The interactions analysis of functional zoning and land use, traffic behaviour in Shanghai, China

Feng-E Zhang Xinjun Wang Hailong Su Yinghui Yong

Fudan University, Shanghai, China

Email for correspondence: fudanqiwu@163.com

ABSTRACT: In the last three decades China has demonstrated remarkable progress in its urbanization as well as urban planning. Functional zoning is an important part in the statutory urban planning "general planning" in China. But now many literatures focuses on the ecological zoning and main-functional zone division, which is proposed by ecologists and economists in China, only few scholars have mentioned the functional zoning in urban planning, not to mention the effects of the function on traffic behavior and land use. Selecting 30 stations from 267stations in 11 rail transit lines in Shanghai , the study focuses on the urbanized rail station areas within a 500 m-radius of a rail station and examines the influence of functional zoning on land use factors like land use type, LUM, FAR and traffic behavior factors like trip mode, public transit ratio, travel duration. Data on density, floor area ratio, land use types(dwelling, office, commerce &finance, industry, education and others) , diversity and the public transit ratio was acquired from investigation and then calculated by Entropy formula, GIS，CAD and SPSS. Data on travel behaviors, the quality of transit service, and the characteristics of passengers was gained from questionnaires. And the data of bus lines, frequency, operation time, the quantity of transit stop etc. was gained from diverse databases such as Shanghai metro, ddmap and then checked through other public authorities and spot checks.This work will demonstrate the correlation of functional zoning and land use as well as traffic behavior, enhance viewpoints of general planning towards a more systematic, comprehensive insight of functional zoning development, and most importantly find a new way to both optimize land use and enhance the traffic design.

KEYWORDS: Functional zoning； land use； traffic behavior； LUM； FAR； public transit ratio

I. INTRODUCTION

Functional city was first clearly proposed in the 1933 Athens Charter produced by CIAM, one where land planning would be based upon function-based zones, referring to the living, working, recreation and circulation functions. Additionally it said that it was important to reduce commuting times by locating industrial zones close to residential ones and buffering them with wide parks and sports areas, which told us that it must have a close correlation between the functional zoning and travel behavior [1].However, in urban planning, planners and policy makers tend to treat it as a necessary but easy decision-making process, few scholars have mentioned the functional zoning in urban planning, not to mention the effects of the function on traffic behavior and land use

Solving land use in mega-cities is not possible without addressing transportation, converse is also true. In China, urban planning includes five stages (Figure1), conceptual planning, general planning, district planning, detailed planning (including regulatory planning and site planning). General planning and Detailed planning are statutory planning and others are non-statutory planning. Functional zoning is usually confirmed in general planning. Meanwhile, traffic planning is one topic of general planning.

Both functional zoning and traffic planning are necessary parts of urban planning, however, functional zoning takes precedence over traffic planning and specified land use. This paper discusses the correlation of land use and travel behavior as well as the correlation of functional zoning and travel behavior, and then explores associations between functional zoning and traffic planning to derive

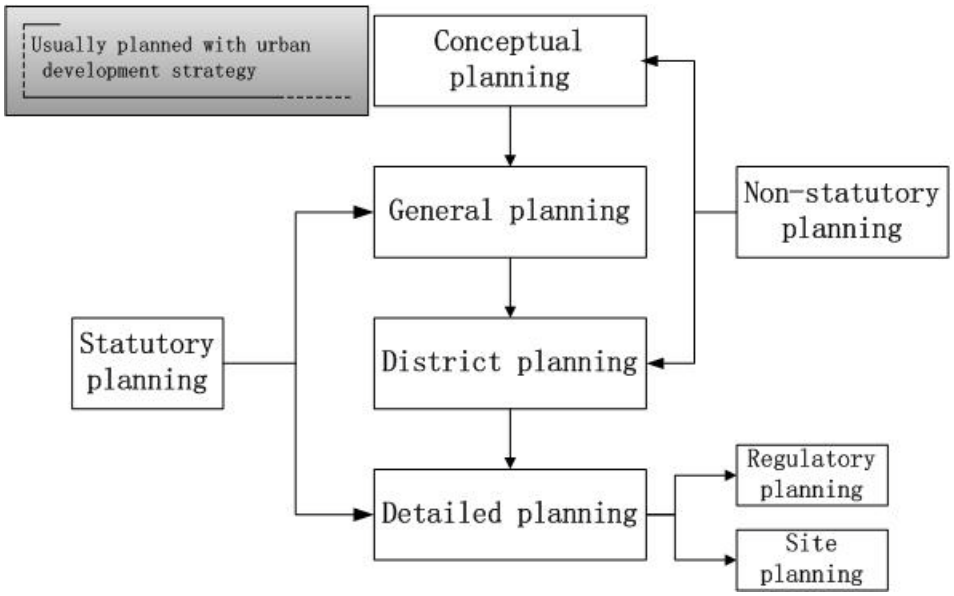

Figure1 Five stages of urban planning in China

visually easily comprehended indicators, assisting practitioners and policy makers in solving transportation.

II. RESEARCH DESIGN

A. Research Background

The study area is the Shanghai Metropolis, which located between latitudes 37 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. Shanghai is one of the most prosperous mega-cities in China. It accommodated 23 million residents within an area of 7037.50km^2 in 2011. As of 2010, it has 11 rail transit lines up to 410 km with 267 stations. It is expected that they will be 22 rail transit lines up to 936 km in Shanghai in 2020, meanwhile the passengers will reach to 14.9 million per day. In the process of urban sprawl, Shanghai has formed a “three rings” urban form. And in inner ring, there is a strict statutory regulation that FAR of residential land should be controlled in 2.5, FAR of commercial land in 4.0.

Zoning is a common way in planning. In America, the government has used zoning act to manage the land use for over 70 years. New York is the first city which passed the zoning act in 1916[2]. After Supreme Court of the United States adjudged that the zoning act did not violate the Constitution in 1926, the Department of Commerce passed A Standard State Zoning Enabling Act[3], giving a solid technical foundation for the extending of zoning act. In zoning act, the function zone and subzone, land use intensity and environmental criteria are concretely set up. With the emergence of traffic problems,

zoning act in many states supplement clauses, for example, Pittsburgh enhanced the density around bus stops and subway stations to encourage TOD programs in 1999, Chicago advocated TOD in 2004[2]. Put forward in 1980s by Peter Calthorpe, the concept of TOD began to enter many researchers' discussions after 2000[4] and partly used in the design of station.

A large body of literature discusses the correlation of land use and travel behavior [5,6,7,8]. The links between urban design and travel behavior are complex: the price of travel and geographic scale are important factors by which land use and design proposals influence travel behavior, and it is quite possible that persons choose their residential location based in part on their desired driving patterns [9]. In rail based TOD, a station characteristics appeared to be the most important dimension in affecting average weekday railway patronage, while place-specific factors are important in influencing railway patronage[10].By examining the impacts of relocation to outlying areas on job accessibility, commuting mode choice, and commuting durations, Cervero and Day[11]concludes that transit-oriented development holds considerable promise for placing rapidly suburbanizing Chinese cities on a more sustainable pathway. In case of Taipei, it is found that enlarging the upper bound of RFS (ratios of floor space to site space) can increase subway ridership, but at a cost of reducing social equity and living environment, it is not necessary to set the upper bound of the RFS greater than 70%, because subway ridership does not significantly increase[12]. Calthorpe and Fulton [13] recommend TODs should devote at least 20% of the land area to housing, with an average residential density of at least 10-15 dwellings per acre. Besides the land use (density, pattern, mix, scale etc.) and travel behavior factors, socioeconomic characteristics, activity participation variables, space–time accessibility are the considered factors that affect the relation of land use and travel behavior[14,15]. Based on the methodology used, the existing studies can be classified into three categories: simulation studies, explanatory analyses and multivariate statistical analyses.

Many literatures focuses on the ecological zoning and main-functional zone division, which is proposed by ecologists and economists in China [16,17,18]. But until now only few scholar have mentioned the functional zoning in urban planning [19], not to mention the effects of the function on traffic behavior and land use. Besides, planners and policy makers tend to treat functional zoning as a necessary but easy decision-making process. The later is the main focus of this research.

B. Research Boundaries,Data and Methodology

To examine the relationship between functional zoning, land use and travel behaviors, the study focuses on the urbanized rail station areas within a 500 m-radius of a rail station in the city of Shanghai. Figure2 shows the 30 stations selected from 267stations in 11 rail transit lines. They are selected for three reasons, firstly, the stations are distributed in the inner ring (10), inner-middle ring(7),middle-outer ring(6) and outer ring(7) of Shanghai; secondly, the stations are distributed in the six function zones(residential, commercial, industrial, hub, university and mix) ; lastly, the selected stations should be typical and agreed by experts from different research areas like transportation engineering, urban planning, environment science, social science and economics.

Data on density, floor area ratio, land use types(dwelling, office, commerce &finance, industry, education and others) , diversity and the public transit ratio was acquired from investigation and then calculated by GIS，CAD and Excel.

Data on travel behaviors, the quality of transit service, and the characteristics of passengers was gained from questionnaires (2076 valid samples). And the data of bus lines, frequency, operation time, the quantity of transit stop etc. was gained from diverse databases such as Shanghai metro, ddmap and

then checked through other public authorities and spot checks.

III. ANALYSIS RESULTS AND DISCUSSIONS

A. Land Use and Function Zones

Table 1 outlines the land use types and their coverage in different function zones. Residential zone has high value in dwelling, commercial zone has high value in both dwelling and commerce & finance, as well as office, industrial zone has high value in industry and office, mix zone has high value in dwelling and office, as well as industry, university zone has high value in dwelling and education, hub

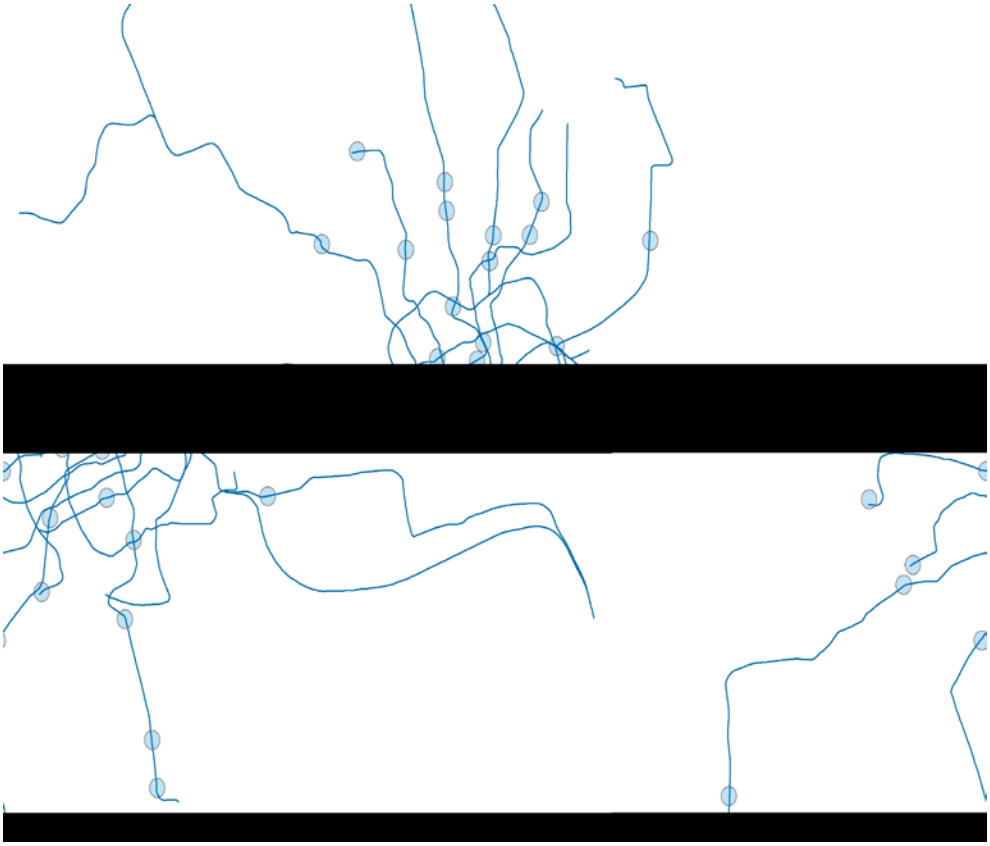

Figure 2 rail transit network and the select 30 stations with 500m-radius in Shanghai

area has very high traffic land, so its dwelling and other land types are not so high.

TABLE I. THE LAND USE TYPES OF FUNCTION ZONES

	dwelling	office	Commerce & finance	Industry	education	mix
Residential	38.54%	2.61%	3.02%	6.21%	3.67%	1.63%
Commercial	23.13%	8.51%	13.73%	0.12%	3.82%	3.09%
Industrial	5.01%	10.31%	1.89%	35.86%	0.09%	0.36%
Mix*	26.64%	10.73%	3.86%	9.25%	2.28%	0.67%
University	29.77%	1.90%	3.40%	0.03%	10.62%	0.06%
Hub	10.81%	6.60%	4.23%	9.74%	0.00%	1.01%

Mix*: zone with more than one obvious function

Dwelling is a very important land use type in urban planning. Except industrial zone and hub zone, other function zones all have high coverage in dwelling. Hub zone focuses on traffic facilities building, so it is normal that it doesn't have high dwelling, though the dwelling still ranks second. But why industrial zone has so low dwelling, it needs deep analysis in travel behavior.

Table 2 shows the land use mix degree of function zones. The land-use mix (LUM) index is computed via the following formula. As the level of land use mix increases, the index value becomes larger. The LUM index has been previously used by other researchers to represent the degree of land-use diversity for a given area [20].

$$Entropy = -\sum_{i=1}^{n} P_i Log_{10} P_i$$

$$\sum_{i=1}^{n} P_i = 1$$

n: the types of land use

P_i: the percentage of i-type land area

TABLEⅡ. LUM FOR SIX LAND USES

	Residential	Commercial	Industrial	Mix	University	Hub
LUM	0.40	0.46	0.37	0.46	0.35	0.36

Commercial zone and mix zone all have high LUM. Corresponding to Table 1, Commercial zone and mix zone all have three land use types that covered more than 8%, so their land use mix are higher than others. University zone has lowest LUM, because it has high value in dwelling and education, and the value of other land use types are low.

The function zones without high dwelling all have low LUM. It demonstrates that the mixture of dwelling and non-dwelling uses is found to better promote LUM, compared to the mixture between non-dwelling uses.

TABLEⅢ. FAR OF FUNCTION ZONES

	Residential	Commercial	Industrial	Mix	University	Hub
FAR	1.86	2.01	0.68	1.26	0.90	1.38

Table 3shows FAR of industrial zone is very low. Most of factories in China only have one floor and often locates in suburb where land resource is richer. University zone also has low FAR, no matter in suburb or downtown. Commercial and residential zones have high FAR. Commercial zone usually is designed as the center or sub-center of a city, a district where land resource is more precious, so it is often high-density. Residential zone is a main function in all districts no matter in downtown or suburb, due to the high population in megacity like Shanghai, its high FAR is obvious.

From the analysis above, we could find some general characters in functional zoning in urban planning of China:

- Residential, commercial, mix and university zones often have high value in dwelling.
- Commercial and mix zones have high LUM, while university zone has lowest LUM.
- Industrial zone has low FAR, while commercial and residential zones have high FAR.

We also get some policy and status which may connect to these characters:

- China is a country with high population; dwelling is a main function in all cities.
- Density, diversity and design (3D) are three principles of TOD. Commercial zone usually locates in the most prosperous area of a city or a district. In China, areas around stations in commercial

zone are often designed with the concept of TOD. So it has high LUM and FAR.

- Industrial transfer is an important strategy in urban development in China. The government advocates “suppress the second industry and develop the third industry” in big cities since 2001. So industrial zone usually locates in suburb. Because of the relative low technology content, many factories only have one floor and need many lands.
- University zone has high value in dwelling and education, and its LUM and FAR are low. There are two reasons. Firstly, in earlier urban planning, under the system of “job-housing balance” and “welfare-oriented public housing distribution (abolished in 1998)”, the dwelling house of teachers are built around university; secondly, in current, the planning of education resource in an area is an attraction of land sale and housing transaction.

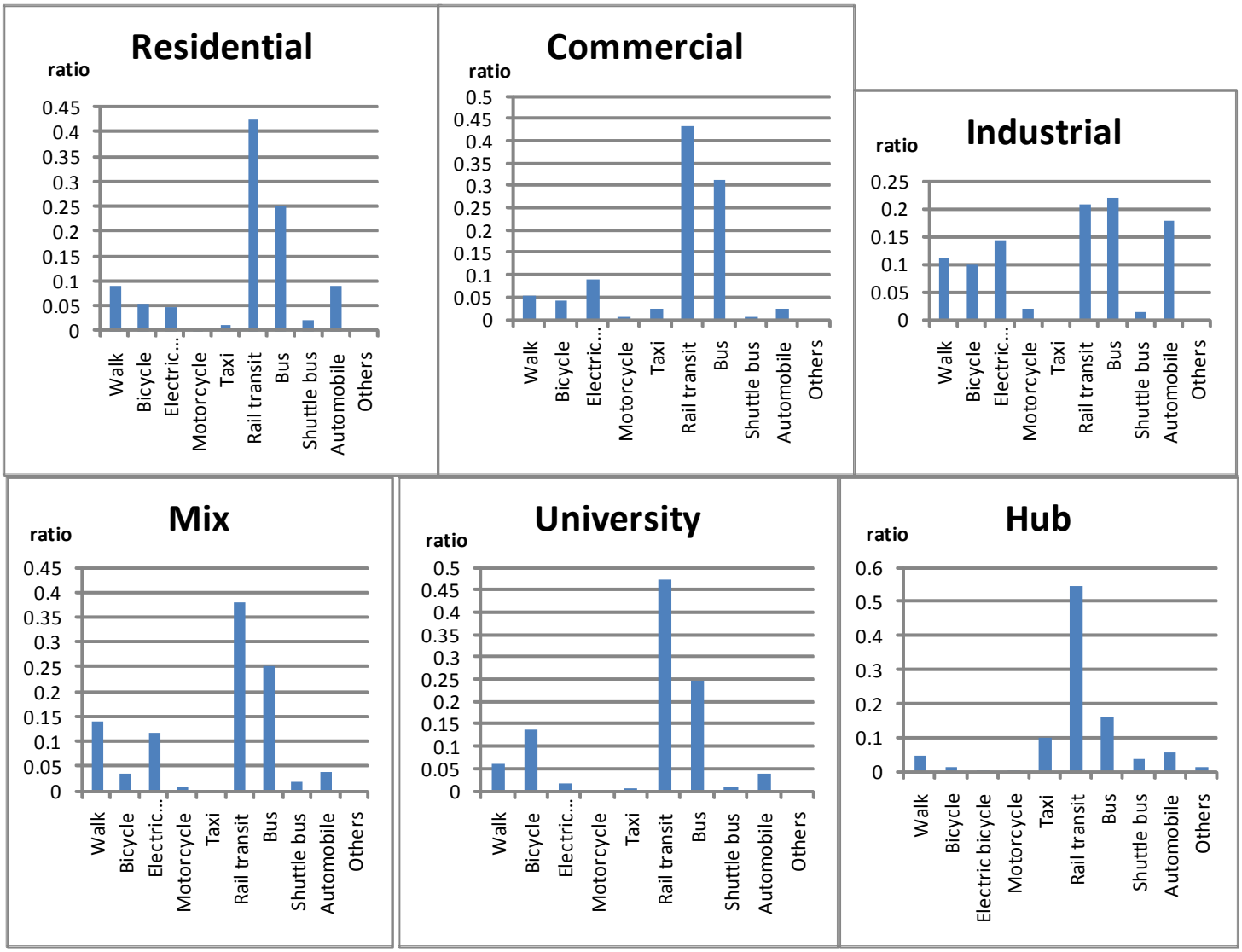

Figure3 The ratio of public transit in different function zones

B. *Public transit and function zones*

Figure3 shows the ratio of public transit in different function zones. The original data was gained from

investigation, and then classified by function zones. Since the quantity of questionnaires was different in every station, we used the percentage to show the result.

Figure 4 shows the ratio of public traffic (rail and bus) decreased from 75.69% (inside the inner ring) to 51.86% (outside the outer ring). By contrast, the contribution rate of car is the highest outside the outer ring (11.74%) and the lowest inside the inner ring (2.76%). Meanwhile, the contribution rate of walk, bike and e-bike outside the outer ring was also higher than other spatial area. The other modes' contribution rate in various spatial areas was relatively low.

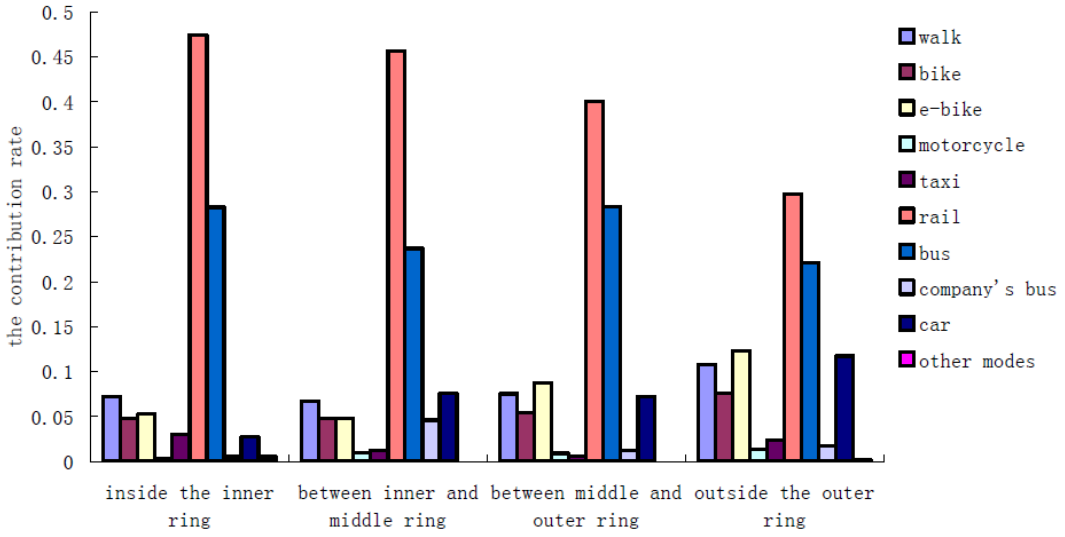

Figure4 The ratio of public transit in different spatial zones

Table.4 shows the average travel duration of each function zone.

TABLEⅣ. AVERAGE TRAVEL DURATION IN DIFFERENT FUNCTION ZONES (MINUTES)

	Residential	Commercial	Industrial	Mix	University	Hub
Avg.T	43	43	35	39	51	65

Obviously, "Rail Transit" and "Bus" occupies the biggest share since the selected areas are around stations. We can see that hub zone has highest value in rail transit, which shows the construction of transport hub is efficient, at the same time, hub zone has lowest value in walk, bicycle, and electric bicycle, which has a close relation with its original object "to ease traffic pressure and transform transportation of a city", not a "district". From table 4 we can see that in hub zones the average travel duration reaches 65 minutes, the longest time in six zones, which demonstrates the hub zone is for the city too.

From the investigation, since industrial zone all located in suburb, most of the investigation interviewees are workers or employees in factories. Industrial zone has more average ratio in different transit ways, connecting to its land use, we can find that: industrial zone has low dwelling and high walk share. That is to say, many workers of the factories are living around the industrial zone, 11.26% of them live within 11 minutes (average time, Figure5) walking distance. Not thinking of the transit way, the average travel duration in industrial zone is 35minutes. In other words, in industrial zone, there is a "job-housing balance" in 35minutes-radius travel durations.

Residential and Commercial zones have a median value “43 minutes” in average travel duration. Commercial zone and mix zones have a same LUM, but the value of travel duration in mix zone is much lower than commercial zone. Data from table 1 may explain it. Table 1 shows commercial zone has high value in commerce & finance, where attracts people from far to some extent, and mix zone has a relative high value in industry where often attracts people from nearby to some extent. Commercial zone often locates in the center of a city or a district, while mix zone inclines to the “proper” location. The result also demonstrates that mix of different function is more efficient in travel efficiency.

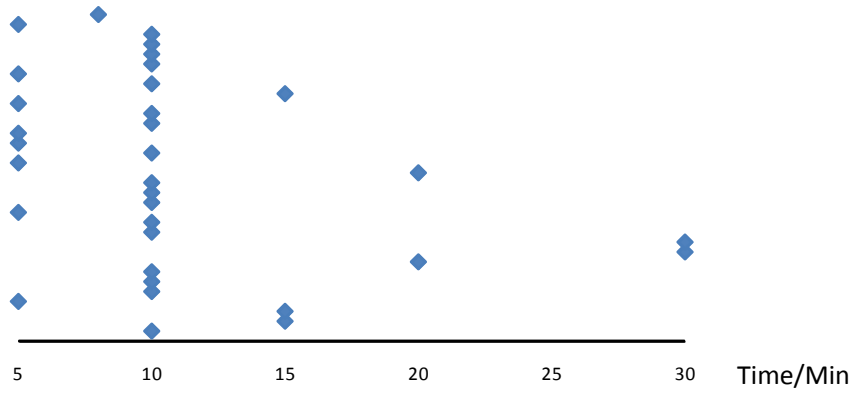

Figure 5 walking time from home to factories in industrial zone

University zone has a high value in travel duration. The low LUM influences the trip of dwellers in this zone.

From investigation we found that people in this zone have very low travel frequency and travel willing because they should go for a long time to reach the destination like big shopping mall.

Table.5 shows the satisfaction to quantity of bus lines in function zones. Interviewees are people by bus in the station area. Data shows that hub zone has a high degree of satisfaction to the bus lines though it has a relative low degree of bus ratio, while mix zone has relative low degree of satisfaction. On the whole people in different zones all get a 2-3 degree of satisfaction, without obvious difference.

Table Ⅴ. SATISFACTION TO QUANTITY OF BUS LINES IN FUNCTION ZONES

	1	2	3	4	5	Avg.
Residential	9.93%	40.40%	29.14%	18.54%	1.99%	2.62
Commercial	9.74%	40.00%	37.69%	10.51%	2.05%	2.55
Industrial	10.34%	32.76%	38.79%	15.52%	2.59%	2.67
Mix	5.77%	36.54%	42.31%	13.46%	1.92%	2.69
University	8.21%	45.52%	41.04%	4.48%	0.75%	2.44
Hub	22.35%	36.47%	34.12%	5.88%	1.18%	2.27

1-very satisfied 2-satisfied 3-common 4-unsatisfied 5-very unsatisfied

IV. CONCLUSION

Overall, this study identified that functional zoning is very effective in land use and has a close correlation with traffic planning.

Firstly, functional zoning has a potential power to instruct the concrete land use and potentially influences people’s willing. For example, education resource is an important resource that many family with school-aged kid take account of, so the function zone like university(In China, an university often

companied with relative complete and better school system including kindergarten, junior school, middle school and high school) often attracts this group to buy house and move in. Similarly, small business and retail tends to locate in residential zone or zone with high dwelling considering to the consumer groups. As has been pointed out, the land use type, diversity, FAR and LUM all has close correlation with functional zoning. Since in general planning, functional zoning comes first before land use, planners should pay much attention in the zoning considering to the different attractive forces.

Secondly, functional zoning affects traffic planning. Travel behaviors differ in function zones. In general planning, functional zoning has precedence over traffic planning topic. At the same time, the comprehensive transport plan, which is the head of all traffic planning, should plan and regulate according to general planning. So functional zoning has a comprehensive influence over traffic planning, which calls for strict working attitude and professional skills. Meanwhile, according to the investigation result, especially the satisfactory degree of local traffic, we can regulate the traffic planning partially.

REFERENCES

[1] The Fourth Conference of International Congresses of Modern Architecture. *Athens Charter*. Athens, August 1933.

[2] Zhang H.H. How Do Local Governments in the USA Amend Their Zoning Ordinance? Urban Planning Forum, No.4, 2010, pp. 52-60.

[3] U.S. Department of Commerce. *A Standard State Zoning Enabling Act: Under Which Municipalities May Adopt Zoning Regulations*. Washington D.C USA, Washington Government Printing Office, 1926.

[4] Gu D.Z. and Yan P. Research on New Urban Area Planning Based on TOD Mode: A Study on Binhu New District of Hefei City. *China City Planning Review*, Vol.20, No.1, 2011, pp.66-72.

[5] Badoe D.A. and Miller E.J. Transportation-land use Interaction: Empirical Findings in North America and Their Implications for Modeling. *Transportation Research Part D*, Vol.5, 2000, pp.235-263.

[6] Newman P.W.G. and Kenworthy J.R. The Land Use-Transport Connection. *Land Use Policy*, Vol.13, No.1, 1996, pp.1-22.

[7] Pitombo C.S., Kawamoto E. and Sousa A.J. An Explanatory Analysis of Relationships Between Socioeconomic, Land Use, Activity Participation Variables and Travel Patterns. *Transport Policy*, Vol.18, 2011, pp.347-357.

[8] Sung H. and Oh J.T. Transit-Oriented Development in a High-Density City:Identifying its Association with Transit Ridership in Seoul Korea. *Cities*, Vol.28, 2011, pp.70-82.

[9] Boarnet M. and Crane R. The Influence of Land Use on Travel Behavior: Specification and Estimation Strategies. *Transportation Research Part A*, Vol.35, 2001, pp.823-845.

[10] Loo P.Y., Chen C. and Chan T.H. Rail-based Transit-Oriented Development: Lessons from New York City and Hong Kong. *Landscape and Urban Planning*, Vol.97, 2010, pp.202-212.

[11] Cervero R. and Day J. Suburbanization and Transit-Oriented Development in China. *Transport Policy*, Vol.15, 2008, pp.315-323.

[12] Lin J.J. and Gau C.C. A TOD Planning Model to Review the Regulation of Allowable Development Densities around Subway Stations. *Land Use Policy*, Vol.23, 2006, pp. 353–360

[13] Calthorpe P. and Fulton W. *The Regional City: Planning for the End of Sprawl*. Island Press, Washington, D.C., 2001.

[14] Olaru D., Smith B. and Taplin J.H.E. Residential Location and Transit-Oriented Development in A New Rail Corridor. *Transportation Research Part A*, Vol.45, 2011, pp.219-237.

[15] Kwana M.P. and Weberb J. Scale and Accessibility: Implications for the Analysis of Land Use–Travel Interaction. Applied Geography, Vol.28, 2008, pp.110–123.

[16]Shao H.B. and Chu L.Y. Resource Evaluation of Typical Energy Plants and Possible Functional Zone Planning in China. Biomass and Bioenergy, Vol.32, 2008, pp.283 – 288.

[17] Liu X.H. and Li J.H. Scientific Solutions for the Functional Zoning of Nature Reserves in China. *Ecological Modelling*, Vol.215, 2008, pp.237-246.

[18] Shi G. The Evaluation and Division of Chinese Homogenous Functional Region. *Urban Studies*, Vol.7, No.3, 2010, pp.44-50.

[19] Rossi-Hansberg E.Optimal Urban Land Use and Zoning. *Review of Economic Dynamics*, Vol.7, 2004, pp.69-106.

[20] Lin H. and Li J. Relationship Between Spatial Distribution of Resident Trips and Mixed Degree of Land Use: A Case Study of Guangzhou. *City Planning Review*, Vol.9, No.9, 2008, pp.53-56.