A Study on Spatial Design and Usability of Station Plazas for Compact City Planning

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Abstract: Most of the current station plazas are now left behind as spaces for road traffic in order to deal with increasing traffic demands especially in suburban areas. This paper aims to examine a methodology for the improvement of the spatial design of station plazas that can restore the inherent functions of *plazas*, open spaces for conviviality and sociability. Firstly, the method to determine an appropriate environmental space rate for station plazas was developed in order to strike a balance between road space for traffic and environmental space for people. Based on this consideration, the necessity to set up a new additional standard for station plaza planning was addressed. Secondly, the paper developed a system of indicators to assess social usability that enables us to identify problematic station plazas among existing ones. Finally, design principles for the improvement of station plazas with higher usability were proposed

Keywords: Railway Station, Station Plaza, Environmental Space, Social Usability, Priority, Compactness

1. INTRODUCTION

In recent years, the importance of closer relationship between cities and transport systems has been emphasized for realizing a compact city, under the situation of declining and super-aging population in Japan. Policymakers and urban planners are thus discussing the necessity to develop a 'railway station-centered' city that is Japanese transit oriented development (TOD). As shown in Figure 1, Station plazas are not only placed in nodal points of track traffic and road traffic but also in nodal spaces of city and road infrastructure. Station plazas have three important roles, as a transport hub, community space and round trip space. However, many of the existing station plazas in the suburbs have been developed under the pressure of motorization and therefore been forced mainly to accommodate automobile traffic, resulting in actuality to be left behind in city-space merely as *road plaza.* As a consequence, it is now difficult for people to find them as authentic *plaza*, where they can turn out freely to communicate with each other, or in short, the space of conviviality and sociality.

Recently, people have put greater importance on usability (or usefulness for consumers themselves) of urban infrastructures including transport, as their needs for urban functions are becoming more diversified. For an example, the Photo 1 shows that many of the existing station plazas are not regarded as user-friendly, as they are not designed barrier-free or human safety is heavily compromised by traffic congestion. Moreover, many of the commercial facilities around the station plaza are now worn out or emptied, reducing its function as the open and central space of conviviality and sociability. On the other hand, many of the local governments responsible for the administration of station plazas tend to regard it merely as part of grand station area, making little efforts to improve the function of station plaza space itself. This paper proposes that station plazas should be seen as the center of the organic whole of station area, in order for urban designers to realize a compact city prioritizing public transport.

Therefore, in this study an alternative methodology is proposed by which inherent functions of station plazas can be restored, where people can turn out freely to communicate with each other. First, the technique to achieve balance between traffic space for automobiles and environmental space for pedestrians is examined. In this study environmental space is defined as space in which people walk and gather, such as sidewalks, stairways, and waiting areas for buses and taxis. Environmental space rate is also shown as people's space over the total area of a station plaza. Then an evaluation method of social usability targeting a wide range of users is proposed, and finally its applicability to evaluate the existing station plazas and to design new ones is examined.

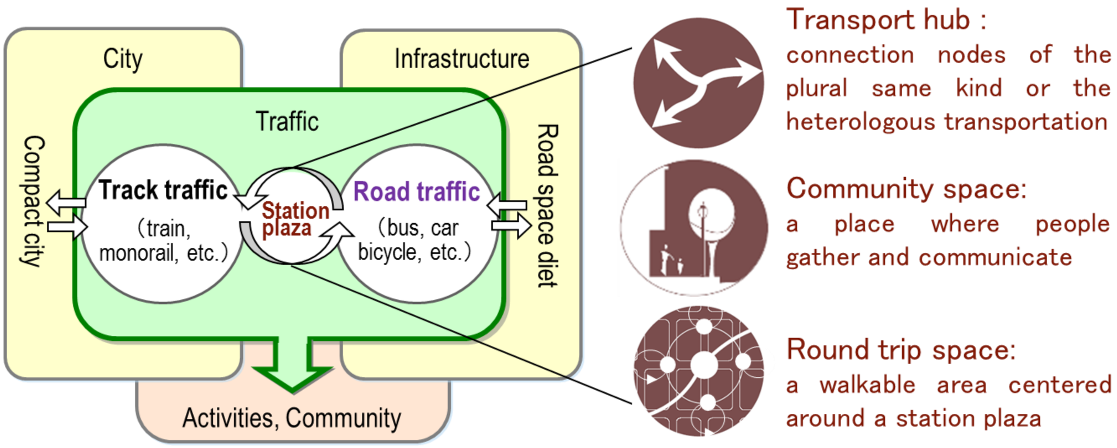


Figure 1. Station plaza as functional space

Photo 1. Station plaza sceneries from the viewpoint of users

2. LITERATURE REVIEW

Transit Oriented Development (TOD) is a mixed-use residential and commercial area designed to maximize access to public transport. There are many previous studies about TOD which discuss the current situation, future direction and existing problems of applying TOD in Japan.

Renn (2009) demonstrated how a station that was due to undergo TOD was placed in a transit adjacent development (TAD) – TOD spectrum. Where a station is placed in the TAD – TOD spectrum is determined by some indicators, such as high/low densities, segregated/mixed land use, surface/underground, structured parking and so on. In the study by Sunaga et al (2011), the authors dealt with TOD in the three metropolitan areas in the State of Oregon, and attempted to clarify the issues and practice of TOD policies. Further, the study demonstrated the need for a platform that encourages intercity cooperation among local authorities with shared views and improvement in high standard public transit services in order to develop TOD in Japan.

In addition, Wey (2013) studied and classified the category of smart growth principles based on a literature review and an empirical study of the Taipei metro transit system that demonstrated the application of their methodology.

In this study, the authors focus on a station plaza which was built in the nodal point of a city and traffic space, in order to develop a Japanese version of TOD policies.

Some recent studies have focused on quantification of the quality of spaces and facilities in and around station plazas.

Kii (2004) suggested that the qualitative grade of station plazas is still unsatisfactory and therefore their upgrading to enhance safety, usability, and amenity ultimately result in the improvement of attractiveness and quality of community life. It also pointed out that the extent of necessity to upgrade the public infrastructures for station plazas are varied according to the characteristics of the station it surrounds, but suburban station plazas are in the highest need of renovation.

Takahashi et al. (2006, 2009) suggested that, in order to meet the diversifying needs, usability of station plazas should be enhanced by reducing the terminal space/function to make it more compact, which allows planners to introduce novel and additional functionalities to the newly opened area.

Kotaki et al. (2013) discussed that limited capacity of present station plazas could be ascribed not only to the internal factors like deterioration over time or misfit of the adoption formulae but to external factors like environmental changes due to traffic expansion. They tried to examine the possibility of developing new ways to cope with these factors: not by expanding the plaza itself but by radically reviewing the configuration of existing facilities.

In this study, it is important to consider an evaluation from the viewpoint of the general public. Previous studies in this area are as follows. Jiang et al. (2012) conducted at BRT stations along three corridors, with BRT users about the origins and destinations of their BRT trips. They demonstrated that the lessons help to develop more public transportation-friendly urban road infrastructures. Sugiyama et al. (2005) attempted to develop an assessment method for Quality of Transport (QoT) in congested pedestrian spaces designed according to universal designs. In a case study of a pedestrian space plan, the enhancement of QoT by setting moving-walkways, resting spaces, information offices etc. was quantified by the following four elements: mobility, amenity, information, and assistance. In the study by Eitoku et al. (2008), the authors argued that Quality of Life, which assesses living conditions of the general public, is important for evaluating public transport. In particular, they defined indicators to evaluate transportation services from the viewpoint of an individual, or Quality of Mobility. Some scenarios were presented as simulations for applying this method to mobility evaluation, and future transportation policies were proposed.

As above, previous studies have largely been focused on the current conditions and existing problems concerning station plazas. But none of them have tried to propose station plaza's ideal design, to restore its original functions and to mention its concrete design principles, taking the demographic and demand changes in the future into account. Therefore, this study examines and proposes the basic principles of designing station plazas toward the future. It will provide the basis for the project of realizing the concept of railway station as city hub, which is one of cornerstones of the new urban planning policy, meeting the challenge of diversifying needs in the future.

3. HOW TO DETERMINE THE APPROPRIATE ENVIRONMENTAL SPACE RATE

Station plazas are usually designed from the dual viewpoints of transport planning and city planning. From the former, calculations are made to determine the area necessary for each transport means and the traffic space surrounding them. From the latter viewpoint, areas for the city facilities/space and their environmental space area are estimated to be added to the former, resulting in the determination of the total area for the station plaza in question. However, space demand often exceeds supply by this procedure, and environmental space is difficult to estimate in a quantitative manner. Therefore, it is very often the case that traffic space occupies most of the surface area, leaving only limited space for the environmental area.

This paper therefore proposed to change the design paradigm from the conventional method above to a more integral one, taking into account the tendency of reduction of commuters/students number due to aging population and lower birthrate. Figure 2 shows the basic scheme of a new method in which the design paradigm is changed from the conventional additional method to an integral one. In the conventional method, emphasis is put on transport demand on which are piled up space demands for each necessary facility, resulting in a systematic underestimation of the environmental space rate. In this study, considering the priority to the space's attraction for people and the balance of conflicting space demands of each facility, the method to decide the appropriate environmental space rate was important. It was possible to establish an optimal environmental space rate by balancing out the supply and demand in placing facilities and space in limited space, like a station plaza. Then, the equilibrium could be were expressed, based on the method described in the previous study by Doi et al. (1997) on the equilibrium of space supply-demand. Figure 3 shows the flowchart of derivation of the equilibrium solution of the environmental space rate.

First, a demand function and a supply function were supposed in order to define traffic space and environmental space, which were in a trade-off relation in a station plaza. The demand function related to the area of a station plaza planned by administrators and the supply function related to the number of station plaza users. Second, to identify a model, these functions were derived as a log- liner model, assuming a Cobb-Douglas type technological relationship. Finally, an equilibrium point of the rate of environmental space was derived, and given as an equilibrium solution of these equations. The equilibrium point was expressed as in the following equation as expatiated in Appendix A.

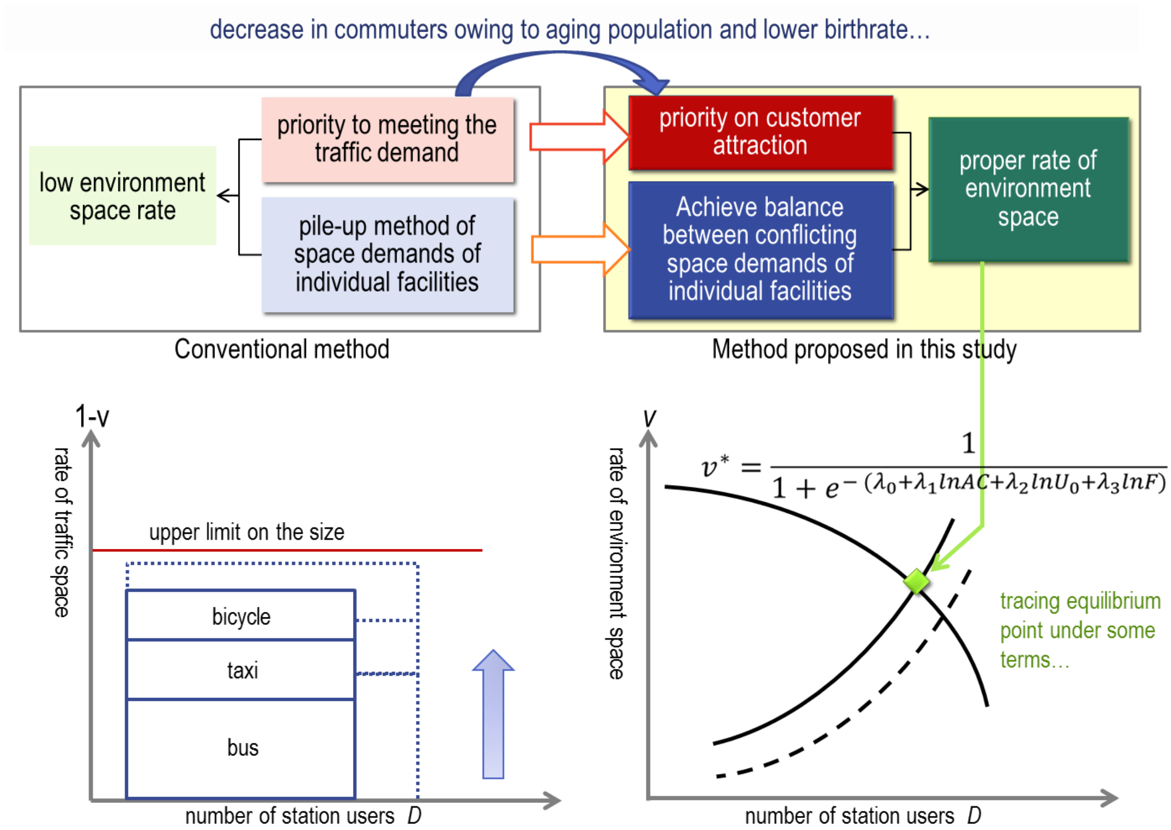


Figure 2. Comparison of design principles of station plazas: the proposed method against the conventional one

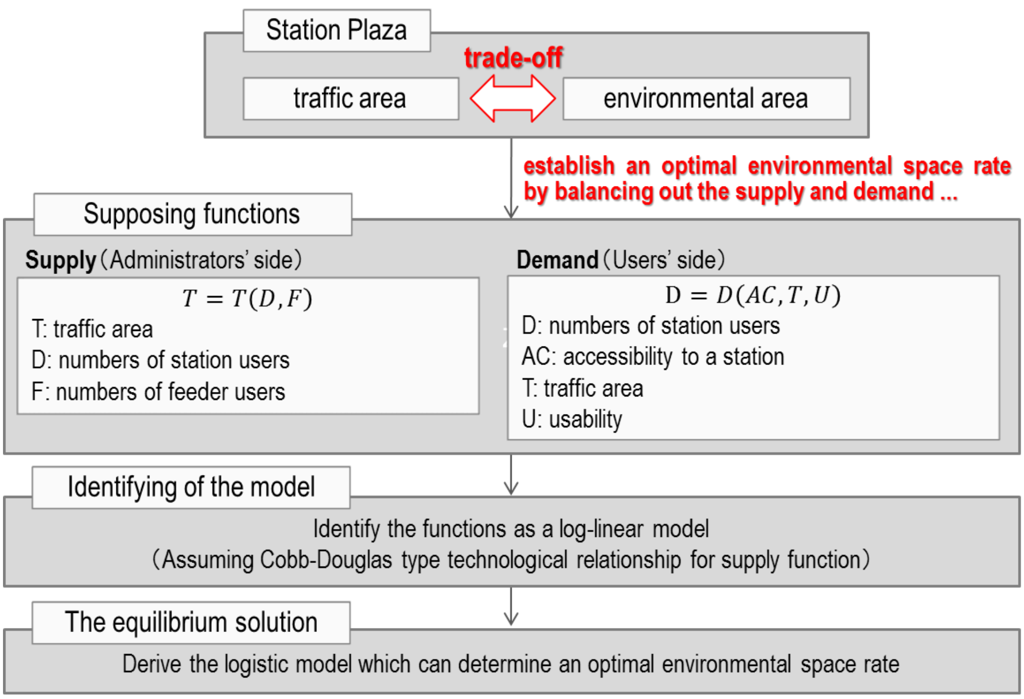


Figure 3. How to lead a balance solution formula to establish an optimal environmental space rate by balancing out the supply and demand

$$v^* = \frac{1}{1+e^{-(\lambda_0+\lambda_1 \ln AC+\lambda_2 \ln U_0+\lambda_3 \ln F)}} \quad (1)$$

, where

v^*:	equilibrium solution
AC:	accessibility
U_0:	factor associated with usability independent of space plaza area
F:	number of feeder users
$\lambda_0, \lambda_1, \lambda_2, \lambda_3$:	parameters.

It is possible to draw a logistic curve by tracing out the equilibrium points under various conditions given. But environmental space rates v of many existing station plazas did not conform to this equilibrium curve and vary widely as shown in Figure 4. This is probably because they have been designed and maintained based upon the conventional pile-up method. According to the city planning manual for a station plaza, the rate of environmental space should be more than 0.5, but some station plazas in Figure 4 do not satisfy this requirement. Therefore, it seems necessary to put a new additional standard for a station plaza in addition to the existing ones which are based on the urban planning manual, as shown in Figure 4. This standard would be able to strike a new optimal balance between transport function and city function. Next, the authors thus categorized station plazas into three groups and tried to establish a standard incorporating various indicators of social usability, by focusing on the qualitative differences among station plazas for each of which are assigned different environmental space rates.

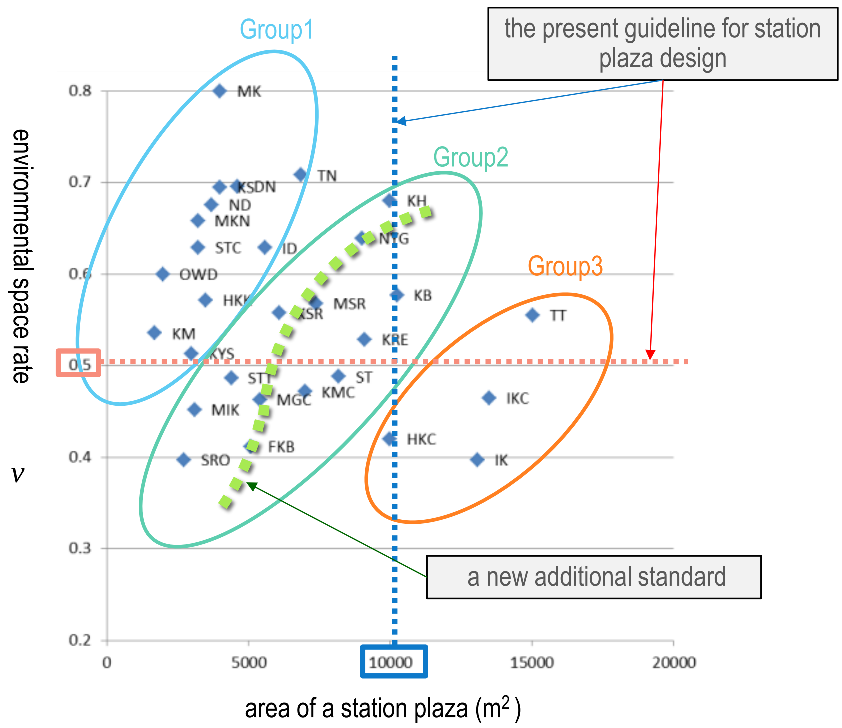


Figure 4. The present guideline for station plaza design and a new additional standard

4. CONSIDERATION OF THE EVALUATION METHOD FOR SOCIAL USABILITY TARGETING A WIDE VARIETY OF USERS

4.1 Social Usability

ISO 9241-11(1998) defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Originally, the term usability was coined to denote user-friendliness of software and websites. The concept can be adapted to connote user-friendliness of public facilities which are requested to meet the demands of diverse users in the era of diversification of needs. In this study, social usability of public facilities is defined as *the extent to which a facility and infrastructure can be used by variety of users to achieve original goals, with effectiveness, efficiency and satisfaction,* as Figure 5 shows.

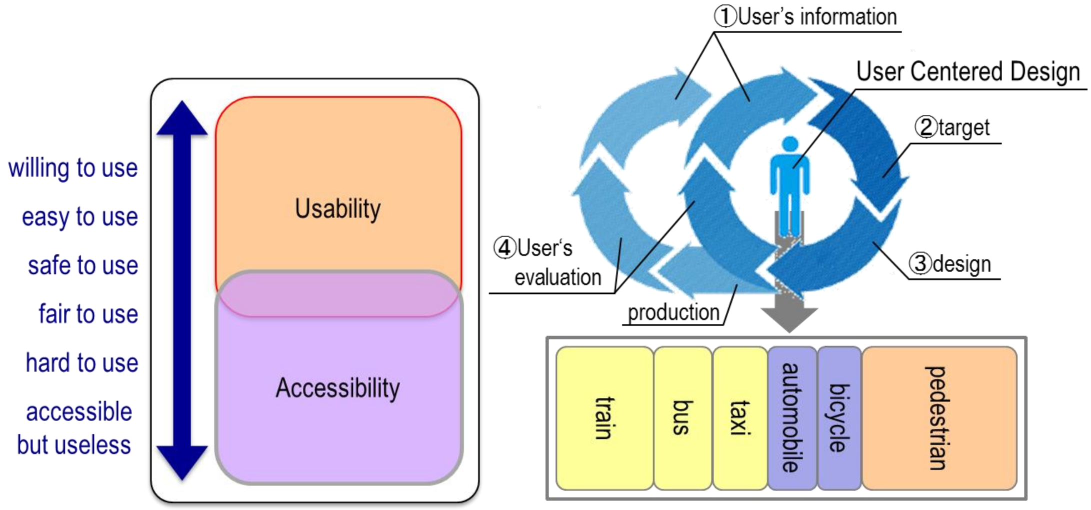


Figure 5. Definition of social usability for diversity of users

4.2 A Stepwise Improvement Procedure of Social Usability

It is proposed in this study that, as mentioned in the last section, the concept of PCU for a step-wise procedure to improve social usability of public facilities. The term PCU stands for: priority, compactness, and usability. As shown in Figure 6, for priority, transport modes in station plazas and the space around them are systematically prioritized. This makes station plazas open to diverse users. Next in compactness, the possibility of compactification of the station plaza is considered, based upon the priority order as set out above. Two procedures already exist for this, as described in the previous studies by Takahashi and others (2006, 2009) on compactification: first, spatial compactification procedure can be adopted by reducing the excess station space, reducing the moving distance when connecting rides; and secondly, by reducing the traffic functions of station plazas, functional compactification procedure can also be tried, , in order to provide richer functions to the environmental area for meeting the needs of users. It is to be noted that this Compactification procedure plays the role of linking the Priority procedure to the next, or usability. And for usability, considerations are made as to improvement of usability targeting various users**.** Thus, the concept of PCU is to set forth a practical procedure in order to improve usability through stepwise process from priority, compactness, and finally to usability.

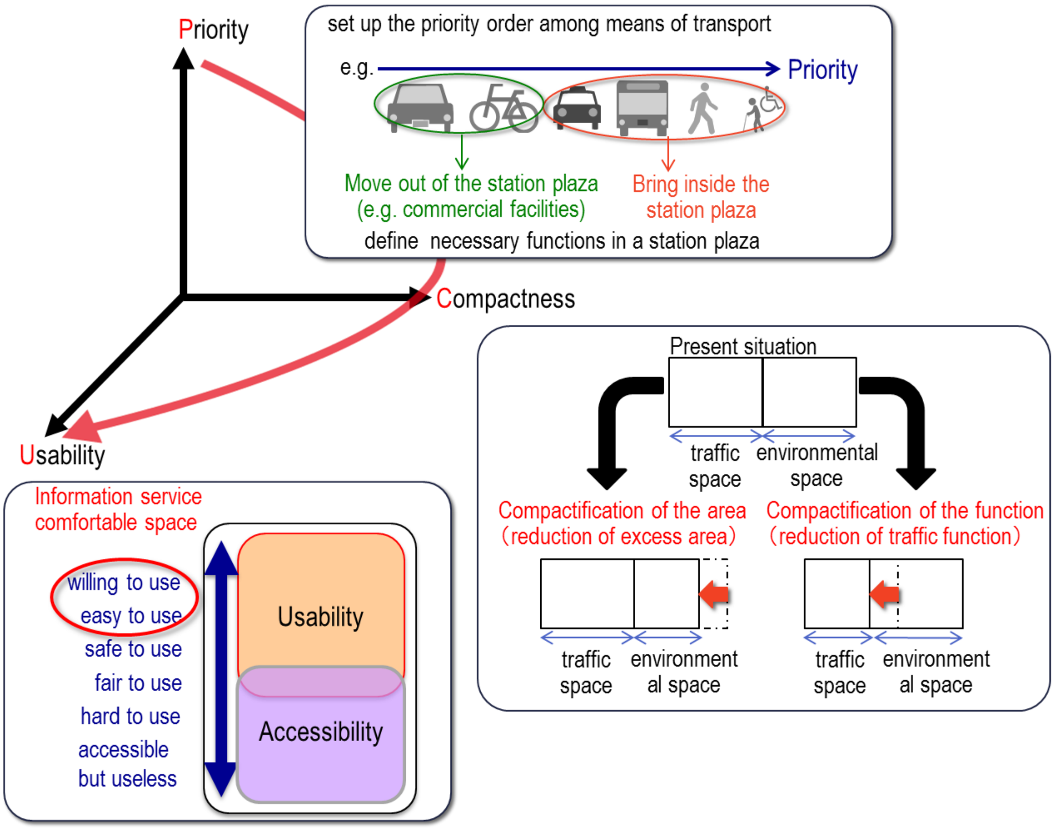


Figure 6. The concept of PCU (Priority-Compactness-Usability)

4.3 Indicators for Assessment of Station Plazas

This paper proposes a system of indicators to assess the quality of station plazas for administrators of local government on the basis of the PCU concept. Considering the relationship among PCU elements, some viewpoints for evaluation of social usability are defined. First, the authors took up four viewpoints on the study by Sugiyama et al. (2005): Ease of Movement, Space comfort, Information provision and Movement assistance. These viewpoints were useful for evaluation of social usability because they quantify the quality of pedestrian space experience from the users' side. In this study, the factors were expanded to identify evaluation indicators for station plazas, taking into account the design requirement for its spatial characteristics: that balance should be achieved between transport functions and environmental functions. Then evaluation indicators for the social usability were elaborated, which are composed of 40 indicators from eight viewpoints, after careful interview and pretests in the local community. Figure 7 shows the eight evaluation viewpoints concerning the social usability of station plazas. Table 1 represents the evaluation indicators for the social usability of station plazas. By utilizing these indicators, a social usability survey to enhance station plazas' function was performed in collaboration with the administrators of local government. Figure 8 shows the outline of this survey. The scope of the survey was the suburban area of northern Osaka where commuters/students are decreasing in numbers owing to the aging population and lower birthrate. The number of samples was 34 station plazas in 8 municipalities. Both distribution and collection were by mail, and the response rate was 100%. The questionnaire for this survey is shown in appendix B. The survey first asked the administrators in charge of the station plazas to answer their basic characteristics; transport space, environmental space and number of berths, and evaluate the degree of their satisfaction by five grades. Next, the survey asked for a five-grade evaluation of the importance and satisfaction for each evaluation indicator on social usability of station plazas as mentioned above. Here, the term importance denotes priority in planning the plaza for management and maintenance, while the degree of user satisfaction denotes the degree of satisfaction of the present state against the most desirable state of affairs. It would be desirable for social usability evaluation to be asked to users alike. But general public are still not very well informed about the definition and range of the station plaza, so in this survey, it is decided first to ask administrators of the local governments to check and evaluate.

Movement easiness	Easy for pedestrians and people in wheelchairs to move around	Information provision	Information provided as required by pedestrians
Movement safety	Safe for pedestrians to move around	Space comfort	How pleasurable for various users to visit the station plaza
Movement assistance	Facilities or services available for handicapped people	Management sufficiency	How well the station plaza is managed by joint efforts of public and private sectors
Transport connectivity	Easy for users as transport hub, including the station plaza	Attractive creation	Capability of the station plaza to produce conviviality as the main entrance of the city

Figure 7. Viewpoints for social usability evaluation

self-assessment survey of usability

- TITLE : A survey for the functional improvement of the station plaza for urban development with the railway station as city core
- TERM : 3 Dec. 2013 to 20 Dec. 2013
- METHOD : Mail distribution and collection
- SUBJECT : Station plazas in 8 cities (number of samples: 34 stations)
- RESPOSE RATE : 34 stations (100%)

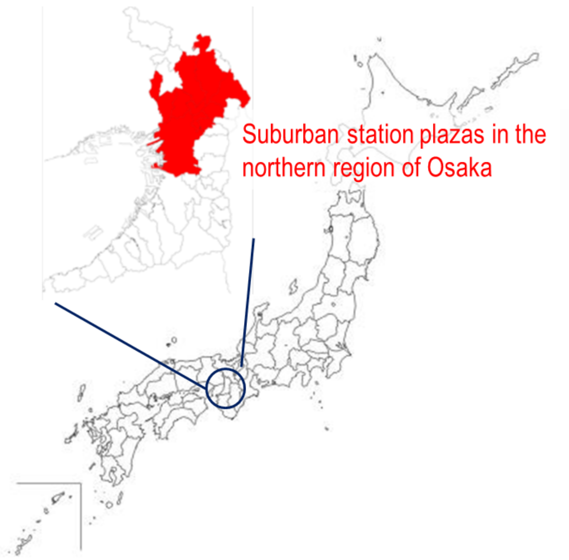


Figure 8. Outline of the social usability survey

Table 1. Indicators for the evaluation of social usability of station plazas

Viewpoint	Indicators	Viewpoint	Indicators
Movement easiness	1 Sidewalk around the station plaza is smooth and level.	Information provision	1 Clear signs to show loading zones for cars, buses and taxis.
	2 Slope is mid and stairs few in the station plaza.		2 Clear signs/guides to show parking lots for cars and bicycles.
	3 Few bicycles left-over or cars illegally parked.		3 Information about public transportation services are clearly and well presented.
	4 Ample space for pedestrians and wheelchairs to move around.		4 Guidance devises for handicapped pedestrians, like braille blocks.
	5 Two-sides of the station are well-connected.		5 Audio assists available to guide pedestrians.
Movement safety	1 Safe enough to move and stick around at night.	Space comfort	1 Ample space for users to relax.
	2 Well illuminated.		2 Ample and comfortable space to stop over.
	3 No danger for pedestrians of cars.		3 Rest areas at regular intervals for people not to feel tired.
	4 No danger for pedestrians of bicycles.		4 Universal design is introduced.
	5 Not crowded so that pedestrians can move around freely.		5 Easy for pedestrians to move around even in bad weather.
Movement assistance	1 Help-desk or apparatus to ask for support.	Management sufficiency	1 Responsible organizations exist to manage the whole or part of a station plaza.
	2 Station staff ready to assist movement.		2 Managers in charge of dealing with left-over bicycles.
	3 Parking slots for vehicles for disabled people near the station.		3 Signs/alarms to control illegal abandonment of bicycles and parking.
	4 People around the station plaza are friendly and willing to assist.		4 Regular clean-ups.
	5 Electric wheelchairs and/or electric scooters are available for lease.		5 Green space is regularly and well maintained.
Transportation connectivity	1 People won't get lost during connection between public transportations.	Attractive creation	1 Council organized to activate the city with the station as its core.
	2 People can make connections easily and speedy between public transportations.		2 Station plaza is maintained as the front entrance of the town.
	3 Rental bicycles and/or community bicycles are available at the station plaza or near the station.		3 Event space for communion and enjoyment.
	4 Park-and-ride facility available to enable smooth connection between bicycle and train/bus.		4 Regular events held in the station plaza.
	5 The motility environment among the station building and facilities around is well organized.		5 Commercial facilities effectively and charmingly arranged around the station plaza.

4.4 Extraction of Target Indicators for Future Improvements

In order to extract target indicators for improvements, a screening method using AIMS criteria was applied. This was proposed by Lingayah and Sommer (2001) and applied in the study by the European Commission Joint Research Centre (2004). AIMS is the acronym: “Action focused”,”Important”,”Measurable” and”Simple”. Based on evaluation by AIMS criteria, this paper extracted appropriate indicators, following the stepwise procedure as shown in Figure 9. On the basis of the results of the self-assessment, firstly indicator groups were extracted for which importance rated by the administrators exceed the average in a pre-given level. After that, principal component analysis narrowed down statistically measurable indicators by principal component analysis**.** Finally, indicator groups were identified that are easily given significance in the context of PCU and also are practically targetable. Based on the screening procedures above, PCU evaluation indicators was introduced as shown in Figure 10. Those PCU indicators represent the central check-points that are of high practical utility in identifying target aspects for future improvement of a given station plaza, starting from a comprehensive self-assessment of a wide range of usability evaluation indicators.

However each PCU indicator is categorized by this analysis, so attention must be paid to the fact that each indicator is related with each PCU element.

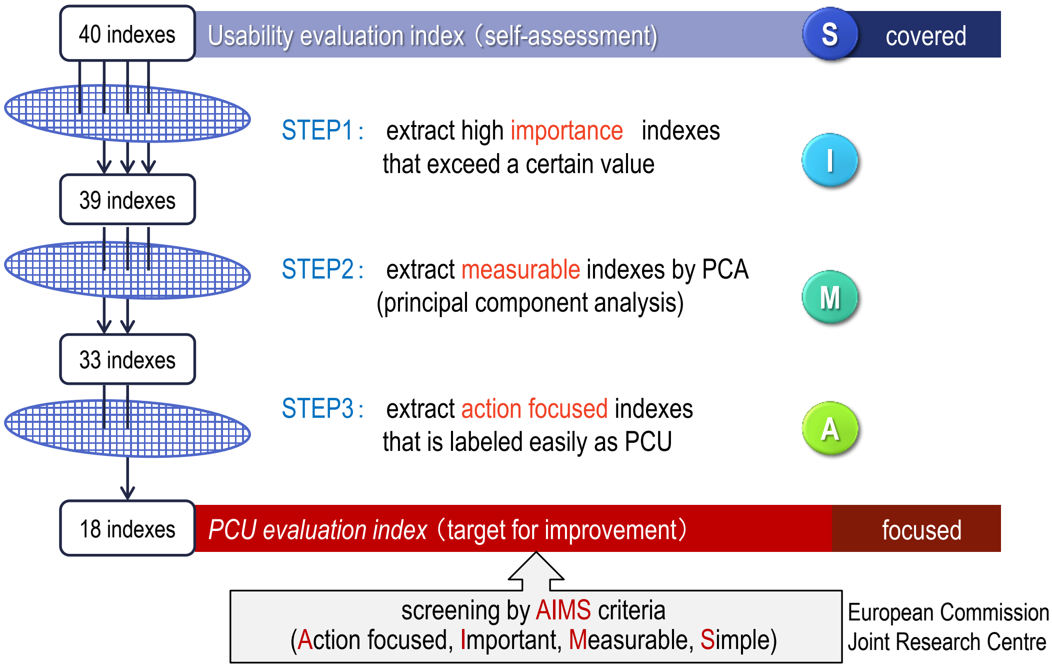


Figure 9. Extraction procedure to narrow down PCU evaluation indicators based on the social usability survey

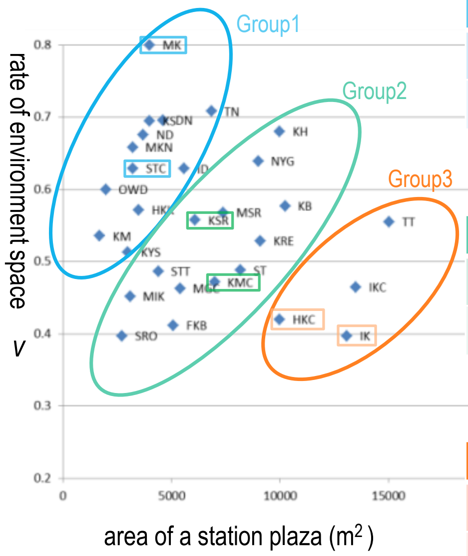
P	1	Slope is mild and stairs few in the station plaza.	priority to pedestrians
	2	Few bicycles left-over or cars illegally parked.	
	3	Ample space for pedestrians and wheelchairs to move around.	
	4	No danger for pedestrians of cars.	
	5	No danger for pedestrians of bicycles.	
	6	Guidance devises for handicapped pedestrians, like braille blocks.	
C	7	Two-sides of the station are well-connected.	safe and comfortable space
	8	Well illuminated and safe enough to move and stick around at night.	
	9	People can make connections easily and speedily between public transportations.	
	10	Ample space for users to relax.	
	11	Managers in charge of left-over bicycles.	
	12	Regular clean-ups.	
U	13	Clear signs to show loading zones for cars, buses and taxis.	improvement of convenience
	14	Information about public transportation services are clearly and well presented.	
	15	Easy for pedestrians to move around even in bad weather.	
	16	Council organized to activate the city with the station as its core.	
	17	Regular events held in the station plaza.	
	18	Commercial facilities effectively and attractively arranged around the station plaza.	

Figure 10. PCU evaluation indicators as extracted on AIMS criteria

4.5 Gap Analysis of PCU and its Application to Planning of a New Station Plaza.

Using the PCU evaluation indicators, a gap analysis was performed for existing station plazas, focusing on the difference between importance and satisfaction scores. Larger gap value implies that the station plaza in question have many PCU problems. As seen in Figure 11, the results of gap analysis on existing station plazas clearly show that station plazas with high PCU scores reside in the group 3, the cluster which is less likely to be attentive to environmental space rate.

The usability analysis was also conducted at Shin-Minoh station being newly developed along the north extension of North Osaka Express Railway line. Minoh city is located in the norther area of Osaka Prefecture, where the railway network is insufficient, and is planning a TOD development around the new station. The station in question, Shin-Minoh, aims to sufficiently secure the functions of conviviality and scenery, prioritizing safety for pedestrians and bicycle riders, under the general principle of priority of public transport over the for-profit businesses. Therefore, the basic plan itself is considered to be in accordance with the idea of PCU. The present environmental space rate is set to be above 0.6, as shown in Figure 11. This results in the PCU and gap values, in which high importance and satisfaction (feasibility) values, and a low gap value. This is probably because environmental space is secured by distancing part of bus berths and other spaces for private transport from the station plaza itself by arranging them in the surrounding roads, and for that goal efforts with discussions were made among relevant agents.



	PCU	P	C	U
STC Sta.	0.14	-0.17	0.00	0.58
MK Sta.	0.39	0.67	0.25	0.25

	PCU	P	C	U
KSR Sta.	0.39	0.33	-0.42	1.25
KMC Sta.	0.69	1.00	0.42	0.67

	PCU	P	C	U
HKC Sta.	0.69	1.33	0.00	0.75
IK Sta.	1.14	2.17	1.17	0.08

area	traffic	environment
9,200㎡	3,300㎡	5,900㎡

rate of environment	bus standby area	
	ride	get off
0.64	9	4
	in station area	on secondary road

	importance	satisfaction	gap
P	5.0	5.0	0.0
C	5.0	4.9	0.1
U	5.0	4.8	0.2

Figure 11. Gap analysis for improvement of existing station and its application for designing a new station

5. CONCLUSIONS

This study examined an alternative method to achieve a balance between traffic space and environmental space and then evaluate the usability for diverse users, in order to improve the conviviality of station plazas, which has been so far slighted. The key findings of the study are summarized as follows:

a) Based on the usability survey, a system of PCU (priority, compactness, usability) indicators were developed to quantitatively assess the status quo of station plaza utilization. It was evidenced that spatial and functional compactness of station plazas is crucial for the effective design to ensure priorities among users and enhance overall usability.

b) After extracting problematic stations based on the gap analysis utilizing the PCU evaluation indicators, it was confirmed that they suffer from relatively lower rates of environmental space.

c) The case study focusing on Shin-Minoh station indicated that environmental space rates more than 0.6 will lead to higher values of PCU evaluation indicators that represent social usability.

The remaining challenges are as follows. In this study only administrators were surveyed instead of users. Because the general public is still not very well informed about the definition and scope of a station plaza, this survey was conducted as the first step in the evaluation of social usability. In the future, it is important that the present results are fed back to users, as it is necessary that user's opinions are incorporated. This process constitutes an iPDCA cycle, in which the inclusive process is added into the ordinary PDCA cycle.

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Appendix A: Derivation of the equilibrium solution of the environmental space rate

(1) Upgrading and maintenance of the station plaza by its administrator

Let us first define *administrator* as the agent who upgrade and maintain the station plaza. Taking into consideration that the station plaza is composed of traffic space and other spaces, its surface area is represented as;

$$L = T + E \tag{a1}$$

, where L is the surface area of the station plaza and T is that of traffic space. E is the surface area of the environmental space around the space plaza, in other words, the area excluding the traffic space, namely the automobile roadways.

Let us define the *environmental space rate* as the ratio of the environmental surface area against the total station plaza surface area. Then the surface area of the station plaza is represented as;

$$L = \{(1 - v) + v\}L \tag{a2}$$

, where v is the environmental space rate, which satisfies the condition;

$$0 \leq v \leq 1 \tag{a3}$$

To note, the environmental space defined here includes facility space like bicycle parking and bus stops, excluding the automobile roads, in the station plaza.

Assuming that administrators supply traffic space in the station plaza in accordance with the numbers of station users and feeder users, the supply function can be represented as;

$$T = T(D, F) \tag{a4}$$

, where D and F are the numbers of station users and feeder users, respectively.

$$\frac{\partial T}{\partial D} \geq 0,\ \frac{\partial T}{\partial F} \geq 0 \qquad \text{(a5)}$$

The (a5) implies that the surface area for traffic space is an Increasing function of both station users and feeder users.

(2) Demand function of station use

In modeling the demand for a station, the following was taken as its essential factors:
a) accessibility to the station (AC);
b) the surface area of traffic space (T) which puts restraint on the functions as transport node and prioritization of conviviality function;
c) usability (U) which represents effectiveness, efficiency, and satisfaction in utilizing the station plaza as urban facility .

Then, the number of station plaza will be represented in the following demand function, assuming that D in the right side satisfies the condition (a7).

$$D = D(AC, T, U) \qquad \text{(a6)}$$

$$\frac{\partial \mathrm{D}}{\partial \mathrm{AC}} \geq 0, \frac{\partial \mathrm{D}}{\partial \mathrm{U}} \geq 0 \qquad \text{(a7)}$$

The condition (a7) implies that the number of station users is increasing function of both accessibility and usability of the station.

(3) Specification of the model

Assuming Cobb-Douglas type technological relationship for administrator's supply function, the supply function of the traffic space in (a4) can be specified as a log-linear model. In addition, if the surface area of the traffic space of a given station is represented as supplied by the administrator as $(1-v)L$, where v and L are environmental space rate and the surface area of the station plaza, respectively, the supply function of the traffic space in (a4) can be represented as;

$$lnT = ln(1 - v)\, L = \alpha_0 + \alpha_1 lnD + \alpha_2 lnF \qquad \text{(a8)}$$

, where α_0 , α_1 , and α_2 are parameters which satisfy the condition: $\alpha_1 \geq 0, \alpha_2 \geq 0$ on the condition of (a5).

Next, the demand for station use in (a6) is represented as a log-linear model (Cobb-Douglas type model) as;

$$lnD = \beta_0 + \beta_1 lnAC + \beta_2\, ln(1 - v)\, L + \beta_3 lnU \qquad \text{(a9)}$$

, where , β_0 , β_1 , β_2 and β_3 are parameters which satisfy the condition: $\beta_1 \geq 0$, $\beta_2 \geq 0$, $\beta_3 \geq 0$ on the condition of (a7).

The usability U above is factorized into two components, one of which is independent of the surface area of the station plaza (U_0), and the other is the surface area of the environmental space;

$$lnU = lnU_0 + \gamma lnvL \qquad \text{(a10)}$$

, where vL represents the surface area of the environmental space, and γ is a parameter satisfying the condition $\gamma \geq 0$.

(4) The equilibrium solution

The environmental space rate and the number of station users are given as the equilibrium solutions v^* and D^* of (a8), (a9), and (a10). As those formulae are non-linear for v and D, it is difficult to obtain v^* and D^* by a general method. Therefore, the relationship $\alpha_1(\beta_2 + \beta_3\gamma) = 1$ among the model parameters was introduced. Under this assumption, the v^* is derived as;

$$v^* = \frac{1}{1 + e^{-(\lambda_0 + \lambda_1 lnAC + \lambda_2 lnU_0 + \lambda_3 lnF)}} \qquad \text{(a11)}$$

, where $\lambda_0 = \frac{\alpha_0 + \alpha_1\beta_0}{\alpha_1\beta_3\gamma}$, $\lambda_1 = \frac{\beta_1}{\alpha_1\beta_3\gamma}$,

$$\lambda_2 = \frac{\alpha_1\beta_3}{\alpha_1\beta_3\gamma}, \quad \lambda_3 = \frac{\alpha_2}{\alpha_1\beta_3\gamma} \qquad \text{(a12)}$$

The formula above implies that the environmental space rate v^* is determined by the logistic model which contains external variables AC, U_0, and F as the only explanatory variables.

Appendix B: Questionnaire for the survey of social usability of station plaza

Questionnaire Survey to Improve the Function of Station Plaza toward Urban Development with Railway Station as City Core

Ikeda station (Ikeda city)

1. Basic information about station plaza

Space	Dimension of station plaza		Bus berth		Taxi berth		Bicycle parking capacity*3
Numerical data	(road space*1) m²	(other area*2) m²	(get on)	(get off)	(get on)	(get off)	
Sufficiency*4	5 / 4 / 3 / 2 / 1		5 / 4 / 3 / 2 / 1		5 / 4 / 3 / 2 / 1		5 / 4 / 3 / 2 / 1

*1 Dimension of street area in station plaza
*2 Dimension of other area (area for pedestrian, communication and green, etc.)
*3 Bicycle parking capacity in other area
*4 Please put a circle on the number of your choice. Sufficiency is about the quantitative excess or deficiency about station plaza dimension, number of berth and capacity. Meaning of each option is as below;
5: Too much 4: Much 3. Well enough 2: Little 1: Too little

2. Evaluation index of usability

Please choose an option and put a circle on the number for both Importance and Satisfaction in each item. Importance is about the priority level of a policy of construction or maintenance in a station plaza and Satisfaction is about the sufficiency of current state in a station plaza.

No.	Item	Importance: 5. Very important	4. Important	3. Neither	2. Not so much important	1. Not important at all	Satisfaction: 5. Very much satisfied	4. Satisfied	3. Neither	2. Not so much satisfied	1. Not satisfied at all
1. Movement easiness : Easy for people to move around											
1-1	Sidewalk around the station plaza is smooth and level.	5	4	3	2	1	5	4	3	2	1
1-2	Slope is mid and stairs few in the station plaza.	5	4	3	2	1	5	4	3	2	1
1-3	Few bicycles left-over or cars illegally parked.	5	4	3	2	1	5	4	3	2	1
1-4	Ample space for pedestrians and wheelchairs to move around.	5	4	3	2	1	5	4	3	2	1
1-5	Two-sides of the station are well-connected.	5	4	3	2	1	5	4	3	2	1
2. Movement safety : Safe for people to move around											
2-1	Safe enough to move and stick around at night.	5	4	3	2	1	5	4	3	2	1
2-2	Well illuminated.	5	4	3	2	1	5	4	3	2	1
2-3	No danger for pedestrians of cars.	5	4	3	2	1	5	4	3	2	1
2-4	No danger for pedestrians of bicycles.	5	4	3	2	1	5	4	3	2	1
2-5	Not crowded so that pedestrians can move around freely.	5	4	3	2	1	5	4	3	2	1
3. Movement assistance : Support for people to move around											
3-1	Help-desk or apparatus to ask for support.	5	4	3	2	1	5	4	3	2	1
3-2	Station staff ready to assist movement.	5	4	3	2	1	5	4	3	2	1
3-3	Parking slots for vehicles for disabled people near the station.	5	4	3	2	1	5	4	3	2	1
3-4	People around the station plaza are friendly and willing to assist.	5	4	3	2	1	5	4	3	2	1
3-5	Electric wheelchairs and/or electric scooters are available for lease.	5	4	3	2	1	5	4	3	2	1
4. Transport connectivity : Transportation well connected											
4-1	People won't get lost during connection between public transportations.	5	4	3	2	1	5	4	3	2	1
4-2	People can make connections easily and speedy between public transportations.	5	4	3	2	1	5	4	3	2	1
4-3	Rental bicycles and/or community bicycles are available at the station plaza or near the station.	5	4	3	2	1	5	4	3	2	1
4-4	Park-and-ride facility available to enable smooth connection between bicycle and train/bus.	5	4	3	2	1	5	4	3	2	1
4-5	The motility environment among the station building and facilities around is well organized.	5	4	3	2	1	5	4	3	2	1
5. Information provision : Informative											
5-1	Clear signs to show loading zones for cars, buses and taxis.	5	4	3	2	1	5	4	3	2	1
5-2	Clear signs/guides to show parking lots for cars and bicycles.	5	4	3	2	1	5	4	3	2	1
5-3	Information about public transportation services are Cleary and well presented.	5	4	3	2	1	5	4	3	2	1
5-4	Guidance devises for handicapped pedestrians, like braille blocks.	5	4	3	2	1	5	4	3	2	1
5-5	Audio assists available to guide pedestrians.	5	4	3	2	1	5	4	3	2	1
6. Space comfort : Space is amicable											
6-1	Ample space for users to relax.	5	4	3	2	1	5	4	3	2	1
6-2	Ample and comfortable space to stop over.	5	4	3	2	1	5	4	3	2	1
6-3	Rest areas at regular intervals for people not to feel tired.	5	4	3	2	1	5	4	3	2	1
6-4	Universal design is introduced.	5	4	3	2	1	5	4	3	2	1
6-5	Easy for pedestrians to move around even in bad weather.	5	4	3	2	1	5	4	3	2	1
7. Management sufficiency : Well managed											
7-1	Responsible organizations exist to manage the whole or part of a station plaza.	5	4	3	2	1	5	4	3	2	1
7-2	Managers in charge of dealing with left-over bicycles.	5	4	3	2	1	5	4	3	2	1
7-3	Signs/alarms to control illegal abandonment of bicycles and parking.	5	4	3	2	1	5	4	3	2	1
7-4	Regular clean-ups.	5	4	3	2	1	5	4	3	2	1
7-5	Green space is regularly and well maintained.	5	4	3	2	1	5	4	3	2	1
8. Attractive creation : Convivial and creative											
8-1	Council organized to activate the city with the station as its core.	5	4	3	2	1	5	4	3	2	1
8-2	Station plaza is maintained as the front entrance of the town.	5	4	3	2	1	5	4	3	2	1
8-3	Event space for communion and enjoyment.	5	4	3	2	1	5	4	3	2	1
8-4	Regular events held in the station plaza.	5	4	3	2	1	5	4	3	2	1
8-5	Commercial facilities effectively and charmingly arranged around the station plaza.	5	4	3	2	1	5	4	3	2	1