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# Environmental Sustainability Increase by Activation of Public Transport and Personal Mobility

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Currently, a variety of shared mobility services are available. Shared mobility services serve as first/last mile transportation options to enhance personal mobility and improve access to transportation services. Among these shared mobility services, Personal Mobility (PM) is garnering attention due to its potential to address urban traffic issues by offering environmentally friendly benefits such as reducing traffic congestion and facilitating easier parking. Moreover, by solving the first/last mile problem of public transportation and employing a PM-specific algorithm for route guidance, the efficiency and competitiveness of public transportation can be improved. Existing route guidance algorithms do not adequately account for PM-specific characteristics and often direct users along inefficient routes primarily designed for vehicles or public transportation. This study aims to propose an algorithm exclusively tailored for PM and present an efficient path that incorporates PM characteristics. By effectively addressing the first/last mile service for users, this algorithm aims to enhance traffic efficiency and user convenience. In fact, the commuting route around a subway station in Seoul was set as a demonstration area to analyze the mode shift effect of applying the PM application algorithm. through the modal split process of the transportation demand forecasting model. As a result of the analysis, the modal shift to public transportation by applying the PM application algorithm was 269,925 in 2025, and the air pollution reduction benefit was calculated to be 82.85 billion KRW/y. The increased utility of PM can lead to environmental benefits by bolstering the competitiveness and ridership of public transportation. The findings of this study are expected to serve as a quantitative foundation for establishing shared mobility distribution policies aligned with the era of mobility transformation.

## 1. Introduction

Personal mobility (PM), represented by electric scooters, has emerged as a new mode of urban transportation. It has been demonstrated that integrating micro mobility with public transportation can make cities better by increasing accessibility and reducing congestion and pollution. (Oeschger et al., 2020). It has been demonstrated that PMs are preferred by short-distance users and will be in high demand, especially close to public transportation transit stations. (Cao et al., 2021). If PM is integrated to solve the first/last mile problem of public transportation, it can have a complementary effect by providing efficient door-to-door access (Fistola et al., 2022). Using an algorithm for route guidance can reduce total travel time (Khoza et al., 2020), by avoiding congested routes in busy situations and selecting the optimal route when congestion is relieved (Jindal and Bedi, 2018). When PM replace conventional car traffic, about 5.8 kt of CO2 is saved each day, and it is much more energy efficient than conventional cars, making them an eco-friendly mode of transportation that reduces carbon emissions (Ayözen et al., 2022). There are not many studies that have calculated environmental benefits by comprehensively considering the networks of pm and public transportation. Therefore, this study aims to present an algorithm that finds the shortest route by setting the PM speed differently according to the terrain, reflecting the characteristics of PM. The proposed algorithm is applied to a commuting route in Seoul and the results are presented. By comparing the results before and after applying the existing PM algorithm and the PM-only algorithm, we calculate the effect of mode shift to public transportation through the proposed algorithm and analyze the impact of mode shift on air pollution using the calculated mode shift rate. The purpose of this study

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is to promote the utilization of public transportation by contributing to the improvement of accessibility and urban environment through the improvement of PM algorithm.

## 2. Literature Review

### 2.1 The characteristics of Shared Mobility and Personal Mobility

Shared mobility, one of the main areas of smart mobility, includes carsharing, personal vehicle sharing, bike sharing, scooter sharing, shuttle services, ridesharing, and on-demand ride services (Shaheen and Chan, 2016). Among them, compared to taxis and bicycles, PM offers flexible choices with faster or shorter routes, no return location, allowing users to be picked up and dropped off anywhere (Ma et al., 2022), and can be easily booked and unlocked using a mobile app (Fistola et al., 2021). However, the speed of PM decreases or increases depending on terrain factors such as slopes and hills (Heumann et al., 2021), and people start to feel uncomfortable at a speed of 8 km/h for road types with rough road surfaces, and at a speed of 16 km/h for slightly bumpy roads (Cano-Moreno et al., 2021). The highest speed of PM defined in the current law of micro mobility in Korea is 25 km/h (Kim and Kim, 2021), and the lowest speed is defined as 5 km/h under the assumption that it should be faster than the average walking speed of 1.31 m/s (Lee et al., 2019).

### 2.2 Algorithm for Integrating PM with Existing Modes

The current existing route guidance service uses real-time traffic information collected from the vehicle network to calculate the optimal route and predicts real-time traffic conditions (Lin et al., 2017). Existing route guidance services focus on personal movement using automobiles and people using public transportation. When PM is linked to public transportation, it provides a solution to the first/last mile of public transportation by connecting stations with origins or destinations (Medina-Molina et al., 2023). When shared mobility systems were introduced, the mode share of shared mobility for first/last mile trips was found to be 45.9 %, leading to a decrease in automobile use (Fan et al., 2019). This study aims to provide PM customized route guidance along with existing route guidance focused on public transportation by using an algorithm to provide an optimal route considering public transportation transit distance, public transportation usage time, user's destination, and travel pattern.

### 2.3 Types of Algorithms

Route guidance algorithms include various algorithms such as the Dijkstra algorithm, the A* algorithm, the state lattice algorithm, rapidly exploring random trees (BRT), the genetic algorithm, and artificial intelligence route guidance (Wang et al., 2021). The Dijkstra algorithm can find the optimal route with minimum weight from origin to destination, convenient to use on road networks in uncomplicated nodes (Risald et al., 2017). It also has the potential to find routes faster than the A* algorithm and the ant colony algorithm by taking a G-graph with weights between nodes, an initial node, and a final node that is the destination of the route search as input (Fitro et al., 2018). As the complexity of the path increases, Dijkstra's algorithm's path selection accuracy and the number of selected paths appear to be 100 % optimal (Zhou and Gao, 2019). Based on the overview of previous studies, this study aims to search for exact optimal paths among various route guidance algorithms based on the most reliable Dijkstra algorithm and apply it to PM optimal paths.

## 3. Methodology

### 3.1 Frame of the study

In this study, a commuting route around a subway station in Seoul was selected for analysis. The PM application algorithm is based on the Dijkstra algorithm, and we analyzed how to find the shortest path by setting the speed differently depending on the terrain. The results before and after applying the existing PM algorithm and the PM-only algorithm were compared. Through the application of the PM algorithm, we calculated how much environmental benefit can be brought by switching to subway and bus, which is calculated from the modal split process. The framework of the study is shown in Figure 1.

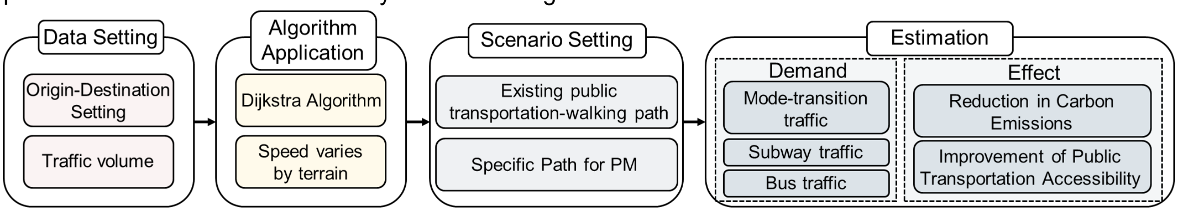


*Figure 1: Framework for* demand and effectiveness analysis according to PM-specific algorithm

### 3.2 Improvement of Dijkstra algorithm

Dijkstra algorithm is usually used to find the shortest path between two cities on the map, calculated incrementally by establishing nodes based on the starting point and destination and assigning an initial distance value (Makariye, 2017). In this study, we calculated the equation by adding the PM velocity value $\alpha \times \mu$ based on the terrain. The detailed process is as followed.

In the given weight graph $G = (V, E, W)$,
let $v_1, v_2, \cdots, v_n \in V$ are the nodes, $e_1, e_2, \cdots, e_n \in E$, here , $e_i$ is the side connected $v_{i-1}$ with $vi$ , whose side length is $w_{(i-1)i}$ . A is the abutment matrix of the weighted graph. If there is no side between $v_i$ and $v_j$ , then $a_{ij} = \infty$; if one link exists, then $a_{ij} = w_{ij}$; if $i = j$, then $aij = 0$. $S$ is the set of nodes with the shortest path from the initial node $v_1$, each component of Vector $D$ represents the current shortest path length from the initial node to each destination. (Xiao and Lu, 2010).
Step 1. Initialize $S$ and $D$: $S = \{v_1\}, D[i] = A[1][i], i = 1,2, \cdots, n$
Step 2. Choose $v_j$ which satisfies the following condition. $D[j] = \min\{D[i] | v_i \in V - S\}$. Let $S = S \cup \{v_j\}$.
Step 3. Modify the length of the shortest path from $v_1$to $v_k$ in the set $V - S$.
If. $D[j] + A[j][k] < D[k]$, then modify $D[k] = D[j] + A[j][k] + \alpha \times \mu$.
Step 4. Iterate operations step 2 and step 3 for $n - 1$ times, then we can get the shortest path length from $v_1$ to $v_j$
Step 5. We can draw the shortest path tree from the above steps to show the path clearly. And then we can get the shortest path and the length from the matrix or the tree.

$Given\ G$ : find the shortest weight path between a given source and destination
$v_n$ : the nodes
$e_i$ : the side connected $v_{i-1}$ with $vi$
$w_{(i-1)i}$ : side length
$S$: the set of nodes with the shortest path from the initial node $v_1$
$D$ : the current shortest path length from the initial node to each destination

### 3.3 Modal spilt and environmental benefit

In this study, a travel demand forecasting model was used to predict the model split effect of the PM- specific algorithm by comparing the results before and after the algorithm was applied. The O/D matrix and network were constructed using KTDB (Korea Transport Database) data, and the means selection and traffic assignment stages were performed during the demand forecasting model process. In the modal split process, a logit model was employed to predict the modal share by identifying the characteristics of individual travelers' travel behavior. The means selection model was calibrated through the incremental logit model, which calculates the utility of the project without implementation and with implementation and determines a new modal split considering the change in utility, as shown in Equation (1) (Ku et al., 2022).

$$P_i^* = \frac{P_i \cdot exp\ \Delta V_i}{\sum_{j=1}^{J} P_j \cdot exp\ \Delta V_j} \quad (1)$$

$P_i^*$: Revised probability of choosing mode $i$
$P_i$ : Baseline probability of choosing mode $i$
$\Delta V_j$: Change of utility of mode $j$ in the choice set $J$ $(j = 1,2,3, \ldots, J)$

The modal split value calculated using the methodology is utilized to quantify the environmental benefits resulting from the reduction in passenger car usage and the increased utilization of PM and public transportation. The air pollution costs associated with different vehicle types and speeds were calculated by the Korea Development Institute (KDI), an organization that conducts comprehensive research on economic and social phenomena in Korea. This calculation was performed using Equation (2) outlined in the “Transportation Sector Business Benefit Calculation Methodology Study (Lee, 2017)”

$$VOPCS = VOPC_{Unimplemented} - VOPC_{Implemented} \quad (2)$$

$$VOPC = \sum_{l} \sum_{k=1}^{3} (D_{kl} \times VT_k \times 365) \quad (3)$$

$D_{kl}$ : By link($l$), by vehicle type($k$) vehicle·km
$VT_k$ : By vehicle type($k$)Air pollution cost per km of the driving speed of the link
$k$ : Types of Vehicle (1: Car, 2: Bus, 3: Truck)

## 4. Results

### 4.1 Example of PM algorithm application

An analysis was conducted on two commuting scenarios from a subway station: walking and using a PM (Personal Mobility) device. Based on the residential area around the subway station in Seoul, the analysis was conducted as a case study. These scenarios were labelled as Scenario A and Scenario B. In Scenario A, the analysis focused on the travel time for walking and using the PM-specific algorithm at the subway station. In Scenario B, the analysis examined the travel time for both the existing PM guidance algorithm and the PM-specific algorithm at the subway station. The PM-specific algorithms consider different PM speeds based on the terrain, with traffic speeds set to 25 km/h on flat or smooth surfaces, and 8-16 km/h on hilly or rough surfaces. The analysis was conducted assuming that individuals walk at an average speed of 1.31 km/h. For the comparison of the existing PM guidance algorithm, the shortest route guidance was assumed. The maximum speed of the PM device was set to 25 km/h, while the minimum speed was set to 5 km/h in compliance with current Korean laws. Figure 2 illustrates the routes resulting from the analysis of the four scenarios. By utilizing the equations described in the methodology, the analysis examined the travel times for walking and regular PM routes, as well as the travel times for regular PM routes and routes with the PM algorithm (Table 1).

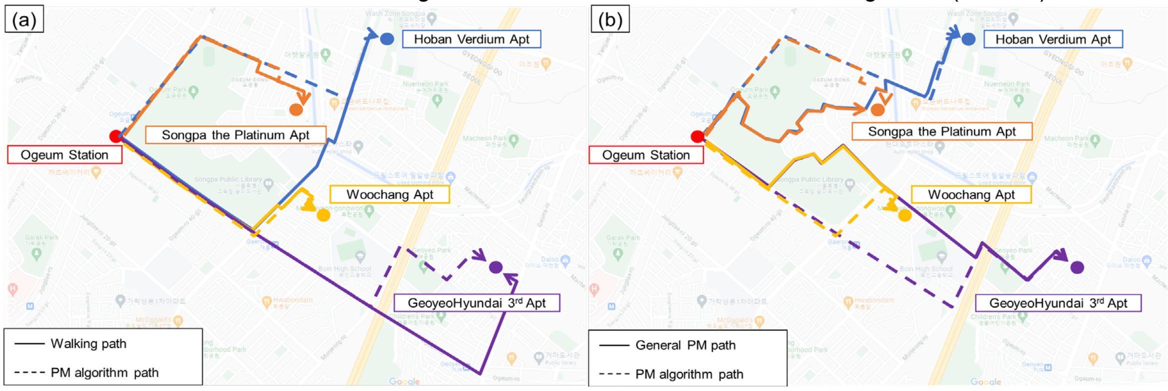


*Figure 2: Path route of (a) Scenario A (Walking vs PM algorithm), and (b) Scenario B (PM vs PM algorithm)*

*Table 1: Travel Time (Unit: min)*

| Classification | | Woochang apartment | Hyundai 3rd apartment | Songpa the Platinum apartment | Hoban Verdium apartment |
|---|---|---|---|---|---|
| A (Walking vs PM algorithm) | Walking | 15.2 | 32.09 | 19.08 | 22.9 |
| | PM algorithm | 4.69 | 8.16 | 4.614 | 6.34 |
| | Difference | 10.51 | 23.93 | 14.466 | 16.56 |
| B (PM vs PM algorithm) | PM | 7.16 | 9.166 | 6.94 | 9.477 |
| | PM algorithm | 4.6 | 8.16 | 4.614 | 6.34 |
| | Difference | 2.56 | 1.006 | 2.326 | 3.137 |

### 4.2 Modal split Effect & Benefit evaluations

The base year for transportation demand forecast and benefit analysis due to changes in mode share was set to 2021, and traffic assignments were made according to Origin/Destination data for future years. Based on Eq (1) presented in the methodology, the mode share rate was estimated. As a result of the analysis, there are a lot of means of switching from passenger cars to public transportation per day as of 2021 through the application of the PM customized algorithm scenario. Table 2 shows the results of the transportation demand analysis. It can be observed that the number of daily trips for passenger vehicles (including cars and taxis) decreased from 21,282,736 vehicle/d to 21,014,911 vehicle/d in 2021, while public transportation trips increased from 6,323,329 vehicle/d to 6,443,345 vehicle/d.

Based on the methodology presented above, we applied it to the scenarios to calculate the benefits of reducing environmental costs and analyze the difference in benefits from the existing situation. We calculated the benefits by multiplying the change in pollutant emissions by the unit cost of environmental damage per pollutant and converted it into a monetary value.

*Table 2: Modal split (Unit: vehicle/d)*

| Division | | Unimplemented | Implemented | Difference |
|---|---|---|---|---|
| | | Amount of traffic | Amount of traffic | Amount of traffic |
| 2021 | Auto | 18,303,550 | 18,073,216 | 267,824 |
| | Taxi | 2,979,186 | 2,941,695 | |
| | Bus | 2,833,587 | 2,953,603 | |
| | Subway | 3,489,742 | 3,489,742 | |
| 2025 | Auto | 18,447,124 | 18,447,124 | 269,925 |
| | Taxi | 3,002,555 | 3,002,555 | |
| | Bus | 3,198,548 | 3,198,548 | |
| | Subway | 3,939,213 | 3,939,213 | |
| 2030 | Auto | 18,248,927 | 18,248,927 | 267,025 |
| | Taxi | 2,970,295 | 2,970,295 | |
| | Bus | 3,259,131 | 3,259,131 | |
| | Subway | 4,013,826 | 4,013,826 | |
| 2035 | Auto | 17,879,619 | 17,879,619 | 261,621 |
| | Taxi | 2,910,184 | 2,910,184 | |
| | Bus | 3,163,655 | 3,163,655 | |
| | Subway | 3,896,241 | 3,896,241 | |

The air pollution cost by vehicle type and speed due to the reduction in passenger vehicle traffic was applied according to the methodology presented in the Korea Development Institute (KDI)'s 'Transportation Sector Business Benefit Calibration Methodology Study'. A discount rate of 4.5% was applied to the air pollution reduction benefit calculation formula. It was quantified by multiplying the change in pollutant emissions by source by the unit price of environmental damage by pollutant. As a result of estimating the benefits based on the year 2025, it was estimated that the benefits of reducing environmental costs would be approximately 82.85 B KRW/y. The results as bellow Table 3.

*Table 3: Comparison of environmental benefit results (implementation, not implementation)*

| Division | VKT (km) | Car Air Pollution Cost Factor (KRW/km) | Cost (B KRW/y) | Difference (B KRW/y) | Difference Ratio (%) |
|---|---|---|---|---|---|
| Not implemented | 372,693,573 | 16.25 | 5,848 | -82.85 | -1.46 |
| Implemented | 367,412,786 | | 5,765 | | |

* 1) Korea Transport Institute (KOTI), 2020, Metro Area passenger O/D Explanatory Data as of 2020 (KTDB).
* 2) KDI (Korea Development Institute), 2020, A Study on the Amendment and Supplementation of Standard Guidelines for Preliminary Feasibility Study of Road and Railway Sector Projects ($6^{th}$ Edition)

## 5. Conclusions

Recently, there has been a growing interest in shared mobility as an alternative to conventional transportation to improve the accessibility of metropolitan railways in metropolitan areas. In this study, we propose a customized route guidance algorithm for personal mobility, which is an eco-friendly alternative transportation method for shared mobility. PM-specific route guidance connects PM with public transportation. As the total travel time of public transportation decreases, the transportation share of road and rail was estimated. We analyzed the scenario of commuting to a subway station using two modes of access: walking and PM. Implementing the PM-specific algorithm resulted in a modal shift of 269,925 person/d to public transportation in 2025, and the air pollution reduction benefit of reducing the use of passenger cars through the modal shift to public transportation was calculated to be 82.85 billion KRW/y. Based on the results of the study, the application of the PM-specific algorithm has the effect of switching to public transportation and can be expected to reduce air pollution. In the future, by reflecting the access characteristics of passengers based on the agent-based model, it is expected that it can be applied in more detail to consider individually optimized routes and means. In addition, the validity of this algorithm can be better examined by analyzing a wider study area than the case area.

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