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Research Article

A Study on Building a Sustainable Transportation System through the Introduction of Bicycle–Public Transport Transfer Stations

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Abstract: Bicycles play a vital role in sustainable urban mobility, yet they remain largely disconnected from public transport in the Seoul Metropolitan Area, limiting their potential to reduce carbon emissions, enhance mobility efficiency, and promote healthier lifestyles. (1) Background/Purpose: According to the Korea Transport Institute (2023), approximately 13.4 million South Koreans ride bicycles, with 3.3 million using them daily. Despite Seoul's public bike-sharing service Ddareungi recording a 298-fold growth since 2010, the absence of dedicated transfer stations and MaaS (Mobility as a Service) integration restricts their widespread adoption for commuting, particularly for distances over 9 km. Infrastructure gaps, hygiene concerns, and seamless connection deficiencies discourage regular bicycle use. This study analyzes the feasibility of establishing bicycle–public transport transfer stations in the Seoul Metropolitan Area and proposes a model for their integration with K-MaaS. (2) Study Design/Methodology/Approach: The study combines quantitative analysis (transport statistics, survey of 32 metropolitan residents conducted in February 2025, Chi-Square test, WTP analysis, CO_2 reduction estimation using 208 g/km as the benchmark, and WHO HEAT model application) with qualitative analysis (prior research review, international case studies, simulation scenario design). (3) Findings: Survey results show that 93.8% of respondents would more actively use personal mobility if hygiene, storage, and transfer inconveniences were minimized. Eco-mileage integration could increase personal mobility use intention by approximately 193%. The proposed transfer stations at Digital Media City, Yeouinaru, and Sports Complex stations are estimated to yield monthly CO_2 reductions of approximately 18,720 tons. A public–private partnership (PPP) operation model with monthly subscription fees of KRW 30,000–50,000 is identified as the most economically viable approach. (4) Originality/Value: This study establishes a new concept of bicycle transfer stations as multi-functional smart mobility hubs integrating MaaS, contributing to carbon reduction, public health improvement, and sustainable urban transport system construction.

Keywords: bicycle transfer station; MaaS; sustainable transport; public transport integration; carbon reduction; public health; K-MaaS; PPP model; personal mobility; metropolitan commuting

1. Introduction

1.1. Research Background

Historical Role and Background of Bicycles

Bicycles have long been utilized as a means of transportation, leisure activity, and health promotion. During periods when transport infrastructure was inadequate, bicycles were established as a primary mode of transport, and even after the spread of motorized vehicles and cars, they continued to serve as an essential means of transportation for economically vulnerable groups or those with limited access to public transit. However, in modern society, the purpose of bicycle use is gradually shifting from a simple means of transportation to an important tool for leisure and health promotion, and accordingly, the need to improve bicycle infrastructure and related services has emerged.

Seoul and the surrounding metropolitan area are experiencing extreme traffic congestion and environmental problems. In particular, road congestion during commuting hours causes serious socioeconomic costs, and the need to connect public transportation with personal mobility devices (PM) has been emphasized as a solution.

Since the opening of the Four Major Rivers bicycle path on October 8, 2011, the bicycle-using population has continuously grown. According to Korea Transport Institute statistics, as of December 2023, the national bicycle-using population amounts to approximately 13.4 million, of which approximately 3.3 million use bicycles at least once daily, and approximately 1.605 million metropolitan area residents use bicycles at least once per day. Seoul’s public bicycle service has seen the bicycle-using population rapidly increase over approximately 10 years since the start of the public bicycle service, with monthly usage of 120,000 cases representing a 298-fold increase since the service began (Seoul Research Institute Seoul Infographics No. 352, 2024). The reason for the increase in usage is that within Seoul, it has been recognized and established as a short-distance transport means.

Table 1. Bicycle-using population by frequency of use (unit: thousand persons). Source: Korea Transport Institute, 2017.

Region	Daily (≥1×/day)	Weekly (≥1×/week)	Monthly (≥1×/month)	Annual (≥1×/year)
National Total	3,326	10,222	13,353	14,044
Seoul	737	2,633	3,292	4,029
Busan	305	582	859	859
Daejeon	87	446	619	681
Incheon	207	392	622	622
Gwangju	132	372	444	444
Daegu	79	436	555	555
Ulsan	66	263	403	403
Gyeonggi-do	868	2,851	3,612	3,826
Gangwon-do	72	295	345	345
Chungcheongbuk-do	122	340	365	365
Chungcheongnam-do	110	341	456	456
Jeollabuk-do	128	289	422	422
Jeollanam-do	112	302	443	443
Gyeongsangbuk-do	174	482	583	583
Gyeongsangnam-do	193	504	746	850
Sejong	8	46	68	91
Jeju	34	126	149	149

Note: Data reflect national bicycle usage survey results.

Figure 1. *National bicycle usage rate. Source: Korea Transport Institute, 2017.*

These data show that bicycles have secured efficiency and accessibility as short-distance transport, and at the same time suggest that the potential for bicycle use in the metropolitan area is very large. However, the current use of bicycles in the metropolitan area depends on fragmented individual systems not connected to public transportation, making the construction of an integrated bicycle–public transport transfer system necessary.

Necessity of Bicycle Transfer Stations

Therefore, to address the main causes of metropolitan transport problems—increased car use causing traffic congestion and parking space shortages; inconvenience due to insufficient connection between public transportation and personal mobility; need for a sustainable transport system to reduce environmental pollution and carbon emissions; and insufficient safe and efficient movement routes due to inadequate pedestrian and bicycle infrastructure—constructing bicycle transfer stations that can effectively connect the growing bicycle-using population with public transportation (subway, bus, electric bicycle, and Ddareungi) services will be able to offer alternatives to these problems.

1.2. Research Necessity

With the recent introduction of MaaS (Mobility as a Service), smart mobility services through mobile linkage of public transportation have been continuously developing. MaaS is a concept that supports optimal route guidance, reservation/payment, and integrated settlement by integrating various means of transportation (bus, subway, taxi, shared mobility, etc.) on a single platform, targeting user-centered Door-to-Door Seamless mobility.

According to existing research, “the government announced the ‘Mobility Innovation Roadmap’ ('22.09), established an integrated management system for various mobility data, and announced the full-scale promotion of national K-MaaS” (Ministry of Land, Infrastructure and Transport, 2022.09.19). Also, “Research and development and pilot operation are being promoted led by local governments and private companies nationwide through the government’s Smart City Challenge project for user-customized services based on the integrated mobility (MaaS) platform, and it is scheduled to be developed and operated as a core mobility service for smart city national pilot cities (Sejong 5-1 Living Zone, Busan Eco Delta City)” (Kim Tae-hyeong et al., KOTI, 2023, p.12).

However, existing MaaS research and introduction cases mainly focus on connectivity between public transportation and shared mobility and travel convenience, and the connectivity with personal-owned mobility such as bicycles has not been a major subject of discussion. This means that while MaaS has concentrated on improving transportation convenience centered on integration with public transportation, research on bicycle use activation and connectivity is relatively insufficient. Existing research also “points out the limitation of major components and functions of MaaS platforms, and the limit of data linkage and sharing of various public and private mobility means, as reasons why MaaS services are not properly activated and established” (Kim Tae-hyeong et al., KOTI, 2023, p.3).

Therefore, this study aims to expand the advantages of MaaS to analyze the economic and environmental value of bicycle–public transport linkage, and to propose an efficient linkage model centered on transfer stations.

Bicycles can contribute to long-term transportation cost reduction due to low maintenance costs, and if a systematic movement system is established in connection with public transportation, commuting and school transportation costs can be reduced and movement convenience can be further improved. Existing research also analyzes that "if connectivity between various mobility means through MaaS is improved, not only will users' mobility and transportation accessibility improve, but efficient utilization of various means of transportation will also be possible" (Kim Tae-hyeong et al., KOTI, 2023, p.12).

Seoul has declared carbon neutrality (Net-Zero) by 2050, and reducing car use and expanding eco-friendly means of transport is essential to achieve this. An average of approximately 4.6 tons of CO_2 per vehicle is estimated to be emitted annually, and if bicycle use in connection with public transportation is activated, an annual reduction of tens of thousands of tons of carbon emissions can be expected. This is consistent with the construction of eco-friendly transportation systems emphasized in existing K-MaaS research.

Furthermore, if a bicycle transfer system is established, existing public transportation users will be able to transfer more conveniently, likely leading to an increase in bus and subway usage. This can be expected to alleviate traffic congestion during commuting hours in the long term and contribute to reducing public transportation congestion in the metropolitan area.

To further activate bicycle use in the metropolitan area and link it with public transportation, the construction of an integrated transfer service station is necessary, including shower and changing facilities to ensure convenience for commuters; storage and charging stations for electric bicycles and regular bicycles; maintenance and accessory shops for real-time bicycle repair; public bicycle and electric bicycle rental service provision; and additional facilities such as cafes and rest areas considering users' leisure and convenience needs.

1.3. Research Objectives and Methods

The study ultimately aims to analyze the impact of various mobility linkage measures provided by MaaS platforms on public health improvement and metropolitan transportation linkage. In particular, it examines the possibility of contributing to transportation environment improvement and achieving carbon neutrality goals by strengthening connectivity with public transportation centered on bicycle use cases. For this purpose, the study evaluates the feasibility of introducing public transport–bicycle transfer station services as an additional supplementary function of Korean-type MaaS services.

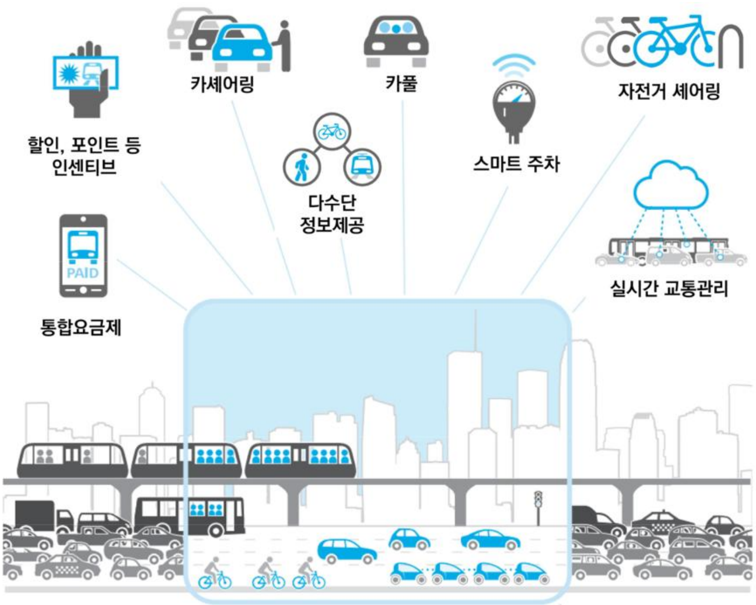
Quantitative and qualitative analyses are conducted in parallel to analyze changes in traffic volume and modal share, evaluate environmental effects (particularly CO_2 reduction effects) and health contribution (using the HEAT model), and investigate user satisfaction and inconvenience factors. Additionally, overseas case studies are conducted to derive implications applicable to Korean-type MaaS services.

Furthermore, various MaaS simulation scenarios are designed and analyzed to comprehensively review the impact of an integrated strategy connecting public transportation and bicycles on user behavior and the transport environment, and to propose practical policy and operational improvement directions.

2. Theoretical Background and Prior Research Review

2.1. MaaS (Mobility as a Service): Concept and Development Trends

Figure 2. *MaaS service concept diagram. Source: Seoul Institute Policy Report, Introduction of Seoul-type Integrated Transportation Services, 2019.09.09.*



자료: Tiffany Dovey Fishman, 2012, Digital Age Transportation: The Future of Urban Mobility, Deloltte의 내용을 재구성

Mobility as a Service (MaaS) is a concept that provides customized mobility services to users by offering various means of transportation on a single integrated digital platform. The core goal of MaaS is to combine individual means of transportation (public transit, shared mobility, bicycle, electric scooter, taxi, car-sharing, etc.) as a single service, enabling users to perform route planning, reservation, and payment on a single platform. MaaS provides a new paradigm that optimizes user-centered mobility experiences through an integrated approach, unlike the existing movement method of using individual transportation independently.

MaaS includes the following main features: Integrated service provision – integrated provision of public transportation, shared mobility, rental cars, bicycles, etc. on a single platform; Customized route planning – proposal of optimal travel routes reflecting real-time traffic information, weather, and personal preferences; One-stop payment system – monthly subscription fee or batch payment support rather than individual payments per transportation type; Sustainable transportation system – reducing carbon emissions and promoting use of public transportation and eco-friendly means of transport.

Looking at recent technological trends, MaaS platforms continue to develop through advances in artificial intelligence (AI), big data, Internet of Things (IoT), and 5G technology, including AI-based customized services analyzing user patterns and recommending optimal routes; real-time traffic information systems that optimize routes by analyzing waiting times and weather factors; and cloud-based MaaS infrastructure connecting various transportation and service providers in one network.

Payment systems and profit distribution models are also becoming more diversified, with payment methods expanding to monthly subscription models and Pay-as-you-go methods. Finland's MaaS service "Whim" provides a monthly subscription service allowing users to use various means of transportation unlimitedly for a fixed fee, while Japan and the Netherlands have introduced single payment systems that integrate payments for each mode of transportation to increase convenience.

Overseas examples include Finland's "Whim" providing all means of transportation integrated in a single app; Sweden's "Ubigo" providing customized transportation packages suited to user movement patterns; Japan's "JR East MaaS" providing various means of transportation linked to railway; and Singapore's "Zipster" as a MaaS ecosystem created through government-private cooperation. Korea is also promoting smart city pilot projects utilizing MaaS platforms and expanding MaaS service introduction in Seoul and the metropolitan area.

2.2. Prior Research Review and Differentiation

Existing MaaS service research in Korea has pursued independent improvement measures through data collection by developing and constructing its own models by local governments and cities through pilot service operation, but the service model itself has not significantly contributed to inducing changes in service users' usage patterns.

This study aims to expand fundamental motivation that can more substantially increase health promotion and public transportation usage by extending the usage pattern of personal mobility (bicycles, etc.) from leisure to commuting form, in addition to convenience of connection with existing means of transportation such as buses, subways, kick-scooters, and shared bicycles.

In particular, this study addresses the theft risk of expensive personal mobility devices, equipment malfunction during frequent travel, inappropriate attire for commuting and hygiene limitations, and difficulty of convenient transfer to subway/bus with quick access to workplaces in Seoul—topics not reviewed in prior research—and will greatly contribute to national health and carbon neutrality through MaaS service improvement and increased public transportation usage.

Table 2. Differentiation from prior and other research. Source: Korea Transport Institute, 2023.

No.	Study Title / Author / Year	Research Objective	Method	Key Content
1	Seoul-type Integrated Transport Service Introduction / Yoon Hyeok-ryeol (Seoul Institute, 2018)	Propose differentiated integrated transport service for Seoul	Domestic/foreign lit. review; Seoul status diagnosis; citizen survey; expert consultation	Seoul MaaS basic research; MaaS introduction plan for Seoul
2	Ulsan-type MaaS Introduction / Park Jin-kyung (Korea Research Institute for Local Administration, 2021)	Propose Ulsan-type MaaS introduction for regional issues	Domestic/foreign lit. review; Ulsan diagnosis; expert consultation	Overseas MaaS cases; domestic MaaS trends; Ulsan-type MaaS introduction plan
3	Integrated Payment Technology for Smart Mobility / Bae Jung-cheol (KOTSA, 2018)	Develop integrated payment technology for Jeju Island	Lit. review; payment system framework; Jeju pilot; expert consultation	Device-based payment tech; package-type integrated settlement platform
4	Smart Mobility & Parking Sharing Technology / Kim Tae-hyeong (KOTI, 2018)	Develop integrated smart mobility tech for Daegu	Lit. review; expert consultation; Daegu mobility analysis; tech development; citizen pilot	Scenario development; real-time traffic data; big-data optimal route algorithm
5	K-MaaS Strategy & Activation (Kim Tae-hyeong et al., KOTI, 2023)	Propose K-MaaS promotion strategy and activation measures	Domestic/foreign cases; MaaS expert committee; inter-ministry cooperation	Mobility data linkage; MaaS platform guidelines; governance; business model
6 (This Study)	Feasibility of MaaS-based Bicycle Transfer Center Service (This study, 2025)	Examine feasibility of bicycle transfer center within K-MaaS	Domestic/foreign cases; metropolitan transport statistics; survey (Feb 2025)	Transfer center necessity & criteria; business model–MaaS integration improvement

3. Research Methodology

3.1. Research Method

The purpose is to comprehensively analyze the impact of the public transport–bicycle transfer connection system on changes in movement behavior, environmental impact, health contribution, and policy effectiveness by analyzing prior research data and statistical data.

This study conducts quantitative analysis (survey, traffic pattern data analysis, environmental and health impact assessment, etc.) and qualitative analysis (in-depth interview, policy case study, simulation-based policy evaluation) in parallel.

- **Quantitative Analysis:** Analyzing the quantity of public transportation and bicycle-linked users.
- **Qualitative Analysis:** Deriving policy implications through the opinions of major stakeholders when introducing policies and analysis of overseas cases.
- **Simulation Analysis:** Setting various scenarios to evaluate the impact of public transport–bicycle linkage on traffic volume, carbon emission reduction, and user benefits, and researching the necessity, appropriate location, business feasibility, and MaaS linkage methods of bicycle transfer stations.

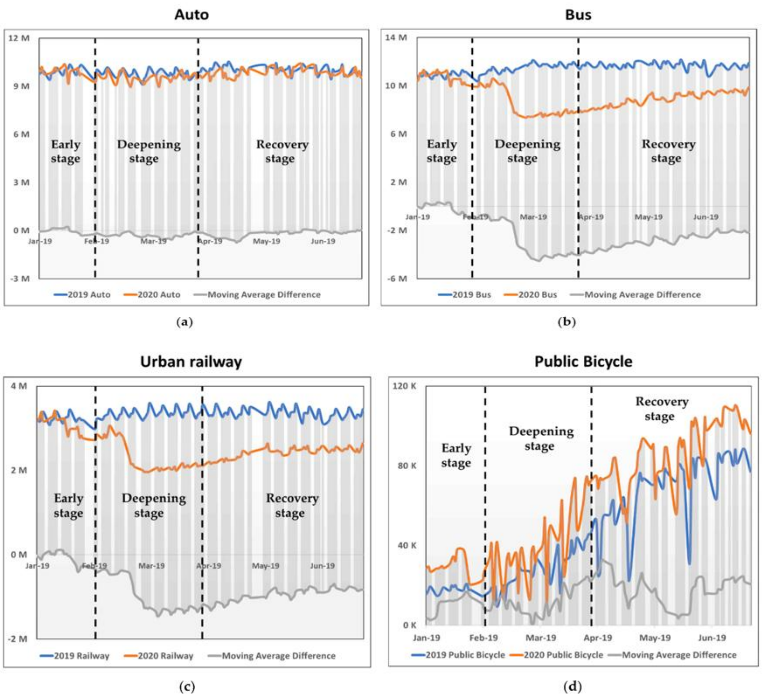
3.2. Data Collection and Analysis

This study uses analysis data from existing research materials and statistical data from a survey conducted in February 2025 to explore measures for commuting patterns of metropolitan area users, utilization of personal mobility, necessity and improvement of transfer parking lots, and improvement measures for increased use of personal mobility, and to research methods to increase public transportation usage through the necessity of transfer centers and improved connectivity with public transportation, and further contribute to carbon reduction.

Analysis of Metropolitan Commuting Patterns Based on Data

According to 2020 National Statistical Office data, the commuting/school population from Gyeonggi Province was counted at 1.25 million, and recent statistics compiled by the Gyeonggi Research Institute show 2 million trips per day (including commuting/school and others) between Seoul, with car usage ratio of 54.7% and public transportation 45.3% (Gu Dong-gyun et al., 2023). This study result was based on a survey targeting only car and public transportation users, so data on pedestrians, bicycles, and other mobility (electric bicycles, kick-scooters, etc.) appears insufficient and should be supplemented by other data.

Figure 3. *Changes in passengers' travel behavior due to COVID-19. Source: Ku, D.G., Um, J.S., Byonk Y.J., & Lee, S.J. (2021). "Changes in passengers' travel behavior due to COVID-19." Sustainability, 13(14), 7974.*



One meaningful statistic visible in this figure is that public bicycle usage rates increased even during and after the COVID-19 era. Such statistical data show that users' perceptions regarding public bicycles are changing, indicating the possibility of public bicycles or personally owned bicycles as means of transportation.

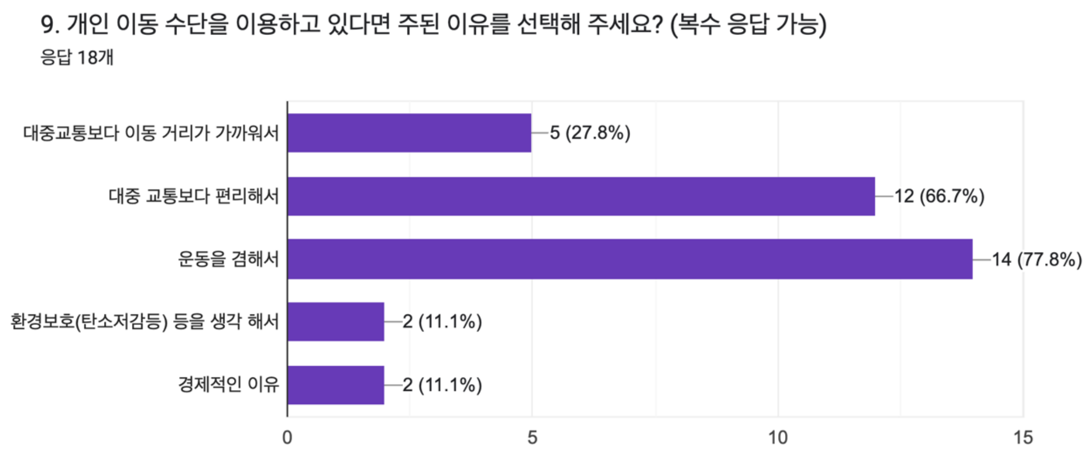
Additionally, in November 2017, Seoul conducted a survey of 886 members of the internet cafe ‘People Who Commute by Bicycle’, with the most frequently cited reasons why bicycle commuting is difficult being lack of changing/shower facilities (66%) and bicycle storage problems (64%) (Gwanak FM, 2018.03). Based on these results, Seoul has been piloting free changing/shower facilities and a bicycle storage in the Digital Sports Field in Geumcheon-gu, the area with the highest commuting floating population according to big data (Seoul Metropolitan Government, 2018.02.12).

Survey-Based Commuting Analysis

A survey of 32 persons, both male and female aged from their teens to 50s, investigated personal mobility (bicycle, kick-scooter, electric bicycle, etc.) ownership and current commuting usage status.

According to the survey, 18 of 32 residents in Seoul and Gyeonggi Province were found to be using personal mobility devices, with 14 respondents (77.8%) stating they use them combined with exercise and 12 respondents (66.7%) stating they use them because it is more convenient than public transportation.

Figure 4. *Survey on purpose of personal mobility use. Source: Researcher, 2025.*



Analysis of Metropolitan Bicycle Usage Data

There are two main reasons bicycles attract attention: first, they are an environmental and energy-efficient means capable of exceeding 15 km/h with only about 6% of the kinetic energy compared to automobiles (Kim Yong-jin et al., 2008); and second, bicycles have sufficient potential for activation as a latent transportation mode easily used in daily life (Kim Geon-wook et al., 2010).

Recently, Seoul’s public bicycle service Ddareungi has recorded daily usage of 120,000 cases as of 2023 since its introduction in 2010 (Seoul public bicycle usage status), representing a 298-fold increase from the beginning. This is a case demonstrating that bicycles have secured convenience and accessibility as short-distance transportation. However, metropolitan bicycle use depends on systems operated by individual local governments and companies, and new technology mobility such as electric bicycles is not integrated with public transportation.

Table 3. Distribution of trip purposes for bicycle travel in Seoul. Source: Seoul Research Institute, 2012.

Purpose	2006 Trips	2006 Share	2006 (excl.return)	2006 Seoul total	2010 Trips	2010 Share	2010 (excl.return)	2010 Seoul total
Return home	148,303	41.1%	—	—	219,006	45.1%	—	—
Commuting	55,556	15.4%	26.1%	31.1%	79,250	16.3%	29.8%	32.3%
School	27,828	7.7%	13.1%	12.2%	41,778	8.6%	15.7%	13.2%

Purpose	2006 Trips	2006 Share	2006 (excl.return)	2006 Seoul total	2010 Trips	2010 Share	2010 (excl.return)	2010 Seoul total
Academy	37,390	10.4%	17.6%	6.7%	34,493	7.1%	13.0%	6.2%
Business	18,528	5.1%	8.7%	17.8%	14,877	3.1%	5.6%	17.1%
Shopping	16,073	4.4%	7.6%	6.7%	20,514	4.2%	7.7%	6.6%
Other	57,310	15.9%	26.9%	25.5%	75,270	15.5%	28.3%	24.6%
Total	360,988	100%	—	—	485,188	100%	—	—
Sub-total (excl. return)	212,685	—	100%	100%	266,182	—	100%	100%

Note: Analysis targets bicycle trips by single mode. Trip volume is based on Seoul city origin. Source: Metropolitan Transportation Authority, 2006 Metropolitan Household Travel Survey; O/D Total and Future Demand Forecast Joint Survey, 2012.

Seoul’s 2010 bicycle movement data showed a total traffic volume of 485,188 cases, with commuting-related traffic volume being the highest at 79,250 cases. This accounts for 16.3% of the total composition ratio and 32.3% of Seoul’s total bicycle traffic volume. Therefore, bicycles continue to prove their necessity as an alternative means of transportation to cars.

Status of Bicycle–Subway Transfer Parking

According to 2023 Ministry of the Interior and Safety data, the number of bicycle parking lots in Seoul is 4,619 and in Gyeonggi Province 8,691, with Seoul’s bicycle parking capacity counted at 123,529 units and Gyeonggi Province’s at 222,880 units. In addition, at each subway station, some have bicycle parking lots installed separately in a self-propelled or mechanical style to prevent theft of personal bicycles.

Table 4. Status of self-propelled open-type bicycle storage facilities. Unit: million KRW. Source: Lee Pil-shin, Oh Seok-sun (2011), “Methods for Installing Bicycle Storage Facilities in Stations.”

District	Location	Capacity	Budget (million KRW)	Cost/bike (million KRW)	Notes
Guro-gu	Sindorim Station	400	525	1.4	Free
Gangbuk-gu	Suyu Station	700	3,300	4.4	Paid

Table 5. Status of mechanical closed-type bicycle storage facilities. Unit: million KRW. Source: Lee Pil-shin, Oh Seok-sun (2011), “Methods for Installing Bicycle Storage Facilities in Stations.”

District	Location	Capacity	Budget (million KRW)	Cost/bike (million KRW)	Notes
Seongbuk-gu	Seokgye Station	20	135	6	Paid
Songpa-gu	Seongnae Station	18	120	6.5	
	Sports Complex Station	20	Not disclosed		
Yeongdeungpo-gu	Yeongdeungpo-gu Office	120	780	65	Free
Yongsan-gu	Samgakji Station	30	Not disclosed		Paid
Gangnam-gu	Samseong Station	60			

District	Location	Capacity	Budget (million KRW)	Cost/bike (million KRW)	Notes
	Hagwaryul Station	30			
	Suseo Station	60			

Although mechanical bicycle parking facilities were additionally installed at six more stations after 2011, two of them were closed, and the others have low utilization rates, annual maintenance costs exceeding 10 million KRW, and frequent breakdowns, leaving them as eyesores. The four still in operation also have a usage rate as low as 1% (KBS News, 2023.09.15).

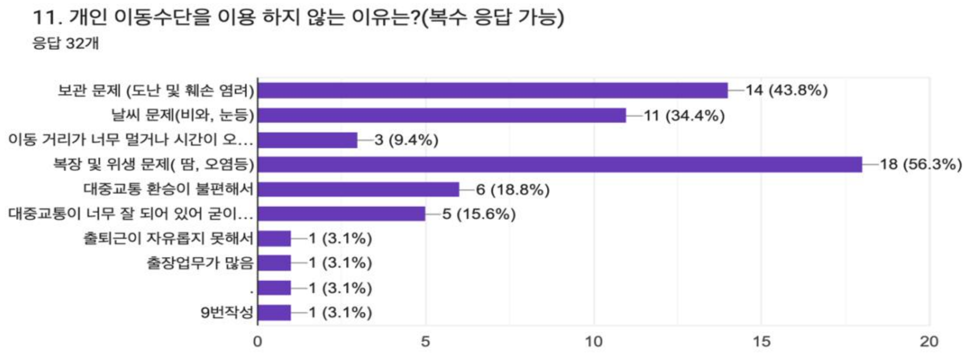
Current Problems with Bicycle–Subway Transfer

Although closed bicycle parking lots were established at great expense to address the increasing theft problems of high-end bicycles, utilization rates have continued to decline due to various factors. The main causes are as follows:

First, due to the upgrading of ordinary bicycles, users are unwilling to risk damage from mechanical parking at currently operated station parking lots. Second, tire and handlebar sizes differ for each bicycle, causing situations where bicycles do not fit precisely in racks, requiring awkward positioning that takes more time when removing them and may damage the bicycle. Third, cyclists who sweat and accumulate dust during summer travel find it difficult to address the discomfort caused to others when boarding public transportation such as subways (Coppola et al., 2025: “Willingness to use increases by 40% when shower facilities and electric bicycle charging stations are installed at bicycle transfer stations”). Fourth, bicycle storage takes more time for subway boarding, as the process of storing, paying fees, and moving from the parking lot is burdensome (Butler et al., 2021: “If the distance between subway station and bicycle parking lot exceeds 100m, usage rate decreases by 25%”). Fifth, alternative means have increased significantly, greatly reducing bicycle usage rates (Qiao et al., 2022: “After the introduction of electric kick-scooters and shared bicycles, personal bicycle usage at subway transfer parking lots decreased by 30%”). Sixth, there is the burden of paid parking fees; despite bicycles having no transportation costs, using closed parking lots for security adds an extra cost burden, and users’ willingness to pay additional parking fees is very low (Narayanan et al., 2023: “If public bicycles are provided free or at low cost, personal bicycle usage decreases by 20–35%”). Finally, psychological factors and usage habits: people generally prefer to travel to their destination by a single mode rather than combining bicycle–subway–walking, and those who have experienced inconvenience during transfers tend more strongly not to use them (Le Pira et al., 2021: “As the number of transfer stages increases, the willingness to use transfer services decreases by up to 45%”).

Furthermore, according to the researcher’s survey, the largest element of problems or inconvenience in existing bicycle–subway transfers was “clothing and hygiene issues (sweat, contamination)” at 56.3% (18 respondents), followed by “storage problems (theft/damage concerns)” at 43.8% (14 respondents), “weather problems” at 34.4% (11 respondents), and “inconvenient public transport transfers” at 18.8% (6 respondents). The four main factors cause inconvenience and prevent use of personal mobility, with hygiene issues being the biggest obstacle.

Figure 5. *Main reasons for not using personal mobility. Source: Researcher, 2025 survey.*



4. Bicycle Transfer Station Model Development

4.1. Concept and Functions of Transfer Stations

A Bicycle–Public Transport Transfer Station is a transportation infrastructure that serves as a hub effectively connecting personal mobility (PM) with public transportation. These stations are evaluated as core elements in constructing a sustainable urban transportation system, targeting the enhancement of commuting/school convenience for bicycle users, improvement of transportation accessibility, and reduction of carbon emissions.

However, existing bicycle transfer facilities, by concentrating solely on providing physical space without sufficiently reflecting users' requirements, are causing actual decline in utilization rates and operational inefficiency. Accordingly, this study closely analyzes the limitations and improvement directions of existing transfer facilities to propose a more effective transfer station model.

According to the researcher's survey, the main reason people who own personal mobility do not use it for commuting is inconvenience (transfers, hygiene, storage, weather). If the main inconveniences are resolved, personal mobility can be used more actively. 93.8% (30 respondents) answered that they would use their own mobility more actively if inconveniences were minimized. Therefore, the role and necessity of transfer centers in increasing personal mobility utilization is clear.

Figure 6. *Willingness to use mobility when hygiene, transfer, storage inconveniences are minimized. Source: Researcher, 2025.*

4.2. Core Functions and Improvement Directions of Transfer Stations

To overcome the limitations of the existing bicycle transfer system that only provided bicycle parking and to build an efficient bicycle–public transport linkage system, a transfer station model including the following improved functions is needed. Additionally, convenient services that can be shared with runners who are recently becoming popular would create good synergy.

Introduction of Enhanced Security Bicycle Storage System

Smart locks (CCTV-integrated type) are introduced for theft prevention, and dedicated storage facilities for electric bicycle and personal mobility (PM) users are established. A function for real-time storage availability confirmation linked with the MaaS app is added.

Expansion of Amenities

The expansion of amenities should provide several services differentiated from existing services: first, installation of shower rooms and changing rooms to provide convenience after long-distance travel; second, securing electric bicycle and electric kick-scooter charging stations; third, operation of bicycle repair and maintenance shops with resident Mechanics capable of repairing professional high-end bicycles and selling bicycle accessories (high-end brands, general brands) suited to demand; fourth, cafe and convenience store operation selling energy bars, coffee, beverages, energy drinks, health drinks, and energy gels for more professional athletes, with Wi-Fi provision; and finally, laundry service for workout clothes and commute attire (e.g., shirts) so cyclists can shower after morning exercise, change into laundered clothes, and transfer to public transportation, and change into workout clothes for the bicycle or running commute home.

Accessibility Improvement

Transfer stations are placed near exits to shorten public transportation transfer time, supplemented by bicycle-friendly facilities such as elevators and ramps.

MaaS-Based Linkage Service Provision

An integrated fare system combining bicycles, electric kick-scooters, shared bicycles, and public transportation is introduced (membership, monthly, non-member rates), and real-time route guidance and transfer station reservation functions through MaaS applications are added.

Transition to Eco-Friendly Transportation Hub

Solar and eco-friendly energy charging stations are introduced for transition to an eco-friendly hub, and public bicycle, electric bicycle, and shared mobility services are expanded.

4.3. Analysis of Optimal Operation Methods

The optimal operation method of the transfer station must be designed considering efficiency, sustainability, user convenience, and economic feasibility. For this, it is important to include elements such as public–private partnership (PPP) models, MaaS linkage, smart operation systems, and revenue model optimization.

Types of Business Operation Models

Transfer station operation can be categorized into three types: public operation, private operation, and public–private partnership (PPP) models.

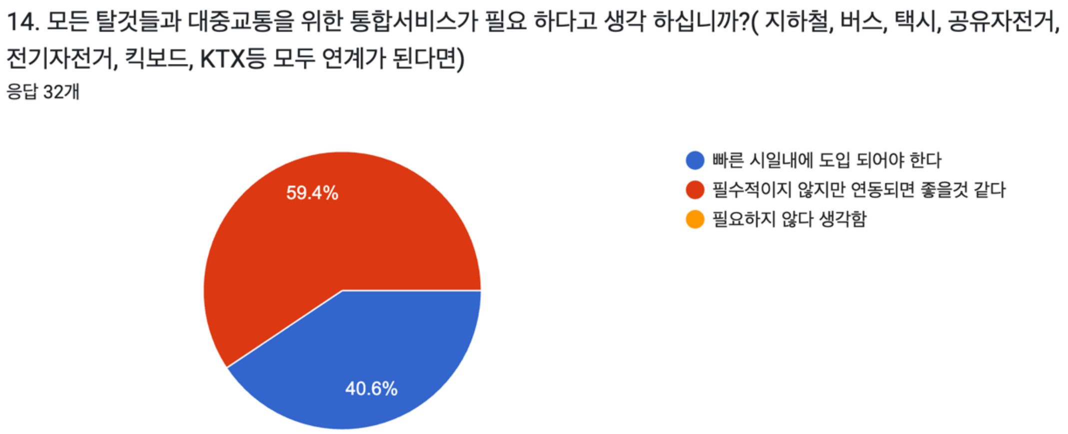
- **Public Operation Model (Government-Operated Model):** The government or local government directly operates the transfer station, which has strong public nature and low user fees. However, high dependence on government budget carries operational risk due to budget cuts and policy changes.
- **Private Operation Model (Privately-Operated Model):** A private company directly operates with a self-sustaining revenue model that has high operational efficiency (Yu Zhou, 2024) and allows immediate technological and service improvements, but service fees may become expensive and there is high potential for conflict with public purposes. The domestic Minimum Cost support (MCC) model can minimize private operator losses.
- **Public–Private Partnership (PPP) Model:** Government and private companies cooperate in operation (e.g., government builds infrastructure, private company operates), providing the advantage of securing both public nature and profitability simultaneously (success case: France’s Vélib’ Paris–JCDecaux cooperation model). However, contract condition adjustments and stakeholder coordination are required, and service quality may change upon contract renewal.

MaaS Linkage Service Operation

Utilizing the MaaS platform enables integrated operation of bicycle transfer stations with public transportation, shared bicycles, electric kick-scooters, etc. in a single system.

Survey results showed that 13 respondents (40.6%) said fast MaaS service introduction is necessary, and the remaining 19 respondents (59.4%) said it would be good to have it connected even if not essential; no respondents said it was unnecessary. Therefore, respondents recognize that services capable of smoothly linking and integrating various public transportation and personal mobility are necessary.

Figure 7. *Necessity of public transport linkage service. Source: Researcher, 2025 survey.*

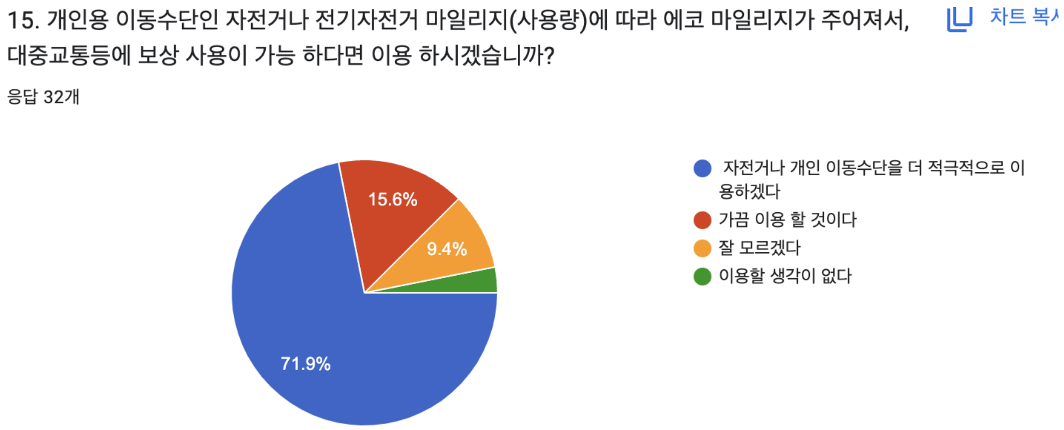


Through MaaS service integration, the expected effects include: an integrated payment system enabling payment for all mobility on a single app; real-time movement route guidance providing optimal bicycle and public transportation transfer routes; and reservation and availability confirmation for mobility (Ddareungi, kick-scooter, electric bicycle) to shorten user waiting time. Therefore, transportation services must be connected like a mobile phone network to be convenient (Donald, 2024).

Linkage with commercial mobile software and data is also necessary. If Korean-type MaaS services take hold, API account linkage with internationally popular apps such as Strava, Mywhoosh, Garmin, Runday, and Nike Run Club through exercise logs and movement mileage confirmation would enable Eco Mileage services on the MaaS platform, providing benefits for public transportation transfers. Compatibility with sport devices (Garmin, Apple Watch, Mi-Watch, Samsung Watch, Suunto, etc.) via Bluetooth + ANT+ is also required.

According to the survey, if movement (eco) mileage is applied, 71.9% (23 respondents) said they would use personal mobility more actively, and 15.6% (5 respondents) said they would use it occasionally. Previously, 13 respondents commuted by personal mobility, but with eco-mileage usable as reward for public transportation, 25 respondents said they would "actively use" it, showing that eco-mileage benefits can increase personal mobility (bicycle, kick-scooter, electric bicycle, etc.) usage intention by approximately 193%.

Figure 8. *Personal mobility use according to movement (eco) mileage reward use. Source: Researcher, 2025 survey.*



4.4. Location of Transfer Stations

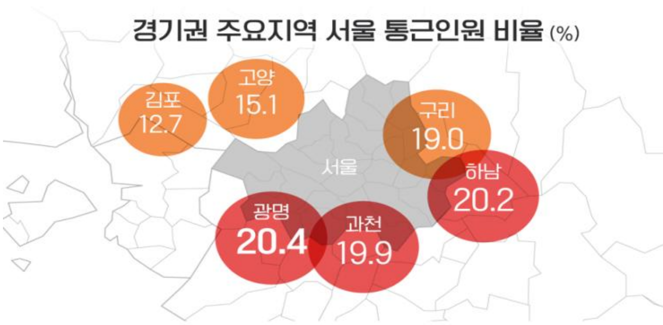
Analysis of Commuting/School Population by Region

According to 2020 National Statistical Office data (Housing and Population Census), the commuting/school population from Gyeonggi Province to Seoul is 1.25 million, with the highest population (excluding Incheon) in Goyang-si (approximately 163,000). Seongnam-si had approximately 128,000, Bucheon-si approximately 105,000, and Namyangju-si approximately 102,000, showing that residents of Seoul-adjacent areas commute/attend school in Seoul in large numbers.

Figure 9. *Metropolitan area–Seoul commuting/school population. Source: National Statistical Office 2020 data; RealToday/Newsis, 2023.11.*

In terms of population ratio, Gwangmyeong showed the highest at 20.4%, being adjacent to Geumcheon-gu, Guro-gu, and Mokdong where workplaces and academy districts are close to Seoul. Hanam had 20.2% of its residential population commuting/attending school in Seoul, mainly toward Jamsil and Songpa. For Gwangmyeong, bicycle paths are connected to adjacent areas, and for Hanam and Gwacheon, which are farther from Seoul (over 15 km in some areas), the Yangjae stream bicycle path can also be used.

Figure 10. *Metropolitan area–Seoul commuting/school population ratio. Source: National Statistical Office 2020 data; KBS News, 2023.10.31.*



Analysis Centered on Work Regions

According to 2024 National Statistical Office data, among 12.2 million nationwide commuters with commuting records (based on three mobile carriers), 20% commute from Gyeonggi Province to Seoul, and the proportion working in Gangnam recorded the highest at 6% (National Statistical Office press release, 2024). Therefore, the establishment of a transfer center in the Gangnam area is necessary.

Three Candidate Transfer Center Locations

From multiple possible locations, three were selected: the Goyang area adjacent to the north of Seoul; the Samseong/Songpa area where commuting populations are highest; and the Yeouido area connecting Gangseo and Anyang.

Digital Media City (DMC) Station

With approximately 163,000 Goyang-si residents commuting/attending school in Seoul, the appropriate planned location for commuting population dispersal and a bicycle transfer center is Digital Media City Station, at a straight-line distance of 14.6 km from Ilsan-gu's Lake Park, with easy connection to Gyeongui-Jungang Line and Line 6 subway.

Figure 11. *Digital Media City Station. Source: Naver Maps.*

Yeouinaru Station

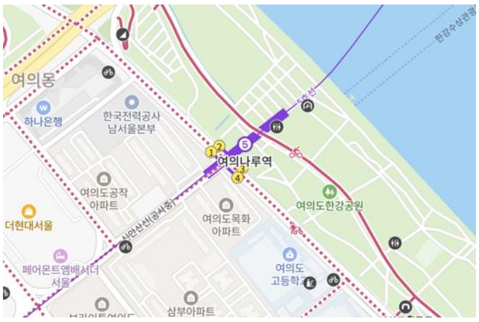
Bicycle paths are connected as far as Gwangmyeong, Siheung, and Anyang, and statistics show the highest number of Ddareungi rentals here from 2010 to 2015, making it the best position for transferring to Line 5 or switching to Ddareungi after personal maintenance by bicycle or running. While Songpa-gu became the top rental station in 2024, it is adjacent to Gangseo-gu and the Mapo area, or applicable for Goyang-Ilsan residents commuting directly.

Table 6. Ddareungi rental ranking. Source: Seoul Facilities Corporation, Public Bicycle Comprehensive Status, 2024.

Period	1st Rank	2nd Rank	3rd Rank
Nov 2010 – Apr 2015	Yeongdeungpo-gu (Yeouido) – 26 stations	Mapo-gu (Sangam-dong) – 18 stations	—
2016	Mapo-gu (76 stations)	Yeongdeungpo-gu (70	Seongdong-gu, Jongno-gu

Period	1st Rank	2nd Rank	3rd Rank
		stations)	(50 stations each)
2024	Songpa-gu (217 stations)	Gangseo-gu (192 stations)	Gangnam-gu (174 stations)

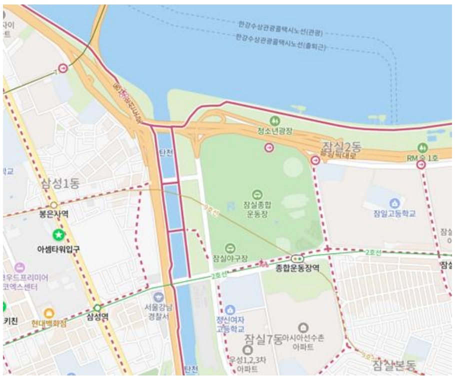
Figure 12. *Yeouinaru Station. Source: Naver Maps.*



Jamsil / Sports Complex Station

Among the highest working population in Seoul (6%, approximately 73,000 people), the location with Line 2 transfer capability and adjacent to the Han River bicycle road is Sports Complex Station, a complex of stadiums and various sports complexes, making it the optimal condition for creating a transfer center as a complex sports culture space with minimal facility improvement.

Figure 13. *Sports Complex Station. Source: Naver Maps.*

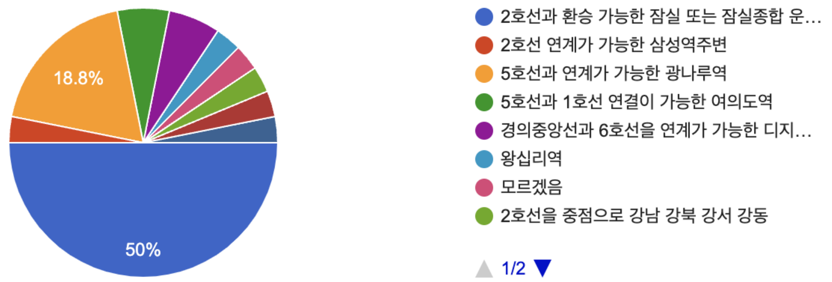


Survey Respondents' Transfer Center Location Selection

Of 32 total survey respondents, 16 (50%) selected the vicinity of Jamsil Station or Jamsil Sports Complex with Line 2 transfer capability, 6 respondents (18.8%) selected Gwangnaru Station with Line 5 connection, and 2 respondents each (6.3%) selected Yeouinaru Station and Digital Media City Station.

Comparing this study's survey with existing research (National Statistical Office, 2024), it aligned with existing research data showing many workers in Gangnam, confirming the highest location demand for a transfer center connectable to Line 2 in the Jamsil–Samseong section. Minor opinions included Pangyo Station and Wangsimni Station, each at 3.1%.

Figure 14. *Preferred locations for transfer center. Source: Researcher, 2025 survey.*



4.5. Operating Fees and Methods

WTP Analysis and Payment Willingness

For economically sustainable operation of bicycle transfer stations, it is necessary to identify the price range at which Koreans are willing to pay (Willingness to Pay, WTP) for MaaS and transfer services.

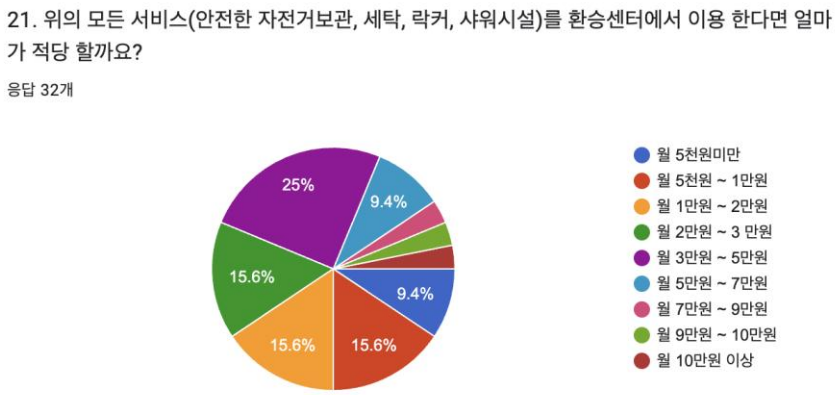
Willingness to Pay for Services

MaaS service usage willingness (WTU) (Kim S., 2021): Research target of 173 Seoul and metropolitan area residents randomly sampled in December 2018, using web-based survey and statistical analysis, found approximately 65% of Seoul residents expressed willingness to use MaaS if provided, with 72% of commuter-time users willing to pay if more convenient than existing transportation.

Willingness to pay for MaaS packages (WTP) (Kim S., 2021): Basic type (bus + subway) MaaS package is payable at KRW 5,000–7,000/month; public transport + shared bicycle package at KRW 10,000–15,000/month; public transport + shared bicycle + electric kick-scooter package at KRW 20,000–25,000/month.

Respondents' WTP from this study's survey (Researcher, 2025): 8 respondents (25%) stated KRW 30,000–50,000/month is appropriate for bicycle storage, laundry, locker, and shower facility use; 5 respondents (15.6%) stated KRW 20,000–30,000/month is appropriate.

Figure 15. *Monthly WTP for transfer center service. Source: Researcher, 2025.*



Based on survey and statistical analysis, the most appropriate price is KRW 30,000–50,000/month for combined services of basic public transportation + shared bicycle + shower facilities, parking, and locker use. For those only using shower facilities and lockers additionally, WTP for extra cost is KRW 2,000–3,000, as answered by 34.4% of respondents (11 persons) (Researcher, 2025).

4.6. Environmental and Economic Effect Analysis

Carbon Emission Reduction Effect

The amount of greenhouse gas emissions reduced by Ddareungi use as disclosed by Seoul City is announced as an annual average of 962 tons (Seoul City, 2024). The greenhouse gas reduction per bicycle compared to automobiles is 208g/km. If the bicycle usage volume increases by 1.2% of the Gyeonggi Province commuting population (Im Young-tae et al., KRIHS, 2008) due to transfer center construction, this amounts to 150,000 persons (Gyeonggi–Seoul commuting population: 1.25 million/day), and assuming an average round-trip distance to the transfer center of 30 km (one-way 15 km):

Monthly carbon emission reduction estimate: 150,000 persons × 6.24 kg/day × 20 days = 18,720 tons

Carbon credit conversion: 18,720 tons × KRW 7,020/ton (August 2023 basis) = approximately KRW 131.4 million

That is, monthly carbon emission reductions of 18,720 tons can be achieved, convertible to approximately KRW 131.4 million in carbon credit trading. This estimate uses a simple calculation; with more actual users, contribution to carbon reduction will be even greater.

Economic Effect on Public Health Promotion

Personal economic effect: An economic benefit of approximately KRW 3.5 million is generated when one citizen commutes 30 km round trip by bicycle for 100 days (Green Post Korea, 2020), including health promotion, CO_2 emission reduction, and reduction of congestion costs from decreased traffic volume.

Social economic effect: Denmark estimates a social-economic effect of 765 million euros (approximately KRW 1 trillion) from bicycle expressways (Green Post Korea, 2020), including CO_2 emission reduction, resident health improvement, reduced sick days, and traffic congestion resolution.

National economic effect: If South Korea's bicycle transport share increases from 2% to 10%, an economic effect of approximately KRW 20 trillion is expected (Green Post Korea, 2020). Energy savings: bicycles save 52 times more energy than regular passenger cars and 3 times more energy than walking.

5. Conclusions

5.1. Summary of Research Results

This study aimed to analyze the relationship between ownership of personal mobility (bicycles, electric bicycles, kick-scooters, etc.) in the metropolitan area and the main reasons for using mobility. A Chi-Square Test was used to examine the independence between the two variables and analyze the response pattern of respondents.

Cross-tabulation analysis was performed to evaluate the association between personal mobility ownership (non-ownership: 0, ownership: 1) and reasons for mobility use. Each response category's observed and expected frequencies were compared to evaluate statistical significance.

Figure 16. *Reasons for use by personal mobility owners. Source: Researcher, 2025 survey, Jamovi.*

Contingency Tables

Contingency Tables

		사용이유									
이동수단보유 여부		대중교통보다 편리해서	대중 교통보다 편리해서, 운동을 겸해서	대중교통보다 이동 거리가 가까워서	대중교통보다 이동 거리가 가까워서, 대중교통보다 편리해서, 운동을 겸해서	대중교통보다 이동 거리가 가까워서, 대중 교통보다 편리해서, 운동을 겸해서, 환경보호(탄소저감등) 등을 생각 해서	대중교통보다 이동 거리가 가까워서, 운동을 겸해서	운동을 겸해서	운동을 겸해서, 경제적인 이유	운동을 겸해서, 환경보호(탄소저감등) 등을 생각 해서, 경제적인 이유	**Total**
2	Observed	0	0	1	0	0	1	0	0	0	2
	Expected	0.33	0.67	0.11	0.22	0.11	0.11	0.22	0.11	0.11	2.00
1	Observed	3	6	0	2	1	0	2	1	1	16
	Expected	2.67	5.33	0.89	1.78	0.89	0.89	1.78	0.89	0.89	16.00
Total	Observed	3	6	1	2	1	1	2	1	1	18
	Expected	3	6	1	2	1	1	2	1	1	18

χ^2 Tests

	Value	df	p
χ^2	18.00	8	0.021
N	18		

Chi-square test results: Pearson $\chi^2 = 18.00$, p-value = $0.02 < 0.05$, so the null hypothesis is rejected, meaning "because it is more convenient than public transportation and combined with exercise" shows a significant difference for personal mobility owners ($\chi^2 = 18.00$, $p < 0.05$). Therefore, respondents who own personal mobility tend strongly to use it "because it is more convenient than public transportation" or "combined with exercise," while non-owners showed a pattern of selecting various reasons.

Therefore, personal mobility owners tend to value convenience and health (combined exercise) aspects. Accordingly, safe storage facilities and shower/locker amenities within transfer centers are necessary. Non-owners' mobility selection factors are relatively diverse, and economic and environmental factors may also act as important consideration factors. Therefore, introduction of public transit transfer services linked to bicycle and electric kick-scooter sharing systems can be effective.

As a policy recommendation, incentive policies such as eco-mileage reward programs for use of carbon-reducing mobility may be effective in encouraging personal mobility use.

5.2. Necessity and Expected Effects of Transfer Stations

This study analyzed the limitations of existing bicycle transfer infrastructure and proposed a more efficient transfer station model. While the number of bicycle users in the metropolitan area is increasing, the lack of systematic transfer facilities is reducing user convenience and impeding connectivity with public transportation. Introducing smart transfer stations and constructing systematic transfer hubs is expected to maximize bicycle-public transport connection effects.

- User mobility convenience improvement: Construction of enhanced-security bicycle storage, electric bicycle charging stations, and real-time usage information provision systems.
- Transfer waiting time maximization: Service improvement through introduction of amenities such as shower facilities, laundry services, cafes, and shared offices.
- Eco-friendly transportation activation: Carbon emission reduction effect through reduced car and motorcycle usage rates.

5.3. Service Advancement through Amenity Addition

This study presented the possibility of expanding from a simple bicycle parking lot to a multi-functional hub that increases user dwell time and considers public transportation transfers. In particular, to address users' main inconveniences—insufficient shower and changing space, laundry service necessity after long-distance travel, and absence of cafes and amenities for waiting time use—various service provisions within transfer stations were confirmed to be necessary.

- Shower facilities and changing rooms to resolve inconvenience for long-distance users and commuters.
- Laundry service provision to increase convenience for repeat users and create additional revenue.
- Cafe and amenity operation to increase waiting time utilization and sales for transfer users.

5.4. Economic Sustainability and Optimal Operation Model

For sustainable operation of transfer stations, introduction of a public–private partnership (PPP) model is essential. Research results confirmed that rather than a simple public infrastructure provision method, construction of a complex revenue model through collaboration with private companies is necessary.

- Introduction of MaaS-based regular subscription services → operation of fare systems combining public transportation and bicycle transfers.
- Advertising and sponsorship attraction → securing additional operating costs through corporate cooperation models.
- Regular membership program operation → provision of premium services including shower, laundry, and electric bicycle charging.

5.5. Research Contributions and Limitations

Research Contributions

This study established a new concept for bicycle transfer stations beyond the existing simple storage lot concept, introducing the smart mobility hub concept and concretizing a linkage model with public transportation, shared mobility, and personal mobility (PM). It presented the possibility of MaaS-based bicycle transfer systems, performed economic feasibility analysis of integrated subscription services (KRW 10,000–25,000/month), and analyzed carbon emission reduction effects—estimating annual carbon emission reduction of 18,720 tons per month—along with social benefit analysis including health promotion, traffic congestion relief, and economic activation.

Research Limitations

More precise empirical experiments are needed to verify the operational effectiveness of transfer stations and strengthen data-based research that can analyze user behavior patterns. In particular, operational tests in various environments are needed to understand usage changes by time slot, day of week, and season. More detailed financial analysis of initial construction and maintenance costs is essential to compare the economic feasibility of various operation methods including PPP models and establish a financially sustainable structure. Additional surveys and in-depth interviews reflecting user requirements are needed, and WTP analysis should be further segmented to derive the fare systems and service levels users actually prefer.

Furthermore, location selection should comprehensively analyze users' actual movement routes, major destinations, and traffic congestion sections beyond simply considering bicycle usage rates and public transportation accessibility. Integration with MaaS-based smart integrated transportation systems must be reviewed, integrating public transportation, shared bicycles, electric kick-scooters, and car-sharing on one platform. Bicycle transfer stations should also be designed for flexible operation according to climate change and weather patterns, with indoor storage facilities expanded and solar power generation and rainwater recycling systems introduced for eco-friendly and sustainable operation.

5.6. Future Research Directions

MaaS-Based Service Optimization Linkage Research

Linkage possibilities for integrated payment systems (T-money, KakaoPay, Naver Pay, etc.) between public transportation and shared mobility under MaaS services should be examined, and the efficiency of bicycle and personal mobility linkage services including eco-mileage accumulation strategies with various mobility services should be analyzed. Sustainable economic model analysis is also needed, including the scope and budget securing of local government financial support, commercial advertising attraction, and research on items and services for creating profitability models. Deeper research is needed for job creation maximization and sustainable operation through PPP models.

Concept Expansion of Transfer Centers

Expanding the concept of transfer stations from the basic bicycle + public transport mobile hub role to accommodate additional users of popular exercises like running, expanding to a complex sports station hub concept to increase usage convenience, encourage public transportation use, and reduce carbon emissions while achieving the goal of promoting national health.

5.7. Final Conclusion

Through this study, it has been confirmed that metropolitan bicycle transfer stations have high potential to develop from simple bicycle storage lots into MaaS-based mobility hubs, enabling bicycle use activation, strengthened public transportation linkage, and eco-friendly transportation system construction.

If shower facilities, amenities, maintenance shops, and shared mobility linkage systems are introduced to actively utilize bicycles for commuting and long-distance travel, economic sustainability can be secured, and social benefits such as carbon reduction, health promotion, and increased public transportation usage can be maximized.

Future research should derive more specific revenue models and policy support measures through pilot tests applying actual operation models, and based on this, Korean-type MaaS and smart mobility policies can be further developed.

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