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Assessment of Eco-Friendly Effects on Green Transportation Demand Management

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Transportation demand management has been implemented in Seoul to realize the transit-oriented development for its evolution into an eco-friendly city. The policies include reorganizing road space, restricting the operation of fifth-grade vehicles, increasing parking fees, and expanding shared bicycles. The Seoul Metropolitan Government monitors traffic changes by installing cameras at the point of entry into the city center for policy assessment. Furthermore, it acquires data about the number of public parking lots and shared bicycles. In this study, a quantitative evaluation of green traffic promotion area designation and implementation policies is conducted using various data. The analysis is conducted by classifying the effects of increasing and reducing eco-friendly transportation, and the benefits of reducing public bicycle use, air pollution, and parking costs are considered. The benefits of reducing air pollution by reducing traffic volume and the benefits of reducing parking costs by decreasing the number of parking units are calculated and estimated. The analysis shows that the cost-benefit of reducing air pollution by reducing traffic volume is approximately 42.5 B KRW/y. This qualitatively translates to approximately 1.3 M trees. The cost benefit of reducing the number of parked cars is estimated to be 18.2 B KRW. In addition, the average daily use of public bicycles, an eco-friendly mode of transportation, increases by approximately 390 units, as proven statistically. The results of this study confirm that transportation demand management enables eco-friendly goals to be achieved. Finally, It is expected to be used as an indicator for the Seoul Metropolitan Government's public transportation-oriented development policy.

1. Introduction

Rapid economic growth and urbanization have resulted in various traffic problems, such as air environment problems, traffic accidents, and traffic congestion (Ku et al., 2020). As this traffic problem intensifies, the paradigm of transportation policy is changing worldwide from vehicle- to human-oriented to eco-friendly. This trend has resulted in the implementation of a transit-oriented development policy through expanding the use of public transportation and curbing the use of passenger cars in developed countries (Ibraeva et al., 2015). In London, the Low Employment Zone was designated in 2008 to reduce air pollutant emissions. The number of vehicles in the district decreased, the proportion of low-pollution vehicles increased (Ellison et al., 2013). Inspired by this, the Seoul Metropolitan Government implemented a transportation demand management policy to transform Seoul into an eco-friendly city and promote changes in the urban structure. The Seoul Metropolitan Government's Green Transport Promotion Area Policy, which was implemented at the end of 2019, was benchmarked with low-pollution areas (Ku et al., 2020) in large cities worldwide, including Milan, Rome, and Paris. The target area included Jongno-gu and 15 dongs in the Seoul metropolitan area described in Figure 1b. In the area, vehicles will be classified into 5 grades based on the degree of hazardous gas emissions; Grade 5 vehicles with the highest hazardous gas emissions will be restricted from entering the district and fined for violations. The reorganization of road space, and improvements in parking ceiling are also implemented. The ultimate aim is to circumvent and reduce traffic in the area, reducing congestion and air

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pollution. Various traffic big data are required to quantitatively evaluate the policy. The Seoul Metropolitan Government acquired data by installing cameras at 45 locations. A car traffic management system based on a control camera can acquire various transportation data such as traffic examination, traffic changes, and toll charges collection. Real-time monitoring and systematic post-evaluation can be performed using these data.

In this study, the effectiveness of implementing policies in green transportation promotion areas shall be classified as an increase in eco-friendly transportation and a decrease in non-eco-friendly transportation through such collected data which is verified quantitatively.

2. Methodology

2.1 Discharging pollutant

Hanpatanakit et al. (2018) conducted a survey using the bottom-up approach to estimate carbon dioxide emissions from tourist traffic on the island of Kok Mak in Thailand, where transport energy consumption was calculated using the method presented by the Intergovernmental Panel on Climate. Zhang et al. (2016) presented a mixed-integer programming model for the energy consumption optimization of intercity high-speed transport systems. In this study, they optimized the connections between large population centers and the transportation methods, as well as calculated costs while considering the lifespan of transport infrastructure and energy consumption. Li et al. (2015) developed a cost-optimization superstructure model to derive an optimal oil-saving route for road passenger transport by 2030. Seven vehicle categories, alternative fuels, and eight powertrain options were considered to minimize fuel and vehicle costs. Chen et al. (2018) developed an optimization model for safe and efficient logistics route exploration for hazardous chemicals. They derived improved path navigation capabilities by solving a dual-purpose optimization model that minimizes transport risk and distribution distance based on the type and weight of hazardous chemicals.

2.2 Evaluation of environmentally friendly transportation policy

Ku et al. (2021) investigated a methodology for evaluating the economics of rapid transit. The demand for bicycle use was derived by considering bicycle rental stations as transportation zones. Regarding the benefit analysis, it was deemed inappropriate to evaluate eco-friendly transportation projects such as Cycle Rapid Transit (CRT) based on only the benefits of reducing travel time and vehicle operation costs and adding them as a benefit analysis item of existing transportation projects. Sellitto et al. (2012) presented a model for evaluating user perceptions of the environmental effects of public transport operations. A survey of 300 public transportation users was conducted and analyzed via structural equation modeling. Although vehicle safety and pollutant emissions affected user perception, it was reasonable to conclude that user satisfaction increased significantly. Awasthi et al. (2011) introduced fuzzy TOPSIS to derive a comprehensive score for sustainability assessment and to select the best alternative for eco-friendly transportation systems. Decisions were made via a multicriteria decision-making approach by weighting the corresponding scores.

2.3 Summary

Research has been conducted on estimating pollutant emissions or solving optimization problems, and evaluating eco-friendly transportation policies, but it focuses on the development of general and theoretical models and methodologies. When evaluating a specific policy, the focus was on the environment before the implementation of the policy, failing to accurately derive the effect from the implementation of the policy. In the case of this study, data were collected and compared before and after the implementation to analyze the implementation effects of the Seoul Metropolitan Government's green transportation promotion regional policy, and external variables were also verified through statistical significance.

3. Results

The framework of this study is presented in Figure 1.

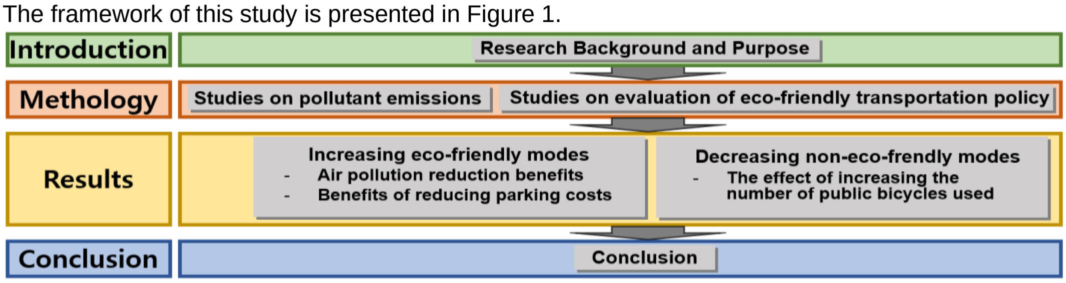

Figure 1: Framework of this study

In this study, separate analyses were conducted by reducing non-environmental transportation modes and increasing eco-friendly ones through implementing green transportation promotion areas. It was estimated that reducing traffic volume would reduce air pollution and parking costs. The benefits of air pollution reduction were presented in terms of the number of trees for estimating its scale intuitively. The effect of increasing the number of public bicycles was analysed by eliminating seasonal characteristics and related infrastructure ones.

3.1 Traffic reduction effect

According to the analysis of the effect of reducing traffic volume owing to the designation of green transportation promotion areas and the implementation of eco-friendly transportation policies, the daily traffic volume decreased by approximately 13 % from 778,000 units/d (July 2019) to 679,000 units/d (September 2020) described in Figure 2a. Based on the analysis, the amount of change in grade 5 vehicles decreased by 47 % from 15,000/d to 8,000/d described in Figure 2b, indicating a significant reduction in traffic volume. The traffic volume of vehicles without pollutant reduction devices among grade 5 vehicles decreased by approximately 87 % from 9,000 units/d to 1,000 units/d, which prevented a significant number of pollution vehicles from entering green traffic promotion areas.

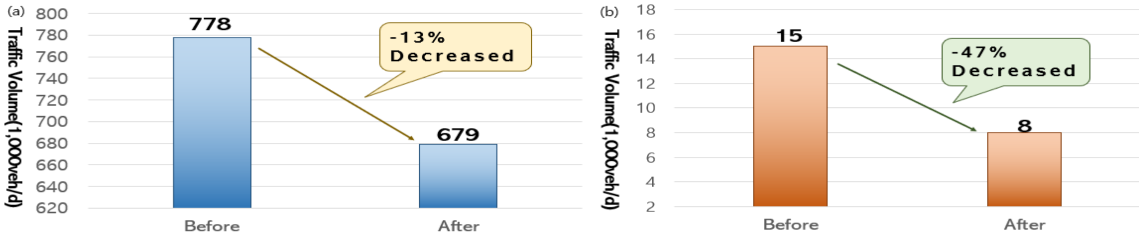

Figure 2: Effect of reducing traffic volume by car type (a) whole vehicles; (b) Type 5 vehicles

Street traffic reduced from 2,202,044 (1,000 veh-km) to 1,494,257 (1,000 veh-km), and the average distance per vehicle reduced from 8.13 to 7.32 km (Table 1). This is primarily due to the transition of medium-and long-distance traffic using other transportation modes and routes.

Table 1: Effect of reducing traffic volume and average travel distance (Units: t/y)

Classification	Before	After	Difference	Difference (%)
Distance-Volume (1,000 veh-km)	2,202,044	1,494,257	-707,787	-32.14
Traffic Volume (1,000 veh/y)	270,965	204,165	-66,801	-24.65
Average Travel Distance(km)	8.13	7.32	-0.8	-9.84

The traffic volume decreased owing to the designation of green transportation promotion areas and the implementation of policies, which benefited the transportation and environmental sectors. The benefits of reducing air pollution in the transportation sector were calculated by comparing the traffic volume, distance, and time of passage in the analysis area before and after the implementation of the policy. A pre-investigated methodology for calculating the benefits of reducing air pollution in Korea's transportation sector was applied (Nam et al., 2008).

This methodology defines CO, CO_2, SO_2, hydrocarbons (HC), nitrogen oxides (NOx), and fine dust (PM) as air pollution contributors. Pollutant emissions are significantly affected by the type and performance of the vehicle, the driving conditions, the traffic, and the road conditions. The original units for each vehicle type and speed were calculated and applied differently. The emission coefficient for each pollutant generated by driving a car was calculated, and the air pollution cost unit for each type and speed was estimated by applying the air pollution cost unit for each pollutant. The emission coefficient for each pollutant generated via motor vehicle operation was applied to the total traffic distance (veh-km) in the analysis area and compared before and after the implementation of the policy. By calculating the change in air pollutants following the implementation of the policy, it was discovered that CO decreased by 42.40 %, CO_2 by 38.69 %, and NO_x by 36.60 % (Table 2).

Table 2: Reduction in air pollution (Units: t/y)

Classification	CO	NOx	VOC	$PM_{2.5}$	CO_2
Before	1,717	1,686	202	49	581,125
After	989	1,069	127	32	356,309
Difference (%)	-728(-42.4%)	-617(-36.6%)	-74(-36.6%)	-18(-36.7%)	-224,817(-38.7%)

The total air pollution reduction benefits, i.e., calculated using Eq(1), multiplying the cost units to handle air pollutant to the amount of air pollutant reduction as in Eq(2), was 42.5 B KRW/y. If the previous methodology pertaining to the absorption volume of CO_2 by trees is applied to this result, then it may be converted to the effect of planting 1.3 M trees,

$$VOPCS = VOPC_{Before} - VOPC_{After} \tag{1}$$

$$VOPC = \sum_l \sum_{k=1}^{3} D_{lk} \times VT_k \times 365 \tag{2}$$

where *VOPC* is Valuation of Pollution Cost Saving, D_{lk} is total travel distance(veh·km) by link(*l*), by vehicle type(*k*), VT_k is air pollution cost (KRW/km) of the link speed by vehicle type(*k*), *k* is vehicle type (1: auto, 2: bus, 3: freight).

3.2 Parking changes

Among the policies to curb demand for passenger cars, parking conditions control policies such as "parking fee surcharge" and "restricting the number of parking spaces" are known to exhibit excellent effects (Zoeter et al., 2014). The Seoul Metropolitan Government implemented a parking fee surcharge policy for fifth-grade vehicles in public parking lots located in Seoul to encourage passengers to switch to public transportation. According to a survey of the number of parking used at 22 public parking lots in the analysis area, an average of 7,679 cars used parking lots daily before the implementation of the premium policy. After the implementation of the policy, an average of 7,062 cars used parking lots daily, indicating an 8.0 % decrease in users (Table 3).

Table 3: Changes in the number uses of parking lots at public parking spaces (Units: veh/d, %)

Classification	Before		After		Difference	
Green traffic promotion areas (22 spaces)	Dec, 2019	7,679	Jan, 2020	7,367	-312	-4.1 %
			Feb, 2020	6,918	-761	-9.9 %
			Mar, 2020	6,930	-749	-9.8 %
			Average	7,062	-617	-8.0 %

A reduction in passenger traffic due to eco-friendly transportation policies may reduce parking demand in non-residential areas. Resources such as land and facility operating costs incurred in operating parking lots can be used for other purposes, resulting in social benefits (Jang et al., 2007). In this study, the methodology proposed by the Korea Development Institute for reducing parking costs was applied. In this methodology, it is assumed that parking fees reflect the cost of constructing and operating parking lots. This is because limitations exist that hinder the opportunity cost of parking to be calculated accurately. The benefits of reducing parking costs were calculated from the savings in parking fees. To calculate the benefits of reducing parking costs, the average parking fee (KRW 2,067) in the analytical area and the percentages of traffic to work and shopping were applied. It can be expressed like Eq(3) and(4). The result indicates an annual benefit of approximately 18.2 B KRW.

$$VOPCS = VOPC_{Before} - VOPC_{After} \tag{3}$$

$$VOPC = \frac{1}{2} \sum_{ij} \sum_{ij} (D_{ij}^{y} \times p \times \alpha_0^{ky}) \tag{4}$$

Where VOPCS is Valuation of Parking Cost Saving, i is the origin of trips, j is the destination of trips, D_{ij}^{y} is auto traffic volume from I to j in y year(veh/y), p is the proportion of purpose trips, y is years, α_0^{ky} is the parking fee per vehicle in y years (KRW/(veh·y))

3.3 Changes in public bicycle use

A public bicycle rental system is essential for reducing passenger car traffic and increasing the number of public transport users. The Seoul Metropolitan Government operates "Ttareungi," a public bicycle rental service, and is expanding related infrastructure such as rental stations and stands to promote its use (Shin et al., 2007). In Table 4, as of June 2020, 167 rental stations were installed in the Green Transportation Promotion Area (Jongro-gu, Jung-gu), which is an increase of approximately 56 % compared with the number in the previous year. The number of bicycle racks increased by approximately 64 % annually to 1,930 (as of June 2020). The designation and implementation of the Green Transportation Promotion Area began in July 2019. To reduce confusion among citizens, a guidance period of six months was provided before the policy was legally implemented. To analyse the policy effects, data regarding the use of public bicycles were acquired and analysed for six months before and after the implementation of the policy, excluding the guidance period.

Table 4: Trends in infrastructure and use of public bicycles before and after implementation of green transportation promotion areas

Classification		Jen	Feb	Mar	Apr	May	Jun
Before (2019)	Rental offices	107	107	107	107	107	107
	Rests	1,180	1,080	1,180	1,180	1,180	1,180
	Number of uses	1,470	1,414	2,279	3,407	4,308	4,498
After (2020)	Rental offices	111	129	111	111	111	167
	Rests	1,277	1,554	1,277	1,277	1,277	1,930
	Number of uses	1,946	1,949	2,804	4,063	4,083	4,870

The abovementioned procedure was performed to measure the effect of implementing green transportation promotion areas that included the effects of the variables by constructing models including other factors such as the effects of increasing public bicycle infrastructure or seasonal factors. For seasonal factors, the effects from each month were regarded as different, and each effect was treated as a dummy variable. It is described in Eq(5).

$$Uses_{bicycle} = \beta_0 + \beta_1 * (RentOffices) + \beta_2 * Rests + \sum_{i=1}^{6} \beta_{i+2} * Monthdummy_i + \beta_9 * implemented + \mu \quad (5)$$

Where $Uses_{bicycle}$ is the daily usages of public bicycles, β_0 is intercepts, $RentOffices$ is the number of rented offices in green traffic promotion areas, Rests is the number of rests in green traffic promotion areas, $Monthdummy_i$ is dummy variables describing month i(e.g. Jan≡(β_3=1, Others=0), Apr≡(β_6=1, Others=0)), $Implemented$ is dummy variables whether the policy is implemented ($before$=0, $After$=1), μ is residuals.

The results of the model are presented in the left part of Table 5. It shows that the infrastructure variable parameters demonstrated negligible statistical significance, and that the number of public bicycles uses, and the degree of infrastructure construction were almost not correlated.

Table 5: A model describing the number of uses of public bicycles, including infrastructure variables

Classification	Before removing infrastructure variables				After removing infrastructure variables			
Variables	Estimated	Std error	T statistics	P value	Estimated	Std error	T statistics	P value
Intercepts	1,572.13	876.82	1.79	1.71E-01	1,499.83	117.54	12.76	1.42E-05
Rental offices	-11.79	32.44	-0.36	7.40E-01	-	-	-	-
Rests	1.03	2.62	0.39	7.20E-01	-	-	-	-
Month dummy1	-11.78	293.40	-0.04	7.05E-02	-	-	-	-
Month dummy2	833.5	280.03	2.98	5.88E-02	846.75	176.31	4.80	2.99E-03
Month dummy3	2,027	280.03	7.24	5.44E-03	2040.25	176.31	11.57	2.51E-05
Month dummy4	2,487.5	280.03	8.88	3.01E-03	2500.75	176.31	14.18	7.67E-06
Month dummy5	2,969	356.98	8.32	3.64E-03	2989.25	176.31	16.95	2.69E-06
Implemented	305.02	279.60	1.09	3.55E-01	389.83	117.54	3.37	1.61E-02

The corresponding variables are removed, and the model is rebuilt. After rebuilding the model, in the right part of Table 5, the statistical significance of the parameters of all variables was verified to confirm that their effects were statistically significant. The analysis showed that the value indicating whether the green transportation promotion area was implemented was estimated to be 389.83, which was statistically significant.

4. Conclusions

In this study, the quantitative effects of the green transportation area policy were analysed. To analyse the effectiveness of this policy, The changes in eco-friendly and non-environmental transportation modes was analysed. For the former, the number of uses of public bicycles was analysed. For the latter, the benefits of reducing air pollution and parking costs due to changes in traffic in the focus area were analysed. After implementing the policy, 707,787,000 km of street traffic was reduced annually, and the average travel distance was reduced by 0.8 km. The cost-benefit of reducing air pollution by reducing traffic volume was calculated to be approximately 42.5 B KRW/y. In terms of the number of parking lots, a decrease of 617 parking lots per day on average was recorded in 22 public parking lots in the green transportation promotion area, and the cost benefit of reducing parking costs was 18.2 B KRW. To analyse the changes in the number of public bicycle use, a model including infrastructure and seasonal factors was established to analyse the actual effect of implementing policies in green transportation promotion areas. The effect of increasing the number of public bicycles used by an average of 390 units/d was observed after implementing the green transportation promotion area. It was confirmed that eco-friendly transportation policies achieved goals that promoted eco-friendliness. In addition to the effects estimated in this study when implementing eco-friendly transportation policies, various effects such as health benefits and noise reduction benefits should be considered. Although they are not yet included in the domestic market as quantitative effects of implementing the policy, other countries are determined to include them. Further studies reflecting these effects should be carried out later. In addition, in the case of green transportation promotion areas analyzed in this study, it was only a short-term effect analysis not long after the policy was implemented. Research should be conducted later to identify trends in policy effects through mid-to-long-term data analysis. We hope that the results of this study will be applicable as an evaluation indicator of eco-friendly transportation policies for developing a completely eco-friendly Seoul.

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