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Estimating Vehicle-Specific Travel Distance Based on Mobile Communication Data for Carbon Emission Calculation

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Abstract

In this study, a methodology is proposed to estimate driving distance more accurately by vehicle type using communication data to calculate carbon emissions. Traditional methods based on historical data collection have limitations in estimating driving distance accurately. However, utilizing communication data allows for more detailed estimation of driving distance across the traffic network, contributing to a more precise calculation of carbon emissions. Although various traffic monitoring devices are currently used to estimate driving distances, it remains challenging to estimate the total driving distance by vehicle type according to road classification. This approach yields higher accuracy and reliability than traditional sample-based estimation methods. The results of this study can be used as critical foundational data for formulating national policies on greenhouse gas reduction and are expected to significantly improve the accuracy of carbon emission calculations in the road sector. In particular, the methodology based on mobile communication data improves vehicle-specific travel distance estimation and enhances spatiotemporal analysis capabilities for road-sector carbon emissions.

Keyword : Carbon emissions, mobile communication data, travel distance, traffic data collection devices, reliability

1. Introduction

As the intensity of disasters and hazards, such as heatwaves, heavy snowfalls, and torrential rains, increases due to climate change, countries worldwide are actively promoting policies to reduce greenhouse gas emissions. In October 2020, South Korea declared “Carbon Neutrality by 2030” and increased the target reduction rate for carbon emissions in the road sector from 26.3% to 37.8% compared to 2018 levels. Accordingly, strategies must be established to monitor the progress and implementation of national greenhouse gas reduction targets every five years from 2023 through the Global Stocktake [1][2]. Because carbon emissions vary significantly based on factors such as vehicle

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type, fuel type, travel speed, and distance, obtaining detailed activity data on the total travel distance by vehicle type is crucial [3]. However, most of the current activity data is based on historical data, making it insufficient to provide information that reflects real-world conditions accurately. Therefore, utilizing communication data can address these shortcomings.

The Tier-3-based formula for calculating road-sector carbon emissions primarily estimates emissions based on total vehicle kilometers traveled (VKT) and emission factors (EFs). Additionally, it can yield more reliable results that reflect actual conditions than Tier-1 and Tier-2 carbon emission formulas by accounting for various vehicle types, fuel types, and driving conditions. However, precisely estimating vehicle-specific travel distances and obtaining measured data are essential to accurately calculate gas emissions.

Recent advancements in data collection technology offer opportunities to significantly improve the accuracy of measurement-based travel distance estimates. In addition to automatic vehicle classification (AVC), vehicle detection systems (VDS), and mobile detectors, the recent use of mobile communication data, such as location intelligence data (LID), has facilitated the precise measurement of vehicle movement patterns and travel distances. Integrating such data for carbon emission calculations promotes accurate estimation of vehicle-specific travel distances and improves the spatiotemporal analysis capabilities of carbon emission estimates.

The purpose of this study was to develop a methodology for accurately calculating carbon emissions in the road sector by estimating vehicle-specific travel distances through the integration of data from various traffic data collection devices.

2. Formula for Calculating Carbon Emissions for the Road Sector

Because the road sector accounts for the largest share of total greenhouse gas emissions, accurate emission calculations are essential for developing national policies on greenhouse gas reduction. The Tier 3 based carbon emissions calculation formula for the road sector yields more accurate results than the Tier 1 and Tier 2 formulas, as it is based on the total VKT and EF. The Tier 3 calculation method applies specific EFs for each vehicle type, fuel type, and emission control technology based on travel distance data. The detailed formula is expressed by Equation 1 [4]:

$$E_{CH_4/N_2O} = Distance_{i,k,l,m} \times EF_{i,j,k,l,m} \times 10^{-6} \tag{1}$$

where ECH4/N2O refers to CH_4 or N_2O emissions (GHG), Distance i, j, k, l, or m represents the travel distance (km), and EFi,j,k,l,m is the emission factor (g/km). Here, i denotes the fuel type (for example, gasoline, diesel, or LPG), j represents the greenhouse gas type (CH_4, N_2O), k is the vehicle type, l represents the emission control technology (or vehicle manufacturing year), and m denotes the driving conditions (average speed during travel).

Emissions (kg) are calculated by multiplying the travel distance of the vehicle (VKT) by the EF (kg/km) that corresponds to the relevant conditions. VKT and EF are calculated considering various factors, such as vehicle type (a; passenger cars, buses, trucks, etc.), fuel type (b; gasoline, diesel, LPG, etc.), and speed (c; km/h) [5].

Lee [6] compared greenhouse gas emissions in the road transportation sector across 31 cities and counties in Gyeonggi-do in 2008 using the Tier 1, Tier 2, and Tier 3 methods and identified differences in the emission calculations of each method. The study focused on the need for data refinement and integration when comparing Tier 3 based solely on arterial roads with a Tier 3 method that includes both arterial and secondary roads.

3. Traffic Data Collection Technologies

Collecting traffic data is essential for estimating vehicle travel distances. Various technologies, such as AVC, VDS, mobile detectors, the Korea Transport Database (KTDB), and mobile communication data, are used for this purpose.

3.1 AVC

AVC is a technique that automatically classifies vehicles passing through roads and surveys traffic volume using various sensors. In South Korea, AVC systems mainly consist of piezo sensors and loop sensors, with piezo sensors detecting the number of axles and loop sensors identifying vehicle presence [Fig. 1].

Source: https://www.satech.co.kr/products-traffic_system04.html

[Fig. 1] Automatic vehicle classification (AVC)

AVC collects various types of data, such as axle count, vehicle length, inter-axle distance, and overhang distance (distance from the bumper to the wheels), and classifies vehicles into 12 categories based on these details. These classification results serve as essential foundational data for traffic management and policy development. [Table 1] presents the basic information collected from AVC.

[Table 1] Basic Data Collected via AVC

Information	Unit	Type
Number of vehicles	Units	Vehicle information
Vehicle speed	km/h	Vehicle information
Vehicle length	cm	Vehicle information
Road occupancy rate	%	Road information
Time between vehicles	ms	Vehicle information
Inter-axle distance	cm	Vehicle information
Number of axles	Units	Vehicle information

3.2 VDS

VDS is a set of equipment installed to collect traffic data, such as traffic volume, speed, and occupancy, enabling real-time detection of traffic characteristics at specific locations [7]. VDS is installed at approximately 1 km intervals on roads, where it collects real-time data on traffic volume, occupancy, speed, queue length, and vehicle length to gather information on traffic flow and unexpected incidents. VDS can be installed in various types based on the road environment, with the main types being loop-, video-, and radar-based systems. VDS primarily collects data using loop and video detectors as a point detection system [Fig. 2]. It gathers data at specific road points, such as the speed of individual vehicles passing through each lane, vehicle length, occupancy, and passage time, and provides traffic information to the control center at regular intervals (for example, every 1 or 5 min).

Source: https://www.satech.co.kr/products-traffic_system04.html

[Fig. 2] Vehicle detection system (VDS)

3.3 KTDB

The KTDB is maintained by the Korea Transport Database Center of the Korea Transport Institute, which collects, processes, and provides various traffic-related data annually. Most of the data are compiled through multiple surveys, including regular surveys such as the passenger travel survey, freight travel survey, special traffic travel survey, and traffic generation unit survey. The passenger travel survey and freight travel survey are particularly used to create vehicle-specific movement routes, serving as crucial foundational data for analyzing SOC demand and planning national transport infrastructure.

3.4 Mobile communication data

Mobile communication data refers to data transformed from wireless mobile communication quality information into call log data using "location intelligence" technology, which can be used to analyze the movement patterns of the national mobile population and vehicles on roads, based on call log tracked by mobile communication base stations. Mobile communication data enables the estimation of positions within 5 min using data collected at 30-second to 1-minute intervals. However, since personal information and location data cannot be disclosed, they are provided only based on traffic data after preprocessing. This call log-based mobile communication data can be used for traffic flow analysis and urban planning, promoting policy-making [8].

4. Proposed Methodology for Estimating Vehicle Travel Distance

4.1 Review of Existing Methods for Estimating Vehicle Travel Distance

Currently, vehicle travel distances are estimated by applying spatial statistical methods to traffic volume data collected from vehicle detectors, field surveys, and the Statistical Yearbook of Traffic Volume. In general, cumulative travel distances are estimated by multiplying the length of a sample segment by the traffic volume data for that segment, rather than for the entire road network. However, because this method estimates vehicle travel distances using sample data, it has the advantage of ease of calculation but lacks accuracy, as it neglects inter-regional travel, vehicle type, fuel, and other factors. Therefore, efforts to use mobile communication data for more precise travel distance estimates have been made in recent years to address these limitations.

[Table 2] summarizes the existing methods used for estimating vehicle travel distances in South Korea and overseas. Methods for estimating vehicle travel distances can be divided into traffic volume-based and non-traffic volume-based approaches. Traffic volume-based estimation methods use traffic volume data collected from detectors, field survey data, and traffic demand models, whereas non-traffic volume-based methods estimate travel distances using historical data, such as fuel efficiency and vehicle odometer readings [9].

[Table 2] Comparison of Vehicle Travel Distance Estimation Methods in South Korea and Other Countries

Category		Estimation Method
Traffic Volume-Based	Korea Transport Institute	▪ Uses traffic volume data from vehicle detectors, field surveys, and traffic demand models to calculate VMT
	Korea Institute of Construction Technology	▪ Estimates inter-regional travel distances based on observed traffic volume
	HPMS	▪ Uses a method that extends the annual average daily traffic of sample areas to the entire road network
	INDOT	▪ Same as that of HPMS
Non-traffic Volume-Based	Fuel Sales-Based	▪ Based on retail fuel sales of gasoline and diesel and unit fuel efficiency
	Odometer-Based (Korea Transportation Safety Authority)	▪ Distance based on odometer readings from vehicles
	Household and Driver Survey-Based	▪ Estimates vehicle travel distances using non-traffic volume data
	Highway/Transit Network Model	▪ Estimation of vehicle travel distance through traffic volume forecasting using the road network

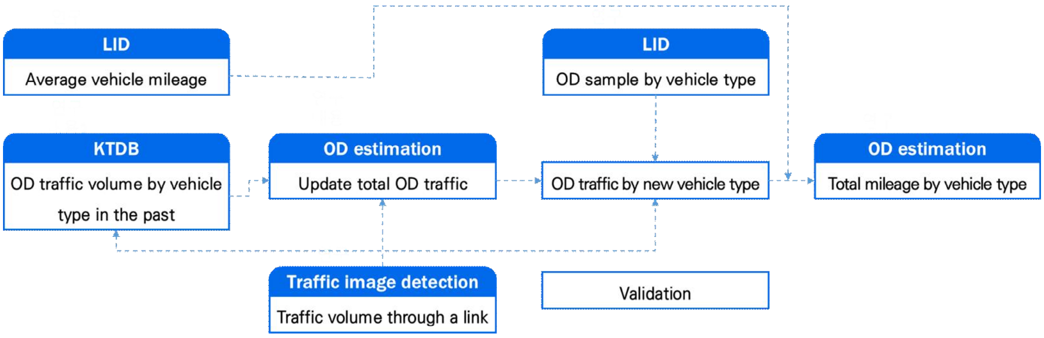
4.2 Proposed Methodology for Estimating Vehicle-Specific Travel Distances for Carbon Emission Calculations

Estimating total travel distance based on vehicle type is crucial for calculating carbon emissions at a micro-level. In this study, a methodology for estimating total travel distances by vehicle type was developed using real-world data rather than historical data (such as national statistics).

First, by calculating the average travel distance for all vehicles without distinguishing by type and multiplying this by the origin-destination (OD) traffic volume for each vehicle type, increased estimation accuracy can be achieved. In estimating vehicle-type-specific OD traffic volumes, it is beneficial to first estimate the overall OD without differentiating by vehicle type and then use sample traffic volumes collected from mobile communication data to estimate OD traffic volumes by vehicle type. This approach increases both accuracy and calculation speed.

In addition, it is possible to estimate travel distances by combining individual vehicle OD and estimated traffic volumes obtained from mobile communication data with past vehicle-type-specific historical data and OD information from the KTDB. In this case, after estimating the total travel distances using mobile communication data, applying the average travel distances from the KTDB by vehicle type facilitates the estimation of vehicle-type-specific total travel distances.

[Fig. 3] illustrates the process for estimating vehicle-specific travel distances using public and private data.



[Fig. 3] Process for estimating total travel distance by vehicle type

5. Conclusion

Currently, estimating total travel distances by vehicle type based on road classifications is challenging. To ensure the accuracy and reliability of vehicle-type-specific total travel distances, it is essential to integrate public and private data and validate the quality of the data. If bias exists in the collected data, the accuracy of vehicle-type-specific total travel distance estimates could be significantly reduced.

In this study, a methodology based on mobile communication data was developed to obtain more accurate estimates of travel distances by vehicle type. This is expected to significantly improve the reliability of carbon emission calculations in the road sector. Although the accuracy of traditional methods based on historical data is low, using mobile communication data provides more detailed real-time information, thereby improving the accuracy of carbon emission calculations.

Additionally, performing cross-validation between mobile communication data and public traffic data in terms of data quality can reduce bias and further enhance reliability. When data collected from various traffic observation devices are integrated with mobile communication data, they can serve as critical foundational data for formulating national policies on greenhouse gas reduction. Currently, in the road sector, there is no systematic standard for calculating carbon emissions at the national and local government levels, which limits the ability to establish consistent policies. Therefore, if data collected from various traffic monitoring devices is integrated with communication data, it could serve as crucial foundational data for ensuring consistency in national greenhouse gas reduction policies. The proposed method is also expected to significantly improve the spatiotemporal analysis capabilities of carbon emission calculations.

In conclusion, this study proposed a foundational methodology for improving the reliability of future carbon emission calculations in the road sector. If the smooth collection of public and private data is achieved, it will play a key role in establishing strategies for minimizing greenhouse gas emissions in the road transport sector through data validation.

This study has the limitation of proposing a theoretical methodology rather than being based on real data analysis. In the future, real data will be collected to refine the proposed methodology, followed by analysis and validation.

References

[1] H. H. Jang, S. H. Choi, B. J. Yoon, "GHGs Emissions Based on Individual Vehicles Speed", Journal of the Society of Disaster Information, vol. 15, no. 4, December 2019, pp. 560-569, doi: 10.15683/kosdi.2019.12.3.1.560.

[2] Presidential Commission on Carbon Neutrality and Green Growth, "2030 National Greenhouse Gas Reduction Target (NDC) Raised", Presidential Commission on Carbon Neutrality and Green Growth, Sejong, South Korea, October 2021, [Online]. Available: https://www.2050cnc.go.kr/flexer/view/BOARD_ATTACH?storageNo=174, (accessed August 1, 2024).

[3] B. R. Bae, G. S. Kim, "A Study on Greenhouse Gas Emissions Estimation based on Mileage Through Accumulation of Activity Databases", Journal of Korean Society of Transportation, vol. 32, no. 1, February 2014, pp. 1-12, doi: 10.7470/jkst.2014.32.1.001.

[4] Ministry of Environment, "Guidelines on Greenhouse Gas and Energy Target Management Operations, etc", Sejong, South Korea, Act No. 2016-255, December 2016, [Online]. Available: https://www.gir.go.kr, (accessed August 5, 2024).

[5] K. D. Kim, T. J. Lee, W. S. Jung, D. S. Kim, "Development of Traffic Volume Estimation System in Main and Branch Roads to Estimate Greenhouse Gas Emissions in Road Transportation Category", Journal of Korean Society for Atmospheric Environment, vol. 28, no. 3, April 2012, pp. 233-248, doi: 10.5572/KOSAE.2012.28.3.233.

[6] T. J. Lee, K. D. Kim, W. S. Jung, D. S. Kim, "Comparison of Greenhouse Gas Emissions from Road Transportation in Local Cities/Counties of Gyeonggi Province by Calculation Methodologies", Journal of Korean Society for Atmospheric Environment, vol. 28, no. 4, July 2012, pp. 454-465, doi: 10.5572/KOSAE.2012.28.4.454.

[7] Ministry of Land, Infrastructure and Transport (MOLIT), “The Performance Evaluation Criteria of ITS in Automobile and Road Transportation”, Sejong, South Korea, Act No. 2023-21, January 2023, [Online]. Available: https://www.law.go.kr/LSW/admRulLsInfoP.do?admRulSeq=2100000218569, (accessed August 5, 2024).

[8] Ministry of Land, Infrastructure and Transport (MOLIT), “Development of signal cross-section optimization service based on real-time mobile location data”, Sejong, South Korea, November 2022.

[9] Auto Journal, “Estimation method of vehicle’s driving mileage”, South Korea, February 2017.