Identifying the Factors Affecting Pedestrian Flow Volume and Walkability Using the 'Seoul Pedestrian Survey' Data

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Abstract

'Seoul Pedestrian Survey' aims to find how many pedestrians move during the day. The survey evaluates the daytime population in metropolitan area. Daytime population can then be used for urban transportation planning and travel demand forecasting. The current study aims at finding behaviors of daytime population complement to residential population. To this end, the paper first categorizes the factors affecting pedestrian flows and walkability using CHAID. The paper then measures the spatiotemporal changes in flow volumes and identifies the outliners (z-score) of walkability index. The result of this study suggests that this application for pedestrian behavior research, need to consider both pedestrian flow volume and walkability properties.

1. Introduction

Travel behavior study is essential for understanding urban spatial structure. Interregional movements take place due to separation between residential area and workplaces. Thus, travel affects the change in spatial patterns and human decision making processes. Previous studies of the activity and trip sequences are based on the analysis of household trip-chains by collecting

data from household surveys or scheduling diaries. It is possible to know not only trip mode, purpose, and peak time of each transportation mode through the household surveys. However, these researches have little interests in behaviors of individual pedestrians.
Pedestrian researches tend to focus on characteristics of the walking environments which influence the volume of flows. On the other hand, the concept of walkability becomes more important than before cause walkability is the extent concept to which the built environment is walking friendly. In addition, most studies found evidence that land-use pattern is the significant factor for understanding pedestrian behaviors. Travel is derived from daily participation in activities in that space is chosen by specific land-uses (Timmermans, et al., 2002).

This paper focuses on factors affecting pedestrian movements; flow volumes and walkability indices. Pedestrian volumes are affected by properties of facilities and land-use patterns, such as attractiveness of commercial district to consumers. Walkability is a concept of integration of pedestrian's subjective cognition. For instance, some authors define walkability as level of service (after LOS), others establish how friendly an area is to walk. But it's still not clearly defined. As this study according to Abley, S (2005), 'walkability is the extent to which walking is readily available as a safe, connected, accessible and pleasant mode of transport'.

Data resource of the analysis is "Seoul Pedestrian Survey, 2010", which was carried out from August to October 2009 in order to examine pedestrian's spatiotemporal flow volumes at 10,000 points in Seoul. The purpose of the survey is to figure out pedestrians' daily movement patterns in Seoul. The methodology of this survey is divided into two parts. One is measuring pedestrian's flow volume survey by counting the number of pedestrians on 10,000 designated points by pollsters; the other is interview surveys on 1,170 spots.

This paper aims to estimate which indicators are more influential on pedestrian's behaviors with regard to pedestrian flow volume and walkability. The analyses of discovering affective factors by using a CHAID (Chi-squared automatic interaction detection) analysis categorized to difference among the resultant groups. CHAID will discover influential factors and categorize them into distinctive groups.

The study suggests the following research implications. First, CHAID analysis identified of the relevant factors among the pedestrian flow volume and walking environment, land-use patterns. Second, classified the case that find the affective factors to walkability. Overall, the suggested method provides statistically more defendable pedestrian flow volume and walkability measurement.

2. Problem

Most pedestrian studies adopt quantitative method to analyze walking conditions using direct observation, video data and survey data collection techniques (New York City, 2006; Park, et al., 2008; Schneider, et al., 2009; Kim and Kim, 2011). These studies show that pedestrian flow volume and behaviors are influenced by the accessibility to public transportation, land-use patterns and walking environments (e.g., road width, obstacles, and crosswalk). Some other studies are interested in pedestrian's level of service and safety (Lee, et al., 2010; Lee, 2012). Walkability is one of the popular issues in health and welfare (Lesile, et al., 2007; Owen, et al., 2007), which estimates pedestrian's mental condition affected by walking conditions of pedestrian facilities and amenities.

In Korea, most researches are interested in evaluating environment conditions of subway station influence area. Those studies using 'Space syntax' method evaluate pedestrian walking-roads by analyzing integration, connectivity, and intelligibility indices. As well, some studies are proposed that pedestrian-friendly environments are closely related to the road network shapes (e.g., wheel or grid) and controlled to uniformity density (Park et al, 2008; Kim and Kim, 2011).

However, these studies are not applied to pedestrian's comfortableness. Walkability is a complex concept, where pedestrian considers walking conditions using subjective consideration such as weather, walking conditions and trip party. It is necessary to evaluate both concepts of pedestrian flow volume and walkability in order to better understand pedestrians' behaviors. Flow volume is measured by counting the number of pedestrians and walkability is estimated by measuring pedestrian's comfortableness or 'either easy to walk or not'. Thus, those two concepts play a significant role in understanding pedestrian behaviors.

This study goes as follows; first, CHAID analysis categorizes factors affecting pedestrian flow volume and walkability. Second, classified the group-case that find spatiotemporal changes in flow volumes and finds outliners (z-score) of walkability indices (Fig. 1).

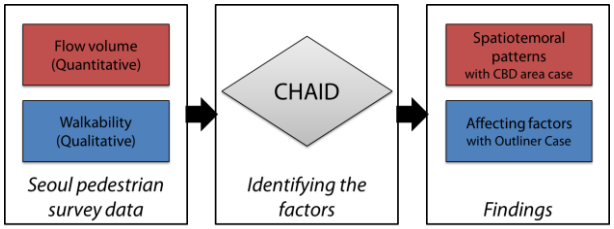


Fig. 1. Overview of this study process

3. Data

'Seoul Pedestrian Survey' is carried out from July 2009 to June 2010. As it is observed that spatial mismatch between employment and residence becomes wider, the survey attempts to measure the flows during daytime.

The methodology of the survey is in direct and questionnaire survey. As similar case, Vancouver (2009) holds direct survey at 396 avenues to find pedestrian volumes and the direction of pedestrian moving-axis. In addition, alternative method employs laser scanner and computer vision (Kim and Kim, 2011).

'Seoul pedestrian survey' adopted both ways to explore pedestrian flow volume and walkability**.** Pedestrian flow volume is surveyed at 10,000 points in Seoul by using counting machines and also, interview surveys that respond to walkability is hold at 1,170 spots (Fig. 2, 3). Thus, it is possible to know that there are differences among districts of Seoul in terms of pedestrian flow volume. Seoul pedestrian survey also surveyed pedestrian's trip behavior and walkability. In this study, used to two ways of collecting the data between direct observation (flow volume) and interview survey (walkability). Observation method is better than video technique (e.g. record or capture the pedestrian's movements) to data quality and accurancy. Survey interview also got more detailed information (e.g. trip purpose, trip party) and context (e.g. weather, situation) of respondent than calculating LOS by walking space length and pedestrian flow did.

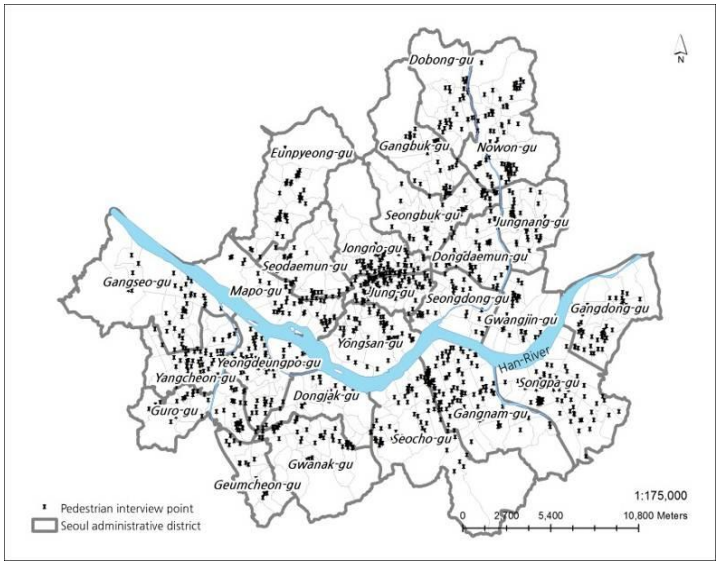
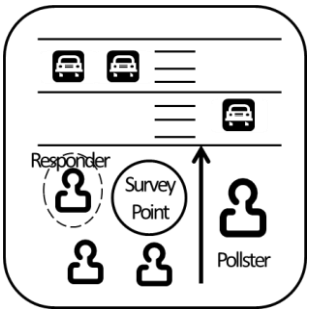


Fig.2. Pedestrian interview survey spots in Seoul (a total of 1,170 spots)



Interview survey questionarie

- Personal information
  sexuality, ages, addresses (gu) and job.
- Trip characteristics
  trip purpose, trip frequency, trip party (whom with), pre-use transportation modes
- Walkability
  5-Scale (used Likert scale)

Fig.3. Pedestrian interview survey questionarie

Fig. 4 represents the temporal distributions of pedestrian flow volume in Seoul during the day. Compare to the household survey results (Fig. 5); daytime distribution pattern is different between measurement points, which means that pedestrian movement patterns are different from other transportation mode. Pedestrian behavior therefore needs particular survey to find its own characteristics.

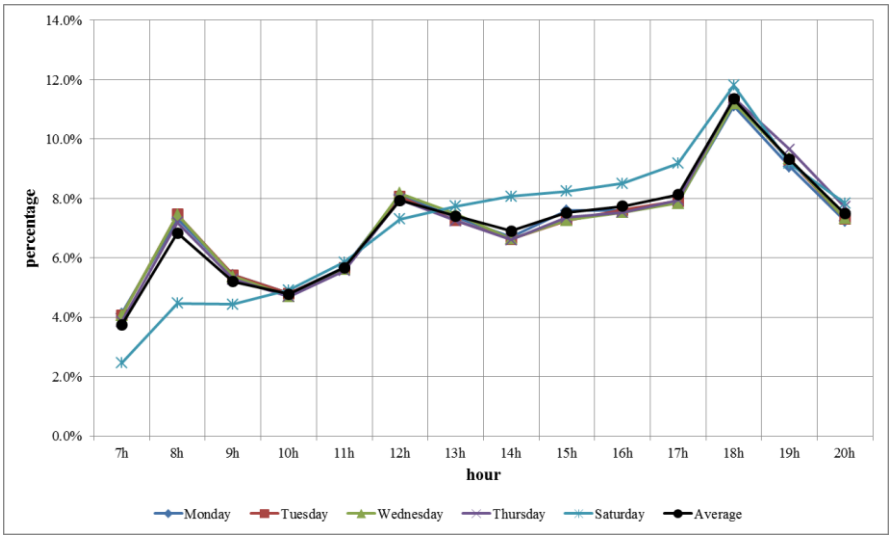


Fig. 4. Temporal distributions of pedestrian flow volume of Seoul in a day (Byun and Seo, 2011)

Note: Averages of 10,000 points, the sum of averages persons are 3,283.

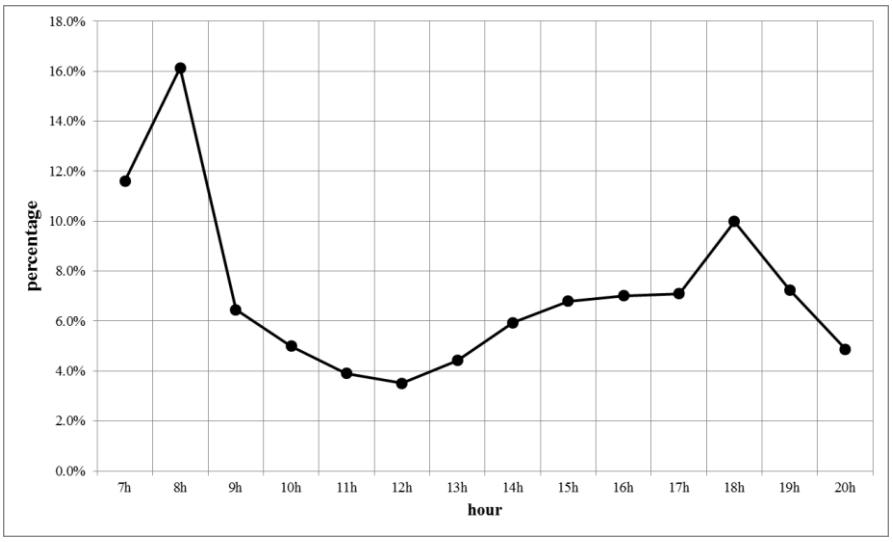


Fig. 5. Temporal distributions of Seoul residents in a day (Seoul metropolitan area household survey, 2011)

Note: based on the departure time, total numbers of trips are 539,701.

4. Empirical analysis

4.1. Methodology

CHAID analysis examines which indicators have the strongest explanatory power on the dependent variable. This method classifies the objects using terminal nodes. Thus, this method is appropriate for understanding which independent variables are significantly influenced to defendant variable. (Joh, et al., 2011).

The analysis will reveal the impact factors by decision-tree induction, and interpret risk report for how much records are possible to classify or not. In addition, CHAID is useful to conduct decision tables even the factor scale is nominal or ordinal.

4.2. Factors Affecting pedestrian flow volume

Pedestrian flow volume is used to average the total volume of pedestrian flow a day. The pre-point survey gathered spatial information on 10,000 points that are related to pedestrian environment. However, this study uses 1,170 points where both pedestrian volume and interview questionnaire survey are carried out. Walking environment, obstacle, and amenities account for the indicators (Table 1).

Fig.6 shows that pedestrian flow-volume is significantly influenced by the fact whether subway entrance exists nearby or not (F-value=111.30, $p<0.00$), land-use type (F-value=6.44, $p<0.01$) and the fact whether bus station exists nearby or not (F-value=58.78, $p<0.00$). These types of nodes are classified into four categories; having subway entrance and bus station (node6 named Group4), having subway entrance but no bus station (node5 named Group3), business land-use type with no subway entrance (node3 named Group1), non-business land use type with no subway entrance (node4 named Group2). These results show that not only accessibility to public transportation is the significant indicator which is affected to pedestrian flow but also land-use types of business. Most previous studies find that pedestrian flow affected to among the type of land-use, public transportation and social-economic characteristics (Schneider et al, 2009).

Table 1. Details of variables affected to pedestrian flow volume.

Variable	Statistics				Total
Walking environments	Walking-road width	Average 4.2 (std 2.30)			
	Total lanes	Average 3.5 (std 2.64)			
	Center-line	Yes 61.3	No 38.7		100.0
	Land-use type	Dwelling 75.6	Business 18.5	Industrial 4.7 Green 1.2	100.0
	Walking road-type	Only Pedestrian 64.4	Both vehicle 30.1	Both bicycle 5.5	100.0
Obstacle existence	Slope	Yes 25.0	No 75.0		100.0
	Fence	Yes 19.2	No 80.8		100.0
	Braille-block	Yes 31.5	No 68.5		100.0
Amenities (with-in 50m)	Subway entrance	Yes 14.2	No 85.8		100.0
	Bus station	Yes 33.1	No 66.9		100.0
	Cross-walk	Yes 57.0	No 43.0		100.0

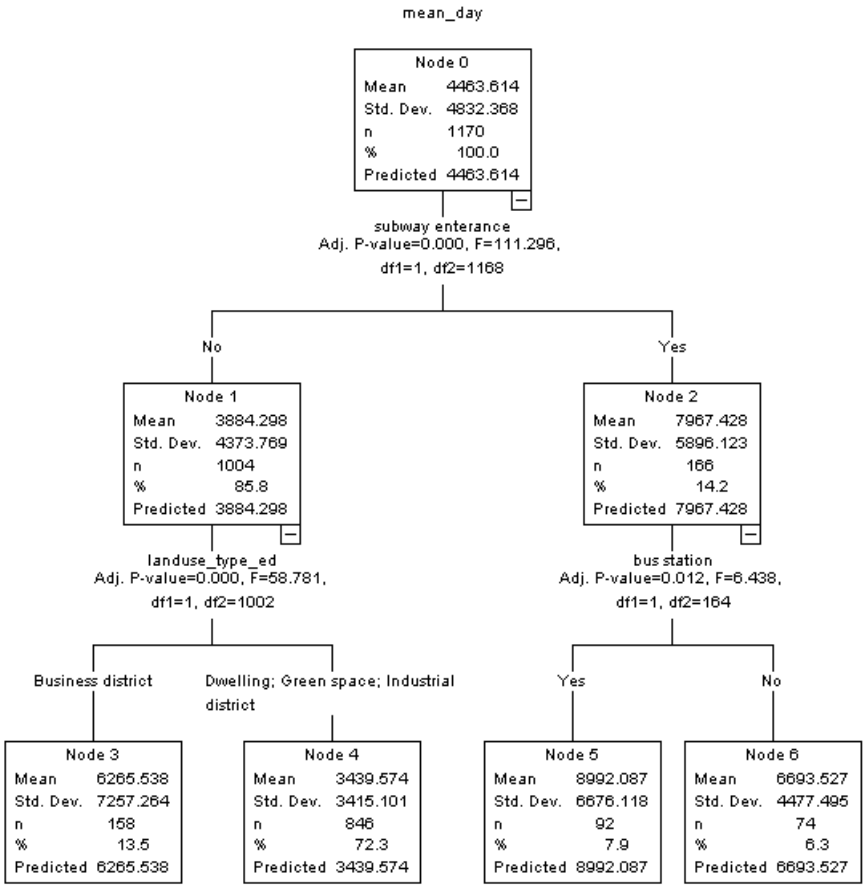


Fig. 6. CHAID tree of flow survey volume acquired

4.3. Affecting factors to walkability

Pedestrian interview questionnaire survey was conducted to measure the walkability. The survey collected questionnaires of 2,400 persons per day, and after all, a total of 83,291 persons. The goal of this survey is finding important indicators to affect pedestrian mentality. In this survey, pedestrians provide personal information and their travel characteristics. As previ-

ously mentioned, walkability is the concept that integrates 'comfortableness', 'good service' and 'easy to walking'.

Walkability is significantly influenced by the clock time of the survey (F-value=402.08, $p<0.00$) as shown in Fig. 7. It is also influenced by pre-used transportation mode for each node. Pedestrians who come to place by car seem having different level of comfortableness in the morning (2.78) and afternoon (2.92).

Table 2. Details of variables affected to walkability

Variable	Statistics						Total
Personal information	Sexual	Male 44.5	Female 55.5				100.0
	Ages	Under 20s 7.0	20s 19.8	30s 20.0	40s 21.2	60s 18.5	Over 60s 13.6	100.0
	Addresses	Seoul 66.3	Other place 33.7				100.0
	Survey date	Tuesday 17.4	Wednesday 33.0	Thursday 16.3	Friday 33.3		100.0
	Survey time	Morning 50.0 (8:00-14:00)	Afternoon 50.0 (14:00-20:00)				100.0
Trip characteristics	Trip purpose	Personal 23.4	Commuting 29.2	Business 23.3	Shopping 13.0	Etc 11.2	100.0
	Trip frequency	Everyday 40.3	Often 45.2	Sometimes 11.5	Stranger 2.9		100.0
	Trip party	Alone 72.9	Family 6.9	Accompany 20.1	Etc 0.1		100.0
	Pre-use transportation mode	Walk 52.1	Public transportation 38.1	Vehicle 10.7	Missing 0.8		100.0

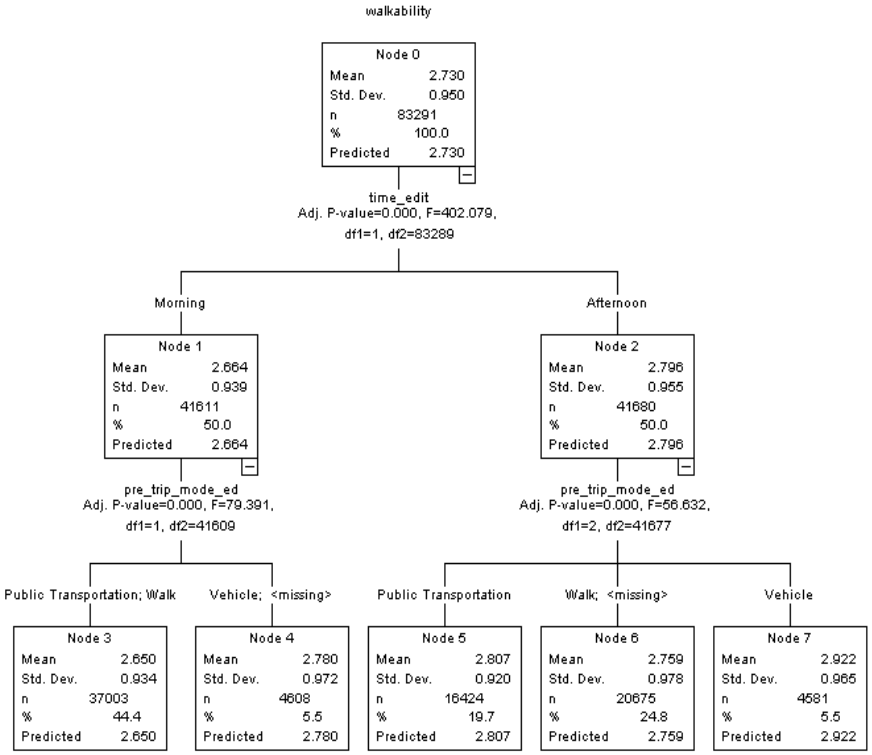


Fig. 7. CHAID tree of walkability acquired

4. Findings

4.1. Spatiotemporal difference in flow volume groups

Group3 marks the largest pedestrian flows. Fig. 8 shows a temporal change of groups classified by a CHAID analysis. Most groups' peak-time appeared at 8-9 A.M and 6-7 P.M. However, Group1's peak-time is 12-1 P.M, different from other groups. The location of Group1 tends to be far from the subway stations; it is classified into business district. As most shops opened at 9-10 A.M, it suggests that potential consumers passing by the place for shopping and that after at 11 A.M flow volumes increases. As

Group3 is close to subway stations and bus stops, A.M 8-9 and P.M 6-7 are very crowded with potential commuters who use public transportation.

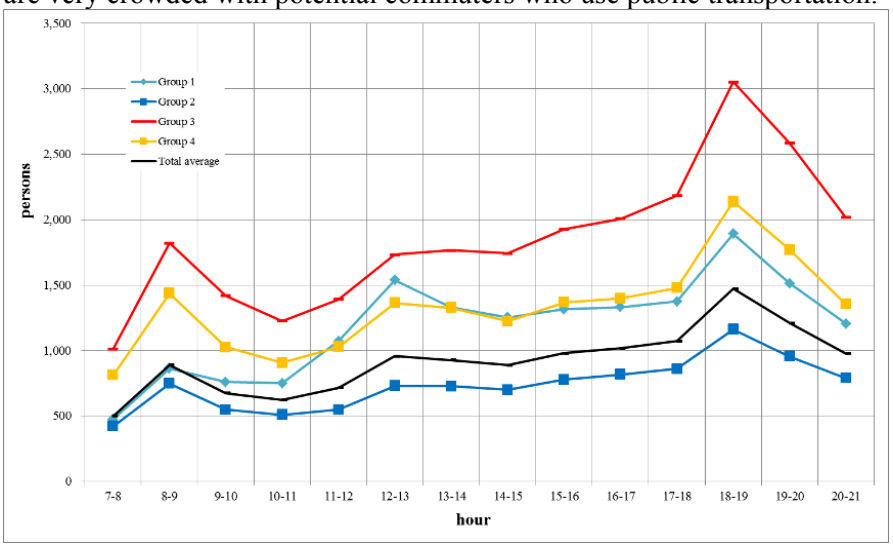


Fig. 8. Temporal changes of pedestrian flow volumes in a day

In addition, public modal split (Fig. 9) is very high in Seoul that is well equipped with subway and bus systems. Such high use of public modes naturally invites high volume of pedestrian movements and intensive land use around the subway stations and bus stops. Pedestrian flow volume therefore finds itself very high around the subway station and bus stop influence areas.

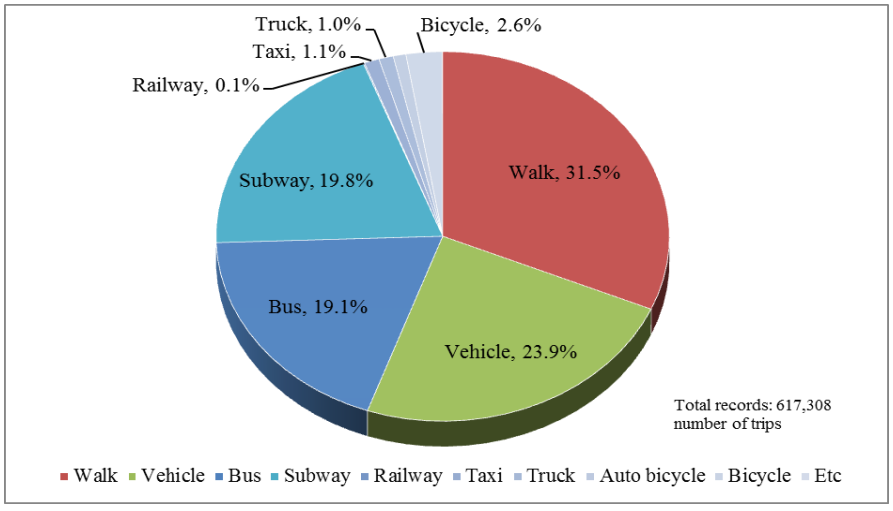
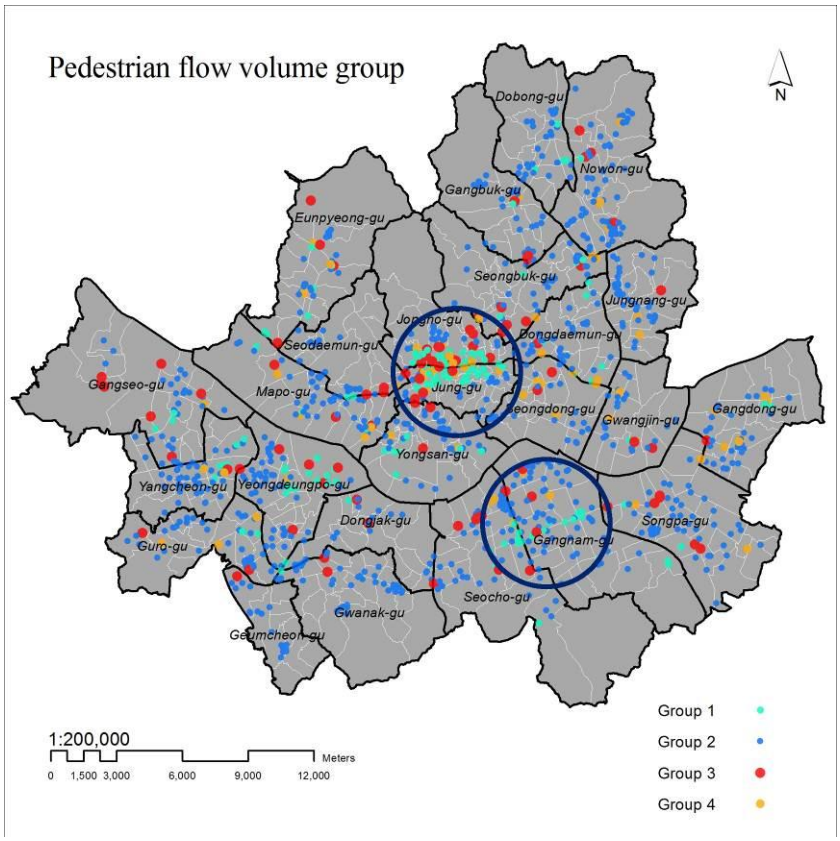


Fig. 9. Transportation mode ratio of Seoul residents (Seoul metropolitan area household survey 2010).

Fig. 10 shows two types of CBD in Seoul. Group3 and Group4 are close to subway stations. As the traditional CBD emerged naturally for a long period of time, road network is complicated and irregular. The Cheonggye stream penetrates the traditional CBD. Most areas are divided into small districts and each district is connected with narrow roads, where many shops and restaurants are also located.

Thus, subway station and place that are close from roads observe many pedestrian moves. New CBD was planned and developed since 1970s. The road network of the new CBD is of grid shaped. In addition, near the subway or bus station that is typically used for the land use of commercial purposes. As distance increases, dwelling zone and industrial districts appeared more frequently.



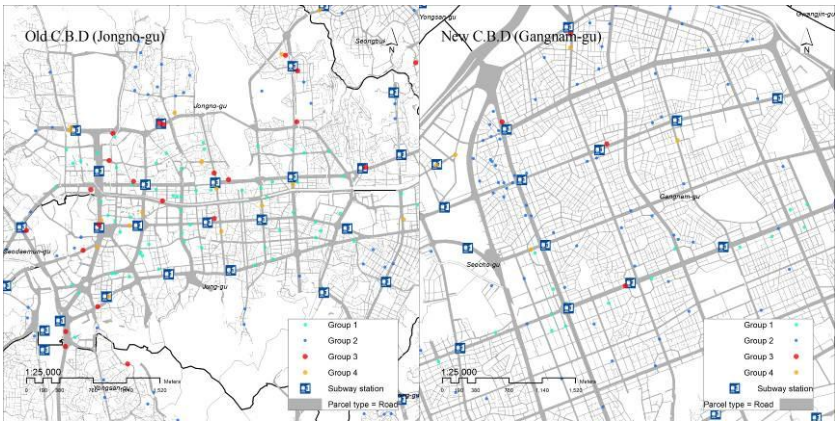


Fig. 10. Pedestrian flow volume groups that located in Seoul CBD area.

4.2. Affecting factors to walkability score

According to the results, pedestrians feel that afternoon (2~6 P.M) is the most comfortable time for walking (Table 3). On the other hand, it represented that walking is more comfortable than driving (Case3) or public mode use (Case2). Seoul also heavily suffers from car congestion in the morning and evening peak-times. Moreover, after 3 P.M, pedestrian volume increases at each point (Fig. 8). These results show that people changing their roles from driver to pedestrian feel more comfortable than public transportation passengers do.

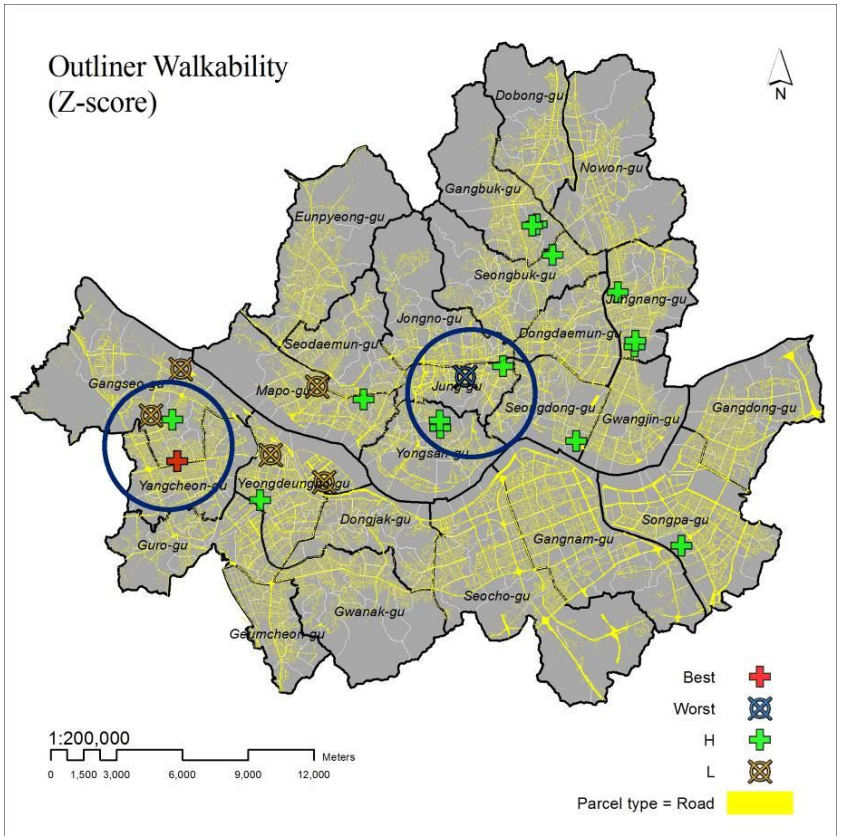
Table 3. Case tables: Transportation mode change and average of walkability.

		Survey Time	
	Case	Morning(8-14)	Afternoon(14-20)
1	Pedestrian → Pedestrian	2.65 (5th)	2.76 (4th)
2	Passenger → Pedestrian	2.65 (5th)	2.81 (2nd)
3	Driver→ Pedestrian	2.78 (3rd)	2.92 (1st)

In addition, the paper calculated average score of walkability at each point, and then conducted to standardization (z-score) to identify outliners ($z \leq -1.96$ or $z \geq 1.96$, $p<0.01$). Fig. 11 shows walkability scores of the outliners. Those points are close to the road, and negatively correlated with pedestrian flow volume. For example, Yeongdeungpo-gu and Jung-gu's flow volumes are high, but walkability-score is low. On the other hand,

Gangbuk-gu, Seongbuk-gu and Jungnang-gu's flow volumes are low, but walkability is high.

Furthermore, the best walkability score point is 16-277 (4.85), located in Yangcheon-gu. That area's pedestrian-moving axis in every direction, and there exist small roads for pedestrain only. On the other hand, the lowest walkability score point is 02-1184 (1.18), located in Jung-gu. That point is surrounded by roads, and intersections. Even in the left side, hotel is located, which induces more traffic. Those places are showing which environments are comfortable for pedestrian.



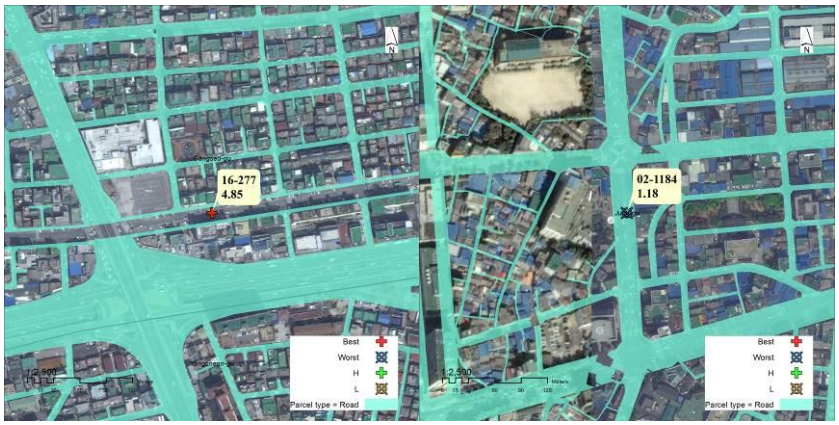


Fig. 11. Outliners of average of walkability-score (left: best, right: worst).

5. Conclusions

This study has been motivated from the fact that day time population is different from residential population. Most travel demand study analyze residential population in analysis zone. However, most metropolises have experienced spatial separation between work and residence. Therefore, measuring 'daytime population' becomes more important than before.

The current research shows that pedestrian flow volume is affected by the accessibility to public transportation (subway stations, bus stops) and land-use patterns. It can be said that Seoul well-developed public transportation infrastructure in this regard. Public transportation system has shown a significant impact on the pedestrian movements. As another focus of the current study, walkability is shown affected by time of the day (morning/afternoon) and transportation modes used before walking.

This result suggests that pedestrian movement research needs to consider both pedestrian flow volume and walkability. Further study is needed to analyze degree of factors that affect the flow volume and walkability in more detail.

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