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Environmental Benefit Calculation on Personal Mobility

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Recently, interest in the first/last mile has increased with the development of personal mobility vehicles (PMVs), a new eco-friendly and easy-to-use transportation mode. As shared transportation has become more active, existing pedestrians have begun using shared PMVs (e.g., e-scooters and bicycles). The main purpose of this work is to compare and analyze the travel characteristics of each shared-PMV usage group and short-distance travel group, interpret intergroup relations, and calculate the benefits of introducing shared-PMV as an alternative means of short-distance travel. First, the data of shared-PMV usage in Korea were analyzed to understand the characteristics (average number of days of use, average time of use, user growth rate, etc.) of the shared-PMV usage group. Mobile data analysis distinguishes the travel mode and extracts short-range travel groups that fit the scope. The travel modes are distinguished by the variables of mobile data (travel speed, department time, travel distance, travel time, etc.), and the short-distance group consists of short-distance passenger cars and pedestrians (main mode and access mode). This study presents similarities and differences between shared-PMV and short-distance groups via mobile data and evaluates the time, cost, and environmental benefits of introducing shared PMVs as a medium distance.

1. Introduction

PMVs are mainly used for intermediate-distance travel, which is long distances on foot and short distances by car. A study by Zagorskas and Burinskiene (2020) found that walking and cycling are traditionally short-distance movements required daily but are now partially replaced by personal mobility vehicles (PMVs). In fact, shared PMVs can reduce the use of high-emission cars, and PMVs can replace up to 1 % of taxi travel in urban areas (Lee et al., 2021). In reality, use of PMVs is more expensive than long-distance travel. Even for long-distance travel, PMVs can be used to shorten the link to transit stops (Smith and Schwieterman, 2018), and in several studies, PMV means are considered time-efficient and eco-friendly, indicating positive effects. To activate use of PMVs, an analysis of intermediate-distance travel is necessary; intermediate-distance travel data are extracted using mobile data and compare it with the average travel distance and travel time of PMVs.
The Seoul Metropolitan Government has actively promoted eco-friendly transportation policies such as green transportation promotion projects, the introduction of hydrogen and electric buses, and the opening of eco-friendly transportation transfer centers. These policies encourage the transition from existing power modes to non-powered modes such as bicycles and walking, and they advocate eco-friendly transportation policies such as shared bicycles to reduce emissions and improve the environment. In this regard, Ku et al. (2020) reviewed European Low Employment Zone (LEZ) policies, evaluated the performance and efficiency of EU policies promoting eco-friendly and green mobility, and Lee et al. (2020) sought to promote eco-friendly transportation by reflecting health benefits and other benefit indicators. In this paper, shared-PMV usage data and mobile data analysis are used to understand the characteristics of the intermediate distance travel, and the benefits of switching mode from mobile data to PMVs are calculated. It is expected to contribute to the introduction and revitalization of the eco-friendly mobility, and it is presented as the basis for new transportation policies.

2. Methodology

In this study, shared-PMV data analysis was used to investigate the current status of PMVs, and mobile data analysis was used to categorize the pedestrian group especially first/last mile pedestrian group, and the travel characteristics (average travel time and travel distance, etc.) of pedestrian and PMV groups were compared to

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determine whether the PMVs are suitable as an actual walking alternative. Shared-PMV data focus on travel distance and on travel time per run, and mobile data focus on the intermediate distance travel extraction. The average distance of PMVs is established to evaluate the time and environmental benefits of transferring modes from walk to PMVs and from passenger cars to PMVs, and the algorithm for this is shown in Figure 1.

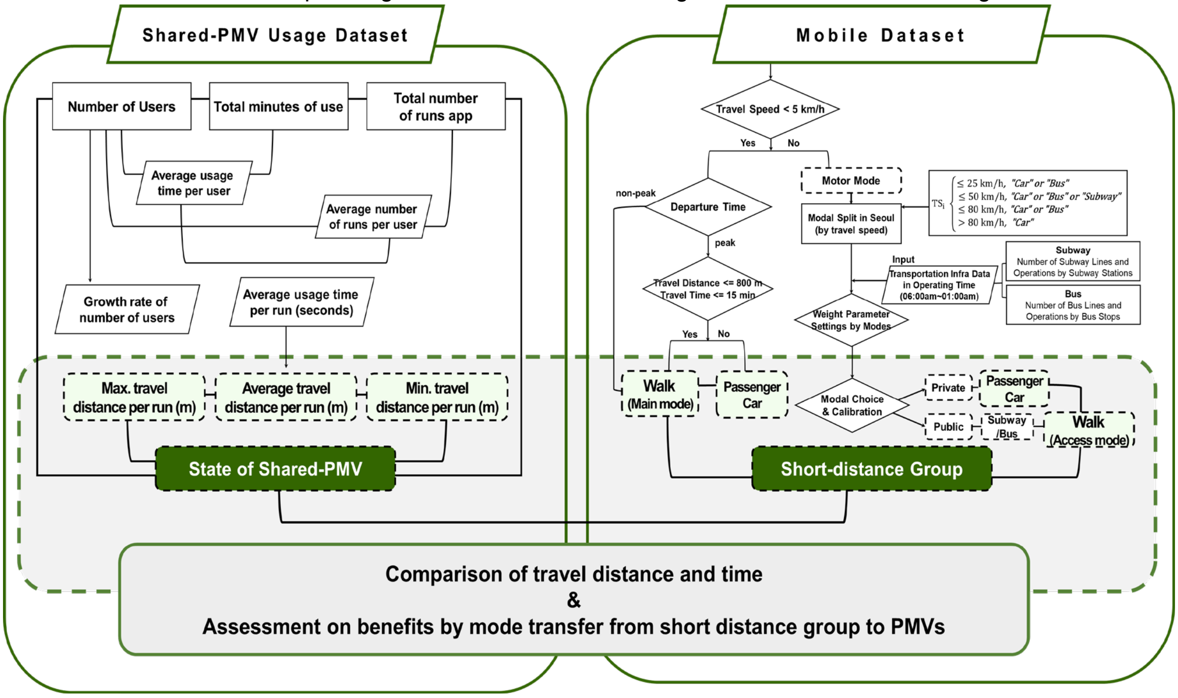

Figure 1: Comparison of mobile data and shared-PMV usage data and analysis algorithm

2.1 Shared-PMVs usage data analysis

Shared-PMV usage data are weekly data collected from users of five shared-PMV companies (Kickgoing, Xingxing, Lime, Beam, and Gogosing) in South Korea during the first year of 2019. Raw data consist of weekly users and growth rate, total hours of use (min), and the total number of app runs per company. However, in this study, the main variables were the average minutes of use per person, the average number of runs per person, the average minutes per run, and the average PMVs speed (15 km/h), resulting in company-specific shared-PMV status (Table 1). For a more detailed analysis, the maximum and minimum travel distance are compared by dividing the distance into quartile.

Table 1: Main variable and state of shared PMVs

Variables	Kickgoing	Xingxing	Lime	Beam	Gogosing
Accumulated users (thousand)	1,367	461	258	38	765
Average growth rate (%)	14.67	12.32	29.61	-10.37	7.69
Max. travel distance per run (m)	365.95	1,908.99	179.12	224.72	848.65
75 %-tile travel distance per run (m)	175.76	239.24	144.63	205.67	416.30
50 %-tile travel distance per run (m)	142.50	177.28	119.23	160.70	325.82
25 %-tile travel distance per run (m)	110.74	121.27	107.79	114.55	213.84
Min. travel distance per run (m)	79.70	59.00	79.28	91.96	56.90
Avg. travel distance per run (m)	154.81	277.74	124.63	159.52	326.36
Avg.travel distance (all company) (m)			235.83		
Weighted avg. travel distance by num. of users			222.84		
Avg. travel time per run (min)	0.89	3.94	0.52	0.63	1.81
Avg.travel time (all company) (min)			1.56		

According to the detailed PMV usage data analysis, the average travel distance per run of five companies is 235.83 m, and the weighted average travel distance according to the number of users is 217.21 m. For PMV travel distances, the deviation is very large, covering everything from very short distances to medium distances.

In this study found that the maximum traveled distance is about 2 km, out of 5 studied companies. This distance is defined as the intermediate distance, then only within 2 km of each mode of mobile data are analyzed.

2.2 Mobile data analysis

The main data used in the pedestrian group estimation algorithm are mobile data provided by Korea Telecom (KT), one of the three largest telecommunication company in Korea. The date range of mobile data is Thursday, May 19, 2016, and it includes 22,378 base station logs in Mapo-gu, as well as all mobile tracks in Korea. In this study, it is unable to analyze all dates because it is impossible to receive data for all dates, but it is confirmed that there is no special date bias for May and Thursday through the 2019 Seoul Metropolitan Government Traffic Survey Data. Raw data variables consist of ID, age, date, dwell location, dwell time, arrival time, and department time. Duplicated locations occurred at the boundary between the two base stations. Repeatable locations were removed and considered as residential locations. Travel speed variable was added by calculating the travel distance (linear distance between base stations) and travel time. Table 2 shows the data structure of the ID-specific timeline of mobile data, and Figure 2 shows the ID-specific trip chain of the mobile data analysis results.

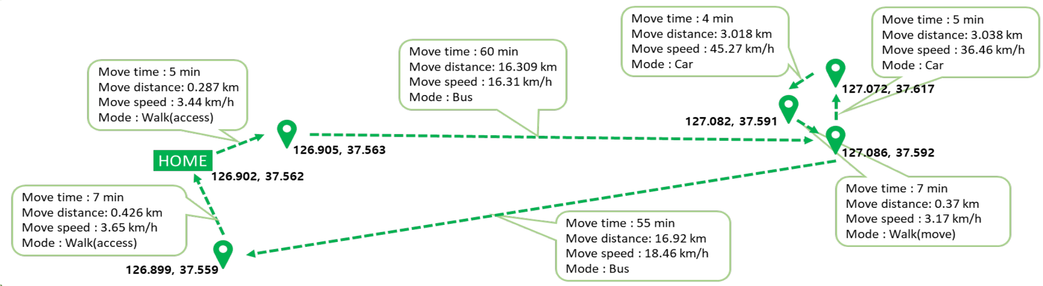

Figure 2: Agent-based trip chain by ID

Table 2: Mobile dataset based on GPS station

ID	Age	Date	Duration	Location	Arr.time	Dep.time	Dwell Time	Move time	Move distance	Move speed
11	45	160519	126.902	37.562	00:00	11:39	699 (min)	2 (min)	265.06 (m)	7.95 (km/h)

Travel speed is a key variable that distinguishes power modes from nonpowered modes (walking). According to Kim et al. (2018), the average speed of ordinary pedestrians without physical constraints is 1.24 m/s (4.5 km/h). According to Perry and Burnfield (1992), the speeds for men and women are 1.3 and 1.2 m/s. In Jang et al. (2021), the pedestrian speed is set to 5 km/h, considering that the distance traveled is a straight line. Passenger car data in peak hours of heavy traffic can be collected at very low speeds, making it look like walking. All data with movement speeds of 5 km/h or less in the non-peak time zone are considered pedestrian groups, but in the peak time zone, it is difficult to distinguish pedestrian groups with only movement speed. According to access sheds in First Last Mile Strategic Plan & Planning Guidelines (2014) in the United States, the appropriate walking distance is 0.5 mi (approximately 800 m). To reflect this value and pedestrian speed, the maximum walking time was set to 15 min, and the travel speed at the peak time was less than 5 km/h, within 0.8 km, and the travel time within 15 min is considered walking. Traveling at speeds below 5 km/h on peak time and not meeting the above conditions should be considered as traveling via a passenger car.

To distinguish pedestrian groups (access mode) to use public transportation, the classification of transportation is necessary. In this study, the probability of selecting each mode according to the Seoul Metropolitan Government's modal sharing rate in 2016 was calculated, and the lowest and highest speeds of the year were considered. In 2016, the Seoul Metropolitan Government's share of modes was divided into cars, subways, buses, taxis, etc.; cars and taxis are unified into one group, so the modes are constructed as follow: cars, subways, and buses (Table 3). In this study, the minimum and maximum speeds of cars are unlimited, and according to the Seoul Metropolitan Government's data, the subway speed ranges from 29.3 km/h to 46.8 km/h and the bus speed ranges from 0 km/h to 80 km/h (Table 4).

Table 3: Modal Split (car, subway, and bus) in Seoul (2016)

Mode	Car	Bus	Subway	Taxi	Other	Total
All modes	24.3	26.1	38.9	6.3	4.1	100
Car, Subway, Bus	32.0	27.3	40.7	-	-	100
Car, Bus	54.0	46.0	-	-	-	100

Table 4: Corresponding mode according to the travel speed interval

Travel Speed	≤ 25 km/h	≤ 25 km/h	≤ 25 km/h	> 80 km/h
Mode	*"Car" or "Bus"*	*"Car" or "Subway" or "Bus"*	*"Car" or "Bus"*	*"Car"*

According to the speed interval, the probabilities of the travel mode selection are different.

Park and Lee (2017) calculated the weight of each mode of transportation based on public transportation infrastructure information, travel time, and distance of passengers. In this work, the weight is calculated if there are public transportation infrastructure facilities for each base station location through public transportation infrastructure information, which distinguishes the first/last mile pedestrian groups. If multiple subway stations and bus stops exist within one base station, the overlapping weights are considered, and both subways and buses have a greater impact on the number of lines ($No.L_{mode}$) than the number of operations ($No.O_{mode}$). The weight of mode (W_{mode}) is set in the same way as in Eq(1):

$$\begin{cases} W_{sub} = \sum(No.L_{sub} + No.O_{sub}\ per\ line) \\ W_{bus} = \sum(No.L_{bus} + No.O_{bus}\ per\ line) \end{cases} \tag{1}$$

where W_{mode} is the weight of mode, $No.L_{mode}$ is the number of lines by mode, and $No.O_{mode}$ is the number of operations by mode.

When moving from a specific base station, the final choice is as shown in Eq(2):

$$Modal\ Choice = \mathrm{Max}\left[\, Prop_{Car}, \quad Prop_{Sub} * \left(1 + \frac{W_{sub}}{\sum W_{sub}}\right), \quad Prop_{Bus} * \left(1 + \frac{W_{sub}}{\sum W_{sub}}\right) \right] \tag{2}$$

where $Prop_{mode}$ is the property of mode and W_{mode} is the weight of mode.

If the $i\ th$ mode is different from the $i+1\ th$ mode, the process of correcting the mode is conducted to estimate the first/last mile pedestrian group for public transportation.

3. Result and discussions

3.1 Comparison of shared-PMV data and mobile data analysis results

Based on the two data analysis results, the PMV and pedestrian characteristics (main and access modes) were compared, and the characteristics of passenger cars within intermediate distances were also compared. The main access mode to other modes, such as public transportation, is the walking mode. As mentioned above, the travel distance of each device is limited to approximately 2 km. The maximum travel distance and intermediate distance of the PMVs, and the comparison of the travel characteristics of each mode is shown in Table 5, and boxplots for the travel distance by mode are shown in Figure 3.

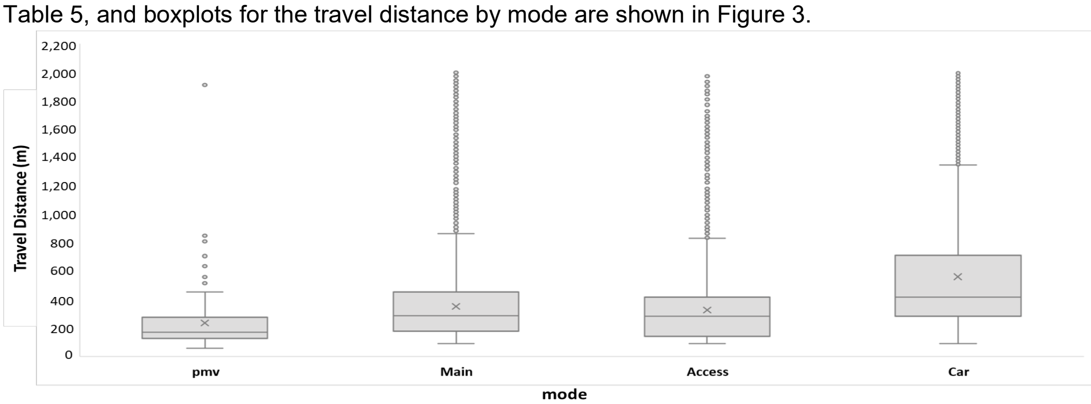

Figure 3: Comparison of travel distance by mode through boxplot

Table 5: Comparison of PMVs with pedestrian groups and cars

	Shared-PMVs usage data	Mobile data		
	PMVs	Walk (main)	Walk (access)	Car
Ratio of travel within 2 km (%)	-	83.24	90.24	65.59
Avg. travel distance (m)	235.83	351.53	325.99	559.76
Max. travel distance (m)	1,908.99	1,999.74	1,992.03	1,999.79
Min. travel distance (m)	56.90	88.10	88.13	88.10
Avg. travel time (min)	1.56	9.31	7.12	3.89

All modes have similar minimum, maximum, and average values; the boxplot shows that each mode has different characteristics. The average distance of the PMVs is 235.83 m, which is smaller than the average distance of pedestrians and passenger cars, but it is analyzed to be similar to that of pedestrians, especially access. The average travel time of PMVs at similar distances is very short compared to that of pedestrians, making PMVs a desirable alternative to pedestrians. It was also found that PMVs are shorter in both the average distance and time compared to passenger cars, while passenger cars are less affected by peak time, and PMVs are generally considered to cover a shorter distance because they are largely affected by high fares. Because of the high fares of PMVs, short-distance travel can be substituted for long-distance travel, and there is a significant difference between short-distance and long-distance travel, which is approximately 1.7 times longer than the pedestrian travel (Figure 4 shows average distance by mode).

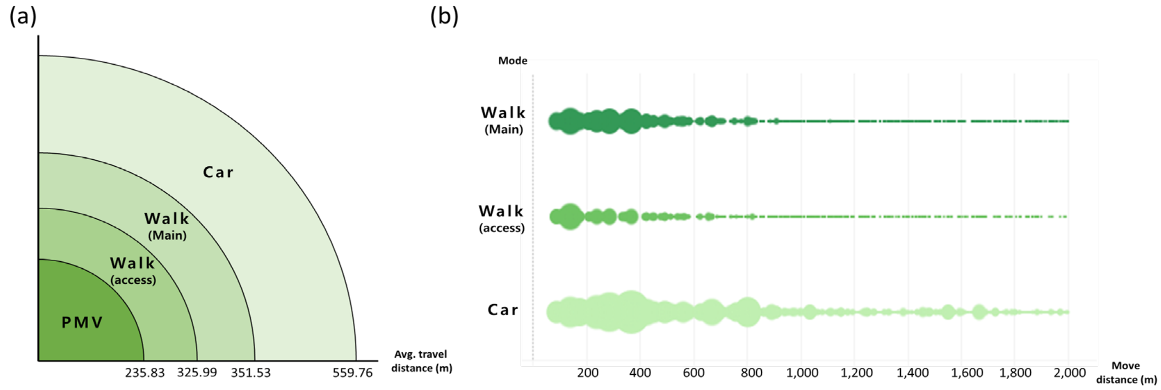

Figure 4: Illustration of (a) average travel distance by modes, and (b) travel distance distribution by modes

3.2 Benefit evaluation

In this study, the maximum PMV activation distance was 2 km, and the time and environmental benefits of pedestrians and passenger cars were calculated. Ku et al. (2021) set the conversion amount to 30 % of short-distance travel; so, in this study, the conversion amount to PMVs is set to 30 % of the short-distance travel of each mode to calculate the benefits of conversion. The travel distance by each mode found in Table 5 is used, and the travel time is calculated by reflecting the average travel speed of each mode. Benefits are calculated to reduce travel time because of speed changes and to reduce air pollution caused by switching to PMVs, an eco-friendly mode (Table 6) where VOTS is the valuation of travel time savings, and VOPCS is the valuation of pollution cost savings.

Table 6: Volume and benefits of mode transfer

	PMVs	Walk (main)→PMVs	Walk (access)→PMVs	Car→PMVs
Avg. number of users/d	10,840	28,712	15,065	85,667
The volume of transfer to PMVs	-	8,614	4,520	25,700
Travel distance (m)	-	351.53	325.99	559.76
Travel time (min)	-	6.39	5.02	0.84
VOTS (x 10^9 KRW/y)	-	2,632.54	1,013.17	-3,084.35
Total VOTS (x 10^9 KRW/y)	-		561.36	
Pollution cost (x 10^9 KRW/km)	-	-	-	8.74
VOPCS (x 10^9 KRW/y)	-	-	-	0.82
Total valuation (x 10^9 KRW/y)	-		562.18	

The valuation of travel time savings from pedestrians to PMVs was calculated positively as the speed of travel increased, but the valuation of travel time savings from cars to PMVs was calculated as negative. Faria (2012) noted that the EU average electric mobility emissions are less than half the fuel mobility ratio, which means that the environmental benefits of the modal shift from cars to PMVs are greater.

4. Conclusions

With the advent of PMVs, a new eco-friendly and easy-to-use mode of transportation, research on PMVs has been underway in many ways. The benefits of transfer from pedestrians, bicycles, and cars to PMVs are expected to be 56.136 x 10^9 KRW in time saving and 0.82 x 10^9 KRW in pollution reduction, which is expected to be 56.218 x 10^9 KRW in total.

This study compares PMV groups with intermediate distance groups by analyzing shared-PMV usage data and mobile data and calculates the benefits (especially environmental benefits) of converting intermediate distance to PMV. Mobile data, however, are limited to Mapo-gu, Seoul, and KT data are used among the three largest mobile telecom companies in Korea, but the data are limited to specific mobile base stations in specific areas. The high PMV rates did not progress further, so the impact of rates on PMV usage will remain a challenge in future studies. With the transition to PMVs, research and development are expected to evaluate policies and activation measures to promote green mobility and environmentally friendly transportation policies. This research is expected to contribute to the introduction and the revitalization of eco-friendly mobility, by understanding the detailed relationship with PMV and by providing environmentally friendly mobility through the main access mode.

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