Carbon-based Performance Evaluation on Urban Road

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ABSTRACT

In Korea, air pollutants caused by mobile sources constitute a large portion of the total contaminants, and carbon dioxide (CO_2) makes up the largest majority of greenhouse gas. There is a need to establish an integrated policy of urban and transportation planning for the reduction in carbon emissions. In this regard, this study provides plenty of evaluation data of air pollution near roads that enable to support the policy decision-making process. To this end, the comprehensive air quality index, time value loss costs and environmental costs were set as key indicators of carbon-based road performance evaluation, and GIS-based prototype was developed. The major findings of this study are expected to be applied to the test-bed and thus utilized as data for decision making in establishment of relevant policies.

Keywords: *Carbon-based, Performance Evaluation about Urban Road, Comprehensive Air Quality Index, Time Value Costs, Environmental Costs*

1. INTRODUCTION

1.1 Background

The number of automobiles registered in South Korea has gradually increased to 18,870,000. And the amount of air pollutants from mobile sources, including carbon dioxide is 1,400,000 tons, accounting for 40% of the entire air pollutants [1], [2]. Carbon dioxide has the largest share in greenhouse gas emitted by humans in urban areas, and 85% of carbon dioxide discharge is related with human activities. Therefore, reduction in carbon emissions requires establishment of carbon emission reduction policies from an integrated aspect considering both urban plans and transportation plans. The purpose of this study is to provide the data for assessing air environment around roads, to support decision making in these areas. This study establishes carbon-based road performance evaluation indicators which combines comprehensive air quality index (CAI) and road characteristics, and develops a GPS-based prototype to be applied to the actual tested.

1.2 Research Scope and Methods

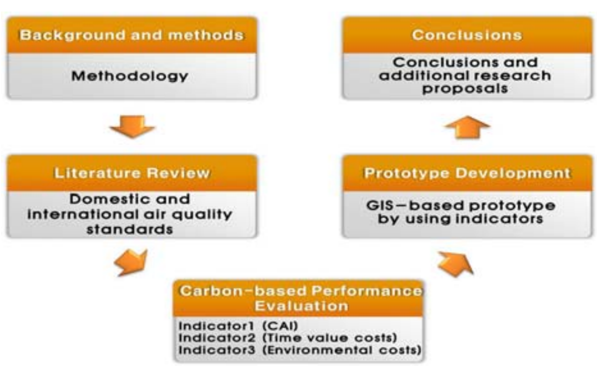

Fig 1: Analysis Process

This study reviews previous literatures to explore both domestic and international air quality index, and defines the indicators for carbon-based evaluation on urban roads.

2. LITERATURE REVIEW

2.1 Foreign Air Quality Standards

The US Environmental Protection Agency (EPA) published 'Air Quality for Particulate Matter' in 1996, which studied characteristics of particulate matters and their impact on human bodies, to use as the basis for setting the air quality standards. They published a revised and extended version of this document in 2004. In addition, the State of California has continued to make active efforts to reduce air pollution on its own, such as forming air quality management district's consisting of groups with similar climate and terrain conditions, and implementing air quality improvement qualities tailored to the characteristics of each district.

Table 1: Air Quality Index in the US [3]

Index	Indicator	Color
0 to 50	"Good"	Green
51 to 100	"Moderate"	Yellow
101 to 150	"Unhealthy for Sensitive Groups"	Orange
151 to 200	"Unhealthy"	Red
201 to 300	"Very Unhealthy"	Purple
301 and above	"Hazardous"	Maroon

In Europe, the CAFÉ (Clean Air for Europe) program is in operation to support establishment of more effective air quality policies. In particular, as new regulations on fine dust (PM2.5) came to be needed, it has been proposed to lower the standard concentration of fine dust particles (PM2.5) by 75% from the current level.

Table 2: Environmental standards for Particulate Matter in Europe [4]

PM	Standards	Time
PM2.5	25 μg/m³	Year
PM10	50 μg/m³	24hours
	40 μg/m³	Year

Unlike the European Union, the United Kingdom has set the percentage contribution of road transport to air pollution in terms of 5 major air pollutants (PM, CO, NO_x, HC_s) as shown in Figure 2.

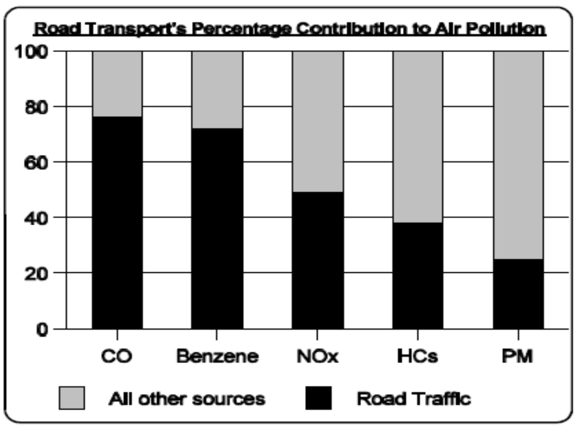

Fig 2: Ratio on the air pollution of the main pollutants in England [5]

In addition, the World Health Organization (WHO) recommended a standard on fine dust particles (PM2.5) through publication of the WHO air quality guidelines global update 2005.

Table 3: Environmental advisory standards for Particulate Matter in WHO [6]

PM	Standards	Time
PM2.5	25 μg/m³	24hours
	10 μg/m³	Year
PM10	50 μg/m³	24hours
	20 μg/m³	Year

2.2 National Air Quality Standards

South Korea lays down the environment standard for various air pollutants as follows in accordance with the environmental policy framework act.

Table 4: National air quality standards [7]

Division	Standards	
SO_2 (ppm)	Year	Less than 0.02ppm
	24hours	Less than 0.05ppm
	1hour	Less than 0.15ppm
CO (ppm)	8hours	Less than 9ppm
	1hour	Less than 25ppm
NO_2 (ppm)	Year	Less than 0.03ppm
	24hours	Less than 0.06ppm
	1hour	Less than 0.10ppm
PM10 (μg/m³)	Year	Less than 50 μg/m³
	24hours	Less than 100 μg/m³
PM2.5 (μg/m³)	Year	Less than 25 μg/m³
	24hours	Less than 50 μg/m³
O_3 (ppm)	8hours	Less than 0.06ppm
	1hour	Less than 0.1ppm
Pb (μg/m³)	Year	Less than 0.5 μg/m³
Benzene (μg/m³)	Year	Less than 5 μg/m³

3. THE ESTABLISHMENT OF A CARBON-BASED PERFORMANCE EVALUATION

3.1 Indicator 1(Comprehensive Air Quality Index, CAI)

Comprehensive air quality indexes are guidelines for action aimed at publicizing air pollution measurements in ways easily comprehensible by the general public, and prevent harms caused by air pollution in advance: they represent a way of expression developed based on consideration of the air pollution impacts on human health and the level of sensible air pollution. The comprehensive air quality indexes proposed by the Korea Environment Corporation uses 6-grade categorization described in Fig 3 and Table 5, from Good: A to Danger: F. It spatially divides certain urban areas with grids.

Comprehensive air environmental index scores are calculated for 5 major air pollutants (SO_2, CO, NO_2, PM2.5, PM10, O_3), and the highest score is used as the final integration index value. In cases where two or more of the index scores for each air pollutants are in the 'sensitive effect' grade or above, additional scores are added to the final integration index value. In addition, the comprehensive air quality index uses a 0~ 500 scales divided into 6 grades, where a higher score indicates worse air quality.

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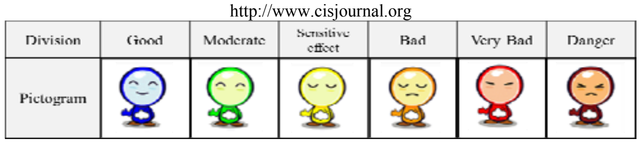

Fig 3: Expression level and color of Domestic air pollution [8]

Table 5: Class of Comprehensive Air Quality Index [8]

Divisions	CAI	PM10 (μg/㎥)	O_3 (ppm)	NO_2 (ppm)	CO (ppm)	SO_2(ppm)
Good	0-50	0-30	0-0.004	0-0.03	0-2.0	0-0.02
Moderate	51-100	31-80	0.041-0.08	0.031-0.06	2.01-9	0.021-0.05
Sensitive effect	101-150	81-120	0.081-0.12	0.061-0.15	9.01-12	0.051-0.1
Bad	151-250	121-200	0.121-0.3	0.151-0.2	12.01-15	0.101-0.15
Very bad	251-350	201-300	0.301-0.5	0.201-0.6	15.01-30	0.151-0.4
Danger	351-500	301-600	0.501-0.6	0.601-2	30.01-50	0.401-1
X	No data	No data	No data	No data	No data	No data

Table 6: Level of Service and Traffic Status [9]

Level of Service	Traffic Flow Status
A	Individual users are not affected by emergence of other users within the traffic flow in any meaningful way. High level of freedom in choosing the desired speed and steering. High level of comfort felt by drivers and passengers
B	Drivers pay attention to other users appearing within the traffic flow. High level of freedom in choosing the desired speed. However, lower travel freedom compared with Service Level A: this is due to fact that individual actions are affected by emergence of other users within the traffic flow
C	Drivers begin to be considerably affected by interaction with other vehicles within the traffic flow. Speed choice is affected by emergence of other vehicles, and drivers within the traffic flow should pay attention. The level of comfort is considerably lowered at this level of service.
D	Freedom is considerably limited in terms of both speed and steering freedom. The level of comfort felt by the driver goes down to an uncomfortable level. At this level, even a slight increase of traffic causes problems with the travel status
E	Severely limited freedom in steering within the traffic flow. Steering requires use of forceful means, such as yielding from other vehicles on the road. Even a slight increase of traffic or confusion causes total disruption
F	The volume of arrival traffic has exceeded the capacity of the point or section. At this state, vehicles show little movement and the road loses most of its functions

$$I_P = \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} \times (C_P - BP_{LO}) + I_{LO}$$

Here, I_p : Air index score of the target pollutant
C_p : Atmospheric concentrations of the target pollutant
BP_{HI} : The maximum contamination level of pollution zone
BP_{LO} : The minimum contamination level of pollution zone

I_{HI} : Value corresponding to the BP_{HI} (Interval maximum index value)

I_{LO} : Value corresponding to the BP_{LO} (Interval minimum index value)

As for road performance, level of service was used as the indicators that describe road traffic situation. This concept is used to describe road traffic situations in terms of travel speed, travel time, driving comfort and traffic safety, etc. The indicators are divided into 6 stages from A to F as shown in Table 6. The indicators for crossroads with traffic lights and urban arterial roads are divided into 8 stages of A-FFF.

3.2 Indicator 2 (Traffic Congestion Level and Time Value Costs)

Using speed, which is the most widely used linked traffic property, the level of traffic congestion and the resultant time value costs were calculated through the following stages, where time value costs refer to the value of time incurred by operation below the normal speed due to traffic congestion.

Stage 1 involves identification of the link property (or road grade), setting of the base speed in accordance with the base congestion speed corresponding to the property. The base congestion speed can be separately determined for different areas, cities, expressways, national highways and local roads.

Stage 2 involves collection of the data of the corresponding links among the speed values for each link, and compares them with the base congestion speed in Stage 1. When the speed value is higher than the base congestion speed, it is defined as 'smooth traffic.' If not, it is defined as 'congestion.'

Table 7: Set the reference speed congestion [10]

Divisions	Reference speed congestion
Regional road	· Expressway: 90km/h(More than 4 lanes), 75km/h(Less than 4 lanes) · National highway : 80km/h(More than 4 lanes), 70km/h(Less than 4 lanes) · Local road : 60km/h
Urban road	· 27km/h

Stage 3 calculates the ratio of congested links using the formula below, to express the levels of traffic congestion for each grid.

$$\text{Traffic congestion ratio}(\%) = \frac{\sum \text{Link length(light traffic)}}{\text{The number of links contained in the grid}}$$

Stage 4 calculates the time value loss costs using the following formula, to express time value loss costs for each scenario during the comprehensive analysis.

$$\text{Time value costs(won/veh)} = \frac{\text{Link length(km)} \times \text{Time value basic unit Load(won/person}\cdot\text{hr)}}{\text{The average travel speed(km/h)}} \times \frac{\text{Auto occupancy(person/veh)}}{\text{The average travel speed(km/h)}}$$

As for the time value loss costs expressed in the basic unit, they are classified by vehicle types as shown in Table 8, and the auto occupancy in the Seoul Metropolitan Area is classified by vehicle types as shown in Tables 8 and 9.

Table 8: Time value of money [10] (unit: won/person·hr)

Divisions	Business traffic	Non-business traffic
Car	19,569	6,700
Bus	18,565	4,859

Table 9: Auto Occupancy [11] (Unit: person/veh)

Regional	Car	Taxi	Car+taxi	Bus
Metropolitan Area	1.27	1.54	1.319	12.95

3.3 Indicator 3 (Environmental costs)

Environmental cost for each grid can be calculated using the travel distance (unit-km) and speed (km/h) depending on the traffic of vehicle types in each link. Environment costs are calculated by applying the basic unit of air pollutant cost depending on the speed, using the travel speed and traffic calculated for links within the grid in accordance with the scenario. In addition, the travel distance depending on the traffic (unit-km) refers to the traffic of each vehicle type multiplied with their travel distance, and the environmental cost of links within a grid is calculated by multiplying the travel distance depending on the traffic with the basic unit for air pollution for each vehicle type based on the average speed of the links.

$$\text{Environmental costs(won)} = \sum_{l} \sum_{k=1}^{3} (D_{lk} \times VT_k \times 365)$$

Here, D_{lk} = Link(l), Vehicle type(k), veh-km

VT_k = Air pollution cost per km about vehicle type(k) of link

k = Vehicle type (1: car, 2: bus, 3: vans)

3.4 Indicators Expression

Using the indicators defined above, the users or decision makers can arbitrarily set their areas of interest so that they can rapidly identify the comprehensive air environment index, time value loss costs and environment costs. For example, as shown in Fig 4, setting the areas where "LOS ≤ D" & "CAI ≤ D" as areas of interest, all areas corresponding to this setting are displayed at the same time.

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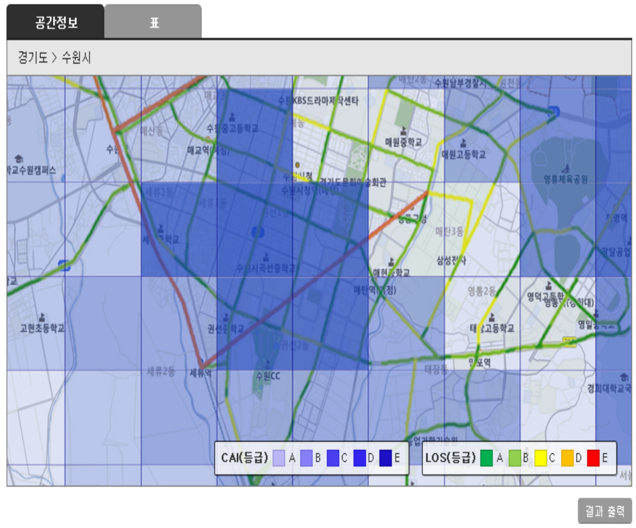

Fig 4: An example of setting interest

Such displays include expressways, urban and suburban arterial roads and 2-lane roads, to display the levels of service on each road. Table 10 shows the level of service on the basic sections of the expressways.

Table 10: Level of service (Expressway) [9]

Level of service	Density(pcpkmpl)	Design speed 120kph		Design speed 100kph		Design speed 80kph	
		Traffic (pcphpl)	V/c ratio	Traffic (pcphpl)	V/c ratio	Traffic (pcphpl)	V/c ratio
A	≤6	≤700	≤0.30	≤600	≤0.27	≤500	≤0.25
B	≤10	≤1,150	≤0.50	≤1,000	≤0.45	≤800	≤0.40
C	≤14	≤1,500	≤0.65	≤1,350	≤0.61	≤1,150	≤0.58
D	≤19	≤1,900	≤0.83	≤1,750	≤0.80	≤1,500	≤0.75
E	≤28	≤2,300	≤1.00	≤2.200	≤1.00	≤2,000	≤1.00
F	>28	-	-	-	-	-	-

4. DEVELOPMENT OF A PROTOTYPE

With the three indicators defined above, the following GIS-based prototype was developed. In particular, as shown in Fig 6, road performance evaluation was implemented for a comparison between scenarios by using indicators such as average speed, time value costs, environmental costs and CAI.

Fig 5: GIS-based prototype

Fig 6: Implementation Performance Evaluation about Urban Road

5. CONCLUSIONS AND FUTURE WORK

In this study, indicators for carbon-based road performance evaluation of urban roads were established through a review of domestic and international literature, and a prototype was developed. In addition, the comprehensive air quality index, time value costs and environmental costs were set as key indicators. It is expected that the results of carbon-based road performance evaluation presented in this study will be utilized as policy decision-making feedback for urban planning and thus used as reference data in modification and improvement of urban policy scenarios. For future work, there is a need to examine the applicability by selecting the actual test bed based on the prototype and conduct a research for its application to urban roads as well as local roads and other roads.

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