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Study on Influencing Factors of Walkability of Rail Transit Station Area

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Abstract**—**Based on the comparative analysis of the relevant evaluation methods of walking environment, this paper selects the combined evaluation method of macro urban morphology analysis and micro urban design quality survey, then investigates and analyzes the walking environment of three rail transit station area in Nanjing to explore the influence factor and internal relation of walkability of rail transit station area. Analysis shows that micro urban design factors have greater impact on the walkability of rail transit station area compared with macro urban morphology factors, the convenience is the key factor in the four aspects of convenience, security, identity and comfortability of the urban design factors, the convenience is not only affected by the block network form, but also related to the quality of the street space. The overall evaluation of walkability comes from the overlapping and regrouping of the walking environment at different levels, but some environmental factors play a leading role. The social attributes of pedestrians also partly influence their walking perception and evaluation.

Keywords**—**Rail transit station area, walkability, evaluation, influence factors.

I. Introduction

IN recent decades, China's urban development has begun to show a trend of expansion, superblock and wide streets have become a prominent feature of many new towns and suburbs, these areas have abandoned transit-oriented urban development goals, besides, the urban spatial structure is unreasonable, people are becoming more dependent on cars [1]. Rail transit is a recognized "green traffic" with low energy consumption and less pollution, except walking and cycling. On the macro scale, rail transit system is beneficial to optimize the urban spatial structure and strengthen the integrity of the urban space-time [2]; on the micro level, it is beneficial to improve the travel efficiency and improve the quality of life. At present, China's urban experience has proved that the opening of rail transit can cause the rising of land price, the change of land function, the promotion of development intensity and the improvement of the surrounding environment [2].

As a geographical concept, rail transit station area has the dual characteristics of "node - place", it is not only a node of the Urban Transportation Network, but also a place where the facilities are centralized, the buildings are diversified and the space is open [3]. Therefore, the walkability of rail transit station area is not only related to the environmental quality, but also related to the construction of traffic behavior and land use oriented by public transportation.

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II. The Evaluation Method of Walkability

As for walkability, there is no clear definition at present. The following definition is appropriate, “Walkability is the degree to which the built environment encourages walking, including a safe and comfortable walking environment for pedestrians, enabling people to reach a variety of destinations within a reasonable time and physical range and providing visual attraction along the walking network” [4]. This is a more comprehensive exposition of the friendly elements of walkability, it is necessary to consider the macro aspects of urban transportation system, but also the micro-urban design level factor into them [5]. At present, there are many ways to evaluate walkability from different stages and different perspectives, some scholars have summarized the related evaluation methods into three categories: Index system method, behavior perception method and the method based on GIS database [3].

A. Index System Method

The index system method focuses on the micro built environment and formulates a unified objective evaluation criteria, including land use, street and transportation, sidewalks, bicycle facilities, public spaces and facilities, building features, parking, maintenance measures, safety-related index and so on [8]. The acquisition of these indexes is selected by sampling; data collection is mainly based on forms. Although you can get detailed walking environment information through the index system method, it is too dependent on the questionnaire design, some micro-elements are not easily quantified, expert scoring is also a lack of empirical research, but this method demands little technology and promotes easily.

B. Behavior Perception Method

Behavior perception method is divided into two ways: Oral walking environment perception and survey walking route choice behavior. The former can assess the perception of walking environment by interviewing pedestrians or watching video clips; the latter requires pedestrians to make a choice between specific paths, and constructs discrete choice model to identify the most important walking environment factors and their influence, which is the criterion of walking environment evaluation [5]. Behavior perception method focuses on the micro-scale walking environment and the pedestrian's environmental preference characteristics, its evaluation indicators emphasize individualization, differentiation and diversification, but the technical threshold is high and it is

difficult to simply copy and promote the application.

C. The Method Based on GIS Database

The method based on GIS database selects the corresponding evaluation index of walking environment from the existing second-hand data, such as population density, mixed degree of land-use, accessibility of entertainment facilities, streets form, sidewalks, vehicle-flow and crime rate [5]. The accuracy and completeness of existing data, evaluation scales, data sources and standards all affect the reliability of GIS method, and the time span of large-scale data collection will affect the accuracy of some dynamic data, and it is difficult to quantify the quality of some micro walking environment characteristics by GIS tools, such as street aesthetic.

In general (see Table I), the three evaluation methods of walking environment have their advantages and disadvantages. The evaluation of walkability of the rail transit station area should not only consider urban morphology and urban transportation system, but also the urban design, Therefore, in the evaluation of macro urban morphology factors, GIS can be selected as a tool to take quantitative analysis; in the evaluation of micro urban design factors, we can take the index system method, combined with the behavior perception method, and finally realize the combination of macro and micro , explore the key indicators of walkability of rail transit station area and its impact mechanism.

TABLE I
CONTRAST OF DIFFERENT EVALUATION METHODS

	Index system method	Behavior perception method	The method based on GIS database
Main Point	Quantify physical environment, single standard	Pay attention to individual, differentiated and diverse behavioral preferences	Urban planning Perspective
Date Sources	Make Questionnaires or field interviews to obtain first-hand data	Make Questionnaires or field interviews to obtain first- hand data	Second-hand data
Reliability	Over-reliance on questionnaire design, expert scoring lack of empirical research	More accurate	Affected largely by data sources, geographical analysis units and other reasons
Application Value	Simple, widely used in community decision-making and planning	Technical threshold is high, it is difficult to promote, and used in Urban planning research	There is a certain technical threshold, and more used in planning research

III. DESIGN OF WALKABILITY RESEARCH OF RAIL TRANSIT STATION AREA

A. Selection of Evaluation Indicators

1) Macro Urban Morphology Factors

General walkers hope to be able to easily reach (leave) the site under the premise of saving time and effort, the shortest path is the straight-line distance from the end point to the site in the ideal situation [7]. In reality, there are different degrees of detour inevitably because of the built street network. Based on the existing research results, this paper uses the street network characteristics and the Pedestrian Route Directness (PRD) around the site area as the macro urban morphology indicators to evaluate the walkability of the rail transit station area. The circle of 500 meter and 1000 meter radius of the rail transit station is selected as the research scope of the two scales, to measure the key morphological indexes of the street network. Among them, Block Length is the average value of all the length of the block in the study area, which is used to evaluate the block scale. Intersection Density is the ratio of the number of road intersections to the area of the study area, which is used to measure the texture of the block. Road Node Ratio is the ratio of road sections number to the sum of road intersections number and road ends number. It is used to measure the path selectivity of different intersections. PRD is the ratio of the actual walking distance between the starting point and the station to the ideal distance of the straight line, the smaller the ratio is, the smaller the pedestrian route. The calculation method of PRD is as follows [6]: First, take the rail transit station as the center of the circle and divide the 8 quadrants with 500 m or 1000 m as the radius, in each quadrant, a street is selected randomly and intersected with the circle, and the intersection point is the end point. Then, from the center of the circle, take the shortest line to the end, get the shortest path length. Lastly, calculate the average length of the above lines; you can get the value of PRD [6].

2) Micro Urban Design Factors

The walkability evaluation of the rail transit station involves a variety of elements, and the perception of the walking environment may be related to a pedestrian's behavior and route choice, depending on the environmental quality of the individual factors or the combination of several factors. This paper chooses the main 13 individual indicators, which can be summarized as convenience, security, recognition and comfort of four indicators (see Table II). Convenience refers to the degree of accessibility of the rail transit station, involving the street network around the station area and the physical and psychological barriers of traffics single time. Safety refers to the degree of psychological and physical protection of pedestrian, and is related to social security situation, traffic safety and night lighting and other. Identification refers to the sign of the station area and the surrounding street. Comfort refers to the feeling of humanization and aesthetic during walking, including life services along the street, shelter, environmental quality, trail width, sidewalk and street visual landscape. Walkability evaluation is based on the Likert scale [5], it adopts 5 semantic descriptions: "very satisfied, satisfied, general, unsatisfied, very dissatisfied", and gives the corresponding calculated scores: 5/4/3/2/1. The survey data can be used for satisfaction analysis through SPSS, Excel and other software.

TABLE II
EVALUATION INDEX AND CLASSIFICATION OF MICRO URBAN DESIGN FACTORS

Aspects	Individual indicators
Convenience	Convenience of network, Length of red light
Security	Public order, Traffic safety, Night lighting
Recognition	Identification guidance system
Comfort	Service facilities, Shelter facilities, Environmental quality, Walkway width, Walkway occupation, Walkway cleanliness, Visual landscape

Fig. 1 Sketch map of Rail transit station selection

B. Selection of Research Stations

Nanjing Metro Line 1 is the first subway line of Nanjing Metro, which is officially operated on September 3, 2005, and its large number of people can guarantee the diversity of passenger social attributes and the accuracy of the survey results. This article selected three representative sites on the Line 1 (see Fig. 1). Xinjiekou Station (Station A) is located in the core commercial circle of Nanjing. It has 24 exports lead to the ground and the sublevels of many surrounding large shopping mall respectively. All of this constitutes a huge underground traffic business system. Sanshanjie Station (Station B) is located in the vicinity of the Confucius Temple in Qinhuai District. The streets around the station B are relatively

narrow, and the density of buildings is high, most of the bottom buildings are old shops and apartment houses, only a few are new houses. Nanjing South Railway Station (Station C) is located in Yuhuatai District, the core area of New Town in the south. It is a National passenger station, connecting eight National higher railways. Nanjing South Railway Station connects the north and south pedestrian plaza with the surrounding branch, the surrounding area showing a wide road, high-rise commercial housing area and the introverted commercial complex is characterized by the new district construction pattern.

C. The Process of Research

The investigation about the three rail transit stations was conducted in December 2016-January 2017. One part of the questionnaires 2qw retrieved by field handout in three sessions (8: 30-9: 30, 17: 00-18: 00, 19: 00-20: 00), and another part of the questionnaire was collected by network. The respondents were passengers who usually walk to the station. A total of 150 valid questionnaires were collected (50 were collected online) of which 63 were recovered at station A, 48 at station B, and 39 at station C. More than half of the respondents were interviewed at least 3 days a week to reach the station, indicating a high degree of familiarity with the surrounding environment and ensuring the validity of the information. In addition, the site survey also used spatial environment annotation analysis, path walking, walking observation and other ways to compare with the questionnaire, map measurements each other to confirm the survey results.

IV. Analysis on the Influencing Factors of Walkability in Rail Transit Station

A. Analysis of Urban Morphological Factors

The electronic map of Nanjing was imported into the GIS database for macroscopic analysis, the urban morphology of 500 m and 1000 m around the three stations were shown in Tables III and IV. The PRD score of Station A is the lowest, Station B follows, Station C is the highest. The intersection density of Station A is the highest, compared with Station B and Station C. This shows that urban central area is divided into small plots, the penetration of the network is good, and the urban periphery has low road density, large partition, poor connectivity of pedestrian network.

TABLE III
SCHEMATIC DIAGRAM OF THE ROAD NETWORK AROUND THE THREE STATIONS

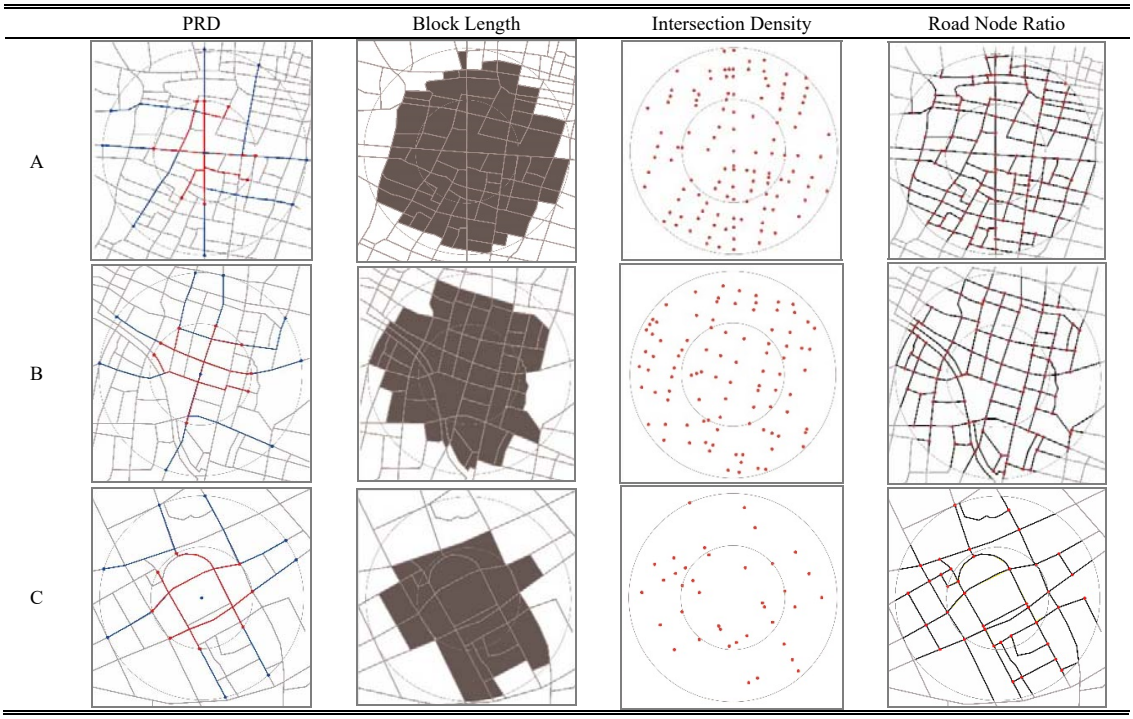

TABLE IV
INDICATORS OF THE ROAD NETWORK AROUND THE THREE STATIONS

Station	500 meter radius				1000 meter radius			
	PRD	Block Length	Intersection Density	Road Node Ratio	PRD	Block Length	Intersection Density	Road Node Ratio
A	1.15	213m.	40/sq.km.	1.56	1.06	226m.	37/sq.km.	1.76
B	1.38	248m.	39/sq.km.	1.72	1.13	253m.	30/sq.km.	2.22
C	1.42	378m.	27/sq.km.	1.58	1.26	323m.	12/sq.km.	1.96

TABLE V
SURVEY RESULTS ON OVERALL AND INDIVIDUAL SATISFACTION DEGREE OF WALKING ENVIRONMENT IN RAIL TRANSIT STATION AREA

Aspects	Individual indicators	Overall	Station A	Station B	Station C
		3.8	3.79	3.68	3.97
Convenience	Convenience of network	3.37	3.39	3.20	3.16
	Length of red light	4.12	4.01	4.34	4.06
Security	Public order	3.62	3.20	3.27	3.36
	Traffic safety	3.26	3.20	3.27	3.36
	Night lighting	3.50	3.69	3.36	4.07
Recognition	Identification guidance	3.58	3.67	3.79	3.22
Comfort	Service facilities	3.38	3.51	3.36	3.28
	Shelter facilities	3.30	3.32	3.38	3.19
	Environmental quality	3.58	3.67	3.79	3.22
	Walkway width	3.62	3.59	3.63	3.62
	Walkway occupation	4.12	4.01	4.34	4.06
	Walkway cleanliness	3.26	3.20	3.27	3.36
	Visual landscape	3.80	3.79	3.68	3.97

	1	2	3	4	5	6	7	8	9	10	11	12	13
1.Convenience of network				314**		186**	326*			176**			
2.Length of red light											279**	309**	176**
3.Public order					306**			197**		323**			345*
4.Traffic safety	304**												
5.Night lighting			325**				223**		431**		222**	243**	
6.Identification guidance	210*				356**					324**			302**
7.Service facilities	306**									276*		324**	
8.Shelter facilities						276**				279**			176**
9.Environmental quality				286**							306**		
10.Walkway width	268**		379**	386*		324**	274**	346**					
11.Walkway occupation				176**			348**		284**				324**
12.Walkway cleanliness				346**	176*					309**			
13.Visual landscape							159**	279**	234**		176**	316**	

Fig. 2 The correlation coefficient between individual indicators of walking environment (Note: * * indicates that the significance test of correlation coefficient is less than 0.01,* indicates that the significance test of correlation coefficient is less than 0.05)

B. Analysis of Urban Design Factors

1) Evaluation of Walking Environment Satisfaction

From the overall satisfaction of the walking environment (see Table V), in the three stations, the overall satisfaction of Station C is the highest, and Station B is the lowest, which is not consistent with the above-mentioned analysis results of urban morphological factors, also not consistent with some individual satisfaction degree of walking environment. As can be seen from Tables IV and V, Station A has the smallest PRD, the smallest block length and the largest intersection intensity, but received the least positive comments (3), the most negative comments (6), and low score on safety and comfort. Station B got the most positive comments (6) of individual satisfaction indicators, in service facilities, identification guidance system, public order, visual landscape and night lighting. The possible explanation is that some of the individual walking environment assessment factors may play a key role in the pedestrian friendliness of the station area, that is, if some basic pedestrian environment needs have not yet been met, the other factors may not be important. From the individual satisfaction of the walking environment, the satisfaction degree of public order, identification guidance system and night lighting of the three stations are generally higher, and the satisfaction degree of walkway occupation, walkway width, length of red light, environmental quality and traffic safety are generally lower. Among them, the assessment of walkway occupation and walkway width reflects the lack of space and management of the walking environment, while the assessment about length of red light, environmental quality and traffic safety reflects that rapid development of motor vehicles bring unsafe walking, traffic congestion and air pollution and other issues. Since Station A and Station C are located near urban trunk roads, the waiting time of red light is too long, this is not conducive to walk across the street for pedestrians. Although the roads around Station B are relatively narrow and the waiting time of red light is short, but the potential risk of walking is also increased because of the large flow of motor vehicle and electric vehicle in the urban center area and the lack of effective management on traffic order.

2) Correlation Analysis of Influence Factors

The analysis of individual indicator satisfaction does not fully explain how the urban design factors interact with each other and act on the walking environment. Considering that there may be cross influence between different urban design

factors, it is necessary to use SPSS software to do correlation analysis and explore its internal relationship.

a) Convenience

As shown in Fig. 2, the urban design factors associated with the walkway convenience are traffic safety, identification guidance system, service facilities and walkway width, which indicate that the pedestrian's assessment about the convenience of the road network will be affected by the quality of micro-level walking environment. If the commercial service facilities around the station area are fully functional, they can meet the pedestrians' needs of handling affairs and shopping, while varied storefronts will attract the attention of the pedestrians and make them feel the transit time is short and the network is convenient. In addition, if the walking space is broad and continuous, rarely threatened and disturbed by motor vehicles, and with clear and distinct identification guidance system, pedestrians also feel convenient about the walkway network. From Table V, we can find that the convenience evaluation of Station C and Station B is lower than Station A, and it is not consistent with the analysis results of macro urban morphological factors about convenience, indicating that the macro-level network form is difficult to percept by pedestrians, the walkers may be more concerned about the passing roads and intersection nodes and they are convenient or not. Through field observation and interviews, although the roads around Station A have high density and good connectivity, high intersection density adds the possibility of intersects between pedestrians and cars, the congested traffic reduces the crossing convenience of pedestrians.

b) Security

Urban design factors related to social security include night lighting, walkway width and visual landscape; this shows that the social security situation perceived by pedestrians is related to the environment's support for criminal behavior. Psychological studies have found that the sense of security is related to people's range of sight, poor night lighting may cause sight obstruction and increase the fear of criminal activities, and it is also related to the individual's defensible space, narrow space may increase the possibility of collision to the surrounding people or other objects. The urban design factors associated with traffic safety satisfaction are walkway cleanliness, walkway width, environmental quality and walkway occupation, which indicates that the board road can broaden the visual range of pedestrians, improve their ability to control the surrounding environment and their safety awareness, in addition, clean and paved ground, unobstructed walkway and comfortable street environment can also increase the sense of security. There is a big difference in the traffic environment between Station A and Station B. Station B is located in the old district, the surrounding streets and alleys are narrow, the buffer space between the traffic and the crowd is lacking, and the illegal acts and traffic noise of cars (electric motorcycle) are very serious. All these situations have increased the safety concerns of pedestrians. While Station A is located in the commercial district, although the traffic and speed of station A is not less than Station B, but the traffic at intersections is ordered, the walkway is clean, there are isolating belts between pedestrians and cars, street environment is improved, the sense of safety and comfort are also better than that of B, all of these may be of the important reasons that Station A is higher than that of Station B in the overall evaluation of walking environment.

c) Recognition

The main factor that affects the recognition satisfaction is night lighting, which can obscure a small fraction of traffic signs in poorly lit places, leading to difficulties in finding stations. For example, the square around Station C is very bright at night, but most of the walking roads are surrounded by the enclosing walls of surrounding habitations, the walking space is very monotonous. Station A and Station B lack commercial climate at night, the road-lighting is mainly served for the motor vehicle, the lighting of walkways is weak, and the traffic identification guide is not obvious. It is clear that the combination of good lighting and traffic signs will improve the satisfaction of rail transit stations.

d) Comfort

Urban design factors that affect comfort of pedestrians also intersect each other. For example, there is a correlation between service facilities and walkway cleanliness and visual landscape, which shows that the streets with rich living functions are usually able to maintain good management and landscape quality. At the same time, there is a strong correlation between the visual landscape and walkway cleanliness, environmental quality, shelter facilities and service facilities, which shows that beautiful and varied street landscape, neat and clean street front, pleasant and comfortable environment are interdependent. The factors associated with walkway occupation are service facilities, walkway cleanliness and environmental quality. According to the field observation, there are illegal parking, illegal street stalls business and unreasonable setting of street facilities on walkways around the three stations, all of the corresponding factors reduce the walkway width, and then affect pedestrians' satisfaction with walkway cleanliness and environmental quality.

C. Analysis of Social Attribute Factors

1) Trip Purpose

From the survey results of trip purpose, commuters and students are less satisfied with the convenience of the road network and the length of red light, indicating that they are more concerned about the basic walking problems, require a higher degree of convenience of walking. For pedestrians with the aim of shopping and entertainment, the comfort and pleasantness of the pedestrian environment in the streets are more important. The requirements about the length of red light, walkway width, walkway cleanliness and walkway occupation are higher (see Fig. 3)

2) Population Gender

From the respondent's gender perspective, both the overall evaluation and the individual indicators evaluation, the average

satisfaction of men is lower than that of women. It indicates that the requirements for walking environment of men are higher than women. However, women have higher requirements for security and comfort (see Fig. 4).

3) Trip Time

From the survey results of the trip time, pedestrians show lower satisfaction with the night lighting, commercial facilities, walkway occupation and walkway cleanliness in the evening, the possible explanation is that the leisure activities are the main part of this period, and the space quality of walking environment is higher. In commuting hours, which is also traffic rush hour, pedestrians are concerned about the convenience and safety of walking, shelter facilities, environmental quality and so on (see Fig. 5).

4) Population Age

Among interviewees, under 30 years old accounted for 53.6%, 30-50 years old accounted for 31.5%, 50 years of age accounted for 14.9%. The evaluation of walkability is relatively low in the elderly, this shows that because of physical reasons, the older people may have higher demands on the pedestrian environment, especially in traffic safety and street facilities. The young people under the age of 30 take the rail transit for main purpose of going to school and commuting, they have a higher demand of convenient road network and short red-light time (see Fig. 6).

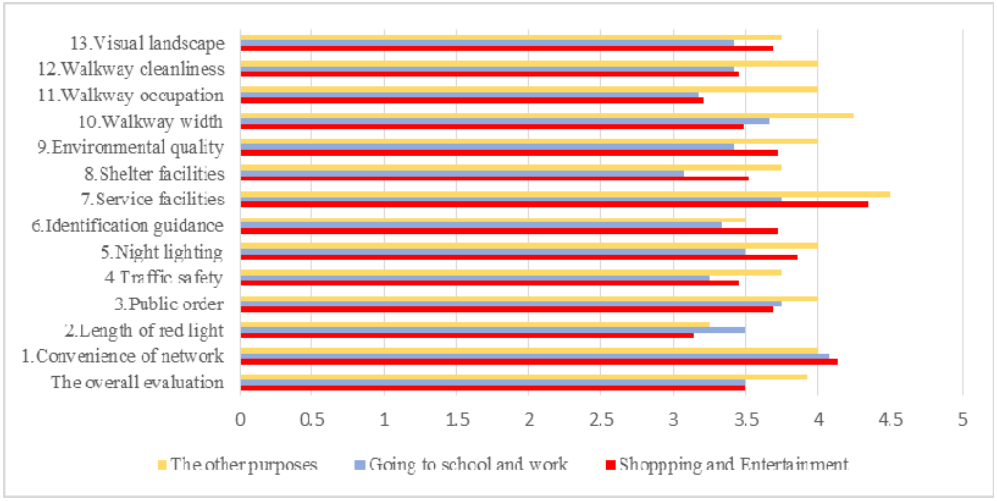

Fig. 3 Satisfaction degree of walkability of Individual influence factors with different trip purposes

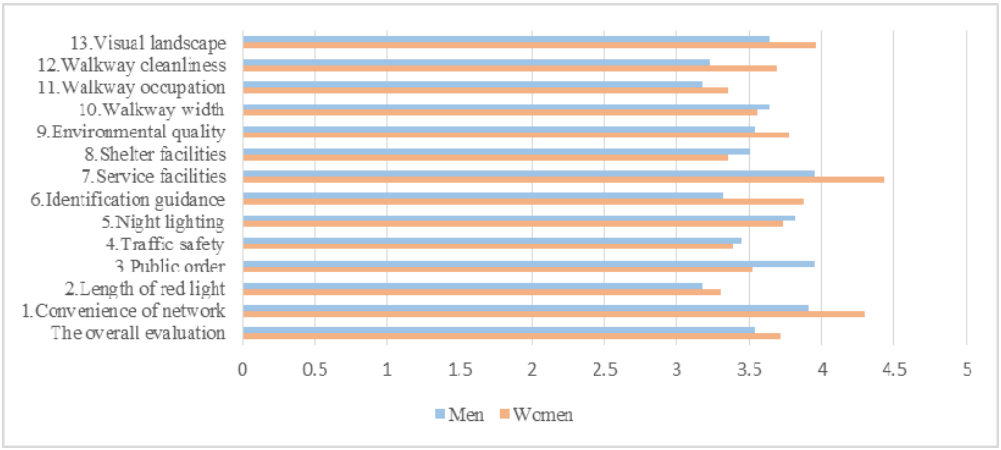

Fig. 4 Satisfaction degree of walkability of Individual influence factors with different genders

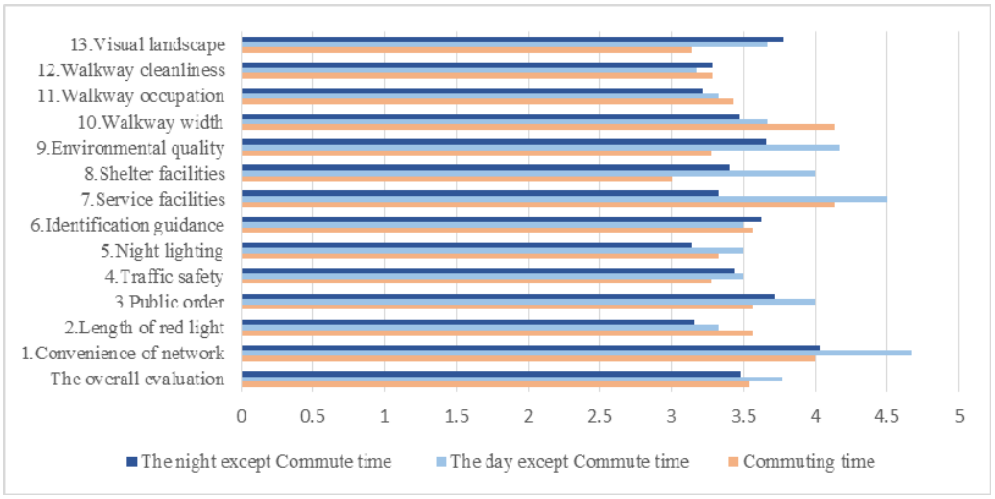

Fig. 5 Satisfaction degree of walkability of Individual influence factors at different time

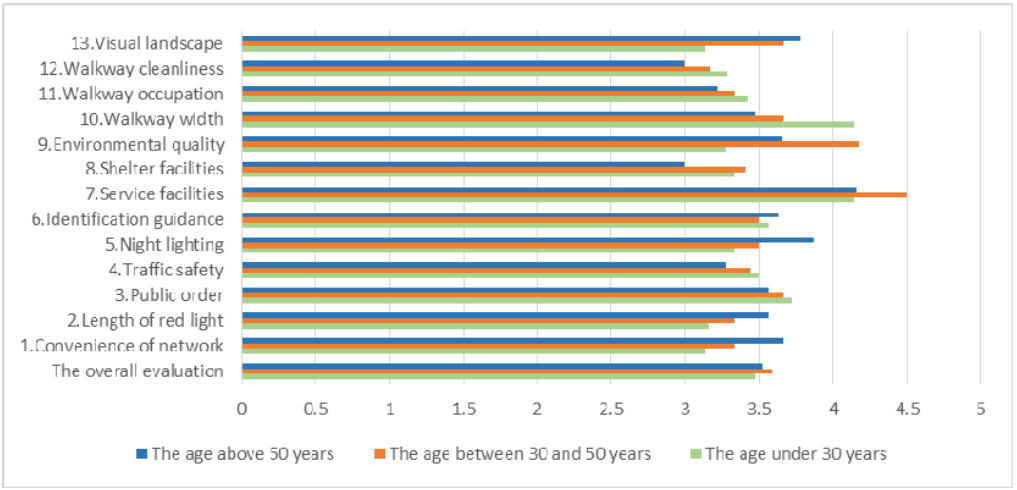

Fig. 6 Satisfaction degree of walkability of Individual influence factors in different age groups

V. Conclusion and Discussion

From the results of this research, the urban design quality of micro level compared to the urban morphology element of macro level may be more important, this means that the improvement of built walking environment around stations and optimization of the surrounding facilities may be more effective than the adjustment of existing road network, and it is also easier to implement [9]. The overall evaluation of walking environment come from the perception at different levels, some individual factors may play a key role, the relevant improvement measures should be implemented based on the investigation.

The walkability of rail transit station area is reflected in convenient and continuous pedestrian network, safe and comfortable service facilities, clear and concise identification guidance system, interesting street life and visual experience. This means that the walkability of rail transit station area should improve the quality of microcosmic urban design factors. Besides, urban design involves architecture, engineering, landscape and other planning system, improving the walkability of rail transit station through urban design is beneficial to the comprehensive study [10].

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