Design and Simulation Evaluation of EcoSmart Driving Control for City Traffic

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***Abstract*— Many traffic signals, intersections, and road signs on city roads result in waves of traffic flow. Fewer waves of traffic flow result in less congestion and reduced fuel consumption of vehicles. In order to ensure that trade and commerce in future are rapid, clean, and comfortable, it is essential to make city traffic smooth by EcoSmart driving. However, it is difficult to accomplish EcoSmart driving "for the benefit of all traffic," even if drivers can use the me-first EcoSmart driving system. A control system that automatically performs EcoSmart driving for the benefit of all traffic was designed in this study. The proposed system overcomes the aforementioned obstacles by combining algorithms that consider traffic signals, preceding vehicles, and traffic flow, respectively. Herein, the details of the proposed control system are explained and simulation evaluations are reported.**

Keywords-text; EcoSmart driving; vehicle control; intelligent transportation system; energy saving; platooning; intelligent driver model.

I. INTRODUCTION

Cities with increasing or dense populations are faced with the problem of increasing travel time between cities and air pollution caused by exhaust gases. Increasing populations in cities should be welcomed because it results in more economic activity. However, this also results in heavier traffic in the city. Traffic speed is closely related to economic activities. Therefore, a method to ensure smooth traffic flow should encourage stability in order to advance economic activities in cities sustainably.

Conventionally, traffic flow can be made smoother by focusing on incidental equipment improvements. Currently, though, this solution does not fulfill the needs to expedite economic activities, because the population of cities is rapidly increasing. For instance, in an intersection with less traffic, traffic can be controlled using a stop line as a substitute for a traffic signal. On the other hand, intersections with heavier traffic often use traffic signals to control traffic. Control using traffic signals can impede traffic if the cycle time of the traffic signals is inappropriate. Traffic usually fluctuates depending on time zones and seasons. If only stop lines are used or if the run time of green signals is short when the traffic is heavier, more congestion would occur and the traffic speed would be lowered. Longer cycle times of red signals, in spite of less traffic, cause excessive idling and slow traffic speed.

Slower traffic speed not only disturbs the economic activities, but also causes air pollution in cities. Moreover, increasing fuel consumption is a direct out-of-pocket cost. The cities with lesser traffic speed than other cities would eventually be deserted by the inhabitants, i.e., there would be an outflow of the population of the cities, causing them to lose their economic competitiveness. In other words, smooth traffic flow is vital for future cities.

This study focuses on improvements in self-driving as a next generation method to enhance traffic flow. Improvements in self-driving can be accomplished by driver education. However, it is extremely difficult to guarantee smooth traffic flow through better individual driving techniques. Driving techniques, which create a smooth traffic flow, require the reduction of all unnecessary acceleration/deceleration. This requires that drivers have less influence from traffic signals and the preceding vehicles by maintaining long vehicle-to-vehicle (V2V) distances. On the other hand, when a driver tries to create a greater V2V distance, it may become difficult for other drivers to maintain their V2V distances, because the vehicle consumes more traffic capacity. In other words, to reduce unnecessary acceleration/deceleration, a "me-first" driving paradigm is required, not one that involves driving "for the benefit of all traffic."

This study focuses on a driving system for the benefit of all traffic by vehicle control. The vehicle control proposed in this study solves two issues: reduction of unnecessary acceleration/deceleration and saving traffic capacity. The proposed driving control for city traffic is called EcoSmart driving control, because it saves energy by reducing unnecessary acceleration/deceleration.

The EcoSmart driving control proposed in this study considers traffic conditions that reduce unnecessary acceleration/deceleration and traffic flow based on platooning control, which saves traffic capacity. Figure 1 is a representation of the concept of EcoSmart driving control.

Many studies in which energy was saved by reducing unnecessary acceleration/deceleration were conducted [1-3]. A driving control system that saves energy by solving optimization problems using model predictive control was also produced [4]. In these studies, driving control was achieved by considering the preceding vehicles, traffic signals, and fuel consumption characteristics of the vehicle. The vehicle controls proposed in these studies use me-first EcoSmart driving. Hence, these systems are obviously

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different from that in this study in that they are not EcoSmart driving systems for the benefit of all traffic.

The EcoSmart driving control proposed in this study aims at EcoSmart driving for the benefit of all traffic by combining me-first EcoSmart driving and platooning control. The platooning control is used to clear congestion, reduce drivers' load, and save energy mainly for expressways. Various methods for platooning control have been proposed [5-9]. Generally, the shorter the maintained V2V distance, the greater the efficiency, in terms of clearing congestion and saving energy. Thus, in recent years, control technologies to maintain a few meters of V2V distance even in driving at high velocity were developed, e.g., California Partners for Advanced Transportation Technology (PATH) in America, Safe Road Train for the Environment (SARTRE) in Europe, and Energy ITS in Japan.

The proposed EcoSmart driving control saves traffic capacity by following the nearest preceding vehicle with a short V2V distance using platooning control, assuming the driver of the nearest preceding vehicle is driving with consideration of the traffic signals and preceding vehicles. The proposed EcoSmart driving control can switch the consideration for traffic conditions and platooning control. Thus, the driving control accomplishes both a margin for V2V distance that is not influenced by the preceding vehicle, which unnecessarily accelerates/decelerates, and saves traffic capacity.

In this paper, details of the EcoSmart driving control are explained and simulation evaluations are reported.

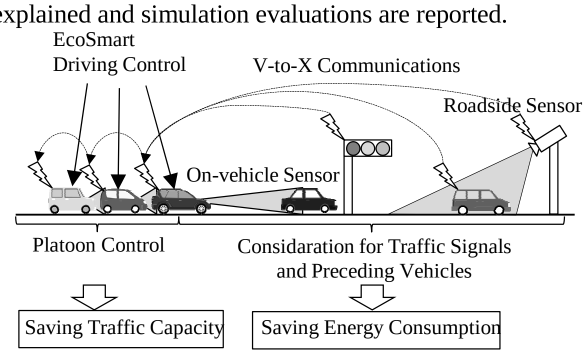

Figure 1. Concept of Proposed EcoSmart Driving Control.

II. ECOSMART DRIVING CONTROL FOR CITY TRAFFIC

This section describes the details of the proposed EcoSmart driving control system. In addition, the design approach for the EcoSmart driving control and its formulation are explained. Herein, the EcoSmart driving control is formulated not as an actual driving control, but for simulation and evaluation of traffic flow. EcoSmart driving control for actual driving requires several kinds of feedback controls in addition to the equations in this paper. The feedback controls are not explained in this paper, because their design is not within the focus of this study.

The EcoSmart driving control formulated in this study is based on an intelligent driver model (IDM). An IDM is simulates driving behaviors of an ordinary driver, considering the preceding vehicles and the traffic signals. An IDM is suitable for comparative evaluation with EcoSmart driving control.

EcoSmart driving control based on an IDM incorporates free road behavior, vehicle consideration behavior, traffic signal consideration behavior, and platooning behavior.

A. Free Road Behavior

The free road behavior simulates driving in a situation with no traffic signals and no preceding vehicles. The equation to calculate target acceleration for free road behavior is shown below:

$$\dot{v}_{t\_b} = \frac{dv_{t\_b}}{dt} = a\left[1 - \left(\frac{v}{v_d}\right)^{\delta}\right], \tag{1}$$

where $\dot{v}_{t\_b}$ is the target acceleration for free road behavior, v is velocity of the vehicle, v_d represents the fixed target velocity of the driver, a is a model parameter of acceleration with efficient fuel consumption, and δ is a model parameter of acceleration exponent.

In a general approach, fuel consumption characteristics of the vehicle are considered in order to accomplish EcoSmart driving control, where no signals and other vehicles are on the road. This study does not consider the fuel consumption characteristics of the vehicle for two reasons: one is that it would result in me-first EcoSmart driving, and the other is that the optimization problem of consideration of fuel consumption characteristics of the vehicle explosively increases calculation costs of the traffic flow simulator.

If no traffic signals and other vehicles are on the road, a driving style that minimizes fuel consumption of the vehicle will also minimize fuel consumption of all the traffic. However, if there are vehicles following the controlled vehicle, and if the fuel consumption characteristics of these vehicles are largely different from those of the controlled vehicle, their fuel consumption would increase. Hence, on city roads where several vehicles are operating, the driving style that considers the fuel consumption characteristics of the vehicle is the me-first EcoSmart driving style.

For the benefit of all the traffic, the average fuel consumption characteristics of the vehicles on the road should be primarily considered, rather than those of the vehicle itself. It is desirable that the average fuel consumption characteristics be calculated using V2V communication. However, on normal city streets, consideration of the preceding vehicles and traffic signals reduces fuel consumption far more than focusing on fuel consumption characteristics of the engine. Thus in this study, each model parameter of the free road behavior is set to the average value of the fuel consumption of the engines of ordinary vehicles, and online changes of the characteristics are not made.

B. Vehicle Consideration Behavior

The vehicle consideration behavior simulates driving in a situation with preceding vehicles. Equations to calculate the

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target acceleration for the vehicle consideration behavior are shown in (2) and (3):

$$\dot{v}_{t\_f} = \frac{dv_{t\_f}}{dt} = \begin{cases} a\left[1-\left(\dfrac{v}{v_{t\_f}}\right)^{\delta}\right] & \left(v \le v_{t\_f}\right) \\ -a\left(\dfrac{s_f^{*}\left(v, \quad \Delta v_{f\_\min}\right)}{s_l}\right)^{2} & \left(v > v_{t\_f}\right) \end{cases} \qquad (2)$$

$$s_f^{*}\left(v, \quad \Delta v_{f\_\min}\right) = s_0 + \max\left[0, \quad \left(vT + \frac{v\Delta v_{f\_\min}}{2\sqrt{ab}}\right)\right], \qquad (3)$$

where s_0 is a model parameter, which determines the minimum desired gap. This behavior does not make the V2V distance shorter than s_0. s_l is the V2V distance between the vehicle and the nearest preceding vehicle in the same lane. T is a model parameter that determines the desired time headway. b is a model parameter that determines the comfortable braking deceleration. $v_{f\_\min}$ is the minimum velocity of the preceding vehicles in the same lane, which can be observed using the vehicle's sensor.

Figure 2 shows an example calculating $v_{f\_\min}$. Figure 2-A shows an example of a vehicle, whose speed is 30 km/h, but its driver's desired speed is 60 km/h. The vehicle observes vehicle A, which is driving at 50 km/h. It is not reasonable that the vehicle accelerates to more than 50 km/h. $v_{f\_\min}$ is thus set to 50 km/h.

Figure 2-B illustrates that the vehicle observed vehicle B in addition to the condition of Figure 2-A. Vehicle B is driving at 60 km/h. However, because vehicle A is driving at 50 km/h, it is not reasonable that the vehicle accelerates above 50 km/h. Then, $v_{f\_\min}$ is set to 50 km/h.

Figure 2-C shows that the vehicle observed vehicle C in addition to the condition of Figure 2-B. Since vehicle C is driving at 40 km/h, vehicle A and B are predicted to catch up to vehicle C, and decelerate to 40 km/h. In other words, it is not practical for the vehicle to accelerate to more than 40 km/h. Then, $v_{f\_\min}$ is set to 40 km/h.

The design approach of the EcoSmart driving, which considers the preceding vehicles, is that the vehicle drives at the minimum velocity of all the preceding vehicles in the same lane. A vehicle control that considers the preceding vehicles is generally a following control such as an adaptive cruise control (ACC). However, if the V2V distance increases, the following control ignores the ecological driving, in order to maintain its target V2V distance. Also, the following control is not directly EcoSmart driving, because the control transfers unnecessary acceleration/deceleration of the preceding vehicle to the vehicle. Especially, in the following control of ACC, of which the string stability is not fulfilled, unnecessary acceleration/deceleration of the preceding vehicle is transferred to the vehicle with amplification, thus the following control should not be applied for EcoSmart driving.

The proposed vehicle consideration behavior of EcoSmart driving control deals the V2V distance between the vehicle and the preceding vehicle as margin for ecological driving. This control never allows acceleration to higher velocity than that of the preceding vehicles in the same lane. Driving at a higher velocity than the preceding vehicle not only spoils the margin of V2V distance for ecological driving, but also yields unnecessary acceleration/deceleration. On the other hand, if a preceding vehicle driving at a lower speed than the vehicle emerges, the vehicle consumes its V2V distance for ecological driving, using most of its ecological means (e.g., reducing fuel consumption and using regenerative braking) according to the vehicle consideration behavior.

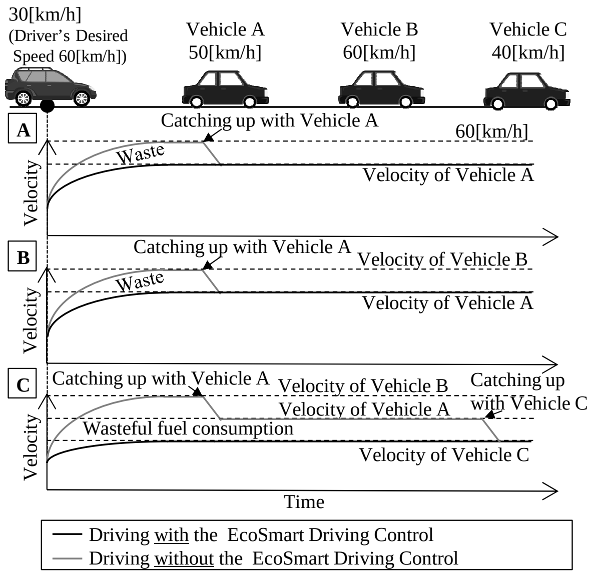

Figure 2. Consideration for Preceding Vehicles

C. *Traffic Signal Consideration Behavior*

The traffic signal consideration behavior simulates driving where traffic signals are on the road. Equations to calculate target accelerations of the traffic signal consideration behavior $\dot{v}_{t\_s}$ is as follows.

$$\dot{v}_{t\_s} = \frac{dv_{t\_s}}{dt} = \begin{cases} a\left[1-\left(\dfrac{v}{v_{t\_s}}\right)^{\delta}\right] & \left(v \le v_{t\_f}\right) \\ \min\left[-b\left[1-\left(\dfrac{v_{t\_s}}{v}\right)^{\delta}\right], \quad \dot{v}_{s\_safe}\right] & \left(v > v_{t\_f}\right) \end{cases}, \qquad (4)$$

$$\dot{v}_{s\_safe} = \frac{dv_{s\_safe}}{dt} = \begin{cases} \infty & (\text{signal is green}) \\ -a\left(\dfrac{s_s^{*}(v)}{s_s}\right) & (\text{signal is red}) \end{cases}, \qquad (5)$$

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$$s_s^*(v) = s_0 + \max\left[0,\ \left(vT + \frac{v^2}{2\sqrt{ab}}\right)\right], \qquad (6)$$

where $\dot{v}_{s\_safe}$ determines a limit acceleration in order to stop safely in case the preceding traffic signal is yellow or red. v_{t_s} is the target velocity to drive in accordance with the timing of green light of the traffic signals, with no unnecessary acceleration/deceleration. Here, the traffic signals are observed using sensors on the vehicle or via communication.

Figure 3 illustrates examples calculating v_{t_s}. Figure 3-A shows an example of the vehicle, which is driving at 30 km/h but the driver's desired speed is 60 km/h. The vehicle observes signal A. First, the vehicle estimates the arriving time at signal A. The vehicle has light timing data for signal A; it is not reasonable that the vehicle accelerates to higher speed allowing the vehicle to arrive at signal A before its timing of green light. Thus, the target arrival time at signal A is set to just after signal A turns to green. Then v_{t_s} is calculated from characteristics of the free road behavior and the vehicle consideration behavior.

Figure 3-B illustrates that the vehicle observed signal B in addition to the conditions of Figure 3-A. The vehicle estimates the arrival time at signal B. As the vehicle has the light timing data of signal B, it is not rational for the vehicle to accelerate to higher velocity making the vehicle arrives at signal A before its timing of green light. Thus, the targeted arrival time at signals A and B is set to just after signals A and B turn green, respectively. Then v_{t_s} is calculated from characteristics of both the free road behavior and the vehicle consideration behavior.

Figure 3-C shows that the vehicle observed signal C in addition to the conditions of Figure 3-B. The vehicle estimates the arrival time at signal C, from the target arrival time at signals A and B, calculated in Figure 3-B. As the vehicle has the light timing data of signal C, arriving at signals A and B at their target arrival times causes unnecessary acceleration/deceleration of the vehicle. Thus the target arrival times of signals A and B is set to any time in the green light period of each signal, and the target arrival time of signal C is set to just after it turns green. Then v_{t_s} is calculated from characteristics of the free road behavior and the vehicle consideration behavior.

Figure 3-D shows that the vehicle observed signal D in addition to the conditions of Figure 3-C. The vehicle estimates the arrival time at signal D, from the target arrival time at signal C, calculated in Figure 3-C. As the vehicle has the light timing data of signal D, arriving at signal C at its target arrival time causes unnecessary acceleration/deceleration of the vehicle. Also, if the target arrival time at signal C is set to just before it turns red, a deceleration is also needed in order to pass the signal D just after signal D turns green. Thus, the target arrival times of signals A and B are set to any time during green light phase of each signal, and the target arrival time of signal C is set to just before it turns yellow. Then v_{t_s} is calculated from characteristics of the free road behavior and the vehicle consideration behavior.

If the aforementioned process is calculated with updated information of the preceding vehicles and the traffic signals, the vehicle can drive reducing unnecessary acceleration/deceleration. As it would cause accidents to pass traffic signals during color transition, the target arriving time should consider of safety margin.

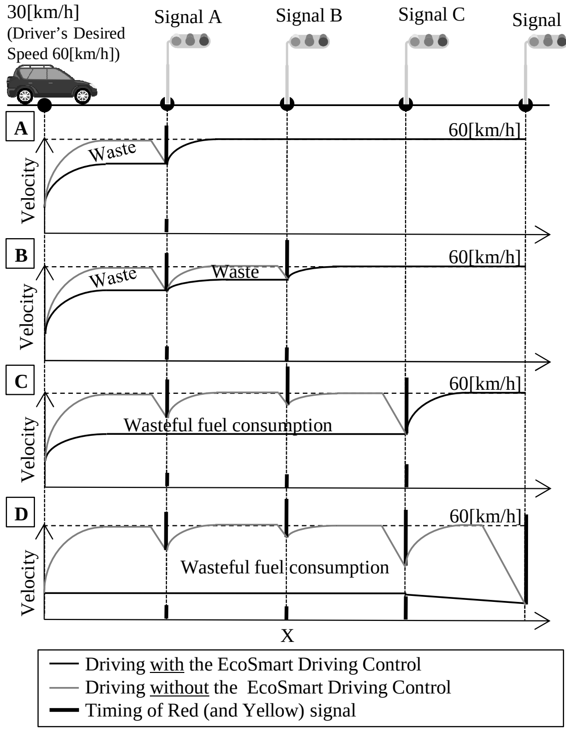

Figure 3. Consideration for Traffic Signals

D. Platooning Behavior

The platooning behavior simulates a driving condition where the preceding vehicles are driving under EcoSmart driving control. The equation to calculate target acceleration of the platooning behavior $\dot{v}_{t\_p}$ is shown below:

$$\dot{v}_{t\_p} = \frac{dv_{t\_p}}{dt} = \begin{cases} \infty & (\text{NOT EcoSmart}) \\ \dot{v}_l & (\text{Eco Smart} \ \& \ s_l \le s_{t\_p}) \end{cases}, \qquad (7)$$

where $\dot{v}_l$ is current target acceleration of the nearest preceding vehicle. s_{t_p} is the target V2V distance of the platooning control.

In addition to the equation, in case the nearest preceding vehicle is driving under EcoSmart driving control, a change is added to the vehicle consideration behavior. The equations to calculate $v_{f\_\min}$ of the vehicle consideration behavior are altered as shown below:

$$\dot{v}_{t\_f} = \frac{dv_{t\_f}}{dt} = \begin{cases} a\left[1-\left(\frac{v}{v_l}\right)^{\delta}\right] & (v \le v_l) \\ -a\left(\frac{s_f^*(v, \quad \Delta v_{f\_\min})}{s_l}\right)^2 & (v > v_l) \end{cases} \quad (2)'$$

$$s_f^*(v, \quad \Delta v_{f\_\min}) = s_{t\_p} + \max\left[0, \quad \left(\frac{v\Delta v_l}{2\sqrt{ab}}\right)\right] \quad (3)'$$

These equations enable a narrow V2V distance necessary to execute the platoon behavior.

The platooning behavior simulates the platooning control, which maintains V2V distances at a constant value, by setting the acceleration of the vehicle to match that of the nearest preceding vehicle.

When a vehicle group is formed, with each vehicle under EcoSmart control, only the lead vehicle considers traffic conditions, and the following vehicles exhibit platooning behavior. In this way, the traffic capacity consumed by the lead vehicle can be compensated for. In addition, if the percentage of vehicles under EcoSmart driving control increases in a lane, the average traffic capacity consumption per vehicle decreases compared to the situation with no vehicles under EcoSmart control driving in the lane. Hence, EcoSmart driving control would clear traffic congestion. With the traffic congestion cleared, the efficiency of the traffic condition considerations, performed by the lead vehicle of the group under EcoSmart control, is enhanced. Thus, more ecological driving is achieved. In other words, EcoSmart Driving control proposed in this paper has a possibility to generate an ecological progression.

E. Integration of the Behaviors

A target acceleration is selected from the target accelerations calculated for the aforementioned behaviors. The equation to calculate the final target acceleration $\dot{v}_t$ is as follows:

$$\dot{v} = \min\left[\dot{v}_{t\_b} \quad \dot{v}_{t\_f} \quad \dot{v}_{t\_s}\right]. \quad (8)$$

The final target acceleration $\dot{v}_t$ is set to the minimum value of the target accelerations of all the behaviors.

In this study, the proposed EcoSmart driving control is evaluated using a traffic flow simulator. In the simulator, the statuses of all the simulated vehicles are determined according to the equations as follows.

$$v(t+\Delta t) = v(t) + \dot{v}\Delta t \,, \quad (9)$$

$$x(t+\Delta t) = x(t) + v(t)\Delta t + \frac{1}{2}\dot{v}(\Delta t)^2 \,, \quad (10)$$

$$s_l(t+\Delta t) = x_l(t+\Delta t) - x(t+\Delta t) - L_l \,, \quad (11)$$

$$s_s(t+\Delta t) = x_s(t+\Delta t) - x(t+\Delta t) \,, \quad (12)$$

where Δt is a calculation interval of vehicles modeled in the traffic flow simulation. s_l and s_s are V2V distances between the vehicle and the nearest preceding vehicle, and between the vehicle and the preceding traffic signal, respectively. x_l, x_s, and x represent the positions of the nearest preceding vehicle, the preceding signal, and the vehicle, respectively. L_l is the length of the nearest preceding vehicle.

III. SIMULATION EVALUATION

In this study, the aforementioned EcoSmart driving control was evaluated using a traffic flow simulator. This paper reports the following four simulation condition evaluations and results: a) evaluation of the efficiency of the vehicle consideration, b) evaluation of the efficiency of the traffic signal consideration, c) evaluation of platooning behavior, and d) evaluation of the efficiency of the whole EcoSmart driving control.

Simulation conditions, except for evaluation on the efficiency of the whole EcoSmart driving control, are evaluated in the simulator, which simulates a straight road with an infinite length. Only the evaluation on the efficiency of the whole EcoSmart driving control is simulated in the ring road, which is 2 km per lap. These roads have one-way traffic, single-lane, and flat. There is no inflow/outflow of vehicles anywhere on the roads. The traffic signal position is stable.

The vehicle model in the traffic flow simulator has each vehicle under EcoSmart driving control or vehicle with an IDM. The model parameters of the EcoSmart driving control and IDM are set to the common values for the vehicles. All the vehicles have the same fuel consumption characteristics map, which simulates a D-segment car equipped with a 150 kW reciprocating engine. The fuel consumption per interval is calculated based on the map.

A. Evaluation of Efficiency of the Vehicles Consideration

In this evaluation, three vehicles drive in order of A, B, and C on the road. Vehicle A drives at 40 km/h of initial velocity, and at 40 km/h of target velocity, with an IDM. Vehicle B drives at 50 km/h of initial velocity, and at 50 km/h of target velocity, with an IDM. Vehicle C drives at 50 km/h of initial velocity, and at 60 km/h of target velocity. Vehicle C is driven with an IDM and, for comparative evaluation, under EcoSmart driving control. The initial position of the vehicles have vehicle B at 200 m preceding vehicle C, and vehicle A is 400 m ahead of vehicle C. There are no traffic signals are on the road.

Figure 4 shows the fuel consumption and velocity of vehicle C plotted against mileage. The result shows that the proposed EcoSmart control targets the velocity of vehicle A and starts to decelerate by running on inertia early on. In this way, vehicle C reduces unnecessary acceleration and results in improved overall fuel efficiency.

The results reveal that the vehicle consideration in EcoSmart driving control yields a reduction in unnecessary acceleration/deceleration and that leads to a reduction in fuel consumption.

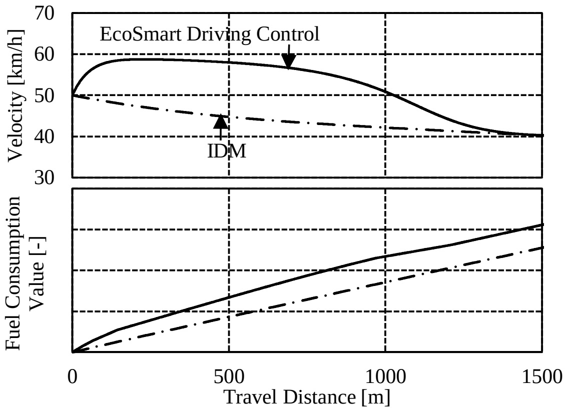

Figure 4. Simulation Result

B. Evaluation of Efficiency of the Traffic Signal Consideration

This evaluation consists of a vehicle and a traffic signal. The initial velocity of the vehicle is 30 km/h, and the target velocity is 60 km/h. For comparative evaluation, the vehicle drives with an IDM and under EcoSmart driving control. The signal is initially red, and it turns green after 35 s. The signal is 300 m ahead of the vehicle at the start time. EcoSmart driving control is shared the light timing of the traffic signal.

Figure 5 shows the resultant fuel consumption and velocity of vehicle C plotted against mileage. The results show that EcoSmart driving control considers the turning timing of the signal, and gently accelerates in order to not decelerate at a red light. In this way, the vehicle reduces unnecessary acceleration and results in improved overall fuel efficiency.

The results demonstrate that the traffic signal consideration in EcoSmart driving control yields a reduction of unnecessary acceleration/deceleration, which leads to a reduction in fuel consumption.

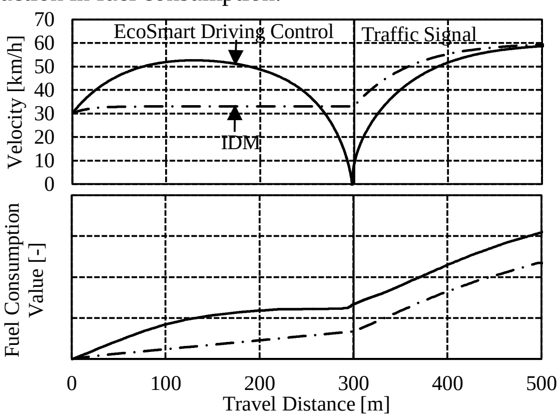

Figure 5. Simulation Result

C. Evaluation of Platooning Behavior

This evaluation consists of three vehicles driving in order of A, B, and C and a traffic signal. The initial velocity of vehicle A is 30 km/h, and the target velocity is 60 km/h, driving with an IDM. The initial velocities of vehicles B and C are 30 km/h, and the target velocities are 60 km/h, driving under EcoSmart driving control. The initial state of the signal is a red light, and it turns to green after 35 s. The initial position of the vehicles is as follows: vehicle B is 200 m ahead of vehicle C and vehicle A is 400 m ahead of vehicle C. The signal is 700 m ahead of vehicle C at the start time. EcoSmart driving control is shared the light timing of the traffic signal.

Figure 6 shows a graph of the velocities and control states of vehicles B and C plotted against mileage. The result shows that vehicle A decelerates and stops because of the red light, and then vehicle B decelerates. Also, vehicle C approaches vehicle B in accordance with the timing of vehicle B’s deceleration, and then the platooning control is enabled. In addition, when vehicle B accelerates, vehicle C follows at the same velocity.

The result shows that platooning behavior in EcoSmart driving control precisely reproduces the platooning control.

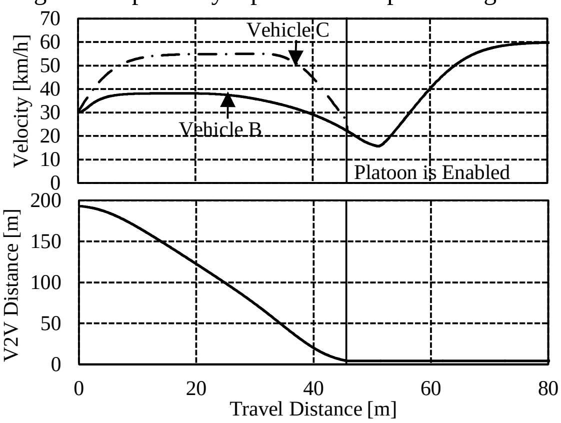

Figure 6. Simulation Result

D. Evaluation of Efficiency of the Whole EcoSmart Driving Control

This evaluation simulates a ring road, which is 2 km per lap. There are 50 vehicles every 100 m, and 10 traffic signals every 500 m on the road. The initial velocities of all the vehicles are 0 km/h, with target velocities of 60 km/h. 30% of the vehicles are under EcoSmart driving control, and the remaining 70% are driving with an IDM. The decision of which control is applied to each vehicle is determined randomly in each experimental run. The light timing of the traffic signals is set in normal random numbers in each experiment, based on statistical information of light timing of traffic signals on average city roads in Japan. An EcoSmart driving control system can obtain the velocity of preceding vehicles up to 400 m ahead and the light timing of the preceding three traffic signals. An experimental run is completed with all the vehicles covering 10 km, and the experiment is repeated 100 times. The average fuel consumptions and the average velocities are recorded in every test. For comparative evaluation, EcoSmart driving control can switch, i.e., enable/disable, the platooning behavior.

Figure 7 shows the fluctuation percentage of average velocity and fuel consumption for all traffic. The fluctuation percentage is calculated in as follows; the value of all the traffic, with no vehicles under EcoSmart driving control, is divided into that of the value where vehicles under EcoSmart driving control are driving on the road. The result shows that both EcoSmart driving control without platooning behavior and EcoSmart driving control with platooning behavior reduce fuel consumption for all the traffic. However, the platooning behavior also reduces the average traffic velocity of all the traffic. That is mainly because EcoSmart driving control without platooning behavior reduced fuel consumption by decreasing the traffic velocity. In other words, if the percentage of EcoSmart driving control without platooning behavior increases, traffic congestion would be generated, and that influences all traffic.

The results show that the EcoSmart driving control proposed in this study reduces fuel consumption of all the traffic, saving traffic capacity, and that the control performs with higher efficiency than other vehicle controls in related studies.

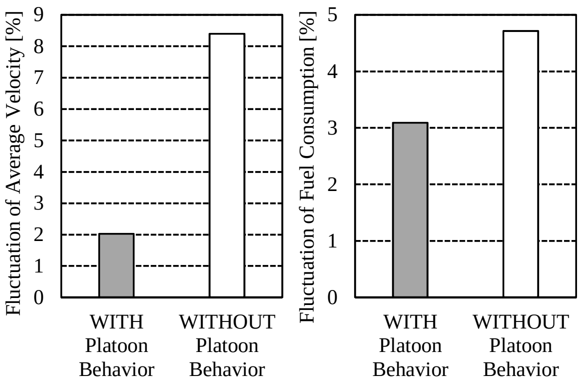

Figure 7. Simulation Result

IV. CONCLUSION AND FUTURE WORK

In this study, we developed EcoSmart driving control in order to enhance the efficiency of city traffic.

First, the importance of efficiency of city traffic in future cities is explained. Driving needs to be improved in order for the efficiency of city traffic in future cities to be enhanced. This requires a driving control system. The related studies would negatively influence traffic flow.

Then, the details of EcoSmart driving control proposed in this study are described. EcoSmart driving control consists of the free road behavior, vehicle consideration behavior, the traffic signal consideration behavior, and platooning behavior. Each behavior is formulated, and the objective is explained.

Next, a simulation evaluation of EcoSmart driving control is reported. Evaluations are conducted based on the following conditions: a) efficiency of vehicle consideration, b) efficiency of traffic signal consideration, c) platooning behavior, and d) efficiency of the whole EcoSmart driving control system. All the evaluation results show that EcoSmart driving control can reduce fuel consumption in traffic while saving traffic capacity.

Our future work is on system development for application to actual vehicles, and on driving evaluation.

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