Pedestrian Level of Service Evaluation Based on Wi-Fi Packet Sensor Data

Guanghui ZHOU[1], Fumitaka KURAUCHI[2]

[1]Member of JSCE, Dept. of Civil Eng., Gifu University
(1-1 Yanagido, Gifu City 501-1193, Japan)
E-mail: zhou.gifu@gmail.com
[2]Member of JSCE, Professor, Dept. of Civil Eng., Gifu University
(1-1 Yanagido, Gifu City 501-1193, Japan)
E-mail: kurauchi@gifu-u.ac.jp

In this study, 20 Wi-Fi packet sensors were used to collect data from the Higashiyama area, Kyoto, Japan. At the same time, a manual count survey was carried out to acquire the real pedestrian count. Based on the data we first study how the real pedestrian counts can be estimated based on the Wi-Fi observations. Then we try to evaluate the crowding level of visitors on a street. As a result, the correlation between the Wi-Fi packet sensor observations and real pedestrian count may fit well with the exponential function was identified and how the installation height and environmental conditions influence the data collection of the sensor was estimated. The crowding level of each link could be defined with the criteria of PLoS (HCM, 2000). This can help the local government or destination managers to balance pedestrian flow on neighbour streets in order to release crowding and improve tourists' experience.

Key words: *Wi-Fi packet sensor data, pedestrian count, Pedestrian Level of Service (PLoS)*

1. INTRODUCTION AND RESEARCH OBJECTIVE

Massive visitors bring not only economic benefits but also impacts and pressures to tourist attractions. The residents may suffer from heavy congestion when driving in these areas because of the crossing of pedestrians and queuing at bus stations. The visitors suffer from crowding caused by too many people or even security threat to their sightseeing experience. In order to relax such problems, it is necessary to understand the travel demand of visitors and evaluate pedestrian performance (whether the pedestrians can move smoothly) of that area so that the authority or community can manage and control movement of people. According to the research of McKinsey & Company, & World Travel & Tourism Council, destinations can mitigate overcrowding by adopting the right mix of tactics which include smoothening visitors over time and spreading visitors across sites, adjusting pricing to balance supply and demand, regulating accommodation supply and limiting access and activities[1)].

This study tries to evaluate the crowding level in a tourist area with the concept of pedestrian level of service (PLoS). The PLoS can be defined as "*an overall measure of walking condition on route, path and facility and it reflects users' perception in terms of sense of mobility, comfort and safety*" [2].

Smartphones have become widespread in recent years; the abundant sensors and interfaces provide potential to researchers to study pedestrian behaviour through tracking the device they carry. Electronic devices, such as smartphones, tablets, and Wi-Fi-enabled computers, periodically transmit so-called probe requests to identify the access points nearby, even when the device is associated with a network. A Wi-Fi packet sensor can capture these probe requests. The probe requests include a MAC address that is unique to each device, and thus the sensor can be used to identify the movement of smart device carriers. The detail information about the tracking system can refer to our previous research (Zhou et al.[3]). The Wi-Fi packet sensor can be used to collect pedestrian count data without the necessity of the researcher's and respondent's cooperation therefore can acquire data of crowds objectively. Moreover, it is possible to acquire long-term and continuous observation data, therefore, in this paper, we try to evaluate PLoS based on the Wi-Fi packet sensor data.

Overall, the main aim of this study is to develop a quantitative PLoS measurement method appropriate for the tourism context that reflects the perceived comfort or safety of tourists based on the Wi-Fi sensing data. This study might be considered as a guideline for evaluating pedestrian level of services for such tourist areas or other business areas.

The remainder of this paper is organised as follows. In section 2, we provide a brief overview of current research on this topic. Section 3 describes the data collection procedure and the research area as well as the research framework of this study. Section 4 aims to estimate real pedestrian count based on Wi-Fi packet sensor data. Section 5 checks the PLoS in the study area under different scenarios. Finally, we give a discussion and conclude the paper in section 6 and section 7 respectively.

2. RELATED RESEARCH

The development of PLoS measures has received considerable attentions from academic researchers (Mōri and Tsukaguchi[4]; Zhao et al.[5]; Kadali and Vedagiri[6]; Raad and Burke[7]; Banerjee et al.[8]; Rahul and Manoj[9]; Ujjwal and Bandyopadhyaya[10]; Molyneaux et al.[11] and practitioners (Otak[12]; Croft et al.[13]; Transportation Research Board[14]; AASHTO[15]). Initially, the traffic engineers assessed PLoS using methods similar to LoS assessment methods for traffic facilities, i.e. based on pedestrian flow volumes and capacity of the pedestrian facility (Fruin[16]; Mōri and Tsukaguchi[4]). Later, researchers tried to integrate qualitative factors into the assessment of LoS offered by pedestrian facilities which marked an important advance in the field of PLoS assessment (Sarkar[17]; Khisty[18]; Parida et al.[19]). Ghani et al.[20] proposed a method to audit pedestrian infrastructure in a heritage site using Pedestrian Index (P-Index) method. The method is based on a star rating system including four indicators namely mobility, safety, facility and accessibility. Ujjwal and Bandyopadhyaya[10] developed a comprehensive PLoS assessment model for mixed land-use of urban areas (having residential, commercial or shopping, and office activity in the same place). Based on the face-to-face interview survey they collected the importance rating score of the 24 walking encouragement and discouragement factors from 550 pedestrians. Then the PCA (Principal Component Analysis) was conducted to define the most important influencing factors. Finally, six important parameters were identified for PLoS assessment including safety issues under pedestrian traffic interaction, pedestrian convenience and sense of security, pedestrian walking comfort and so on. Ahmed et al.[21] introduced a new pedestrian crossing level of service method to promote safe crossing in urban areas. Further, researchers have used other quantitative factors such as footpath width, shoulder width, buffer zone width and presence of on-street parking for PLoS assessment. **Table 1** presents a list of different methodological approaches and factors considered by various pedestrian studies (Gr et al.[22]). Various studies have focused on PLoS model development at intersections (Marisamynathan and Vedagiri[23]), sidewalks (Tan et al.[24]; Gr et al.[22]), midblocks (Kadali and Vedagiri[6]), stairways (Wen et al.[25]), and roadway segments (Asadi-Shekari et al.[26]). According to Raad and Burke[7], Gr et al.[22] and Ahmed et al.[21], the main conventional techniques for data collection in PLoS studies are direct observation (Anciaes and Jones[27]), video techniques (Teknomo et al.[28]; Asadi-Shekari et al.[29]; Al-Mukaram and Musa[30]), and questionnaires (Zhang and Prevedouros[31]; Zahid et al.[32]; He et al.[33]). Simulation methods, regression analysis, and point systems are the main analytical methods that are used to rate the street's condition. However, using direct observation solely can generate biased results, because it is purely dependent on the researcher's perception. Similarly, using only a questionnaire method of data collection limits the results to the respondent's perception. Besides, the questionnaire survey method cannot reflect the situation in real-time and cost more and investigators. As a consequence, there is no universal method that can be used to evaluate PLoS everywhere because it should consider the different characteristics of each place. The methodology developed in this paper only needs the sidewalk width data to derive the pedestrian flow rate and PLoS level, based on which the destination managers can develop strategies to manage crowds and alleviate congestion in the tourist area to make it more convenient.

Table 1 Summary of PLoS studies (Gr et al.[22]).

Source	Methods	Factors considered
Sarkar[17]	Scoring System	Convenience, comfort, safety, continuity, system coherence and attractiveness.
Khisty[18]	Scoring System	Comfort, convenience, continuity, attractiveness, system coherence, safety, security.
Dixon[34]	Scoring System	Path conflicts, amenities, motor vehicle LOS, maintenance problems, provision of basic facilities and provision of multiple modes.
Landis et al.[35]	Ordinary Least Regression	Lateral separation factors, traffic volume, speed of the vehicle, driveway access frequency and volume
Muraleetharan et al.[36]	Ordinary Least Regression	Sidewalk width and separation, pedestrian volume, flow rate and bicycle events
Parida et al.[19]	Scoring System	Footpath width, footpath surface, continuity, comfort, safety, encroachment, potential to vehicle conflict, crossing facilities, walking environment and pedestrian volume
Asadi-Shekari et al.[37]	Scoring system	Footpath surface, footpath, corner island, width of footpath, tactile pavement(guiding), tactile pavement(warning), signal, seating area, drinking fountain, buffer, traffic lanes, crossing, facilities, furniture
Talavera-Garcia and Soria-Lara[38]	Scoring system	Sidewalk width, sidewalk surface, walking distance
Aghaabbasi et al.[39]	Scoring system	Sidewalk width, sidewalk surface, ramps, tactile pavements, utilities and landscape

3. METHODOLOGIES

(1) Research area and data preparation

The data used in this study were collected from the Higashiyama area around Kiyomizu Temple, which is one of the busiest tourist areas in Kyoto city, Japan. The detection area is about 0.8 km^2 (1,000 metres long and 800 metres wide). **Fig. 1** shows the study area on the map. 20 Wi-Fi packet sensors were equipped to collect data for 6 months (from 2017/10/1 to 2018/3/28). At the same time, a manual count survey was carried out to collect real pedestrian count at 6 cross sections (C21 to C26 on **Fig. 1**) for two days (2017/ Nov 12th and 13th). Several famous point of interest (Yasaka Shrine, Entoku Temple, Kodai Temple and Kiyomizu Temple) are circled and pointed out with arrows. **Table 2** lists the sensor IDs and the observation location names.

Fig. 1 Data collection locations in Higashiyama area.

Table 2 Observation locations.

Sensor ID	Location	Sensor ID	Location
1	Higashioji Shinkomichi	11	Higashioji Yasakatsu
2	Shimokawara Shinkomichi	12	Shimokawara Yasakatsu
3	Nenenomichi Shinkomichi	13	Nineizaka Yasakatsu
4	Nenenomichi Chuo	14	Sanneizaka Matsubaradori
5	Shimogawara Yasui	15	Matsubaradori Kiyomizu Temple
6	Higashioji Yasui	16	Chawanzaka Kiyomizu Temple
7	Shimizuzaka Parking	17	Gojozaka Chawanzaka
8	Nenenomichi Kodaiji	18	Matsubaradori Chuo
9	Shimogawara Kodaiji	19	Higashioji Matsubaradori
10	Higashioji Kodaiji	20	Higashioji Gojozaka Naka

(2) The classification of the installation condition of the sensors

As is shown in our previous study (Zhou et al.[40]), the different installation conditions of the Wi-Fi packet sensor will influence the observation counts. Based on the characteristics of the installation locations, three levels of the surrounding conditions and installation height are given as shown in **Table 3**. **Table 4** records the installation conditions of all Wi-Fi packet sensors.

Table 3 The classification of installation conditions of sensors.

Installation height	h_0	2 meters high or more, at a place of a good view that is not easily affected by the surrounding people.
	h_1	1.5m~2m, places can be seen from a person's height.
	h_2	70cm ~1m, places with poor visibility, blocked by people or vehicles.
Surrounding conditions	e_0	Well-reflected: inside a building that reflects radio waves easily (made by concrete or steel), or there is a building that reflects radio waves opposite to the sensor within 10 meters.
	e_1	Moderate reflection and absorption: there are no buildings within 10 meters that easily reflect radio waves, and there are few radio wave absorbers such as people and trees.
	e_2	Well-absorbed: there are no buildings that reflect radio waves opposite to the sensor but many radio waves absorbers such as people and trees.

Table 4 Installation conditions of sensors.

Sensor ID	Height	Surrounding conditions	Sensor ID	Height	Surrounding conditions
1	h_0	e_0	11	h_0	e_1
2	h_0	e_1	12	h_2	e_2
3	h_2	e_2	13	h_0	e_2
4	h_1	e_2	14	h_0	e_1
5	h_2	e_2	15	h_2	e_2
6	h_0	e_1	16	h_0	e_1
7	h_0	e_1	17	h_2	e_0
8	h_2	e_2	18	h_0	e_2
9	h_2	e_2	19	h_0	e_2
10	h_0	e_1	20	h_1	e_1

Fig. 2 shows the name and location of links on the map. Based on the environment of each link we classified the links into 4 types as shown in **Table 5**.

Fig. 2 Link names and locations

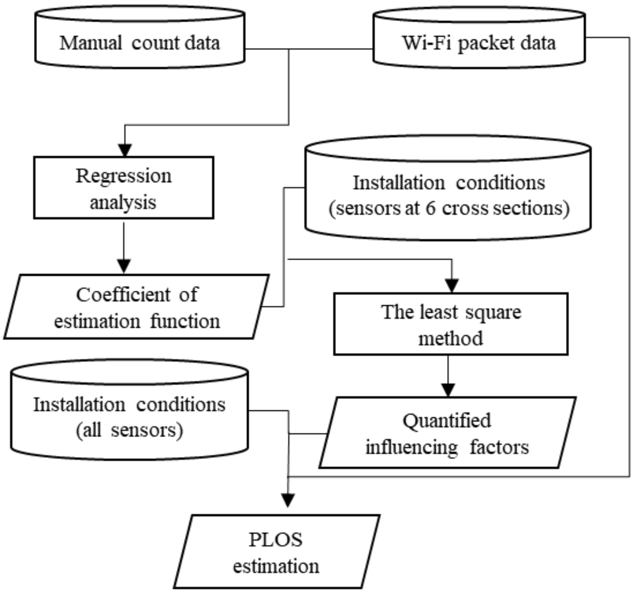

Fig. 3 PLoS estimation framework

Table 5 Classification of links.

Type	Link name	Characterisation
1	L1-L5	Main road for vehicles
2	L6, L7, L8, L9, L13, L14, L16, L17, L18	Good for walking, less POIs
3	L10, L15, L19, L22, L23, L24, L25	Very good for walking, many traditional buildings and POIs
4	L11, L20, L26, L12, L21, L27, L28	Heading to Kiyomizu Temple, many POIs, very popular

(3) Research framework

The framework for evaluating PLoS of a tourist area from Wi-Fi observations is outlined in **Fig. 3**. The regression analysis is carried out to check the relationship between manual count data and Wi-Fi observations. Then the least square method is used to quantify the installation conditions. After that, the quantified influencing factors and Wi-Fi observations of all sensors are used to estimate real pedestrian flow count of a link. Finally, combining with link width data, the PLoS can be identified.

4. ESTIMATION OF REAL PEDESTRIAN FLOW COUNT

The Wi-Fi packet sensor observes the device carried by people instead of the pedestrian themselves. To find a relationship between PLoS and real pedestrian flow, the real pedestrian flow count is needed. In Zhou et al.[40] it was found that the observation result of the Wi-Fi packet sensor can be affected by several factors such as the setting height and sensor type, and a rough correlation exists between ground truth data and Wi-Fi packet sensor observations based on the one-sensor method. Ota et al.[41] studied the acquisition rate of the Wi-Fi packet sensor considering the surrounding conditions, installation height, and the stay behaviour of the pedestrians of the sensor as well as the penetration rate of the devices with Wi-Fi turned ‘ON’. In their study, they set three levels of attenuation rate (level A=5%, level B=15%, level C= 25%) for the surrounding conditions, installation height and the approximate density of the pedestrians. For example, if the three factors are all level A for a sensor, its acquisition rate is 85.7%. Even there are some studies using automatic technologies to estimate pedestrian flow, studies using this kind of data to estimate pedestrian flow is still limited and they didn't consider the effect of surrounding environment on the observations of the sensors. Therefore, we try to quantify the influencing factors of the Wi-Fi packet sensor observations, such as height and surrounding conditions in this section.

The observation data were filtered before checking relationship with survey data since there are meaningless observations such as randomised AMACs. The count survey recorded the pedestrians passed by the cross-section every 15 minutes. The AMACs observed by two sensors at the end of the count survey were also aggregated every 15 minutes. The dataset from 9:00 to 10:30 on Nov 13th at cross-section 21 were removed because the Wi-Fi sensors had no observation. By comparing the two datasets we can get the correlation function as **Fig. 4** shows.

The horizontal axis is AMAC count data from the Wi-Fi packet sensor and the vertical axis is the pedestrian count obtained by manual count survey. It can be found that the correlation may fit well with the exponential function (the detection ability may decrease gradually when the number of pedestrians increases). This is reasonable because when there are too many people, the body of people can be regarded as an obstacle and will absorb the Wi-Fi signal. Furthermore, the unique AMACs under the same pedestrian traffic volume differs greatly for the six cross-sections. The acquisition rate was quite low at cross-sections C26 and C25 while it was high at C24.

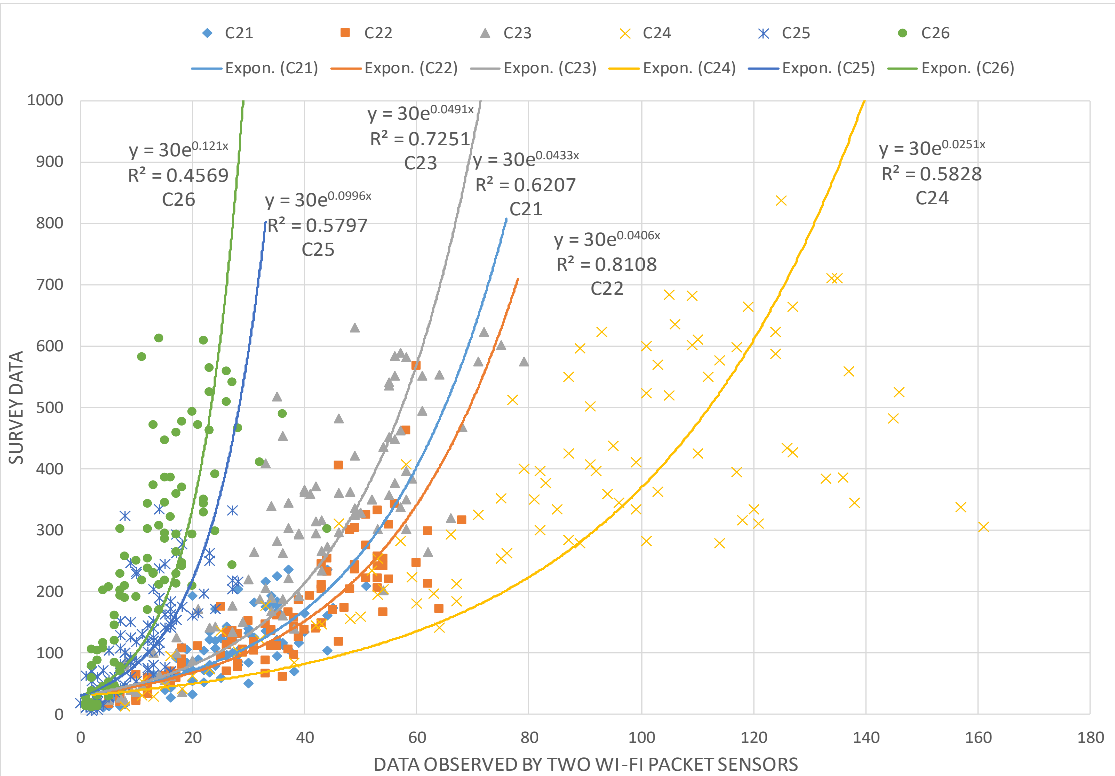

Fig. 4 Correlation between Wi-Fi packet sensor data and survey data

From the **Fig. 1**, C26 and C25 are located on Nene-no-michi and Shimogawara dori that are very popular with tourists. As mentioned above, the Wi-Fi radio waves can be absorbed by human bodies, and the acquisition rate tends to decrease as the pedestrian traffic volume increases. Therefore, it can be said that the number of observed unique AMACs may decrease with respect to the pedestrian volume at these two locations. Another possible reason is that there are streets between C25 and C26 such as Ishibe-koji, which are also well visited by tourists, and the people who use these streets cannot be observed by the two sensors leading to less matched AMACs. On the other hand, C24 is located at a rather wide road and there are sightseeing buses passing by; there may have some observations from the tourists inside buses by sensors 20 and 17. Therefore, the number of observed unique AMACs seems to increase.

Since there are only six cross-sections in this survey, the number of parameters that can be estimated is up to six. Therefore, we decide to estimate the coefficient of the regression curve shown by **Fig. 4** with the installation height (h_0, h_1) and surrounding conditions (e_0, e_1) as the explanatory factors. The equation between the ground truth data and Wi-Fi packet sensor data is assumed as:

$$y = 30e^{\beta x} \quad (1)$$

y: actual pedestrian flow volume, x:number of AMACs observed by two sensors.

Here, β is the result of the combined effect of the installation height and the surrounding conditions of the Wi-Fi packet sensor. Let:

$$\beta = c * h_0^{x_{h_0}} * h_1^{x_{h_1}} * e_0^{x_{e_0}} * e_1^{x_{e_1}} \quad (2)$$

Definitions of variables in the model is shown in **Table 6**.

The least squares method was applied to calculate β of the trend lines in the **Fig. 4** and also be used to estimate the parameters (h_0, h_1, e_0, e_1) of the equation (1). Equation (2) can be transferred to a linear equation by taking the logarithm of both sides. **Table 7** shows the estimation result.

The larger estimates of parameters will result in a larger rise of the curve, meaning that the sensor observations become less when the pedestrian volume is the same, in other words, the acquisition rate of the Wi-Fi packet sensor becomes lower.

Table 6 Definitions of variables

c	Constant, when height is h_2 and surrounding condition is e_2 (unknown variable)
h_0, h_1	Explanation of y when set height is h_0 or h_1 (unknown variable)
e_0, e_1	Explanation of y when surrounding condition is e_0 or e_1, (unknown variable)
x_{h_0}, x_{h_1}	Number of sensors of the link when set height is h_0 or h_1 (it should be 0, 1 or 2)
x_{e_0}, x_{e_1}	Number of sensors of the link when surrounding conditions is e_0 or e_1 (it should be 0, 1 or 2)

Table 7 Parameter estimation result.

Parameter	Value	T-stat	R^2
c	0.09960	-3.19	0.70
h_0	0.84135	-0.36	
h_1	0.84605	-0.17	
e_0	0.88279	-0.12	
e_1	0.48450	-0.84	

From this point of view, the h_0 is smaller than h_1 in **Table 7**, meaning that when putting the Wi-Fi packet sensors at a higher place (2 meters), the observation efficiency will be better. Maybe it is because it can reduce the obstruction of the human body to the Wi-Fi probe. e_0 is larger than e_1 meaning that when the Wi-Fi packet sensors were installed inside a building or the surrounding conditions are easy to reflect the Wi-Fi probe, the acquisition rate is lower. R square is 0.7 means the parameters can explain 70% of the variation of β. The *t* values for the parameters seem not statistically significant (the absolute value is less than 2). This may be because the sample size is too small and more sample is needed to improve the estimation.

5. ANALYSIS OF PLOS UNDER DIFFERENT SCENARIOS

(1) Criteria for evaluating PLoS

According to Highway Capacity Manual (HCM[42]), the PLoS rating of a walkway is determined on the basis of two decision variables: the average pedestrian space and the pedestrian flow rate. Based on section 4, it is possible to estimate the real pedestrian flow count of a road segment using Wi-Fi packet sensor data. The criteria of PLoS based on pedestrian flow rate is therefore used to evaluate the pedestrian flow performance in Higashiyama area. **Table 8** shows the six-level scale PLoS criteria developed by HCM[42].

Table 8 Pedestrian walkway LOS (adapted from the HCM[42]).

Pedestrian LOS	Flow rate (ped/min/m)	Characteristics
A	<= 16	Free speed, no conflict.
B	16-23	Free speed, respond to other pedestrians.
C	23-33	Normal speed, reverse-direction or crossing movements can cause minor conflicts.
D	33-49	Restricted to select walking speed freely, high probability of conflict of crossing or reverse flow movements, reasonably fluid flow but friction and interaction between pedestrians is likely.
E	49-75	Virtually all pedestrians restrict normal walking speed, volumes approach the limit of walkway capacity, with interruptions to flow.
F	Flow rate varies	All walking speeds are severely restricted, and forward progress is made only by shuffling. Frequent, unavoidable contact with other pedestrians.

Level A represents the best condition scenario in terms of the road passability, level F represents the worst condition scenario (i.e., very congested/ unsafe/uncomfortable). If the streets are too congested, people may feel uncomfortable and unsafe to use the street which contributes to the feeling of stress (Krupat[43]). According to Shamsuddin and Ujang[44], the presence of people can increase their feeling of safety in using the street. If there are too many people it will become an unsafe environment. Street users will avoid using streets that are too congested. However, the feeling of crowding is different for each of users with different purposes. The tourists who walk mainly for pleasure may feel satisfied and positive emotions while commuters running for catching a bus will feel negative emotions. There are also some positive effects of crowding. For example, in tourist attraction sites, crowding makes a street lively and inviting. The crowds also reflect vibrancy. People walking along the street during crowded situation tend to walk much slower for shopping purpose. This was because the shoppers tend to stroll and stop to look in windows (Al-Azzawi[45]). According to Radisya Pratiwi et al.[46], during a crowded situation (festival), the pedestrians could observe the environment in detail because they walked at a low speed and they tend to value the availability of amenities the most. Therefore, it is best to keep the pedestrian flow neither too much nor too less.

(2) Comparing PLoS on weekdays and weekends

Fig. 5 shows the AMAC count distribution of the whole observation period. The horizontal axis represents the date and the vertical axis represents the number of observed AMACs. The date is in red-orange when it is a weekend or holiday, and we can see more AMACs were observed on weekends and holidays than on weekdays. Moreover, it can be seen that there was overall the largest number of visitors in November 2017 and the least number of visitors in January 2018. This may be because November is the best time (mid-October to mid-December) for viewing maples in Kyoto.

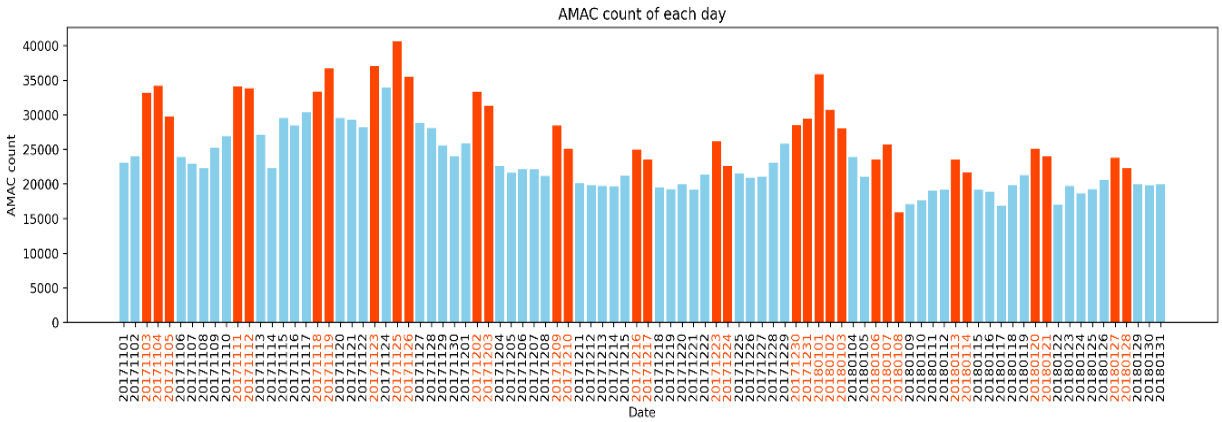

Fig. 5 AMAC count distribution

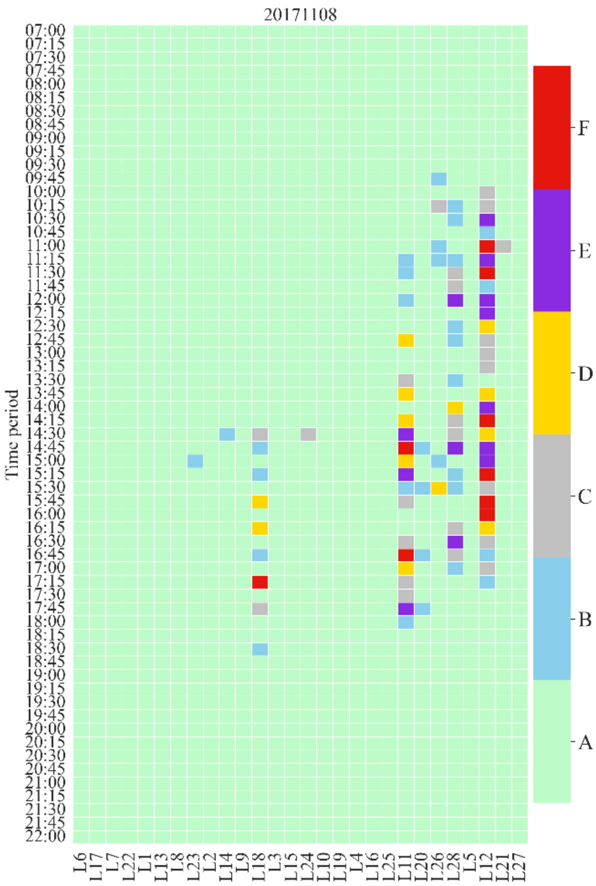

Fig. 6 PLoS on 2017/11/08 (Wednesday)

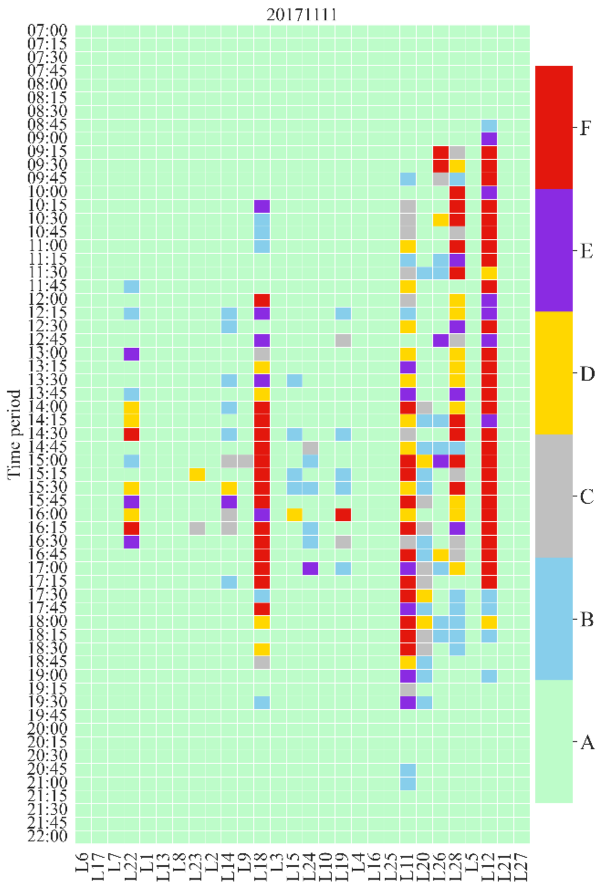

Fig. 7 PLoS on 2017/11/11(Saturday)

Firstly, the PLoS on weekdays and weekends (holidays) were compared because there was an obvious difference between the AMAC observations on weekdays and weekends (holidays). The pedestrian flow rate is the total number of pedestrians crossing the given cross-section divided by the analysis period and the sideway width. The width of a sideway is collected through a field survey.

Figs. 6 and **7** shows the estimated PLoS distribution of different links. The vertical axis represents time period and the horizontal axis represents the name of links. The different colour shows the different PLoS level. Through comparing the PLoS distribution on weekdays (**Fig. 6**) and on weekends or holidays (**Fig. 7**), it can be recognised that the PLoS on weekends or holidays ranks higher over a longer time and more links than that of weekdays. Moreover, the links L12, L28, L11 have a higher PLoS ranking than other places during some time period on weekdays. The links L12, L28, L11, L18 and L22 have extremely high PLoS levels on weekends and holidays. These links are consistent with the frequent patterns identified in Zhou et al.[3]. The links that have obviously high PLoS level (L11, L28, L12), mostly belong to group 4 in **Table 5** followed by group 3 (L22) and group 2 (L18). This means the Kiyomizu temple plays a key role in attracting tourists and visitors prefer narrower streets with fewer vehicles, which are closer to traditional buildings and POIs and are more suitable for walking tour. Among these links, the links L12 and L28 start to have high PLoS levels in the morning around 10:00, while the time period when links L11, L18 and L22 have high PLoS levels happens mainly in the afternoon. The reason may be because there are tourist buses going to the parking place near sensor 7 by using link L12. The parking place near sensor 7 is a special sightseeing parking lot with a large area dedicated to tourist buses and taxis. The vehicles can only access this parking lot through links L12 and L21. Some observations may come from the tourist on the bus and some of the tourist buses come rather early. These tendencies can also be found on other days. As a consequence, it can be said that the PLoS based on the Wi-Fi packet sensor data can reflect pedestrian flow performance.

(3) The PLoS with and without illumination event

To meet with the tourism demand, many of the temples and shrines in Kyoto held illumination events at night. The historic buildings and gardens are illuminated so that visitors can enjoy the very beautiful view of these places extremely with maples in autumn and cherry blossoms in spring. There are three famous temples (Kodai Temple, Entoku Temple and Kiyomizu Temple) that held illumination events in the study area shown by arrows in **Fig. 8**. The illumination events were held during 2017/11/11~12/3 from 17:00 to 21:30.

Fig. 8 Area classification and illumination place

Figs. 9 and **11** represent the PLoS when there had an illumination event and **Figs. 10** and **12** represent the PLoS when there had no illumination event. When comparing the PLoS with and without event, it can be recognised that the PLoS of some links (link L18, link L11, link L28 and link L12) ranked relatively high even after 18:00 (black dotted line) when there had an illumination event while the PLoS was very low after 18:00 if there had no illumination event. There are parking service for private cars and bus stops along the main road between sensors 1 and 20. A major railway station-Kyoto station is in the lower left direction of sensor 20. Links L18 and L28 are near the illumination place and links L11 and L12 are the main corridors to enter and exit the study area.

Based on the characteristics of the locations where the Wi-Fi packet sensor was installed, the whole study area can be classified into three groups named 'Road / Car Parks', 'Mid-area' and 'Tourist area' as shown in **Fig. 8**. **Fig. 13** represents the estimated pedestrian flow distribution at different areas over time. The aggregation time period is 1 hour.

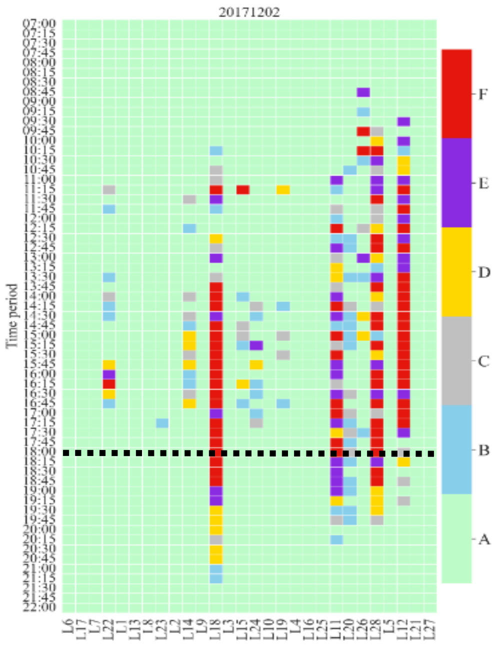

Fig. 9 PLoS on 2017/12/02 (Saturday)

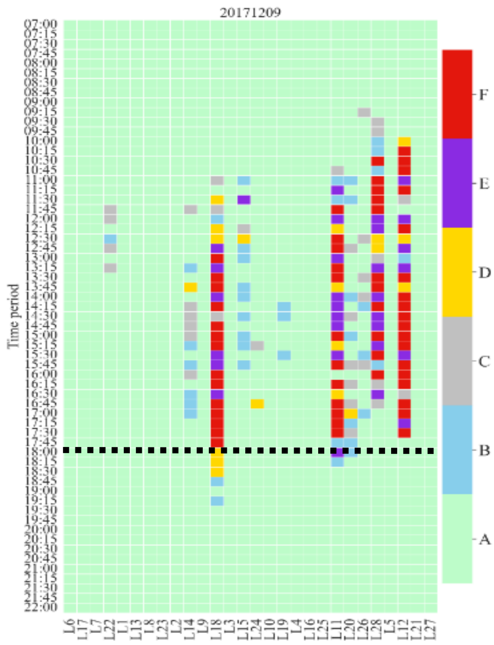

Fig. 10 PLoS on 2017/12/09 (Saturday)

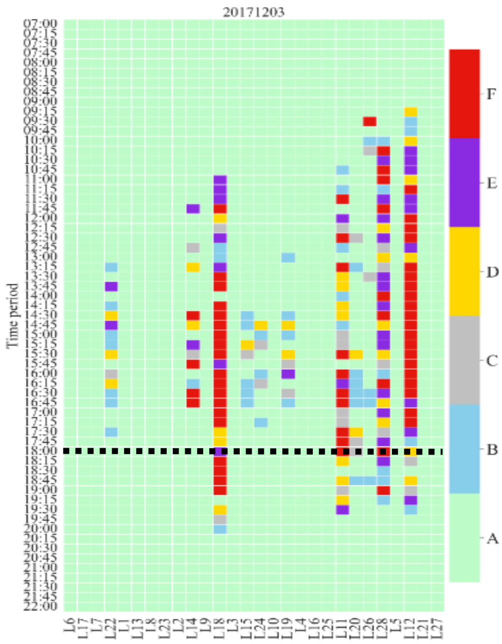

Fig. 11 PLoS on 2017/12/03 (Sunday)

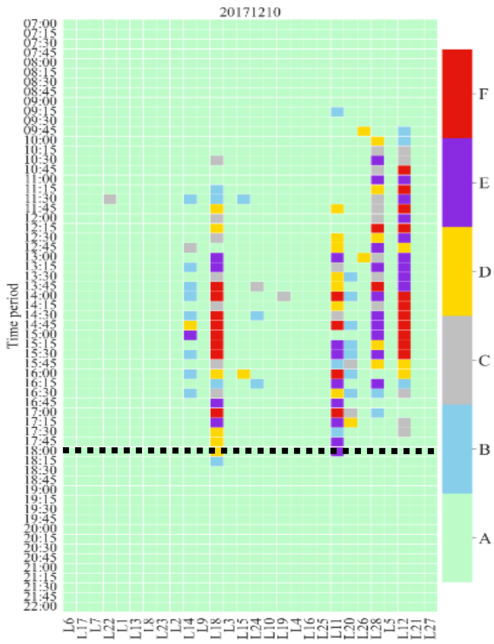

Fig. 12 PLoS on 2017/12/10 (Sunday)

We can see the observations in 'tourist area' rapidly decreased after 17:00 without the event, and the number of observations in 'Road / Car parks' becomes larger than those in 'Tourist area' from 17:00. However, when there had an illumination event, the decreasing speed of pedestrians in 'Tourist area' is slow and the pedestrian in 'Tourist area' kept larger than that in Road/Car parks area. Therefore, it can be said that the leaving time of the tourists becomes later with the illumination event.

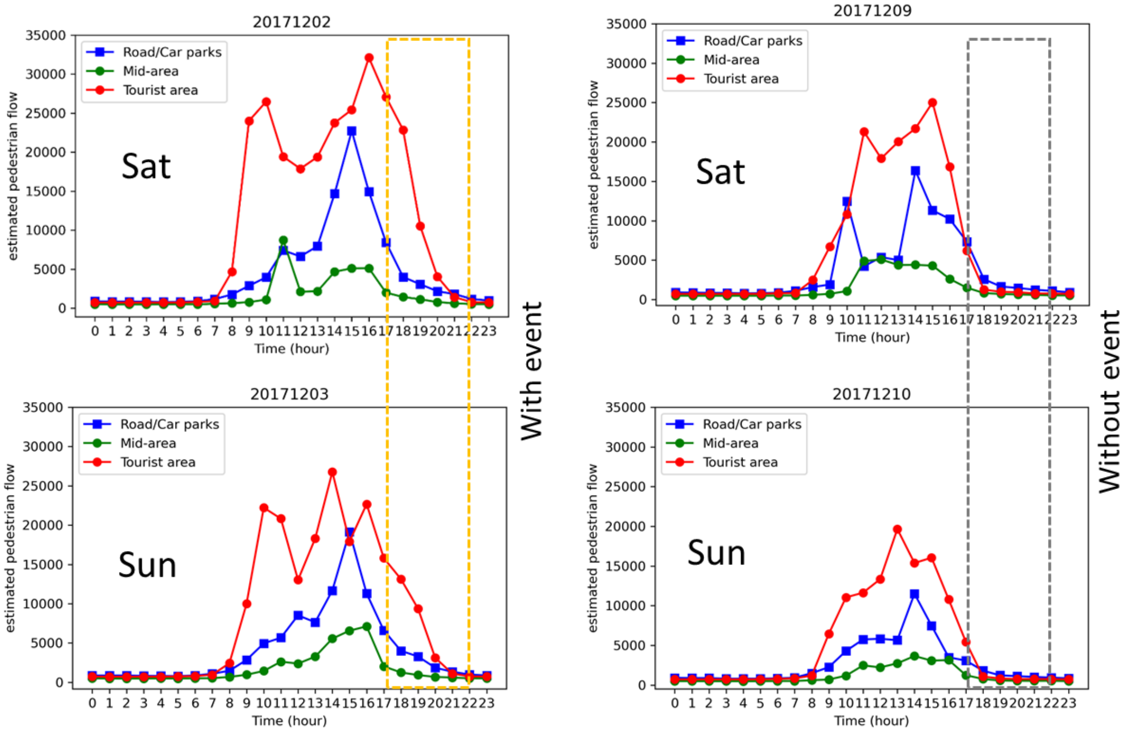

Fig. 13 Distribution of estimated real pedestrian flow of different areas

6. DISCUSSION

Through analysis above, it can be known that the links L12, L28, L11, L18 have rather higher PLoS ranking than other places. These links are consistent with the frequent patterns in our previous research (Zhou et al.[3)]). Because these places were always at level E or F, meaning that the tourists may always suffer from crowding which may make them uncomfortable. Therefore, the local government or destination management organisation managers should take measures to balance pedestrian flow on these streets so as to improve the service. For example, like **Fig. 14** shows, when links L18 and L11 were busy but the surrounding link like links L19 and L10 were not busy, tourism managers can provide such information to tourists to help them make better planning of sightseeing routes or take measures (such as roundabout or direction rule) to guide them to use other circuitous routes.

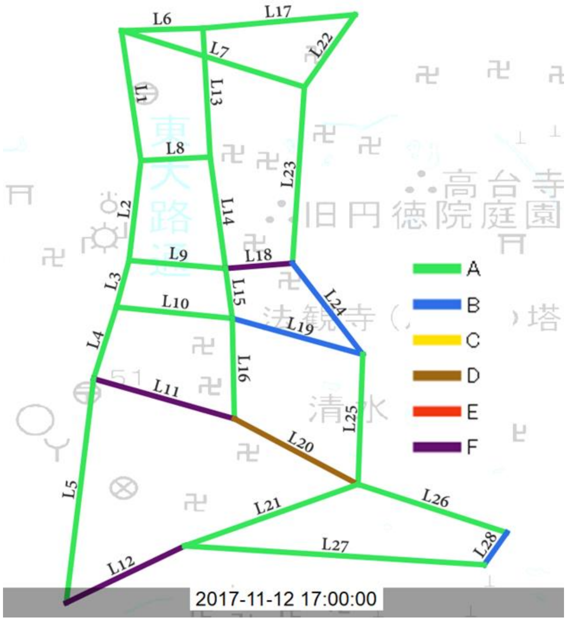

Fig. 14 PloS level of links

7. CONCLUSIONS

A better understanding of the PLoS in tourist areas can help the managers provide better service and the tourists can have a better experience. In this paper, the Wi-Fi packet sensor data was used to calculate pedestrian flow rate and evaluate the level of crowding in a tourist area. This data source has an ability to capture the situations of crowd movement in a simple and tractable way. Based on this method, the pedestrian flow can be controlled by time and space. The criteria developed by HCM[42)] was used as a benchmark and pedestrian flow is estimated through matching the same AMACs observed by two sensors located at ends of a link firstly then converting to real pedestrian flow by using the quantified factors in section 4. As a result, it is possible to evaluate the PLoS of a link and provide ideas which street should be improved in specific. It was also recognized that the PLoS of links near illumination event area were ranked higher than without event and people tend to stay longer in tourist area when there had an illumination event, this inspires us holding such an event may help to improve vehicle traffic conditions because the demand will decrease on bus stations or cross-sections near the tourist area. This may be justified by comparing it with traffic detector data in the future.

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