OPTIMAL LAND USE ON THE NEIGHBOURHOOD AREAS OF METROPOLITAN RAILWAY STATION

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ABSTRACT

For the serious problems of transportation and land use following the rapid urbanization, motorization and urban spatial structure change, people come to realize the necessity of TOD mode for urban development. As the best practices area of TOD mode, the rail transit station areas' land use optimization research is very important for economical intensive land use and urban sustainable development. The study developed a multi-objective decision-making model to explore how to optimize land use nearby rail transit station area, in order to assist the urban planners and policy makers to design appropriate floor area ratio (FAR) of different land uses. This study took the 500 m-radius of the rail station as the research areas, based on the field interview, field survey, Shanghai national economic and social development statistics bulletin, Shanghai urban planning management technology regulations and Quickbird remote sensing images and so on, aiming at acquiring area of

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different land uses, building property, building density, rail transit modal split rate, trip generation rate, population, and so on. On the basis of previous research results, this study developed a multi-objective decision-making model based on TOD and sustainability concept, to explore the land use (this study focused on administrative land, residential land, and commercial-financial land due to the data restrictions) optimization from three objectives of maximizing rail transit ridership, promoting living-environment quality and balancing land use. The Wujiaochang station area, loushanguan road station area and Jiangyue road station area were selected as the three typical rail transit areas of public centre area, residential area, mixed area, and as the case studies to verify the model application and evaluate the current land-use conditions. The results showed that, compared to the TOD mode, the FAR optimization space of residential land nearby Wujiaochang Station and loushanguan road Station area was relatively small, but the administrative land and commercial-financial land needed major adjusting, especially the commercial-financial land; the land use intensity of residential land and commercial-financial land nearby Jiangyue road station area needed appropriate regulation, but the FAR of administrative land should be improved enormously. This study indicates that the multi-objective decision-making model is a quantitative and effective method for land use optimization, which could point the appropriate way for different land uses, and which could provide scientific foundation and decision-making reference for planners and policymakers. Meanwhile, we must be clearly aware that the model is only a mathematical tool for scenario simulation and planning from reality, but in the actual planning and construction project, the planners and policymakers should fully consider the location, surroundings and a series of influence factors of rail transit station area before formulating land use planning of rail transit station area.

Keywords: transit-oriented development (TOD); rail transit station area; land use optimization; multi-objective decision-making model; floor area ratio (FAR)

1. INTRODUCTION

China has experienced rapid urbanization and industrialization in the past several decades. On one hand, urban land expansion catered to the socio-economic development and population growth, but on the other hand, it resulted in a series of increasing social costs such as traffic congestion and ecological degradation, as well as social and spatial integration. To combat the growing urban problem, planners and policy makers have paid a lot of effort and tried a number of ways and strategies to encourage people to use public transit and enhance mode share of transit. Among planning methods, transit-oriented development (TOD), first proposed by and American architect and planner with the name of Calthrope (1993), has recently gained attention and presented a sustainable urban development strategy by creating an efficient integration of land use and public transit. The land use patterns of TOD, especially near transit centers such as rail stations (Sung and Oh, 2011), mainly emphasize high-density development to increase transit ridership, mixed land use to promote accessibility to activities, and pedestrian-friendly urban design to entice people step out of their cars and embrace environment (Cervero and Kockelman, 1997).

The TOD planning strategy is commonly identified with the US and European nations. Many American cities such as San Francisco and Atlanta have incorporated TOD concepts, and such planning and policy concepts as both the Urban Village of England and the ABC Policy of the Netherlands are also well-known TOD policy cases. Recently, some Asian governments like China, Hong Kong and Korea have also begun to examine the possibility of implementing these concepts, in order to address their urban problems (Cervero and Day, 2008; Cervero and Murakami, 2010; Lin & Shin, 2008). Automobile-based development strategies can cause urban sprawl and suburbanization, increasing commuting distances and reducing land use efficiency, while transit systems can potentially promote more efficient resource usage, deliver congestion relief, reduced energy consumption, air quality improvement for its high capacity, reliability, comfort, and positive image (Kim et al., 2007), especially the rail transit.

As the most important component of rail transit, the rail station areas are TOD area. At present, numerous studies of rail station area focus on planning strategies (Cervero, 1994; Bernick and Cervero, 1997; Chang et al., 2000) The strategies discussed in these works were organized into three dimensions by Cervero and Kockelman (1997): enhancing development density; diversifying land use (mixed land use development); and increasing the use of transit. Although TOD planning strategies have been comprehensively discussed, a quantitatively analytical model for assisting planners remains less researched (Lin and Gau, 2006). Feng and Chang (1993), Kaneko and Fukuda (1999) developed a location control model for TOD to maximize transit system ridership, but only focused on economic efficiency and ignored the other aspects of sustainability. Lin and Gau (2006) developed a multi-objective programming model in reviewing development intensity regulations around subway station areas, but the practical value of the model is poor, for the solution of model is difficult and uncertain.

Therefore, in review of the early TOD planning model, this article developed a multi-objective decision-making model with a good practical applicability based on TOD and sustainability concept, to assist planners and policy-makers in planning for TOD area, and to explore the land use (this study focused on administrative land, residential land, commercial-financial land due to the data restrictions) optimization with floor area ratio (FAR) of different land use types as decision variable, from three objectives of encouraging rail transit ridership, promoting living-environment quality and balancing land use. As the three typical rail transit station areas of public centre area, residential area, mixed area, respectively, the Wujiaochang station area, loushanguan road station area and Jiangyue road station area were selected from the investigative 20 rail station areas and as the case studies to verify the model application and evaluate the current land-used conditions. We believe this decision-making model will be useful to assist the urban planners and administrators in the future land use planning of rail station area.

2. RESEARCH AREA AND METHODS

2.1 Study area

The study area is in the Shanghai Metropolis, which located between latitudes 31°22′N~31°27′N, and longitudes 120°52′E~121°45′E. The present administrative boundaries of Shanghai Metropolis consist of the city proper, suburban districts, and Chongming County. Therefore, it covers an area of 6450 km2, with a total of more than 23 million residents as of 2011. Although this area accounts for only 0.05% of China's territory, it plays a very important role in this country's economy. In 2008, it contributed 4.6% to total GDP in China (Zhang et at., 2011).

With 420 km of total urban railways under operation as of 2011, the city of Shanghai has one of the most advanced and extensive transit systems in the world. The first urban heavy rail line of Shanghai opened in 1995; as of June 2011, the city of Shanghai has 11 operating urban railway lines. To study the land use optimization of TOD area, the study focuses on the rail station areas within a 500 m-radius of each rail station. 20 typical rail stations were chosen for the study out of total 275 stations, and covered the major types of rail station area (including public center area, residential area, and mixed area) of Shanghai city and different spatial location divided by Inter ring road, Mid-ring road and Outer ring road. Figure 1 shows the railway networks, and the spatial distribution of the selected 20 stations with 500 m radius circles of Shanghai.

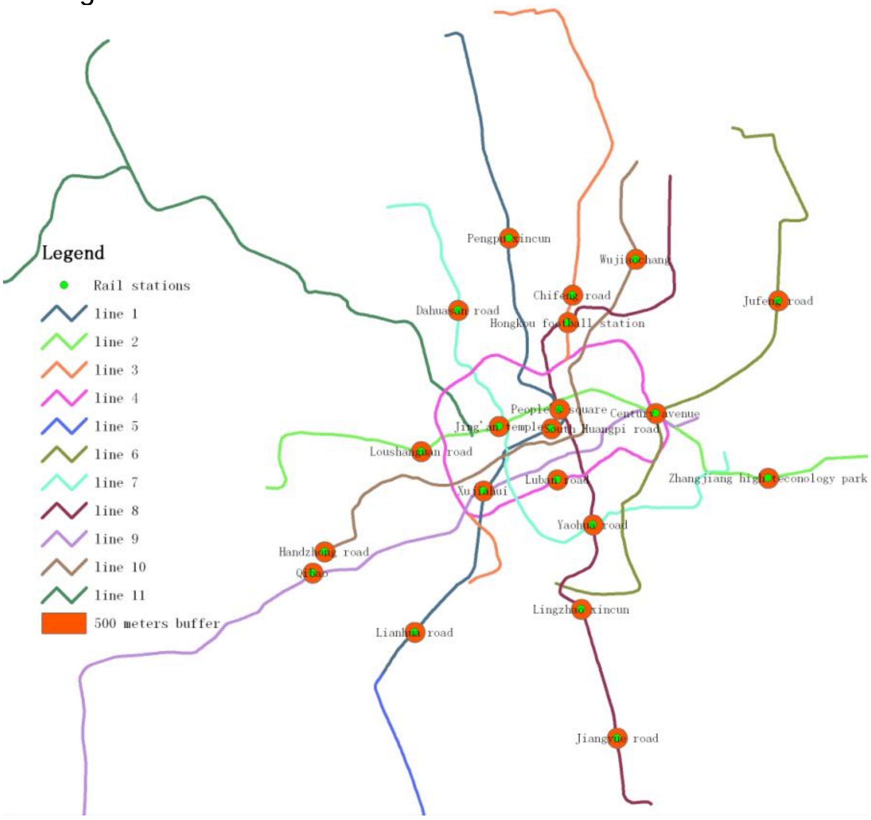

Figure 1 –Railway networks and spatial distribution of the 500 radius circles around the selected 20 stations in Shanghai.

The public centre area aims to enhance development intensity, and increase rail transit ridership, therefore, this type area focuses on the first objective mentioned below. Generally, the residential area pays more attention to living environment quality, so the primary goal of this kind of area is the second objective mentioned below. The mixed area emphasizes the balance of land use, so the third objective mentioned below is the development tendency of this kind of area.

2.2 The multi-objective decision-making model

This model, based on the TOD and sustainability concept, focuses on three major objectives. The first objective is to maximize rail transit ridership, which will improve both rail transit operation and resource utilization efficiency and help economic sustainability. The land use intensity around station areas is a critical factor in increasing mode share of rail transit. The second objective is to promote the living environment quality around station areas. Municipal service facilities play an important role in determining living environment quality, which is helpful for environmental sustainability. Finally, the third objective is to balance land use, which will reduce volume of traffic, and help the social sustainability.

2.2.1 Basic assumptions

The multi-objective decision-making model is based on the following assumptions:

(1) The area of different land use types in each station area is given, but the development intensity for different land use will be decided by the model.

(2) All rail transit riders within the 500 m-radius of each rail station use this station to leave.

(3) According to the city land classification standards of China, this study focuses on FAR optimization of administrative land, residential land, and commercial-financial land.

2.2.2 The decision variables

In this study, FAR of different land uses, as the control index of land use, was defined as the decision variables in this model.

2.2.3 Objective function

The first objective is to maximize rail transit ridership, which is formulated as follows:

$$Max\ Z_1 = \sum_i \left(L_i^r \times X_i^r \times T_i^r \times k_i^r \right) + \sum_j \left(L_j^c \times X_j^c \times T_j^c \times k_j^c \right) \quad (1)$$

In formula (1), Z_1 is the number of rail transit ridership, which is estimated based on floor space, L_i^r is the area of residential land *i* (ha), X_i^r denotes the improved FAR for the residential land, T_i^r is the trip generation rate for the residential land *i*, k_i^r is the rail transit modal split rate for the residential land *i*, L_j^c is the area of public facilities (This paper mainly refers to administrative land and commercial-financial land) j (ha), X_j^c denotes the FAR for public facilities *j*, T_j^c is the trip generation rate for the public facilities *j*, k_j^c is the rail transit modal split rate for the public facilities *j*.

The second objective is to maximize the ratio of municipal service facilities for residential, administrative and commercial-financial floor space, which is formulated as follows:

$$Max\ Z_2 = \frac{L^m}{\sum_i L_i^r \times X_i^r + \sum_j L_j^c \times X_j^c} \tag{2}$$

In formula (2), Z_2 measures living-environment quality. Increasing Z_2 indicates more municipal service facilities per area of floor space, thus, improved living quality. L^m is the area of municipal service facilities, including parks, parking lots, roads, schools and so on.

The third objective is to balance land use based on aim station area (relatively perfect station area), which is formulated as follows:

$$Min\ Z_3 = \left| \frac{\sum_i L_i^r \times X_i^r + \sum_j L_j^c \times X_j^c}{L} - \overline{A} \right| + \left| \frac{\sum_i L_i^r \times X_i^r + \sum_j L_j^c \times X_j^c}{L^e} - \overline{B} \right| \tag{3}$$

In formula (3), Z_2 measures land use balance. *L* is the area of 500 radius circles around station, $\overline{A}$ is the ratio of floor space for residential, administrative and commercial-financial to total area of aim station area, $\overline{B}$ is the ratio of floor space for residential, administrative and commercial-financial floor space to municipal service facilities of aim station area.

2.2.4 Constraints

The bounds of FAR, for residential, administrative and commercial-financial, according to the previous research (Lin and Gau, 2006), are limited as follows:

$$f_i^r \le X_i^r \le 1.4 f_i^r \tag{4}$$

$$f_j^c \le X_j^c \le 1.4 f_j^c \tag{5}$$

In formula (4) and (5), f_i^r, f_j^c is the lower bound of FAR for residential land and public facilities, and the upper bound of FAR for residential land and public facilities is 1.4 f_i^r and 1.4 f_j^c, respectively.

The restriction of floor space, the relationship between residential land and public facilities in station area, are formulated as follow:

$$\sum_i L_i^r \times X_i^r \Big/ \sum_j L_j^c \times X_j^c = a \tag{6}$$

Formulae (6) represents the given development goals of the station area. When a station area emphasizes residential function, such as a residential area, a will be equal or greater than 1. Meanwhile, when a station area aims to be an administrative and commercial-financial centre, a will be less than or equal to 1.

The constraints of current situation of living-environment quality. Taking per capita municipal service facilities and the ratio of floor space of education, science, culture and public health to floor space of residential land as lower bound, to improve the current living-environment quality.

$$\frac{L^e}{\sum_i \frac{L_i^r \times X_i^r}{m_i^r}} \geq d_e \tag{7}$$

$$\frac{\sum_i L_i^c \times X_i^c}{\sum_j L_j^r \times X_j^r} \geq \lambda \tag{8}$$

In formula (7), m_i^r is the area of per capita residential land, d_e is area of per capita municipal service facilities, λ is the ratio of current floor space of education, science, culture and public health to floor space of residential land.

In addition, when we calculated one of the objectives, the other objectives will become constraints.

From the above descriptions, the multi-objective decision-making model is presented as follows:

Objectives: Max Z_1; Max Z_2; Min Z_3.
S.t. formula(4)-(8); formula (1)/(2)/(3); where X_i^r , X_j^c ≥0.

2.3 Data collection and parameters for model

The area of different land use types was measured by six research assistants who traced building footprints taken from Google Earth, Quickbird remote sensing image and field survey. The rail transit modal split rate for the residential land and public facilities was 8.1% and 14.3%, which were taken from investigated data and average level of Shanghai metropolitan.

The trip generation rate for the residential land and public facilities was 2.21 and 3.32, according to average values of Shanghai city.

Xujiahui station, Jufeng road station and Hongkou Football station area were designated as the aim station area of residential, public center and mix area, for their successful development, friendly living environment and mixed land use, respectively. The $\overline{A}$ and $\overline{B}$ of Xujiahui station area were 1.98 and 5.58, which were calculated using investigated data. The lower bounds of the FAR were constrained at the present regulated values, meaning the FAR calculated and modified by the model, should be no less than the present regulated values for the acceptance of property owners. Meanwhile, the upper bounds of the FAR were constrained at the maximum FAR bounds assigned by the city government. d_e and λ was calculated based on investigation data and Shanghai national economic and social development statistics bulletin in 2009.

3. RESULTS AND ANALYSIS

Table 1 listed the optimized results of FAR of different land uses generated by the model. Regarding the Wujiaochang station area, located at the sub-CBD of Shanghai city, with strong focus on commerce-based development, it was showed that Wujiaochan station area with the objective of increasing rail transit ridership, the FAR of administrative and commercial-financial land recommended significant increases, especially the administrative land, which means this kind of area needs to provide more jobs, in order to avoid job-housing unbalance. Meanwhile, the FAR of residential land was also increased slightly from a TOD viewpoint.

Based on the overall development plan of Hongqiao business district in Shanghai city, the Loushanguan road station area was appointed as the typical residential area with the objective of enhancing living environment quality. From table 1, we found the administrative land recommended decrease; after all, the major function of this kind of area is residential community. The commercial-financial land recommended increase, in order to provider daily life needs for local residents.

Jiangyue road station area, located at the suburbs of Shanghai city, with adequate development space, where is most suitable to build large urban community with job-housing balance. The existing problems include insufficient jobs, dispersed residential pattern, and single land usage, and so on. The optimized results showed that the FAR of residential, administrative and commercial-financial land recommended appropriate increases, so as to improve land use mixed degree and reduce trip generation of this kind of area.

Table I –The optimized results of different land uses

Rail transit station	FAR	Residential land	administrative land	commercial-financial

				land
Wujiaochang	Current condition	2.60	3.20	4.61
	Optimized results	2.63	4.81	4.9
Loushanguan road	Current condition	2.49	5.23	4.08
	Optimized results	2.49	4.63	4.59
Jiangyue road	Current condition	2.31	2.12	2.67
	Optimized results	2.52	2.66	2.71

4. CONCLUSIONS AND DISCUSSION

As the sustainable urban development mode, TOD has gained wilder support worldwide in reducing automobile dependency and improving the sustainability of urban development in recent years. But there is a lack of study on how to practice the TOD theory to guide the land use planning. This article developed a multi-objective decision-making model based on TOD and sustainability concept, and took three station areas as case studies from three objectives to explore how to optimize the development intensity of major land uses, in order to assist urban planners and policy makers in designing appropriate floor area ratio (FAR) of different land uses in rail transit station area. To extend the considerations of sustainability, this model incorporated a multi-objective programming, which included not only the economic sustainability aspect of transit ridership, but also the living environmental sustainability aspect of service facilities and social sustainability aspect of balancing land use. The results showed that, compared to the TOD concept, the FAR's optimization space of residential land nearby Wujiaochang Station and loushanguan road Station area was relatively small, but the administrative land and commercial-financial land needed to be adjusted obviously, especially the commercial-financial land; the land use intensity of residential land and commercial-financial land nearby Jiangyue road station area needed appropriate regulation, but the FAR of administrative land should be improved enormously.

This study suggests that the multi-objective decision-making model is appropriate for land use optimization in different rail transit station area with high feasibility and reproducibility. But just like other models, the model developed in this study also has some shortcomings. Firstly, some linear equations applied in the model should be re-formulated into nonlinear equations, which would more closely reflect the realistic situation. Secondly, there exit some subjectivity in selecting aim station areas and constraints, though there is not any standards for defining ideal station area. Thirdly, some parameters in this model, such as trip generation rate, should be adjusted measures to local conditions in different cities. In addition, we must be soberly aware that this model is only a mathematical analysis tool to assist land use planning decision. But during the actual planning and construction process, the experience, subjective initiative and creative thinking of urban planners and policy-makers may be more important.

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REFERENCES

Bernick, M., Cervero, R. (1997). The Transit Village in the 21st Century. McGraw-Hill, New York.

Calthrope, Peter (1993). The next American metropolis: Ecology, community, and the American dream. Princeton Architectural Press.

Cervero, R. (1994). Transit-based housing in California: evidence on ridership impact. Transport Policy 3, 174–183.

Cervero, R., Day, J. (2008). Suburbanization and transit-oriented development in China. Transport Policy, 15, 315–323.

Cervero, R., Kockelman, K., (1997). Travel demand and the 3Ds: density, diversity, and design. Transportation Research D, 2 (3), 199–219.

Cervero, R., Murakami, J. (2010). Rail and property development in Hong Kong: Experiences and extensions. Urban Studies, 46, 2019–2043.

Chang, S.K., Cheng, S.T., Du, U.L. (2000). Transit-oriented strategies for urban development. Journal of Mass Rapid Transit Technology 22, 1–13 (in Chinese).

Feng, C.M., Chang, C.Y. (1993). A transit-oriented land use model. Transportation Planning Journal 22 (4), 429–444 (in Chinese).

Hyungun Sung, Ju-Taek Oh (2011). Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea. Cities, 28, 70-82.

Kaneko, Y., Fukuda, A. (1999). A location control model for transit oriented development. Journal of the Eastern Asia Society for Transportation Studies 3 (4), 137–148.

Lin, J., & Shin, T. (2008). Does transit-oriented development affect metro ridership: Evidence from Taipei, Taiwan. Journal of the Transportation Research Board, 2063, 49–158.

Sungyop Kim, Gudmundur F. Ulfarsson, J. Todd Hennessy.(2007) Analysis of light rail rider travel behavior：Impacts of individual, built environment, and crime characteristics on transit access. Transportation Research Part A, 41, 511-522.

Zhang H, Zhou L, Chen M, Ma W. (2011)Land use dynamics of the fast-growing Shanghai Metropolis, China (1979-2008) and its implications for land use and urban planning policy. Sensors, 11, 1794-1809.