation 1 can be concretely rewritten as Equation 2:

$$P_i = Area_i * GenerationRate_i \quad (2)$$

where $GenerationRate_i$ is mainly determined by the transportation demand of land use.Current road transportation data and experts' suggestions for generation rates were determined according to existing studies (Balling, 2004) and land use characteristics in Shenzhen (Table 1)

Table 1 Generation of each land use plot.

Land use type	Generation rate
Cropland	0.760
Garden plot	0.700
Forest	0.600
Pasture land	0.600
Built-up land	16.447
Water body	0.000
Unused land	1.000

(2) Trip distribution links the end of the trip to the generation step (McNally, 2000). Matrix reproduction is related to the characteristics of the production zone *i*, the characteristics of the attraction TAZ *j*, and the characteristics of the "separation" or "cost" of travel between TAZs *i* and *j*. This principle is expressed as Equation 3:

$$A_{ij} = \frac{P_i * A_j}{d_{ij} * con} \quad (3)$$

where A_{ij} denotes the trips from TAZ *i* to TAZ *j*, P_i is the total number of trips generated for TAZ *i*, A_j is the total number of trips attracted to TAZ *j*, d_{ij} is the distance or other measure of spatial separation, and *con* is a constant. In addition, A_j can be denoted as the multiple of the area of TAZ *j* and its attraction rate, which is determined according to literature reviews and suggestions from planers and experts.

(3) Mode assignment splits the different modes of transport to trips between a given origin and destinations designed by the first two steps**.** In our work, the model adopts a universal mode for simplicity.

(4) Route assignment assigns trips to specific paths from origin to destination. Numerous methods for assignment exist. In our work, the minimum path algorithm (MPA) was employed to assign trips. The trips from TAZ *i* to TAZ *j* was divided into routes according to the distance of routes calculated by the MPA.

Improvement of generation by RS

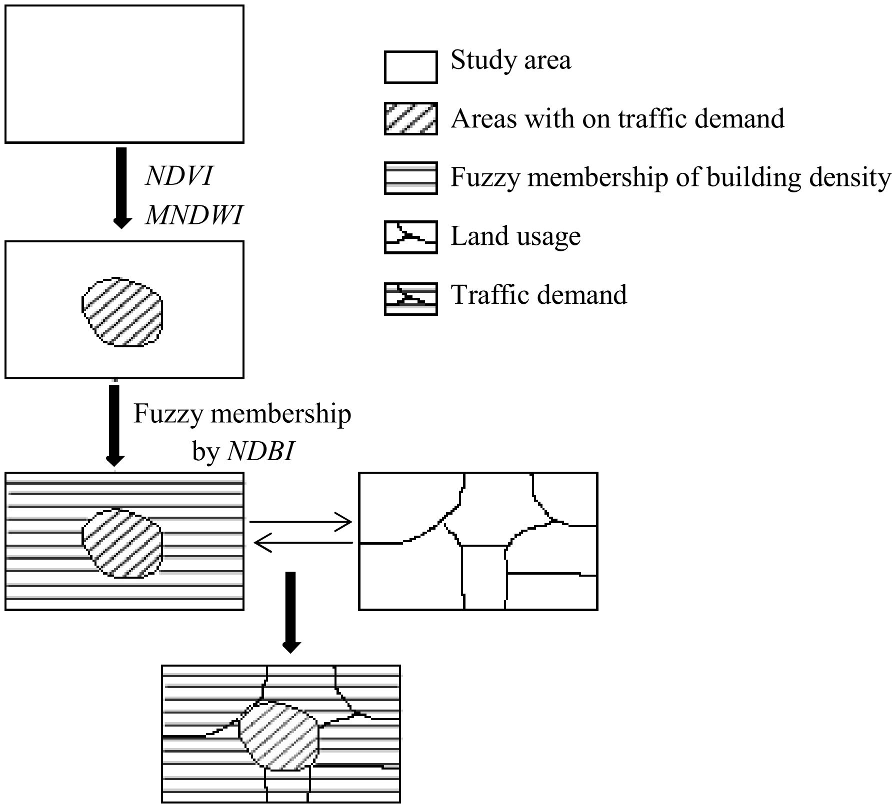


Figure 1 the framework of improvement of retrieving traffic demand

The framework the improvement is represented in Figure 1. Firstly, the NDVI and MNWI were employed to extract the areas where there is no traffic demand. And the TAZs which have been screened by NDVI and MNDWI were retrieved the membership of building density according to the membership function and NDBI. Finally, according to the land usage and membership of building density the traffic generation rate of TAZ can be retrieved.

Extraction of areas with no traffic demand: NDVI is the index that used to extract the vegetation areas and is defined as Equation 4.

$$\mathrm{NDVI} = \frac{NIR-VIS}{NIR+VIS} \quad (4)$$

where VIS and NIR stand for the spectral reflectance measurements acquired in the visible red and near-infrared regions, respectively. By design, the NDVI varies between -1.0 and +1.0. The areas with dense vegetation will tend to positive NDVI values (say 0.3 to 0.8) while clouds and snow fields will be characterized by negative values of this index (Mao et al, 2012).

The MNDWI is derived from the Normalized Difference Water Index (NDWI) defined by Mcfeeters (1996) by the use of middle infrared instead of near-infrared The NDWI is expressed as Equation 5:

$$\mathrm{NDWI} = \frac{Green - NIR}{Green + NIR} \quad (5)$$

where Green is a green band such as TM band 2, and NIR is a near infrared band such as TM band 4. While as the enhanced water information using the NDWI is often mixed with built-up land noise and the area of extracted water is thus overestimated, Xu (2006) proposed the MNDWI based on the NDWI, which is calculated as Equation 6.

$$\mathrm{MNDWI} = \frac{Green - MIR}{Green + MIR} \quad (6)$$

where MIR is the middle infrared band. The MNDWI can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise which is very suitable for the areas with built-up lands.
By the statistic analysis, the thresholds $\varepsilon_{NDVI}, \varepsilon_{MNDWI}$ can be defined. If the *NDVI* value of land use grid (i,j), $NDVI(i,j)$, larger than ε_{NDVI}, the grid can be denoted as “vegetation” with no traffic demand. The same process is done to *MNDWI.* The areas of vegetation and water body are no traffic generation which can be screened from the scale that need to calculate the generation rate. By doing this, the efficiency can be improved.
Determining the membership of building density by NDBI and fuzzy membership function: NDBI is the index that reflects the built up area and is calculated as Equation 7:

$$\mathrm{NDBI} = \frac{MIR - NIR}{MIR + NIR} \tag{7}$$

Where MIR is a middle infrared band and NIR is near-infrared band. The NDBI ranges from -1 to 1, and according to the function when the index larger than 0 then the areas will be built up lands in theory. However, actually the threshold varies for different regions.
Numerous membership functions can be used in different applications. In this paper, the partly bell function was employed according to the suggestions and spatial statistic analysis which is expressed as Equation 8.

$$\mathrm{y} = \mathrm{gbell}(\mathrm{x}, \mathrm{a}, \mathrm{b}, \mathrm{c}) = \left(\frac{1}{1 + \left| \frac{x - c}{a} \right|} \right)^{2b} \tag{8}$$

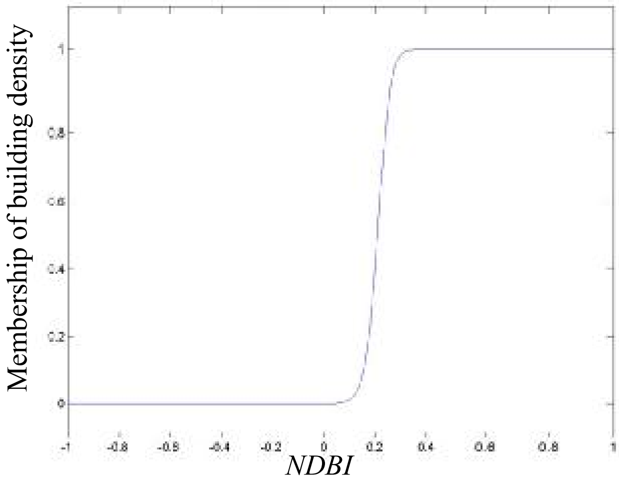


Figure 2 the fuzzy membership of building density according to *NDBI*
By the analysis, we found when *NDBI* ranged from 0.15 to 0.3 the land is mixed with buildings and other kind of land usages. As the *NDBI* approaching to the value of 0.3, the lands used to be built up land with enough buildings. To describe the characteristic of the *NDBI* and the building density, the parameters of bell function are denoted as: $\mathrm{a} = 0.64, \mathrm{b} = 14, \mathrm{c} = 0.87$. The expression is displayed in Equation 9, and the trend line is represented in Figure 2 where when *NDBI* larger then 0.3 the membership equals to 1, and when *NDBI* smaller than 0.15 the membership equals to 0, and the membership drastically varies between 0.15 to 0.3 indicating that the land use raster suffered higher fuzziness.

$$MerShip_{(i,j)}(NDBI_{(i,j)}, 0.64, 14, 0.87) = \left(\frac{1}{1 + \left|\frac{NDBI_{(i,j)} - 0.87}{0.64}\right|}\right)^{2*14} \quad (9)$$

Improved generation rates

Finally, by the operation between membership of building density and the land usage, the generation rates for all land use grids can be calculated (as Equation 10 shows). Conventionally, the generation rates are corresponding to land usages, and each land use plot maintains the same rate (as Equation 11 shows).

$$RG'_{(x,y)} = f'(Landuse_{(x,y)}, MerShip_{(x,y)}) \quad (10)$$

$$RG_{(x,y)} = f(Landuse_{(x,y)}) \quad (11)$$

RESULTS

Futian district is in the center of Shenzhen, and is one of the four districts that have been firstly developed as special economic zone in Shenzhen. The location of Futian district in Shenzhen is represented in figure 3 (c). The Landsat MT images in year 2006 with the resolution 30m by 30m were used to conduct the RS indexes.

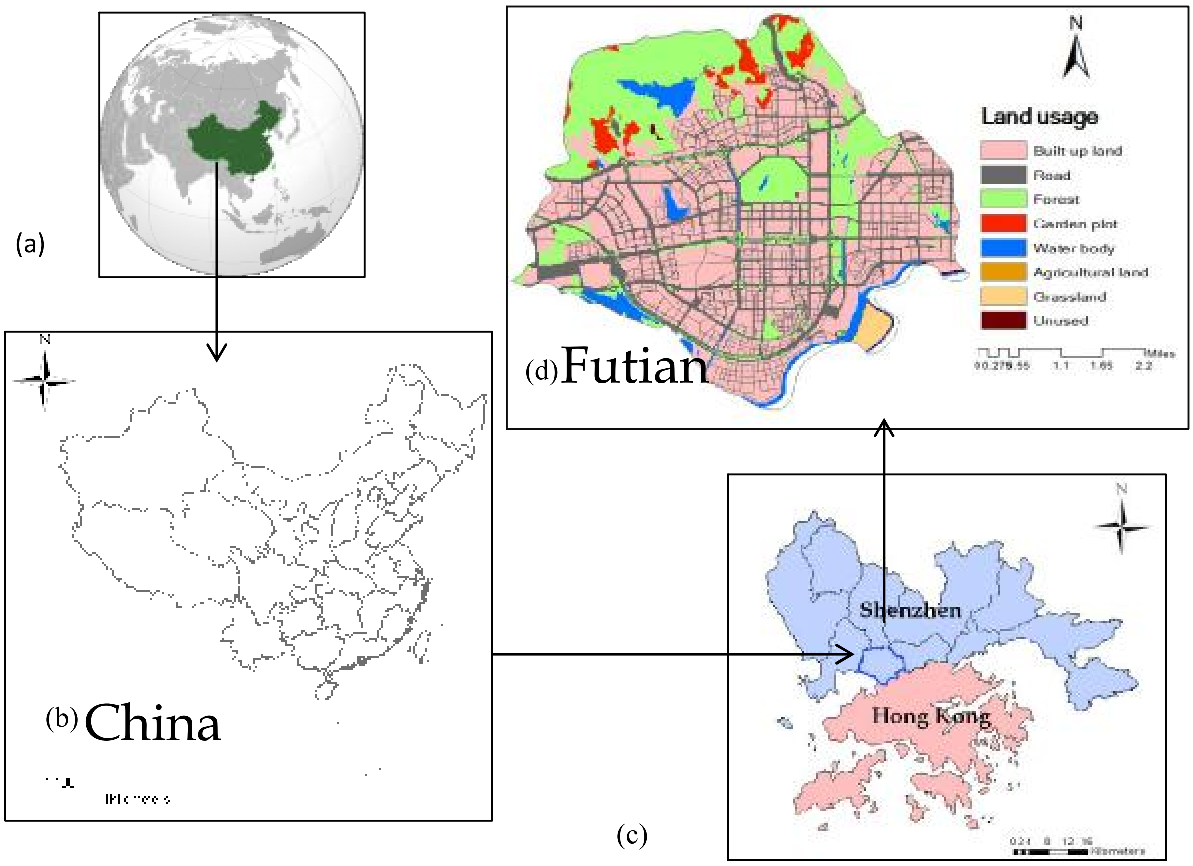


Figure 3 the location of study area a. the location of China in word; b. the location of Shenzhen in China; c. the location of Futian in Shenzhen and the spatial relationship with Hong Kong; d. the land use map of Futian District.

RS index: from the spatial distribution of MNDWI (Figure 4), we found the water body in Futian is around the boundary which is close to Hong Kong named as Shenzhen Bay. The place with higher MNDWI in the top of map is Merlin reservoir, and the other large area of water body is developed as golf course. The value of MNDWI can reflect the distribution of water body in Futian. According to the MNDWI map as well as the suggestions of experts, we selected 0.3 as the threshold suggesting that when the MNDWI value of the grid larger than 0.3 then we can defined the grid as water body. The MNDWI can reflect the traffic demand better than land usage. For example, the water in golf course was classified as "built-up land" in urban areas. While in fact the water body in golf course did not provide any traffic demand.

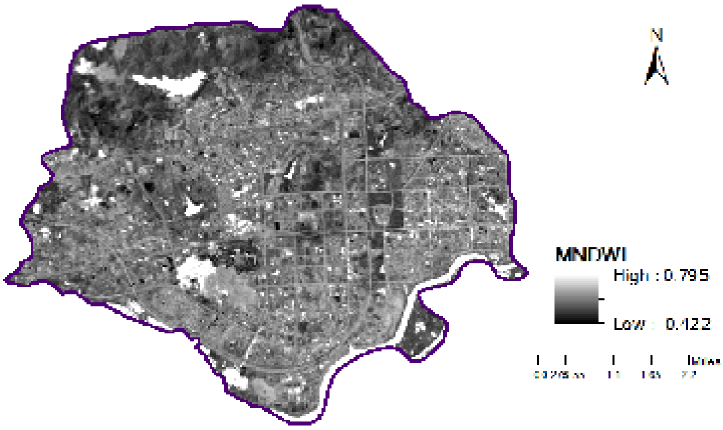


Figure 4 the MNDWI index of Futian District

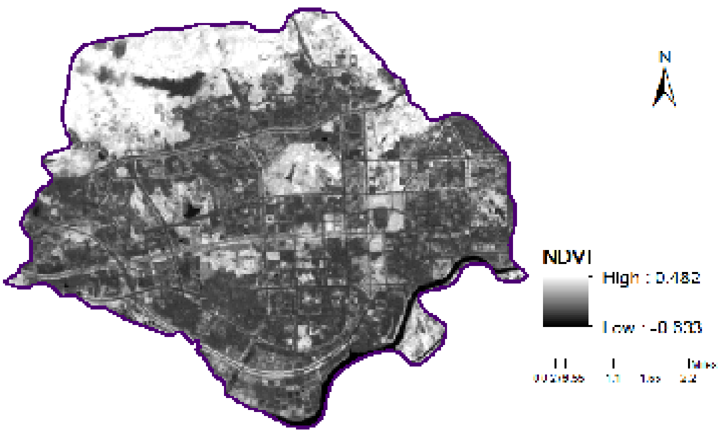


Figure 5 the NDVI index of Futian District

From the spatial distribution of NDVI (Figure 5), we found the high value of NDVI is concentrated on the top and boundary of the district. Some grids in the center of the district with high value tend to be the park or green belt in urban area. Even if these lands were denoted as built-up land, they did not provide any traffic demand.

From the spatial distribution of NDBI (Figure 6), we found the top of district tended to be non-built-up area with the lowest NDBI value. The other areas suffered higher NDBI values where some lower NDBI values interspersed. By the NDBI distribution map, both the buildings and road line can be distinguished.

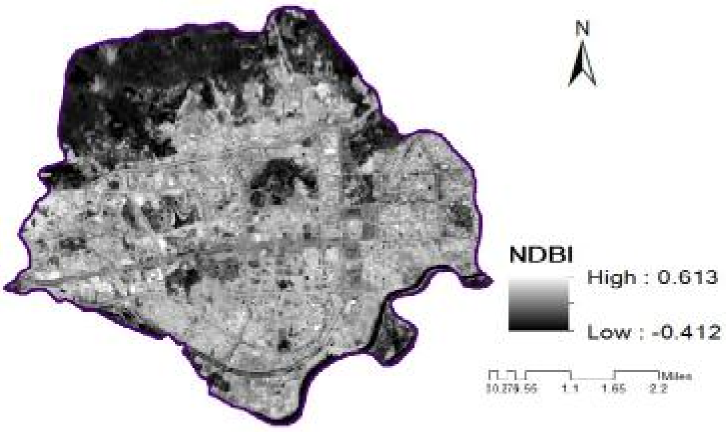
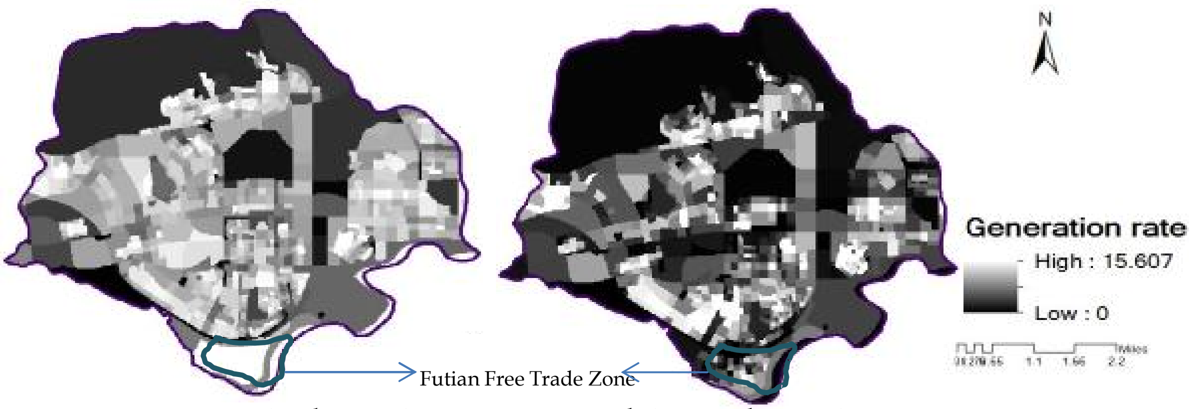


Figure 6 the NDBI index of Futian District

Improved generation rate: conventionally, the land usages corresponded to the generation rate. In our work, NDVI, MNDWI and land usages are considered to identify the generation rates. Figure 7 (a) is the generation rate by conventional method, and (b) is the generation rate retrieved by our proposed method. From the map, we found that (b) is finer than (a) where the litter differences of the land use can be reflected. Taking Futian Free Trade Zone as an example, it was denoted as the same land use type in the land usage map (see Figure 7 (a)) and then the generation rates were the same for the whole zone when use conventional method, while by RS date we can find that differences of building density in Futian Free Trade Zone (see Figure 7 (b)). Therefore, we can say the proposed method can retrieved the appropriate traffic demand.



a. conventional generation rate   b. improved generation rate

Figure 7 the generation rates of TAZs in Futian District

Traffic modeling: by the improved the generation rates of study areas, the traffic demand of Futian district can be predicted. As figure 8 shows, the west is suffered higher traffic flow while the east is underwent ease traffic condition. Also taking Futian Free Trade Zone as an example, we found that the traffic flows in Free Trade Zone were various.

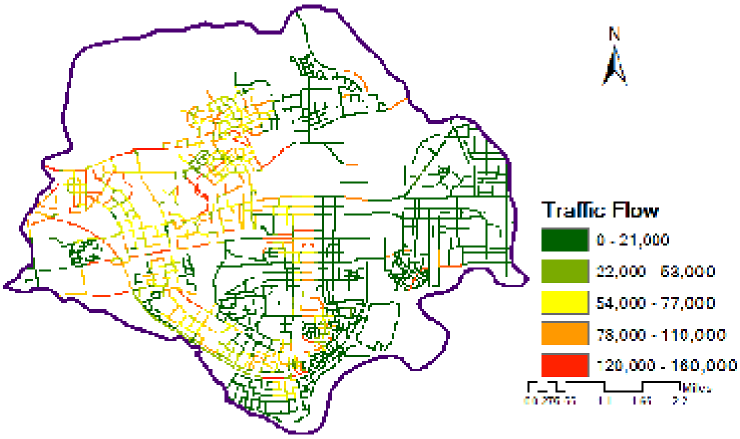


Figure 8 the predicted traffic flow in Futian district

DISCUSSION

The RS data maintains various land use information which can be used in numerous applications widely to assist the accuracy. This paper used NDVI, MNDWI and NDBI to assist the production of generation rate for the four-step model. By NDBI index, the differences in one land use type can be reflected and these differences made sure of the high accuracy in generation rate. As results, the accuracy of the outcome of FSM, traffic flow, also can be guaranteed in follow-up study.
As we know, the traffic modeling is very important in traffic control/ management and urban planning where our proposed method can be applied in future. Without doubt, the improved model can ensure the high performance, and the study in this paper is a basic study which will provide the support for other extensional applications related with transportation system.

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