WIFI-SCANNER TECHNOLOGIES FOR OBTAINING TRAVEL DATA ABOUT CIRCULATOR BUS PASSENGERS, A CASE STUDY: OBUSE, NAGANO PREFECTURE, JAPAN

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ABSTRACT

Recently, a variety of technologies such as the development of Bluetooth, WiFi, smart card and some other technologies has been applied to investigate the movements of the passengers or vehicles. In this study, we describe the use of a WiFi scanner that was installed on a bus and circulated around the bus's route 14 times. The method presented here involves the use of WiFi and GPS to analyze the passengers' movements while the bus is running and while stopped at a bus stop. Nine steps were used to derive travel data from the raw data in order to estimate the number of movements of the passengers. The results of this study describe the travel data collected between bus stops no. 1 and no. 9 and compare the observer data with the WiFi data.

Keywords: WiFi Scanner, Number of Passengers, Travel Data, Bus Stop, Bus Circulation

INTRODUCTION

Data about movements in transit systems in a city or region is becoming increasingly important. For example, it is important to know the number of passengers boarding or alighting at a bus stop in order to implement effective strategies for alleviating congestion and improving the quality of the transportation service. In this case, the collection of transportation data is very important for investigating the current supply and demand for transit in order to formulate better transit strategies in the future. The data of interest for this application is commonly called origin–destination (OD) data, which reflects a person's movements from one place to another. However, traditional methods to record travel data rely on manual counts by on-board observers on each trip. The process of manual counting is very time-intensive, has a high cost, and has the potential for significant errors.

Recently, there has been an increasing interest in advancing collection techniques for travel data by incorporating novel technologies to reduce the survey burden and accurately collect passenger information. However, it is relatively expensive to implement the necessary equipment required for these emerging techniques, such as sensors, smart cards, and smartphones. Many researchers have developed methods for collecting travel data using WiFi, Bluetooth, loop detectors, image processing, and various other technologies. However, several of these methods have a high cost and are difficult to apply for further research. WiFi is one of the communication networks which is most widely used today for the smartphones, laptops, tablets, and other devices that are currently in high demand around the world and, therefore, WiFi can be used as a tool to observe the movement. Consequently, WiFi is one of the most useful options for obtaining travel data. Hence, the objectives of this study are to gather travel data based on WiFi use with a relatively inexpensive tool and to interpret the transit behavior using this data.

The challenge in this research is how to collect travel data or passenger data from a small bus and a small operator with no smart card and a hop on–hop off system. Developing new methods to collect travel behavior via WiFi remains a challenge for better decision-making on the basis of bus travel data. This study therefore seeks to achieve this goal by investigating the utility of WiFi-sensing technologies for affordable collection of travel data. This paper's value is to provide some procedures for distinguishing travel data from raw WiFi data (MAC address).

RELATED WORK

Research into techniques for estimating OD data is gaining momentum. Previous research investigations have used the method of monitoring the GSM (Global System for Mobile Communications) mobile network (*3*). Another approach based on a real-time transit-tracking technique that utilizes mobile phone networks has been proposed, which can count bicycles, buses and other drivers (*16*). Bluetooth and wireless detectors have greatly evolved for use in the transportation sector as a method for collecting travel data. Use of a Bluetooth detector and WiFi on a bus is more predictable because the bus users and the passenger-carrying capacity varies so the process of analyzing OD data for each bus stop is very diverse (*5*, *8*, *9*). Some approaches combine wireless mesh networks with Bluetooth capabilities by detecting Bluetooth devices attached to cars equipped with wireless networking at specific locations (*1, 2, 5*) or by the installation of detection equipment at certain locations such as public facilities (*6*) or terminals and bus stops. This enables the measurement of travel data and vehicle images (*10*) during movement in either direction at a travel node (*12*). Other research has been done to combine the use of a loop detector with Bluetooth that produces multi-mode data in large areas (*13*). However, the tools used in previous research are numerous and diverse and are therefore impractical in terms of funding, operation, and maintenance. For example, a loop detector is placed on the road and a Bluetooth sensor is a large, wireless link sensor that requires a large amount of solar power. In addition, on smartphones and laptops, Bluetooth is more commonly turned off than WiFi is and Bluetooth capabilities are quite limited by its short range. Data collection via wireless or WiFi is relatively effective due to the current network ubiquity, especially with mobile phones equipped with WiFi being more and more widely used by people of all ages. WiFi signals travel over a relatively large range according to previous research and are low cost. Some studies have investigated the use of WiFi on a bus by placing a WiFi-detector tool on-board (*4, 7*). Bluetooth and wireless tools have been used not only to determine the number of vehicles or gather traffic data from the road but also to calculate pedestrian data around pedestrian paths that are equipped with Bluetooth sensors (*11*). However, there is still a bias due to the small number of Bluetooth users among pedestrians in travel nodes, such as bus terminals and bus stops, which hinders the collection of data about the behavior of pedestrians in public facilities (*14, 15*).

METHOD AND FIELD EXPERIMENT

The location of this study is the town of Obuse in the Kamatakai District in the Nagano Prefecture of Japan. Obuse is one of the top tourist destinations in Japan. It attracts 764,000 visitors every year. Obuse is unique for its chestnut processing industry and as a historic city with a variety of tourist attractions (*17*). In October 2016, the town had an estimated population of 10,698 and a population density of 560 people per km^2. Its total area is 19.12 km^2 (*18*).

Test Field

Obuse has a circulating shuttle bus called the “Romango.” The Romango Bus is a hop on– hop off bus, which means the bus stops at each location for only a few minutes and allows passengers to travel around the city with as single tour ticket for an entire a day. The fare for a day-trip ticket is 300 Japanese yen, which is equivalent to approximately 3 US$. Obuse operates two circular buses every Saturday and Sunday, which connect nine bus stops. Visitors can reach several tourist attractions by using these buses.

Route

The Romango Bus traverses seven segments in its circulation from bus stop no. one (BS1) to bus stop no. nine (BS9) and passes nine bus stops: BS1 (Obuse Highway Oasis Park), BS2 (Obuse Station), BS3 (Hokusai Museum), BS4 (Obuse Museum), BS5 (Matsumura Town Parking), BS6 (Obuse Hot Springs) BS7 (Floral Garden), BS8 (Jyokoji Temple) and BS9 (Ganshoin Temple). The circular route is approximately 15 km and the overall route length is 8.8 km. The longest segment is 2.7 km from BS1 to BS2 and the shortest is 0.3 km from BS4 to BS5.

Vehicles (Bus Fleets)

There are two Romango buses, no. 1 and no. 2, seen in Figure 1. Each bus accommodates about 30 passengers.

FIGURE 1 "Romango" circulating buses no. 1 and no. 2

Schedule

Each bus starts every 30 minutes from 9:50 AM to 5:50 PM. It takes 50 minutes for a round trip. Bus no. 1 operates from 9:50 AM to 5:10 PM and bus no. 2 operates from 10:20 AM to 5:50 PM.

Equipment

WiFi Technology

WiFi technology periodically transmits a signal, called WiFi, to all information devices around it. When a device receives a WiFi signal, it sends a query, called a probe request, and the access point returns a reply, called a probe response, which includes the SSID. Although the probe request can be made in as short as 15 seconds or as long as several minutes (and is on the order of one minute on average), this data also includes the media access control (MAC) address that identifies the transmitting device.

WiFi Scanner

Here, a WiFi scanner (shown in Figure 2) was placed on the bus and used to acquire data. This scanner contains a miniature computer, Raspberry Pi 2 B V1.1 (*19*), to control a WiFi antenna and a GPS antenna. It records log files including the record date and time, the longitude and latitude from the GPS antenna and the MAC addresses of the mobile devices of bus passengers and people near the bus from the WiFi antenna. It has a micro SD port for storing data and a micro USB power source (*20*). By collecting and analyzing data, it is possible to determine the spatial flow and distribution of the users of information devices.

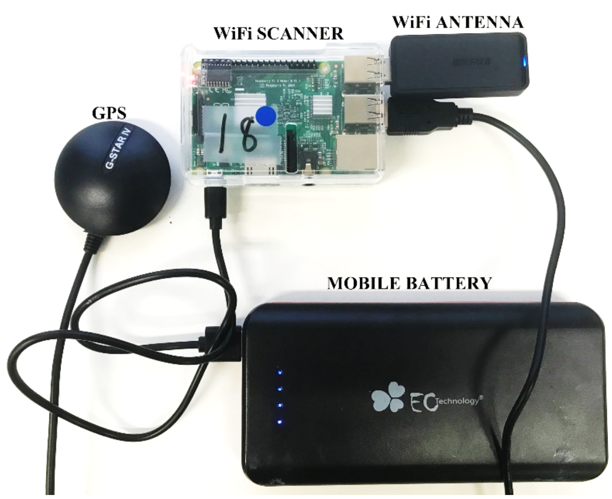


FIGURE 2 WiFi scanner with GPS antenna and mobile battery

Experiment

A WiFi scanner was placed on each of the buses (Figure 3) and a researcher was also stationed on each bus to manually count the number of boarding or alighting passengers at each bus stop. The number of passengers on the bus was estimated for each segment between bus stops. The WiFi Scanner was mounted on bus no. 1 near the left window and on bus no. 2 above the driver during the period of 09:50–17:50 on Sunday, October 30th, 2016. The installation of the tool is simple and it is placed so that it does not interfere with the bus driver and passengers. Initially, we had planned to install both scanners above the driver's seat. However, no appropriate place could be found in bus No. 1, which was a different model from bus No. 2. Due to the differences in the inner layouts at the front of the bus, the scanner was unable to be placed in the same position. Therefore, the WiFi scanner was installed near the front-left window on bus No. 1 and above the driver's seat on bus No. 2. However, these different positions had no influence on the detection results as the differences were negligible in terms of WiFi-scanner coverage.

FIGURE 3 Installed WiFi scanners on buses no. 1 and no. 2

The measured number of boarding or alighting passengers was collected from the WiFi scanner and compared with the manually counted results. The WiFi scanner, which was developed by the author as a prototype, scans for mobile devices which are emitting management packets every five seconds. It can detect people who have devices, such as smartphones and tablets, within an approximately 200 m radius. This scanner records the unique identification codes of the detected mobile devices. The log files were then analyzed to obtain the duration for which each identification code was detected and the beginning and end of each of these periods were interpreted as the boarding or alighting times of the passenger, respectively.

The WiFi scanner also detected identification codes of non-passengers, like pedestrians and drivers outside of the bus. Several rules of discrimination were applied to filter the log data to include only passengers based on the nature of the user's behavior: (1) the passenger boards the bus at a bus stop, (2) the passenger alights at another bus stop and (3) the passenger can be detected between these two stops. The time stamps and longitude and latitude of the devices are also recorded by the GPS antenna and the logger integrated into the WiFi scanner. A bus stop visited by the bus was identified by matching the collected longitude and latitude with the map of the bus route.

DATA PROCESSING

The resulting raw data includes the GPS log and the WiFi log (Figure 4). The GPS log contains time, latitude and longitude information while the WiFi log contains time and MAC ID data. The MAC is a unique identification or address assigned to each network device and can therefore be used to identify each device. The raw data needed to be re-filtered and analyzed before being interpreted. Ninth steps were used to filter the raw data into travel data, as follows:

- The first step is to combine the raw data from the WiFi and GPS logs to obtain WiFi data correlated with latitude and longitude data by using the time data. Latitude and longitude location data were correlated with the MAC data from the WiFi data such that the WiFi log became the primary data set.
- The second step is to unify the same data (based on the MAC ID, latitude, longitude and time) to get a unique data set. The resulting data set is assigned a new column containing "1" for each row to indicate that one row is one datum. After creating the attribute, the data was analyzed by looping (pivoting) to find out how much of data was repeated.
- The third step is to convert the latitude and longitude data to the UTM (universe transverse mercator) WGS 84 Zone 54N in accordance with the real field conditions based on a WGS 84 decimal degree datum map. Therefore, the output data contained X-, Y-data in the UTM form.
- The fourth step is to define new attributes or labels to each unique identifier to indicate the speed. The data that already contains X-, Y-coordinates in the UTM form is re-analyzed with a new attribute, speed, which is calculated by the formula,

$$V_i = \frac{\sqrt{(X_{i+1}-X_i)^2+(Y_{i+1}-Y_i)^2}}{T_{i+1}-T_i} \,. \qquad (1)$$

i = Time frame of data
V_i = Speed at the i^{th} time flame
X_i = Longitude for the i^{th} MAC ID in the rows of the tabular data
Y_i = Latitude for i^{th} MAC ID in the rows of the tabular data
T_i = Time for i^{th} MAC ID in the rows of the tabular data

- The fifth step is to justify each identifier as a moving or stopped based on its speed attribute. Setting a threshold for speed as 5 m/s, it is assumed that a device is moving if its speed is greater than the threshold and it is assumed to be stopped if it is less than the threshold. Each identifier is distinguished as moving or stopped according to its speed. The threshold 5 m/s was used to distinguish a moving or stationary MAC ID. The value of 5 m/s was based on the author's assumption that 5 m/s was reasonable as it was based on the bus's minimum travel speed. Lacking prior knowledge to guide judgment as to the appropriate threshold values, a trial-and-error procedure was used to choose reasonable threshold values that were moderately conservative but not so restrictive as to eliminate potentially viable observations.
- The sixth step is to determine the bus stop locations based on the latitude and longitude positions. Each bus stop location is assumed to be a buffer zone, a region up to 10 meters around the bus stop. Hence, the data attribute will be assigned new labels: "bus stop," "stop" and "moving," where "stop" was introduced to distinguish being stopped at a bus stop from being stopped at a traffic signal.
- The seventh step is separating the categorized data from step six according to the circulation number out of seven round trips made by the Romango Bus. To do this, an original timetable with data about the arrival and departure times at BS1 was used. Many identified stops located between the bus stops can be assumed to be either a red light or a stop due to a slowdown. In these cases, the "stop" attribute is reassigned to "moving."
- The eighth step is to create an OD matrix for each bus circulation with the MAC IDs which are observed more than once between two bus stops. It is assumed that if the MAC ID is included more than once in the data is a device that moves. For each circulation, labels are added

to each row of data, such as from M1-2 or M2-3 meaning “moving” (estimate passenger) the segment from BS1 to BS2 or the segment from BS2 to BS3, respectively.

- The ninth step is to combine the data from both buses (no.1 and no.2). For each bus, there are seven circulations, so after this step, there are 14 circulations in the data set. The data was coded with circulation numbers (CNs) 1–14. The data is then divided again by time into CN1–6 as the AM (before noon) data and CN7–14 as the PM (after noon) data to facilitate a time-based analysis.

All of the data processing was carried out using an Anaconda 1.5 Jupiter Notebook 5.0 with Python 2.7, Microsoft Excel, and QGIS open source software. Total lines of raw data were 71630 and the raw data were processed into 200-300 lines of data for each circulation.

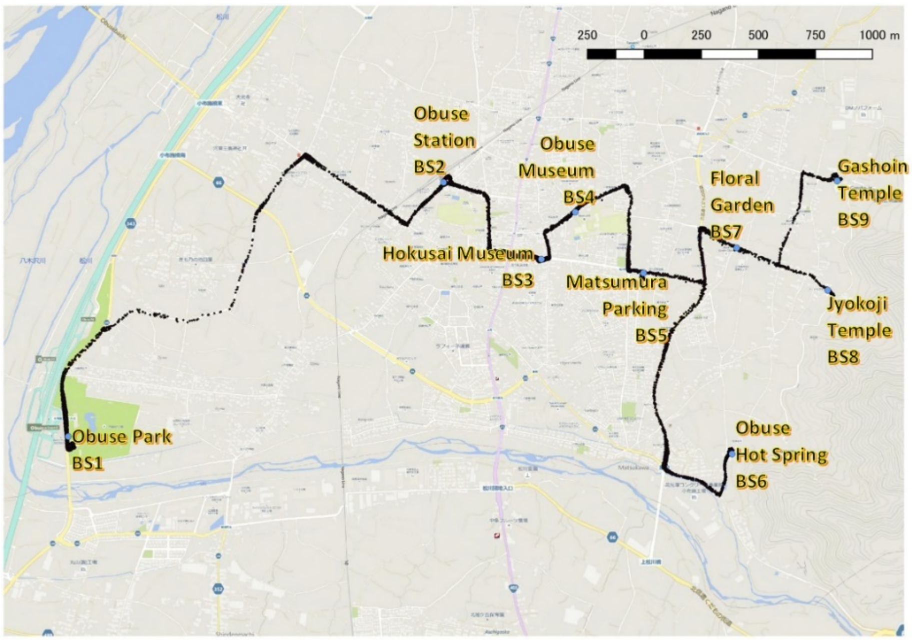


FIGURE 4 MAC ID point data for two bus circulations

RESULTS AND DISCUSSION

The results obtained after data processing generally show significant differences between the trends in the number of passengers in trip segments BS1-BS2-BS3, BS3-BS9-BS3, and BS3-BS2-BS1. The number of passengers between BS1-BS2- BS3 and BS3-BS2-BS1 is high as these routes connect to the entrance of Obuse and provide mobility toward Obuse Station (BS2). This data may be overestimated due to the relatively high incidence of non-passenger data being detected from pedestrians or vehicles around the bus. Congestion and high traffic volume on the road caused the WiFi scanners to detect or catch. On the other hand, the BS3-BS9-BS3 segment data was found to be relatively stable in every circulation. According to the data, the change in travel between circulations was low; this is because the high travel volume in the morning is directed toward Obuse station. In the second through the fifth circulations, there was a higher level of passenger travel because of many people travel in the time period of 10:00–15:00 and the number of passengers began to fall as the afternoon began.

CN1–6 (before noon)

The estimated OD data shown in Figure 5 is based on CN1 to CN6 data from the morning until noon. The pattern of tourist travel is dominated by museums (BS3, BS4), hot spring (BS6), garden (BS7) and, historical places (BS8, BS9). Based on the data, the variation was high on segments from M1-2 to M2-3 and from M3-2 to M2-1 and there was high passenger activity on BS2 and BS1. A medium variation occurred in segments from M3-4 until M6-9, from M9-5 until M4-2, indicating stable movement. There was low variation in M6-9, indicating that the tourist attraction destinations, such as temples, are long distances away from the station.

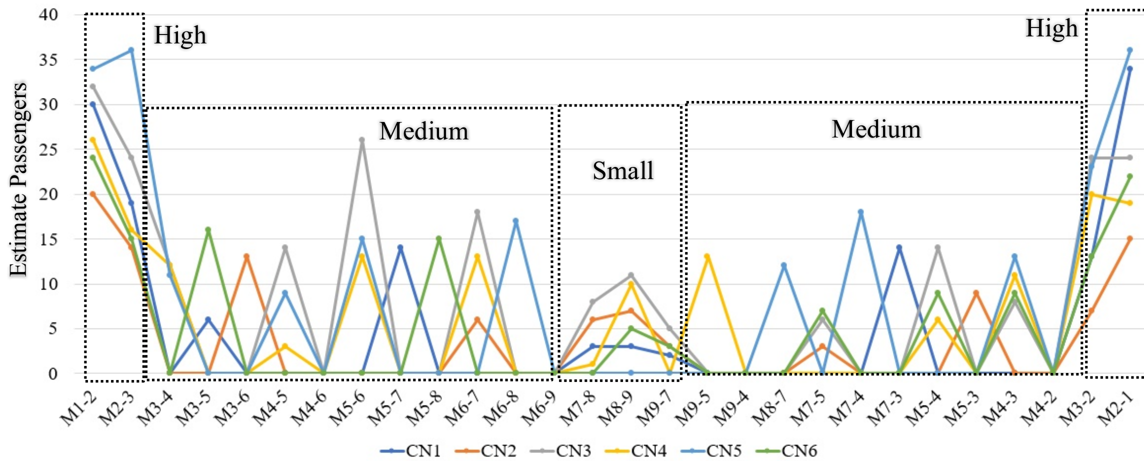


FIGURE 5 Estimated number of passengers for travel data from CN1-6 (AM)

CN7–14 (after noon)

The estimated OD data in Figure 6 for CN7-14 in the afternoon shows a pattern which is almost the same as that in the morning. The relative movement in segments From M3-4 until M4-2 are consistent with the morning data, showing that bus users start to spread evenly throughout the bus stops to reach the tourist destinations. However, compared with the morning travel data, the movement in segment from M1-2 to M3-4, and from M4-2 to M2-1 were higher in the afternoon due to the end of visiting periods.

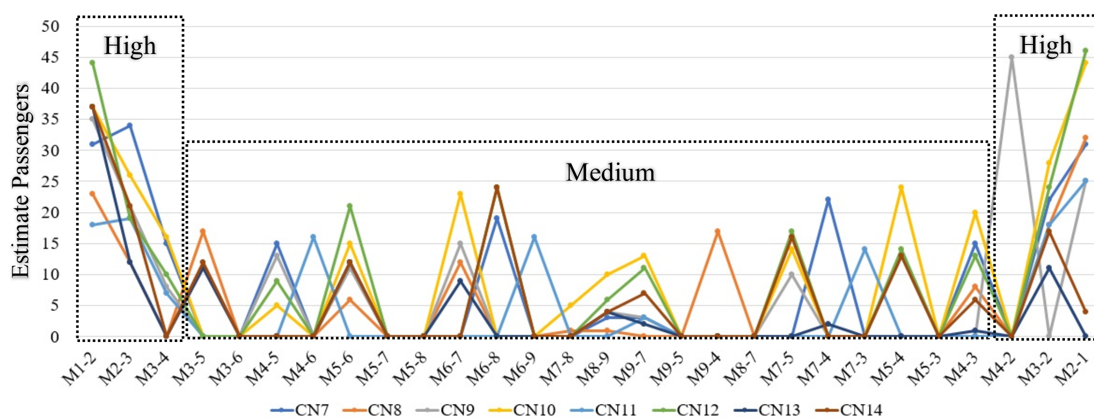


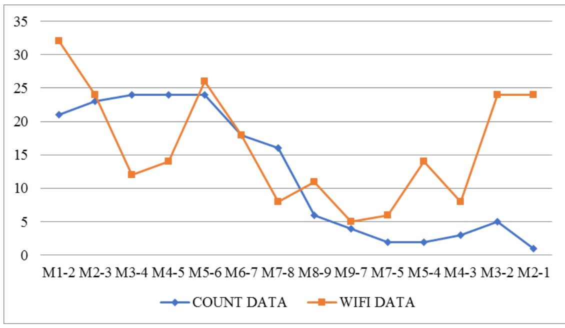
FIGURE 6 Estimated number of passengers for travel data CN7-14 (PM)

COMPARISON BETWEEN MANUAL COUNTING AND WIFI APPROACHES

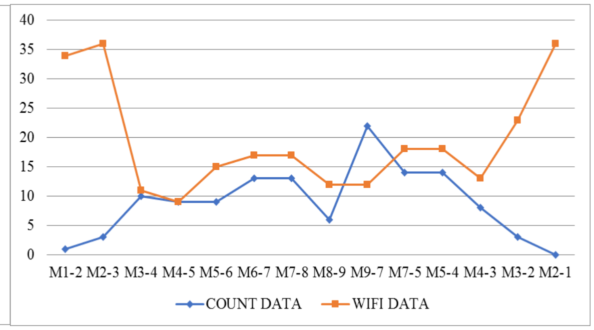
The observer count data was then compared with the results of the proposed WiFi-based method collected simultaneously. The observer data is the number of passengers board and alight at each bus stop. The manual count data was only available for CN3, CN5, CN8, CN10, and CN12.

Figure 7 shows the difference between the manually counted (observer) data and WiFi data in five circulations: CN3, CN5, CN8, CN10, and CN12. In general, the data shows reliable WiFi data compared with the observer data for CN3 in segments M2-3, M5-6 until M7-5, and

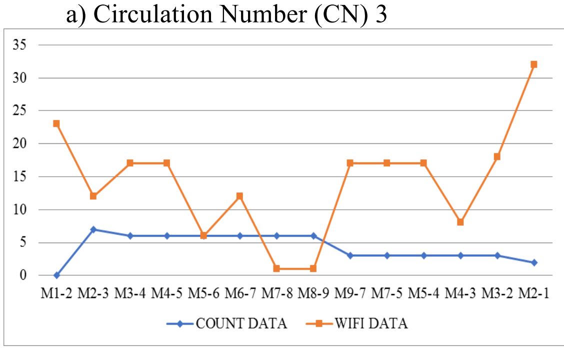
M4-3; for CN5 in segments from M3-4 until M4-3; for CN8 in segment from M5-6 until M8-9; for CN10 in segments M4-5 and M7-8; and for CN12 in segments M3-4 , M4-5 and M8-9. The striking difference between manually counted and WiFi data, indicating unreliable data, was found for the other segments listed above.



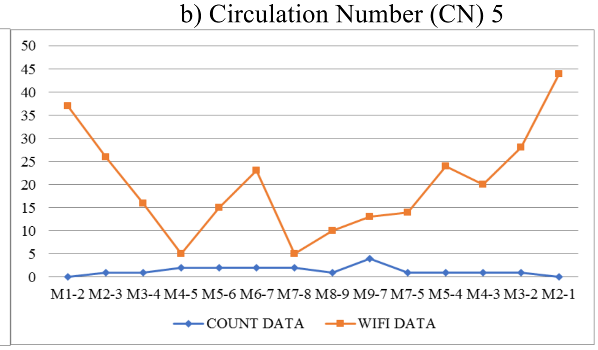
a) Circulation Number (CN) 3



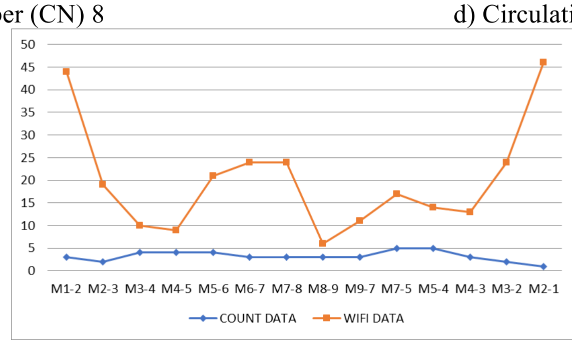
b) Circulation Number (CN) 5



c) Circulation Number (CN) 8



d) Circulation Number (CN) 10



e) Circulation Number (CN) 12

FIGURE 7 Comparison between the WiFi data and observer data

The data was analyzed based on the correlation analysis to determine which WiFi data was related and which was unrelated in each circulation by comparison with the observer data. The correlation analysis for WiFi data compared with the observer data for CN3 reported an r-value of 0.390, indicating a low (positive) relationship. The CN5 data had an r-value of 0.671, which is quite high (positive) relationship. The CN8 data had an r-value of 0.639, which is quite high (positive) relationship . The CN10 data had an r-value of 0.633, which is quite high (positive) relationship. The CN12 data had an r-value of 0.530, which is quite high (positive) relationship. Based on correlation analysis, the observer data and WiFi data generally have a correlation line indicating related because there was such a small difference in the two data sets.

However, if the data is split based on the movement between each bus stop, there is a small difference between the observer and WiFi data that can be considered reliable. All of the circulation data for BS1 and BS2 were associated with a high traffic volume because it is the main route in Obuse, because the main activity center is Obuse Station (BS2), and because the tourist entrance is at Obuse Park (BS1). CN3, CN5, CN8, CN10, CN12 at BS4, BS5, BS6 and BS7 is a daytime route which most pedestrians tend to walk in order to see some of the interesting places alongside the route. To assess the details of each circulation and each bus stop, the observer data and WiFi data was analyzed by the ratio of WiFi over estimated (RWOE) to the observer data. The values of RWOE greater than 8 indicate the unreliable route segments. For values >8 (RWOE) was used based on the author's assumption that if the data difference was between 1–7, it was acceptable. RWOE analysis was employed to illustrate the differences between the WiFi data (MAC address) and the traffic count. According to Table 1, CN3, CN5, and CN8 had more reliable data than C10 and C12. For more details, please refer to Table 1.

TABLE 1 Comparison of observer and WiFi data for each trip segments in five circulations

M	CN3			CN5			CN8		
	MCD	WD	RWOE	MCD	WD	RWOE	MCD	WD	RWOE
M1-2	21	32	11.0	1	34	33.0	0	23	23.0
M2-3	23	24	1.0	3	36	33.0	7	12	5.0
M3-4	24	12	-12.0	10	11	1.0	6	17	11.0
M4-5	24	14	-10.0	9	9	0.0	6	17	11.0
M5-6	24	26	2.0	9	15	6.0	6	6	0.0
M6-7	18	18	0.0	13	17	4.0	6	12	6.0
M7-8	16	8	-8.0	13	17	4.0	6	1	-5.0
M8-9	6	11	5.0	6	12	6.0	6	1	-5.0
M9-7	4	5	1.0	22	12	-10.0	3	17	14.0
M7-5	2	6	4.0	14	18	4.0	3	17	14.0
M5-4	2	14	12.0	14	18	4.0	3	17	14.0
M4-3	3	8	5.0	8	13	5.0	3	8	5.0
M3-2	5	24	19.0	3	23	20.0	3	18	15.0
M2-1	1	24	23.0	0	36	36.0	2	32	30.0

M	CN10			CN12		
	MCD	WD	RWOE	MCD	WD	RWOE
M1-2	0	37	37.0	3	44	41.0
M2-3	1	26	25.0	2	19	17.0
M3-4	1	16	15.0	4	10	6.0
M4-5	2	5	3.0	4	9	5.0
M5-6	2	15	13.0	4	21	17.0
M6-7	2	23	21.0	3	24	21.0
M7-8	2	5	3.0	3	24	21.0
M8-9	1	10	9.0	3	6	3.0
M9-7	4	13	9.0	3	11	8.0
M7-5	1	14	13.0	5	17	12.0
M5-4	1	24	23.0	5	14	9.0
M4-3	1	20	19.0	3	13	10.0
M3-2	1	28	27.0	2	24	22.0
M2-1	0	44	44.0	1	46	45.0

M : Moving
RWOE : Ratio WiFi Over Estimated
CN : Circulation Number
MCD : Manual Count Data
WD : WiFi Data

CONCLUSION

The analysis and interpretation of the WiFi data yielded travel data about passengers' travel from one place to another. This paper presented the application of a new method of collecting data about boarding or alighting passengers at each bus stop. The results of this paper as follows:

1. This paper developed a data processing procedure to combine WiFi raw data and GPS log data into travel data, which shows the number of passengers boarding or alighting at a bus stop and OD information;
2. The travel data was analyzed to be divided into two data before noon and after noon. These two results have characteristics of different travel behavior;
3. The results of comparison between WiFi data and observer data show that similar travel patterns among many bus stops, however due to the non-passenger data a direct comparison cannot be made between some two bus stops.

The results of the conducted experiments indicate not only the benefits of the developed equipment but also the challenges to be addressed in future work. The WiFi scanner could be used for several other purposes:

1. They could assist small bus operators conduct their own surveys.
2. The proposed method is appropriate for the long-term data collection of daily variations.
3. There is no need to communicate with passengers when collecting data.
4. It is possible to know movement demand (origin and destination) between bus stops, which assists bus operators estimate hourly and daily demand and determine the capacity between bus stops. For example, bus demand sometimes increases in certain periods such as the high autumn season and festivals. The WiFi scanner data can be used to estimate capacity at certain seasons, allowing bus operators to add or reduce the number of operating buses to

accommodate the changing demand. They can also make timetable changes to adjust to high demand at certain times.

5. The WiFi-scanner data can also provide information about busy areas such as bus stops, shops, parking lots, bus terminals, and others. If the WiFi scanners detect an area that has many visitors, this data could inform operators to increase capacity. For local governments, WiFi-scanner data could be used to improve the capacity of facilities and provide input to urban planning related to transportation facilities and public transportation, and could also be used to improve the marketing of tourism support facilities.

6. Outside the bus, the WiFi-scanner technology can be used to detect and distinguish vehicles, pedestrians, and buildings (non-passenger data).

The results of the conducted experiments indicated not only the benefits of the developed equipment but also the challenges to be addressed in future work. However, at present, there are several limitations. The WiFi scanner can produce inaccurate results when there is less use of WiFi-enabled mobile devices, there are false WiFi readings because the device is out of range, the MAC address changes (upgrading system devices), and because of slight GPS inaccuracies. As there have been few case studies, the technology needs to be tested in several different places with larger survey areas and longer survey times to improve the analysis. Future work will focus on passenger travel behavior modeling, passenger travel times (how many minutes from origin to destination based on WiFi and GPS data), and non-passenger data analysis such as pedestrians, vehicles, and buildings.

REFERENCES

1. Ahmed. H., El-Darieby. M., Morgan. Y., and B. Abdulhai. *A Wireless Mesh Network-Based Platform for ITS*. VTC Spring 2008 - IEEE Vehicular Technology Conference, Singapore, 2008, pp. 3047-3051. doi: 10.1109/VETECS.2008.329
2. Bachmann, C., Roorda, M. J., Abdulhai, B., and Moshiri, B. *Fusing A Bluetooth Traffic Monitoring System with Loop Detector Data For Improved Freeway Traffic Speed Estimation*. Journal of Intelligent Transportation Systems, November 2012. DOI: 10.1080/15472450.2012.696449
3. Caceres N., Wideberg. J. P., and Benitez. F. G. *Deriving Origin Destination Data from A Mobile Phone Network*. IET Intelligent Transport Systems, Vol. 1, no. 1, pp. 15-26, March 2007. doi: 10.1049/iet-its:20060020
4. Dunlap. M., Li. Z., Henrickson. K., and Wang. Y. *Estimation of Origin and Destination Information from Bluetooth and Wi-Fi Sensing for Transit*. Transportation Research Record: Journal of the Transportation Research Board, No. 2595, Transportation Research Board, Washington, D.C., 2016, pp. 11–17. DOI: 10.3141/2595-02
5. Haseman, R.J., Wasson. J.S., and Bullock D.M. *Real-Time Measurement of Travel Time Delay in Work Zones and Evaluation Metrics Using Bluetooth Probe Tracking*. Transportation Research Record: Journal of the Transportation Research Board, No. 2169. Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 40–53. DOI: 10.3141/2169-05
6. Jackson. S., Lesani. A., Moreno. L.F.M. *Towards A WiFi System for Traffic Monitoring In Different Transportation Facilities*. 93rd Annual Meeting of the Transportation Research Board, January 2014.
7. Jiang. M., Fan. X., Zhang. F. *Characterizing On-Bus WiFi Passenger Behaviors by Approximate Search and Cluster Analysis*. The 7th International Conference on Cloud Computing and Big Data (CCBD2016). 2016. https://www.researchgate.net/publication/308449230
8. Kostakos, V., Camacho, T. & Mantero, C. *Towards Proximity-Based Passenger Sensing on Public Transport Buses*. Pers Ubiquit Comput, 2013, Volume 17 pp:1807. doi:10.1007/s00779-013-0652-4
9. Kostakos. V. *Towards Sustainable Transport: Wireless Detection of Passenger Trips On Public Transport Buses*. International Energy Outlook, 2007.
10. Lozano. J.J.F., Guzmán. M.M., Ávila. J.M., and Cerezo. A.G. *A Wireless Sensor Network for Urban Traffic Characterization and Trend Monitoring*. Sensors Journal. 2015, Vol. 15, pp: 26143-26169. doi:10.3390/s151026143
11. Malinovskiy. Y., Saunier. N., and Wang. Y. *Analysis of Pedestrian Travel with Static Bluetooth Sensors*. Transportation Research Record: Journal of the Transportation Research Board, No. 2299, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 137–149. DOI: 10.3141/2299-15
12. Oransirikul. T., Nishide. R., Piumarta. I., Takada. H. *Measuring Bus Passenger Load by Monitoring Wi-Fi Transmissions from Mobile Devices*. Procedia Technology, Volume 18, 2014, pp:120-125, ISSN 2212-0173. http://dx.doi.org/10.1016/j.protcy.2014.11.023
13. Perttunen, M., Kostakos, V., Riekki, J. et al. *Urban Traffic Analysis Through Multi-Modal Sensing*. Pers Ubiquit Comput, 2015, Volume 19, pp:709–721. doi:10.1007/s00779-015-0833-4

14. Poucin. G., Farooq. B., and Patterson. Z. *Pedestrian Activity Pattern Mining in WiFi-Network Connection Data*. 95th Annual Meeting of the Transportation Research Board, January 2016.
15. Shlayan. N., Kurkcu. A., and Ozbay. K. Exploring pedestrian Bluetooth and WiFi detection at public transportation terminals. *IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, Rio de Janeiro, 2016, pp. 229-234. doi: 10.1109/ITSC.2016.7795559
16. Thiagarajan, A., Biagioni, J., Gerlich, T., & Eriksson, J. *Cooperative Transit Tracking Using Smart-Phones*. In *SenSys 2010* - Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems, 2010, pp:85-98. DOI: 10.1145/1869983.1869993
17. *http://www.obusekanko.jp/download/pdf/english_s.pdf*
18. *https://en.wikipedia.org/wiki/Obuse,_Nagano*
19. *https://www.raspberrypi.org/products/raspberry-pi-2-model-b/*
20. *https://www.element14.com/community/docs/DOC-73827/l/raspberry-pi-2-model-b-1gb-technical-specifications#techspecs*