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Air Pollution Reduction by Optimizing Locations of Mobility Parking Hub

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Environmental pollution and energy waste are intensifying due to the increase in traffic for various purposes in urban centers. While the idea of the 15-min city is about convenient travel within a region, it also needs to cover travel between regions. Accordingly, the purpose of this study is to allow parking and transfer of cars with public transportation and various shared mobility options through mobility parking hub. This is called a Parking and Ride (P&R) system, which can effectively help passenger car drivers to better fulfil the goal of the 15-min city: eco-friendly, efficient intercity travel. First, select a suitable location for your mobility parking hub by considering the location of existing car park buildings, distance to the metro, and distance to your target lifestyle station. Scenarios were set up based on the expected capacity of the selected mobility parking hub and the size of the existing parking lot. Then, for each scenario, the reduction in vehicle kilometers traveled (VKT) is analyzed. As a result, it was found that a total of 1,105.64 t/y of air pollutants could be reduced when used (100 %) by the amount corresponding to the total parking space of the mobility parking hub. The study concluded that building mobility parking hubs can reduce VKT when moving between areas. The results of the analysis show that properly placed mobility parking hubs can reduce VKTs, leading to lower air pollution emissions. In the future, living zones such as 15-minute cities will be formed, which can be used for eco-friendly movement between living zones. In addition, it can be used as a reference when designing a mobility parking hub for inter-living zone movement.

1. Introduction

Air pollution is a health risk, causing premature death from stroke, lung disease, diabetes, and more. And the transport sector is a major contributor to this air pollution (Pietrzak and Pietrzak, 2020). The 15-min city starts with creating a pedestrian-centric environment instead of a vehicle-centric one (Khavarian-Garmsir et al., 2023). The 15-min city policy ensures that residents within an urban area can comfortably walk or bike within the city in a time frame that does not exceed 15 min (Allam et al., 2022). The main benefit of 15-min cities is to reduce internal car traffic in urban centers (Nieuwenhuijsen, 2021). Existing research tends to focus on research to build 15-min cities, such as 15-min city planning. Assuming that the 15-min city concept has been introduced to many cities, this study explores ways to move between living areas and introduces the concept of mobility parking hubs to see its effectiveness. P&R is an efficient and safe transportation demand management policy to reduce the negative impact of private vehicles in central business districts. (Ortega et al., 2020). Mobility hubs are often mentioned as a solution for improving accessibility in urban areas. Mobility hubs are more environmentally friendly than personal transportation and can connect travel between different modes of transportation (Weustenenk and Mingardo, 2023). Existing research has been conducted on the construction of 15-minute cities, and only mobility hubs and P&R services have been studied. However, this study aims to induce the use of public transport and eco-friendly mobility by mixing the concepts of mobility hub and P&R to reduce the use of automobiles when travelling between living areas after the formation of a 15-minute city.

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2. Methodology

This study aims to induce various eco-friendly mobility utilization through the construction of mobility parking hubs in appropriate locations. Mobility parking hubs are anticipated to reduce the distance traveled by vehicles traveling to the downtown area. It is also expected to positively affect the environment by reducing the distance traveled by automobiles. The location of mobility parking hub is designed based on traffic volume in Seoul City Wall, which is promoting a low-emission zone among Korean urban centers. It is set up with parking facilities and shared mobility such as electric scooters and bicycles so that passengers can park their cars and transfer to various eco-friendly modes. In addition, to minimize construction costs, the scale of the existing parking lot is not changed. In this case, the existing parking demand is not considered because it is repurposed from a traditional parking purpose to a mobility hub type of operation. Based on these settings, the change in Vehicle Kilometer Traveled (VKT) was analyzed by setting up scenarios based on the size of each hub and assuming the mode shift from auto to eco-friendly transportation within the hub. Finally, using the VKT calculated for each scenario, a quantitative analysis of how much air pollution could be reduced is performed. Figure 1 shows the framework of this study.

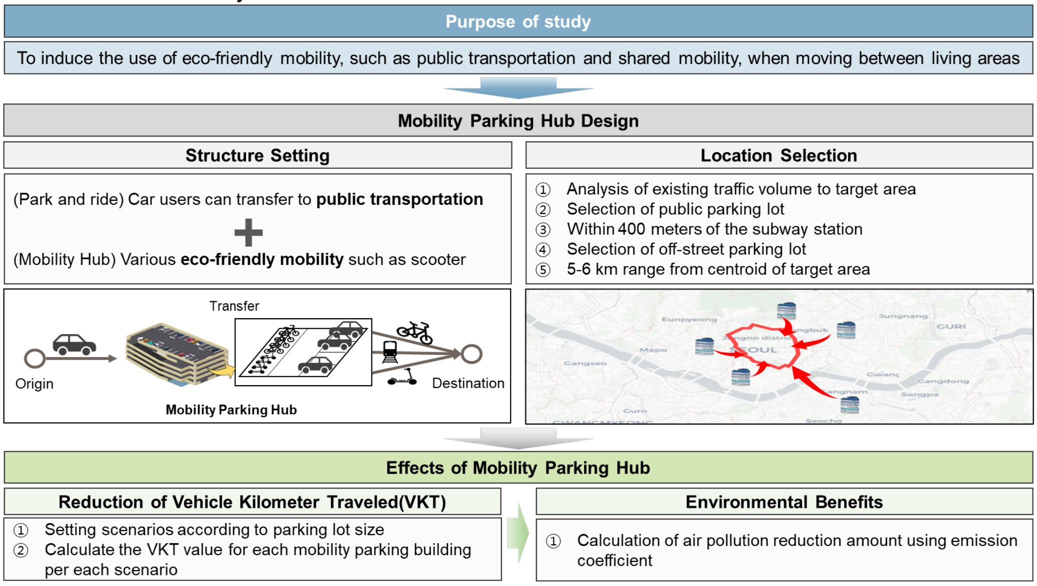

Figure 1: Framework of this study

2.1 Mobility Parking Hub Design

Mobility hubs are an effective way to promote public transportation use, and the commercialization of mobility hubs can reduce greenhouse gas emissions by reducing vehicle miles travelled (Ku et al., 2022). Tennøy et al. (2019) demonstrated that the introduction of three P&Rs reduced car use in the urban area of Coimbra by 19 % and argued that P&Rs are crucial in reducing traffic congestion and air pollution in urban areas. Through this, it is argued that P&R plays an important role in reducing traffic congestion and air pollution in urban areas. In this study, the mobility parking hub, which combines the concepts of Mobility hub and P&R, is applied to verify its effectiveness. While the existing P&R mainly deals with transfers with public transportation, the mobility parking hub proposed in this paper covers a wider range of mobility than the existing P&R by enabling transfers not only with public transportation but also with personal mobility. Figure 2 shows a conceptual diagram of a mobility parking hub with and without a mobility parking hub.

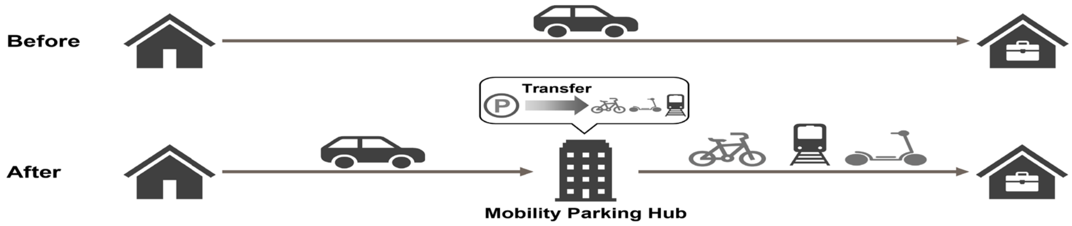

Figure 2: Concept of mobility parking hub

In this paper, a case study was set up to analyze the impact of a mobility parking hub on traffic coming in from the outside. To select the appropriate location of the mobility parking hub, OD data distributed by Korea Transportation Database, which builds origin and destination tables and networks based on Seoul City Wall, is used. OD data was used to analyze passenger car traffic in the case study area to reduce the spatial scope. Blad et al. (2022) stated that low cost can increase the feasibility of a project. Therefore, in this analysis, to minimize the cost of building a mobility parking hub, existing public parking spaces are available to provide data on public parking lots. The public car park data is from "Seoul Public Parking Information" and consists of a total of 16,396 car parks. One of the main criteria to consider for the location of a facility for a P&R system is accessibility to public transportation (Ortega et al., 2021). For this analysis, data from Seoul subway lines 1 through 9 was used.
A walking distance of 400 m is commonly used to design transportation services to be reasonably accessible by public transportation (Foda and Osman, 2010). Thus, candidate public parking lots outside the 400 m range of metro stations are excluded. Finally, Ortega et al. (2021) mentioned that P&Rs are recommended to be located 5~6 km away from the city center. Moreover, locations within 5-6 km from the center of Seoul City Wall were considered for final selection. Due to the introduction of the mobility parking hub, it can be expected that some of the users who used to use passenger cars from the origin to the destination will use the mobility parking hub to transfer to public transportation in the middle. Ku et al. (2021) considered the uncertainty of the modal split due to the introduction of bicycle lanes and conducted a scenario analysis to evaluate the environmental effects Thus, in this study, multiple scenarios of predicted usage were set up to reflect this situation. The scenarios were set based on the size of the parking lot for each mobility parking hub. People who use the parking lot may park all day for commuting, while others may park for a short period for shopping and leisure. In other words, if there are many short-term parking users, the usage may be higher than the actual number of parking spaces. Since parking involves the concept of turning, where each vehicle exits and re-enters the car park, to estimate scenarios for parking turnover, mode shift to green transport via mobility parking hubs was set at 50%, 80%, 100%, 120%, and 150% of the daily demand for mobility parking hubs based on the existing car park size. Vehicle Kilometer Traveled (VKT) can be used as a metric to effectively derive traffic emissions within a city. VKT represents the number of kilometers a vehicle has travelled (Jung et al., 2017). At the mobility parking hub, divide the case study area into wards and calculate the average distance travelled by each ward. The VKT is then calculated by multiplying the demand from the mobility parking hub and the average distance travelled.

2.2 Effect of Air Pollution Reduction

The transportation sector contributes a significant share of carbon emissions, and many efforts are needed to reduce emissions from the transportation sector (Liu and Cirillo, 2016). Air pollutants typically include carbon dioxide (CO_2) hydrocarbons (HC) nitrogen oxides (NOx), and particulate matter (PM). According to data published by the European Environment Agency, a mode shift from private cars to public transportation would result in a reduction in pollutant emissions (Eea, 2009). If 10 % of the car users switch to public transportation, CO2 emissions are reduced by 94 % and, NOx, HC by 94.7 % compared to the previous year (Ong et al., 2011). Hence, based on this, this study aims to analyze how much air pollution emissions are reduced by switching from passenger cars to other transportation modes when a mobility parking hub is installed. To calculate the reduction in air pollution emissions due to the introduction of mobility parking hubs, an equation in the form of Eq(1), Eq(2), Eq(3) was used (Ku et al., 2022). To analyze air pollution emissions, this study uses an emission factor based on distance. The statistical program R studio was used to solve this equation to calculate the benefits of reduced air pollution.
The air pollution reduction formula (Eq(1), Eq(2), Eq(3)) due to the installation of the facility is calculated as the difference between the pollution amount in the scenario without and with the Mobility Parking Hub, which can be represented by $PS_{without}$ and PS_{with}. D and D' express the distance traveled by a road link, l, and a vehicle, k, within a given spatial range in this study, when traveling by auto. E is the pollution coefficient, which includes the condition when the vehicle, k, is traveling at a speed, v, on the link, l.

$$PS = PS_{without} - PS_{with} \quad (1)$$

$$PS_{without} = \sum_{v=1}^{V} \sum_{l=1}^{L} \sum_{k=1}^{K} D_{lk} E^{v}{}_{lk} \quad (2)$$

$$PS_{with} = \sum_{v=1}^{V} \sum_{l=1}^{L} \sum_{k=1}^{K} D'{}_{lk} E^{v}{}_{lk} \quad (3)$$

The establishment aims to calculate the air pollution emission savings that could be generated by the shift of one-directional flow from automobiles to multi-flow of public transportation. Using Eq(1), Eq(2), Eq(3), the emission indicators according to VKT were derived by dividing them by mode and speed. Table 1 shows the emission factors for each air pollutant by the speed of the auto. It uses values calculated by the Korea

Development Institute, an authorized research institute in South Korea (Lee et al., 2021). Lee and Min (2018) performed their analysis using an average traffic speed of 24.2 km/h in Seoul in 2016. For this study, an average driving speed in Seoul from 2017 to 2021 was considered and an air pollution emission factor of 25 km/h was used.

Table 1: Air pollution coefficient by pollutants by speed (Auto) (Lee et al., 2021)

Speed	CO (g/km)	NO_x (g/km)	HC (g/km)	PM (g/km) (Downtown)	CO_2 (g/km)
20	0.80	0.38	0.07	0.01	251.48
25	0.685	0.34	0.055	0.01	224.39
30	0.57	0.30	0.04	0.01	197.30

3. Results

This chapter summarizes the results produced through the above methodology. First, five existing public parking lots were selected as the locations of mobility parking hubs through various criteria presented above. After that, the amount of use of the selected mobility parking hub was expected for each scenario, and the air pollution reduction was calculated through the reduced VKT.

3.1 Seoul City Wall

The case of “Seoul City Wall”, consists of 8 wards in Jongno-gu, 5 wards in Jung-gu, and 2 wards in a part of Jung-gu. It is currently designated as a green transportation area by the Seoul Metropolitan Government and has implemented various eco-friendly policies to manage the traffic of polluting vehicles in the city, making it an important eco-friendly area in Seoul to improve the urban traffic environment and reduce fine dust. Therefore, in order to analyze the effects of this in Korea, which has not yet introduced the 15-minute city concept, the case of the introduction of the P&R system in Seoul City Wall, which has a similar concept to the 15-minute city, was analyzed. For this study, we used data on the location and number of parking spaces in 87 off-street parking lots to ensure sufficient parking among the 154 on-street and off-street public parking lots in Seoul. For subway stations, we used station-by-station location data for 17 lines in the metropolitan area.

3.2 Mobility Parking Hub Location Selection

In 2019, the number of vehicles on the road such as passenger cars, taxis, regular buses, and other buses in the Seoul City Wall range was 41.28 %. To reduce the influx of private cars into Seoul Castle, the traffic volume into Seoul Castle was analyzed and found to be highest in Gangnam-gu, Seongbuk-gu, Dongdaemun-gu, Seodaemun-gu, and Yongsan-gu. Therefore, this study aimed to deploy mobility parking hubs in the above five cities and districts. To do this, public parking lots in different parts of the city were identified as candidates for mobility parking hubs. Figure 3 depicts candidate public parking lots that serve as Mobility Parking Lots within their spatial scope, indicating that they can function as Mobility Hubs where conditions apply.

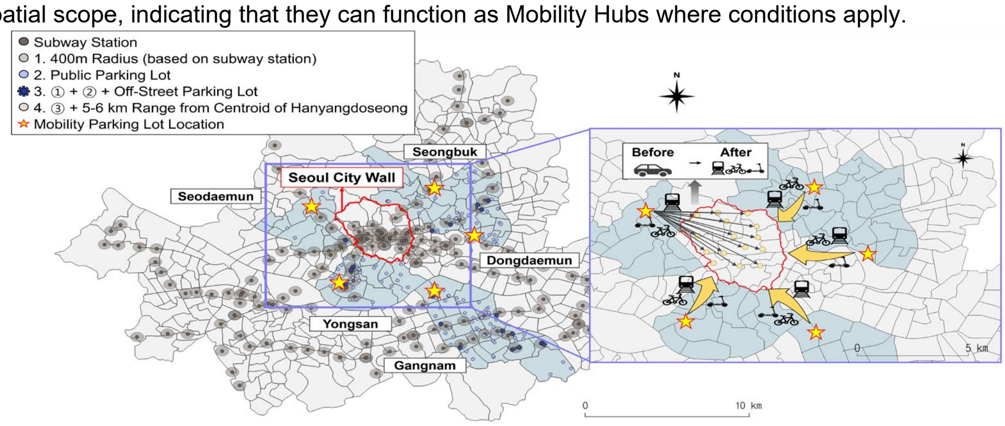

Figure 3: Selection of mobility parking hub

To reduce the scope, a total of 25 candidates were selected by removing public parking lots outside of a 400-meter radius of the metro station. Finally, for the final location selection, we used Arcgis to set the center point of the Seoul City Wall to be within 5-6 km of the location. And using the Arcgis program, the sphere of influence of a place was represented by a circle and a straight line distance was used from the center. The selected locations allow us to calculate the average travel distance from each mobility parking hub to the Seoul City Wall and the number of passenger vehicle trips saved through the usage of mobility parking hubs.

3.3 Reduction of VKT and environmental benefits

The daily usage of the selected mobility parking hubs was calculated for each scenario mentioned in the methodology chapter. In this study, the VKT savings were calculated by multiplying the average value of the distance travelled by car in each of the 15 wards of the Seoul City Wall by the demand for each scenario at each selected mobility parking base. For VKT, we used the average value of round-trip trips from mobility hubs in each region to each ward in Seoul City Wall. Since parking involves the concept of rotation, where each vehicle exits and re-enters the lot, we also looked at the 120 % and 150 % cases to estimate scenarios for the parking turnover rate. This resulted in a VKT savings of 2,451,754 km/y if 50 % of the users in each parking lot were transferred per day. And if 150 % of the parking spaces were transferred, the VKT savings would be 7,355,261 km/y. Table 2 shows the VKT savings by a municipality for each scenario.

Table 2: Mobility parking hub VKT savings by scenario

Division	Dongdaemun (km/y)	Gangnam (km/y)	Seodaemun (km/y)	Seongbuk (km/y)	Yongsan (km/y)	Total (km/y)
50 %	522,702	930,818	172,463	364,139	461,633	2,451,754
80 %	836,323	1,489,309	275,940	582,622	738,612	3,922,806
100 %	1,045,404	1,861,636	344,925	728,277	923,265	4,903,507
120 %	1,254,485	2,233,964	413,910	873,933	1,107,918	5,884,209
150 %	1,568,106	2,792,454	517,388	1,092,416	1,384,898	7,355,261

The reduced VKT values for each scenario calculated above and the air pollution emission factors per kilometer presented in the methodology can be used to calculate the air pollution savings from the construction of a mobility parking hub. Table 3 shows the emissions results by source for each scenario. In the scenarios with the lowest usage of 50 % of the parking spaces per day, 552.82 t/y is saved by switching from cars to green mobility, and 1,658.46 t/y by 150 %.

Table 3: Reduced emissions by air pollutant source

Division	$CO\ (t/y)$	$NO_x\ (t/y)$	$HC\ (t/y)$ (VOC)	$PM\ (t/y)$ (Downtown)	$CO_2\ (t/y)$	Total (t/y)
50 %	1.68	0.83	0.13	0.02	550.15	552.82
80 %	2.69	1.33	0.22	0.04	880.24	884.51
100 %	3.36	1.67	0.27	0.05	1,100.30	1,105.64
120 %	4.03	2.00	0.32	0.06	1,320.36	1,326.77
150 %	5.04	2.50	0.40	0.07	1,650.45	1,658.46

4. Conclusion

Global environmental issues such as global warming and pollution are of interest to the public. To solve these problems, various cities are introducing 15-min urban concepts, starting with Paris. Existing studies analyzed the methodology for the formation of a 15-min city. However, this study proposed a strategy that focused on movement between living areas, not movement within the living area. The study aimed to introduce mobility parking hubs, which combine the concepts of park-and-ride (P&R) and mobility hubs, with the goal of reducing carbon emissions from traveling between living areas. The mobility parking hub was selected for each city, county, and district based on traffic volume and subway accessibility. The analysis of air pollution emissions based on reduced vehicle kilometers traveled (VKT) showed that 552.82 t/y of air pollution emissions could be reduced annually. This reduction could be achieved by shifting only 50 % of the parking area from vehicles to public transportation or green mobility options. In the result of this study, the introduction of mobility parking hubs is an effective way to reduce air pollution at a low cost. When the urban concept is applied for the next 15-min to form a self-reliant living area, it is expected that the environmental effect of the 15-min city will be further amplified through the mobility parking hub when moving between living areas. In addition, this study can be used as a policy when selecting the location of the mobility parking hub in the future. In this study, the amount of mobility parking hub used was assumed through a scenario. If research is conducted to predict the demand caused by the actual mobility parking hub in the future, it will be possible to more realistically derive the amount of air pollution reduction that may occur due to the mobility parking hub. In addition, in this study, the appropriate location was selected based on accessibility to the subway and the location of the existing public parking lot. For future siting of mobility parking hubs, it would be more effective and efficient to consider additional conditions, such as the adoption of autonomous mobility.

Acknowledgments

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