

Estimation of CO₂ Reduction Potential by Traffic-flow Smoothing and Eco-driving Promotion

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ABSTRACT

A case study was conducted by analyzing floating car data from throughout Japan to determine the CO₂ reduction potential due to traffic-flow smoothing and eco-driving promotion. The data used in this study is from hybrid cars equipped with Eco Assist, which has been reported in past studies to enhance fuel economy by approximately 10% as the number of driving times increases. First, multiple regression analysis was performed on the subject floating car data to obtain a polynomial with fuel economy as the explained variable and items related to traffic flow and eco-driving as the explanatory variables. The explanatory variables set the present distribution and the distribution under the assumed conditions of eco-driving promotion and smoothed traffic flow. These assumed conditions were applied to the polynomial to obtain the fuel economy frequency distributions for the present and assumed conditions, and the CO₂ reduction potential was calculated from the difference between the two. The assumed conditions were calculated to have a fuel economy enhancement potential of 18%, mainly due to traffic-flow smoothing. On the other hand, eco-driving was calculated to have fuel economy enhancement potential of 1% over and above the approximately 10% enhancement of Eco Assist. In addition, it was found that 2/3 of the CO₂ reduction potential was enhancement when driving at a travel speed of 30 km/h or less.

1. Introduction

In response to rising sentiment to reduce greenhouse gases and energy consumption, countries are strengthening fuel economy regulations in the passenger car sector. On the other hand, the importance of integrated approaches is being recognized in addition to enhancing the catalog fuel economy of individual cars. These approaches include diversification of fuels, promotion of efficient use such as eco-driving, traffic-flow smoothing, and other measures aimed at increasing fuel economy during actual driving.

The effects of lecture courses, virtual training systems, Eco Assist, aftermarket fuel economy meters, and other eco-driving aids have been individually evaluated, and fuel economy enhancement effects of 10% to 30% have been reported^{(1), (2)}. In addition, various fuel economy enhancement effects have also been reported for individual traffic-flow-smoothing measures such as changes to signal control, road construction, Intelligent Transport Systems (ITS), and Traffic Demand Management (TDM)⁽³⁾⁻⁽⁵⁾. However, these effects depend largely on traffic conditions, and little data could be obtained correlating overall traffic flow and fuel economy for Japan. For this reason, no studies

thus far have quantified the overall CO₂ reduction potential for Japan.

However, the authors analyzed driving data on public roads obtained from onboard GPS navigation systems that use wireless communication such as mobile phone lines, and calculated the CO₂ reduction potential under the assumed conditions of eco-driving promotion and smoothed traffic flow⁽⁶⁾.

In addition to calculating the CO₂ reduction potential, this study also analyzed this potential to clarify how cars should be used to achieve greater fuel economy enhancement and CO₂ reduction effects.

2. Overview of Analysis Subject Data

2.1. Analysis Subject Cars

This study analyzed the floating car data of hybrid cars. Table 1 shows the specifications of the subject hybrid cars. These cars are equipped with the Ecological Drive Assist System (Eco Assist).

Eco Assist consists of an ECON mode function that performs control with priority on fuel economy simply by pressing an ECON switch such as shown in Fig. 1,

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Table 1 Specifications of hybrid cars

Type	1.3L i-VTEC+IMA
Number of engine cylinders and layout	Inline-4
Max. engine output	65 kW
Motor type	Synchronous motor
Max. motor output	10 kW
Transmission	CVT
Vehicle weight	1130 - 1150 kg

a coaching function that displays whether fuel-efficient driving is being performed in real time using a meter such as shown in Fig. 2, and a teaching function that scores the driver's eco-driving level and gives advice such as shown in Fig. 3 and Fig. 4.

It has been reported⁽¹⁾, through analysis of the fuel economy data from 5000 cars for the half-year immediately after new car delivery, that Eco Assist provides fuel economy

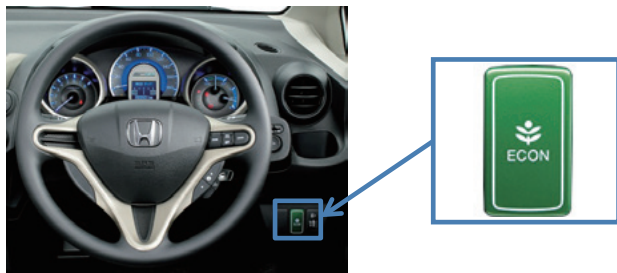


Fig. 1 ECON switch

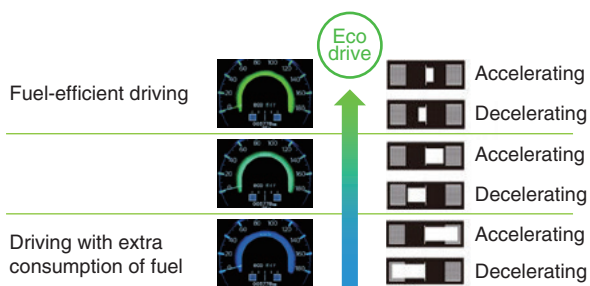


Fig. 2 Real-time fuel-efficient driving guidance at speedometer

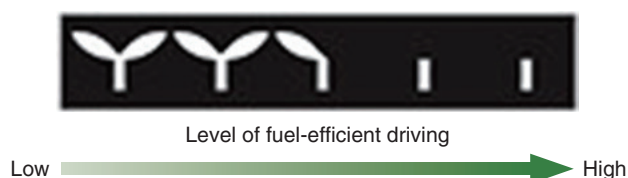


Fig. 3 Display scores current driving performance

enhancement effects of approximately 10% as shown in Fig. 5. This study calculated the additional CO₂ reduction potential due to eco-driving over and above this fuel economy enhancement of approximately 10% due to Eco Assist.

2.2. Floating Car Data

A traffic information system using floating car data (hereafter, “data”) commenced service from 2003. This system collects and processes link travel times for roads driven by members at the Internavi Information Center, and distributes link travel times to the GPS navigation systems of each member as per request to complement the Vehicle Information and Communication System (VICS) data and recommend the ideal route (Fig. 6).

In addition, fuel consumption amounts and other data are also transmitted from some members' cars to the Center



Fig. 4 Advice for enhancing fuel economy at Internavi system display

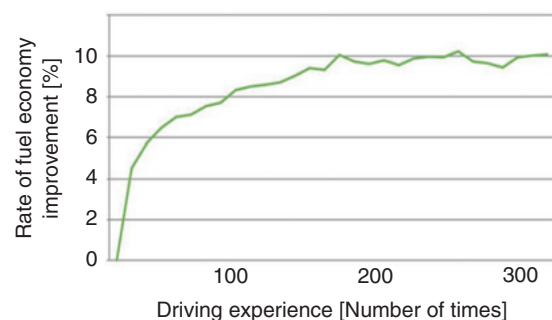


Fig. 5 Effect of fuel economy improvement due to the eco-assist system

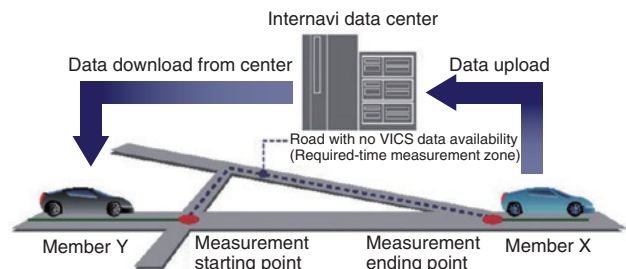


Fig. 6 Chart of floating car data traffic information system

where the data is analyzed to provide information such as fuel-saving routes to members.

The data uploaded from members comprised approximately 2 million km per day on weekdays and approximately 2.9 million km per day on weekends, and the cumulative distance exceeded approximately 1.8 billion km by the end of 2010. Figure 7 is a visualization of the data uploaded from members on August 15, 2009, and shows that data can be acquired from throughout Japan.

This study analyzed data comprising a total travel distance of 78.82 million km collected from hybrid cars throughout Japan from October 2010 to June 2011. The analyzed data consisted of various types of data acquired while driving, averaged in daily units such as the average fuel economy per day and average speed per day of each vehicle.

2.3. Relationship between Present Traffic Flow and Fuel Economy

Figure 8 shows the relationship between the average travel speed, fuel economy and driving amount obtained from the acquired data. Note that in this paper, fuel economy is expressed as a fuel economy index obtained by dividing each fuel economy value (L/km) by the overall average fuel economy γ (L/km).

The average travel speed in the data was 34.3 km/h, which is nearly the same as the average travel speed of 36.4 km/h during the 12-hour daytime period in the 2010 road traffic census, which is a survey conducted by the Ministry of Land, Infrastructure, Transport and Tourism every five years. However, the driving frequency was found

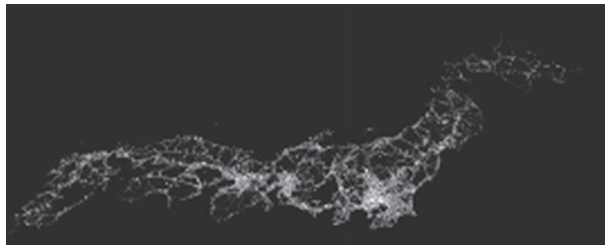


Fig. 7 Visualization of floating car data

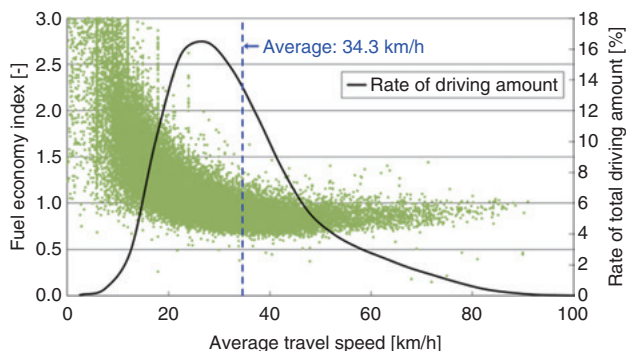


Fig. 8 Average travel speed and fuel economy index

to peak between 20 to 30 km/h instead of near the average travel speed.

In addition, the fuel economy index was also widely distributed, and exhibited higher values over a wider distribution as the travel speed decreased.

3. Method for Calculating CO₂ Reduction Potential

3.1. Overview of Calculation Method

The method of calculating the CO₂ reduction potential due to eco-driving promotion and traffic-flow smoothing, and the method for clarifying how cars should be used to achieve greater fuel economy enhancement and CO₂ reduction effects are described below.

3.1.1. Calculation of CO₂ reduction potential

This study calculated the potential for enhancing the average fuel economy, that is to say the CO₂ reduction potential, from the difference between the fuel economy distributions under the present and assumed conditions as shown in Fig. 9.

The fuel economy distributions under the present and assumed conditions were created by the following method (Fig. 10).

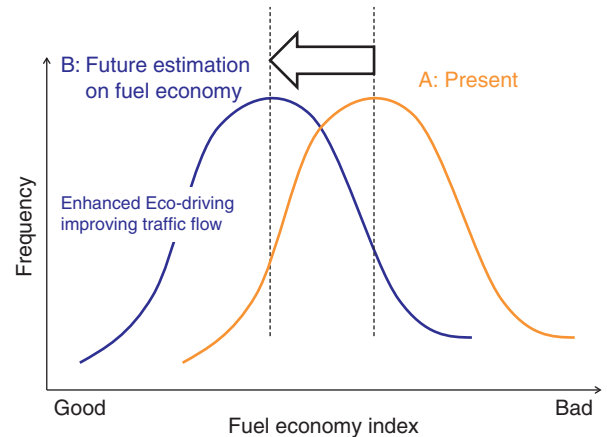


Fig. 9 How to estimate CO₂ reduction potential

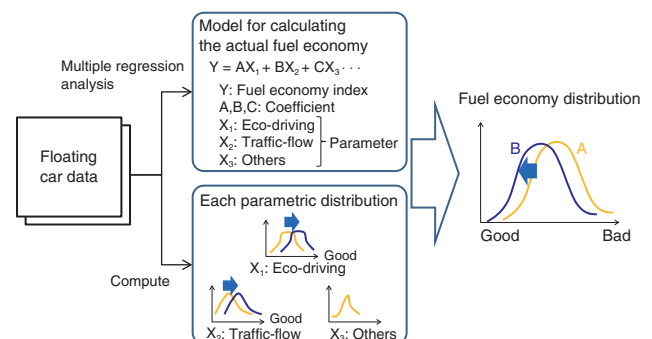


Fig. 10 How to estimate fuel economy distribution

Table 2 In-use fuel economy factors

Factors	Explanatory variable
Efficiency of engine and transmission	Average travel speed
Wasted heat from braking	Acceleration energy equivalent
Driver behavior	Eco-driving rating result
Warm up	Distance Outdoor temperature
Air conditioner	Outdoor temperature
Electricity load	Not adopted
Air pressure in a tire	Not adopted
Road surface, grade	Not adopted
Maintenance defects	Not adopted

- (1) Create an actual fuel economy calculation model that includes explanatory variables related to eco-driving and traffic flow by performing multiple regression analysis on the data.
- (2) Obtain the distributions of the explanatory variables related to eco-driving and traffic flow from the data.
- (3) Apply the distribution of each explanatory variable to the model, and calculate the present fuel economy distribution.
- (4) Set the distribution of each explanatory variable under the assumed conditions of eco-driving promotion and traffic-flow smoothing.
- (5) Apply the distribution of each explanatory variable to the model, and calculate the fuel economy distribution under the assumed conditions.

3.1.2. Method for calculating fuel economy enhancement and CO₂ reduction distributions

How cars should be used to achieve greater fuel economy enhancement and CO₂ reduction effects was clarified by graphing and analyzing the relationship between each explanatory variable related to eco-driving and traffic flow and the fuel economy enhancement rate and CO₂ reduction amount.

3.2. Creation of Actual Fuel Economy Calculation Model

Data extracted randomly from among the acquired data was analyzed and a multiple regression model that describes the fuel economy index Y was created.

The explanatory variables used were based on factors that may cause fuel economy to drop other than the test mode such as shown in Table 2. These explanatory variables were the reciprocal of the average travel speed τ [s/m], acceleration energy equivalent per unit length A [m/s²], eco-driving rating results P [pt: points], the reciprocal of the travel distance d [1/m], and the average daily temperature at the starting point T [C°]. Here, the acceleration energy equivalent is the sum total of subtracting the square of the initial speed when accelerating from the square of the arrival speed when accelerating, as described in the study by Oguchi et al.⁽⁷⁾ The eco-driving

rating results are the driver evaluation results according to the eco-driving index, as calculated by the Eco Assist mounted in the subject hybrid cars (Fig. 11). Note that in addition to the explanatory variables used, there are also other factors that may cause the actual fuel economy to drop, such as electrical load and tire air pressure, but these were not used for reasons of data acquisition.

3.3. Actual Fuel Economy Model

Equation (1) gives the model obtained by multiple regression analysis (multiple correlation coefficient $R = 0.88$, number of data $n = 914$).

$$Y = 0.62 + 10.3\tau + 0.97A - 1.6 \times 10^{-3}P - 7.6 \times 10^{-3}T + 212d \quad (1)$$

Some explanatory variables were not used for reasons of data acquisition, but an extremely high correlation coefficient could be obtained.

Figures 12 to 14 show the relationship between each explanatory variable related to traffic flow and eco-driving and the fuel economy index within the obtained model. Note that in these graphs, the average values are substituted for all other explanatory variables.

This shows that the fuel economy index decreases as the average travel speed increases (Fig. 12).

In addition, the fuel economy index also decreases as the acceleration energy equivalent per unit length decreases



Fig. 11 Vehicle onboard display for eco-driving rating results

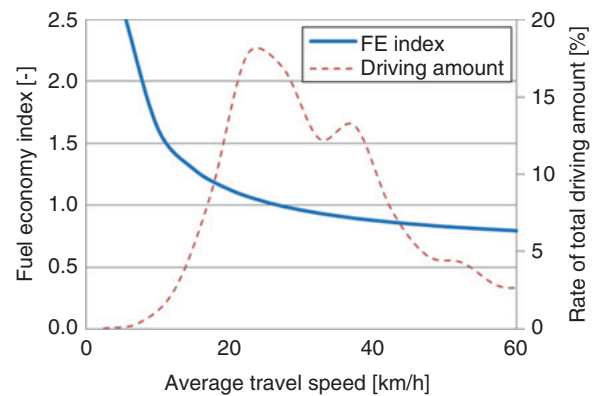


Fig. 12 Relation between average travel speed and fuel economy index for model

(Fig. 13). Furthermore, fuel economy is widely distributed relative to both the average travel speed and the acceleration energy equivalent per unit length, indicating that fuel economy may be increased by enhancing these factors.

On the other hand, the eco-driving rating results distribution is concentrated around a high score (Fig. 14). This is thought to be because the subject hybrid cars are equipped with Eco Assist, and the drivers providing the data have acquired high eco-driving skills.

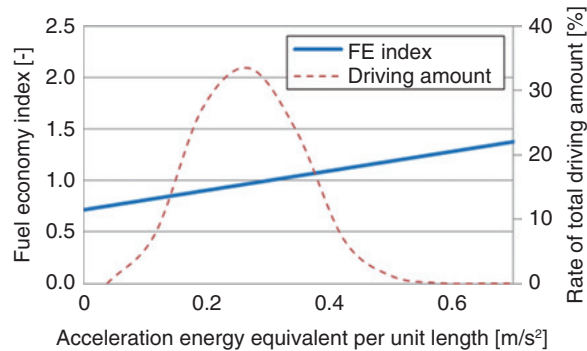


Fig. 13 Relation between acceleration energy equivalent per unit length and fuel economy index for model

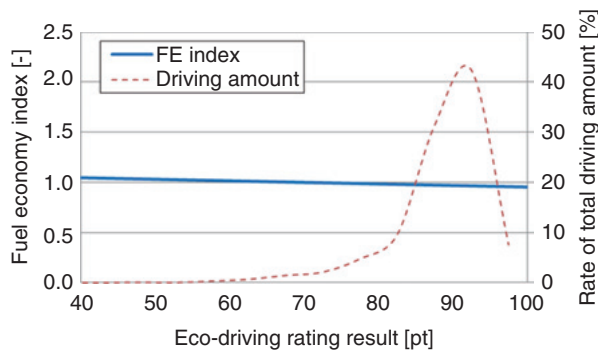


Fig. 14 Relation between eco-driving rating result and fuel economy index for model

4. Estimation of CO₂ Reduction Potential

A case study was performed to determine the potential for reducing CO₂ under conditions assuming traffic-flow smoothing and eco-driving promotion.

4.1. Assumed Conditions

The explanatory variables related to traffic flow and eco-driving used to change the distributions when performing the calculations were the reciprocal of the average travel speed τ , the acceleration energy equivalent per unit length A , and the eco-driving rating results P .

Note that the frequencies of the acceleration energy

equivalent per unit length and the eco-driving rating results are biased according to the travel speed range (Fig. 15, Fig. 16), so the frequency was changed for each travel speed range.

This study assumed that the frequency of the acceleration energy equivalent per unit length changes so that the current maximum value is the center value, and the frequency of the eco-driving rating results changes so that the minimum value is the center value, in each travel speed range (Fig. 17).

It is expected that these changes can be realized by measures such as the Green Wave Running Assistance System that enables drivers to reduce unnecessary

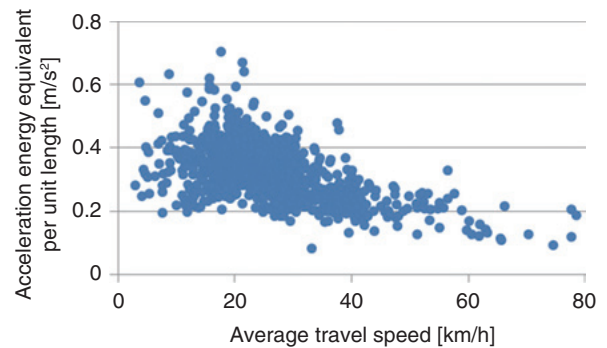


Fig. 15 Relation between average travel speed and acceleration energy equivalent

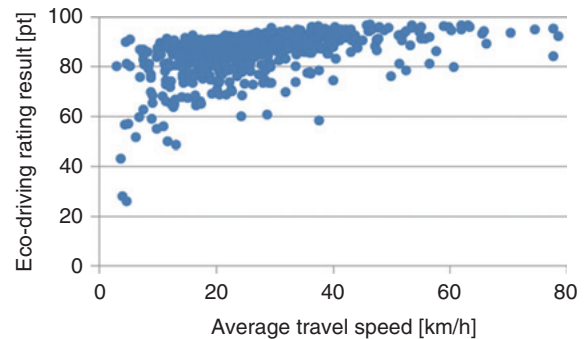


Fig. 16 Relation between average travel speed and eco-driving rating result

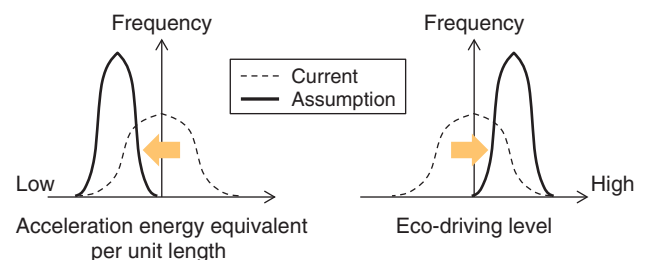


Fig. 17 Assumption for fuel economy improvement

Table 3 Travel-speed smoothing

Type	Effect
Profile signal control	10 km/h
Bypass road construction	6 km/h

acceleration and braking in accordance with signal information.

On the other hand, the references for the average travel speed were past cases of advanced signal control⁽³⁾ and road construction such as bypass road construction⁽⁴⁾ as shown in Table 3. The synergistic effects of the respective measures can also be estimated, but this study set a uniform increase of 10 km/h with an upper limit of 60 km/h.

4.2. Fuel Economy Estimation Results and CO₂ Reduction Potential

4.2.1. Traffic-flow smoothing

Figure 18 shows the change in the fuel economy distribution due to enhancing the acceleration energy equivalent per unit length and the travel speed, as calculated by the method described in section 3.1.1. The calculations showed that average fuel economy enhancement effects and CO₂ reduction potential of 8% could be realized by enhancing the acceleration energy equivalent per unit length, and 18% by also enhancing the travel speed.

4.2.2. Eco-driving

Likewise, the change in fuel economy due to enhancement of eco-driving rating results was also calculated by the method described in section 3.1.1. The subject hybrid cars are equipped with Eco Assist, and the results showed that additional fuel economy enhancement effects of 1% could be realized over and above the approximately 10% increase reported by Imai et al.⁽¹⁾

4.3. Fuel Economy Enhancement and CO₂ Reduction Distributions

The fuel economy enhancement and CO₂ reduction

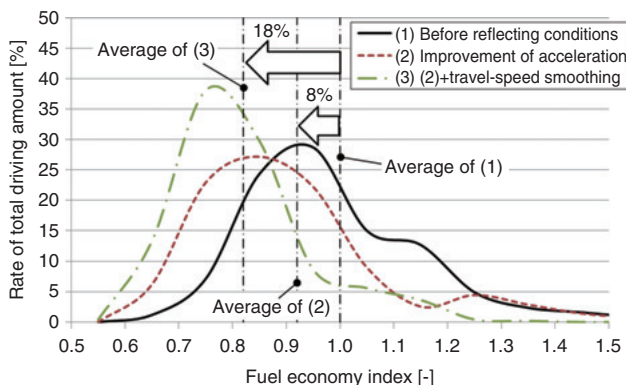


Fig. 18 Potential for fuel economy improvement

potential distributions under the assumed conditions were analyzed. The potential calculation results in section 4.2.2 indicate that eco-driving has a small effect, so the distribution was analyzed for traffic-flow smoothing, that is to say enhancement of acceleration energy equivalent per unit length and travel speed.

Figure 19 shows the distribution of fuel economy enhancement due to enhancement of acceleration energy equivalent per unit length and travel speed. Here, the data with a low average travel speed and high acceleration energy equivalent per unit length exhibits a large fuel economy enhancement width. In particular, effects equal to or greater than the average fuel economy enhancement rate of 18% calculated in section 4.2.1 can be confirmed from the data for 30 km/h or less.

On the other hand, Fig. 20 shows the breakdown by travel speed of the CO₂ reduction potential of 18% due to traffic-flow smoothing that takes into account the driving amount. This shows that the travel speed range of 30 km/h or less not only has a large fuel economy enhancement width, but also accounts for most of the driving distance (Fig. 8). As a result, this speed range accounts for 2/3 of the CO₂ reduction potential.

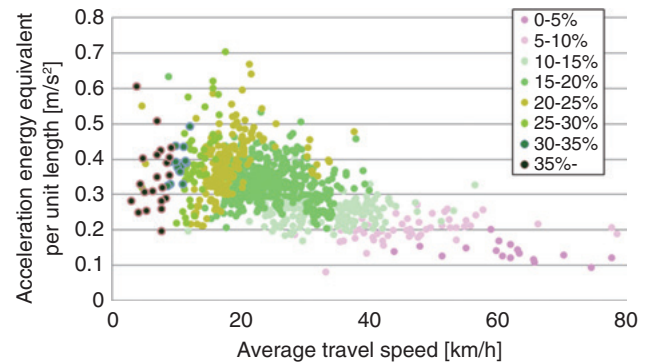
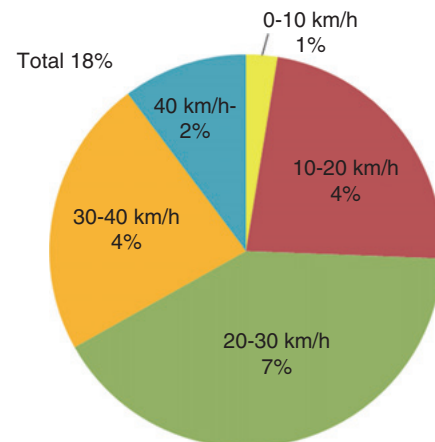


Fig. 19 Distribution of fuel economy improvement


 Fig. 20 Distribution of CO₂ reduction potential

5. Conclusion

This study obtained a polynomial that expresses a fuel economy index from floating car data, and attempted to calculate the CO₂ emissions reduction potential due to traffic-flow smoothing and eco-driving promotion under assumed conditions.

The results estimated a CO₂ reduction potential of 18% mainly due to traffic-flow smoothing. Past studies have reported Eco Assist effects of 10%, and eco-driving was calculated to have an additional CO₂ reduction potential of 1%.

In addition, the fuel economy enhancement rate and CO₂ reduction potential were found to be high at a travel speed of 30 km/h or less.

As shown above, the CO₂ reduction potential due to traffic-flow smoothing and eco-driving promotion under the assumed conditions was estimated and confirmed to have large expected effects. This indicates the importance of integrated approaches in addition to individual car measures, and also the importance of measures for areas with low travel speeds such as urban centers.

In addition to CO₂ reduction, traffic-flow smoothing and eco-driving promotion are also effective for shortening travel times and reducing fuel consumption. Therefore, it is hoped that methods for realizing the assumed conditions in this study will be investigated, and society-wide efforts made.

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