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Procedia Social and Behavioral Sciences

Procedia - Social and Behavioral Sciences 111 (2014) 1015 – 1024

EWGT2013 – 16th Meeting of the EURO Working Group on Transportation

Effect of Information Provision around Signalized Intersection on Reduction of CO_2 Emission from Vehicles

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Abstract

Unnecessary vehicle movements such as rapid acceleration/deceleration and long idling periods occur around signalized intersections, especially in urban areas. It is believed that such unnecessary vehicle movements can be reduced by providing appropriate information. Actual vehicle movements should be understood before providing such information or developing an information provision system. Thus, we observed actual vehicle movements approaching a signalized intersection and then simulated the vehicle movements with a microscopic traffic flow simulation based on the observed vehicle movements. To estimate the quantity of CO_2 emitted from vehicles, each vehicle movement was analyzed by the microscopic simulation when the information was provided. The results showed that the information provided can reduce the amount of CO_2 emissions. However, it also showed that it is possible that CO_2 emissions are increased at higher traffic volumes.

Keywords: Traffic signal; Intersection; Information provision; CO_2; Vehicle movement.

1. Introduction

The short distances between intersections and the presence of long signal cycles are characteristics of the road traffic situation in Japan. These characteristics may cause traffic congestion and lead to unnecessary vehicle movements such as rapid acceleration/deceleration and long idling times around signalized intersections. To mitigate these traffic conditions, providing information to drivers about traffic conditions or signal states may be an effective solution. In particular, it is expected that prior information regarding signal changes is provided worldwide. When a traffic signal is green, drivers approaching a signalized intersection naturally maintain their driving speed. When the signal changes from green to amber and red, drivers near the intersection rapidly

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doi:10.1016/j.sbspro.2014.01.136

decelerate before coming to a stop. Consequently, both the idling time and CO_2 emissions are increased. If drivers were to be informed of the signal change prior to the change from green to amber and red, they would be able to decelerate in advance and reduce their idling time at the intersection. Conversely, when a signal is red, drivers maintain their driving speed and decelerate to a stop near the intersection. However, if drivers know in advance when the signal ahead would change from red to green, they would be able to decelerate at just the right speed to enable them to pass through the intersection at a lower speed, hence preventing them from stopping and idling at the intersection. More efficient vehicle movements therefore lead to reductions in CO_2 emissions from vehicles at signalized intersections.

The availability of signal change information to drivers approaching a signalized intersection is effective in improving vehicle movements. In some countries, signal information is currently communicated to drivers using a countdown signal and pre-information on the signal change to green. However, such information is provided for other purposes such as reducing the stress of waiting drivers and increasing the capacity of the intersection, rather than for reducing CO_2 emissions.

In this study, information regarding signal change is provided to drivers approaching a signalized intersection. Drivers change their driving behavior when they receive the information. Changes in the vehicle movements begin far from the signalized intersection. Therefore, in order to evaluate the effect of the provided signal change information, vehicle movements approaching a signalized intersection must be obtained and analyzed.

Vehicle movements under conditions where the signal information is available have been observed in several studies. A green signal countdown device (GSCD) was installed onto a signalized intersection in Singapore (Lum and Halim 2006). The GSCD, which is set beside a traffic signal, shows drivers a countdown of the remaining time for which the signal will be green. The installation of the GSCD was found to significantly reduce the occurrence of red-light running violations. However, it was found that the effects of a GSCD do not last long. Furthermore, their study observed only vehicle movements near to the front and back of a line of stopped vehicles.

The impact of the Co-operative Systems for Intelligent Road Safety (COOPERS), which is an infrastructure-to-vehicle co-operative system for drivers, has been investigated in five countries: Germany, Austria, Italy, France, and the Netherlands (Farah et al. 2012). COOPERS services are expected to improve traffic safety by providing an early warning of risky traffic conditions such as accidents, traffic congestion, and adverse weather conditions. The results in terms of speeds, following gaps, and physiological measurements indicate that there has been a positive impact. Furthermore, driver feedback indicates that the system is generally acceptable and useful.

Traffic signals in Bangkok typically utilize a long cycle length, and the lengthy signal cycle causes stress among drivers and serious traffic congestion (Limanond et al. 2010). As a countermeasure, over 400 signal countdown systems were installed at signalized intersections. An opinion survey was conducted on more than 300 regular local drivers who are familiar with the system. More than half of the surveyed local drivers reported that the countdown timers have helped to relieve the frustration caused by having to stop for unknown lengths of time during red lights.

The Deceleration Support System (DSS) was designed to reduce fuel consumption by encouraging drivers to release the accelerator pedal earlier at a red signal and to stop safely without hesitation at an amber signal (Iwata et al. 2012). The implementation of the DSS led to a reduction in CO_2 emissions by more than 7%, and had an almost negligible effect on travel times.

These studies suggest that the signal information effectively changes drivers' behaviors, and it is possible to reduce the amount of CO_2 emissions from vehicles approaching signalized intersections. We therefore aim to estimate the CO_2 emission reduction resulting from providing information to drivers using a microscopic traffic simulation. First, we analyze the observed vehicle movements approaching a signalized intersection spatially and temporarily. Next, the observation environment and vehicle movements are reproduced by VISSIM, which is a microscopic traffic simulation tool. Moreover, we construct a traffic environment that provides information regarding signal change by the VISSIM in which the information provision system provides a recommended speed to a driver. If a driver follows the recommended speed, unnecessary vehicle movements can be reduced.

Furthermore, we estimate the reduction in CO_2 emissions caused by the information provision system using the microscopic simulation result.

Finally, we briefly introduce a prototype of the information provision system that has been developed on a driving simulator, UC-Win/Road. In future, we will test the driving simulator to verify the effect of the information provision system on the driving behavior of a driver.

2. METHOD OF OBSERVING VEHICLE MOVEMENTS

Actual vehicle movements were observed around signalized intersections. Observation locations were selected considering the layout of the signalized intersection, the alignment of the approach to the intersection, the perspective of the intersection, and the visibility of the traffic signals. The approaches must cross at a right angle and the alignment of the observed section must be straight to eliminate the influences of the layout and the alignment of the intersection on vehicle movements.

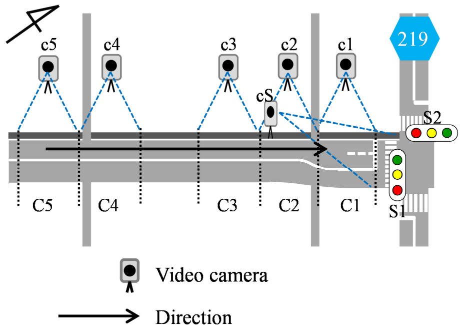

Fig. 1. Layout of Nishiura-Intersection

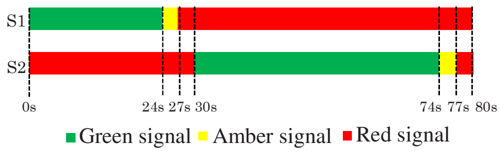

Fig. 2. Signal timing at Nishiura-Intersection

In this study, it was necessary to observe continuous vehicle movements both spatially and temporally for 300 meters. Therefore, there must be no obstacles that prevent observations of vehicle movements within 300 meters of the intersection.

2.1. Selecting observed intersection

The Nishiura-Intersection and the Shiyakusyo-Higashi-Intersection were selected based on the conditions mentioned above. These intersections are located in Nisshin-city in the Aichi prefecture in Japan. The two intersections have some common characteristics: They both are a cross-shaped intersection at a right angle and have one lane in each direction, a 40 km/h speed limit, and a right-turn lane (left-hand side driving in Japan). The most significant difference between the two intersections is the presence of a pedestrian signal at the Shiyakusyo-Higashi-Intersection. The other characteristics of these intersections are almost identical.

2.2. Outline of observed intersection

The layout of the Nishiura-Intersection is illustrated in Fig. 1. The movement of each vehicle approaching the intersection was recorded by six digital video cameras on two days: December 5, 2011 and December 21, 2011. The observed section and time of each observation are shown in Table 1. The length of the observed section for the Nishiura-Intersection was more than 300 meters, which was set to be longer than the distance mentioned by Miyata et al. (2001) in order to observe changes in the vehicle movements.

The signal timings of the Nishiura-Intersection are illustrated in Fig. 2. One cycle of the signal is 80 seconds, where the green lasts for 24 seconds, the amber for 3 seconds, and the red for 53 seconds in the observed direction. The state of all red lasts for 3 seconds to allow vehicles to clear the intersection.

The layout of the Shiyakusho-Higashi-Intersection is illustrated in Fig. 3, where H1 and H2 denote pedestrian signals. The observed section and time are also shown in Table 1. The length of the section is 400 meters. Vehicle movements were observed by six digital video cameras on June 5, 2012. Because there were several

Table 1. Outline of each observation

OBSERVATION LOCATION	Date	Point	Observation segment(m)					
			C1	C2	C3	C4	C5	CS
Nishiura No.1	December 5, 2011 15:30-16:30	Start	0	50	100	200	250	Signal
		End	50	100	150	250	300	
Nishiura No.2	December 21, 2011 14:00-15:30	Start	0	50	100	200	280	Signal
		End	50	100	150	250	330	
Shiyakusho-Higashi	June 5, 2012 10:00-12:00	Start	0	20	100	200	300	Signal
		End	20	100	200	300	400	

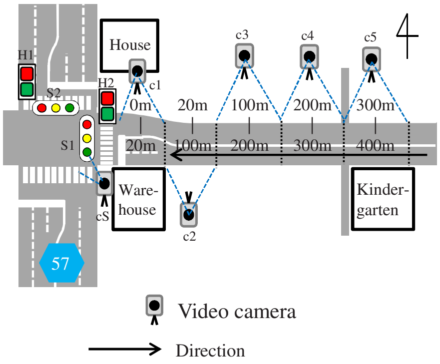

Fig. 3. Layout of Shiyakusyo-Higashi-Intersection

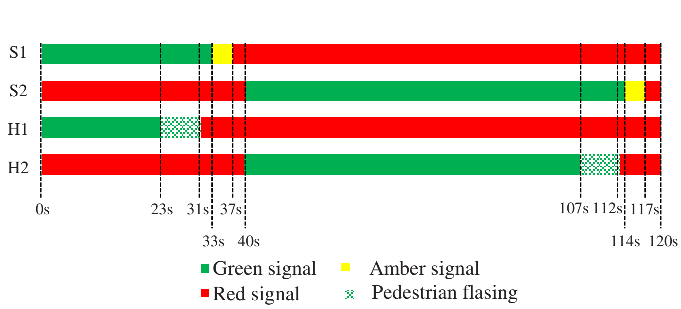

Fig. 4. Signal timing at Shiyakusyo-Higashi-Intersection

obstacles such as a house and a warehouse to the sides of the observed section, it was necessary to observe the section from both sides to avoid the obstacles.

The signal timing at the Shiyakusho-Higashi-Intersection is illustrated in Fig. 4. One cycle lasts for 120 seconds, where the duration of the green, amber, and red are 33, 4, and 83 seconds, respectively. The all red duration is 3 seconds. Drivers approaching the intersection are able to see the pedestrian signal of H1. One cycle of H1 consists of 23 seconds of green, 8 seconds of flashing green, and 89 seconds of red.

2.3. Condition for choosing object vehicles for analysis

Not all vehicles in the observed section could run freely, and some vehicles must follow the vehicle running ahead. For instance, a vehicle with a short headway must follow the leading vehicle regardless of the signal state. These vehicle movements should be removed from the analysis. Therefore, only passenger cars that have a continuous headway of more than 3 seconds, do not turn left or right, and do not stop on the approach sections were chosen for the analysis.

3. Observation result

A total of 137 samples were selected from the observed vehicles approaching the Nishiura-Intersection as object vehicles for the analysis based on the condition mentioned above. The continuous segment average speeds of the vehicles are shown in Fig. 5. Vehicle movements can be seen easily from the lines drawn in Fig. 5. The horizontal axis and the vertical axis represent the time and segment average speed, respectively. The background color of the figure indicates the signal state, which changes with time. The origin point of the time axis is the start

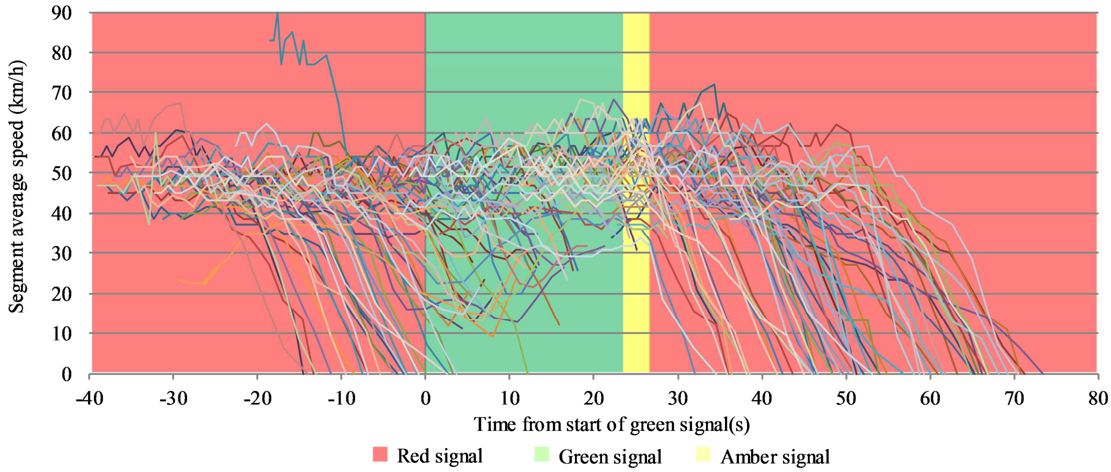

Fig. 5. Changes of segment average speed by each vehicle at Nishiura-Intersection

of the green signal at each cycle. In this figure, the time axis returns to the origin point when the signal changes to green every 80 seconds at the Nishiura-Intersection. This time axis makes it possible to easily understand the vehicle movements during signal changes from green to amber and from amber to red. On the other hand, as the vehicle movements during signal changes from red to green are divided into both ends of the figure, it is difficult to understand the vehicle movements. Therefore, vehicles that entered the observed section earlier than 40 seconds are drawn in the left area of the figure and the other vehicles are drawn in the right area. Consequently, this figure also makes it possible to more easily understand the vehicle movements as the signal changes from red to green.

From Fig. 5, it is found that the segment average speeds tend to decrease as the red signal time elapses. It is also found that the average speeds of the segments tend to increase as the green signal time elapses. Accordingly, the overall tendency of the segment average speeds shows a wavy shape.

A total of 105 samples were selected from the observed vehicles approaching the Shiyakusyo-Higashi-Intersection as object vehicles based on the condition mentioned above. As in Fig. 5, the average speeds of the vehicles in the continuous segment are shown in Fig. 6, in which the pedestrian signal state is also shown as a part of the background color in addition to the vehicle signal state. For the situation in which both the pedestrian and vehicle signals are green, the plot is colored green, and when the pedestrian and vehicle signals are flashing green and green, respectively, it is colored blue, and when the pedestrian and vehicle signals are red and green, respectively, it is colored purple. The overall tendency of the segments' average speeds also shows a wavy shape. However, the shape is different from the case of Fig. 5. The wavy shape in Fig. 6 is not clearer than that in Fig. 5 because drivers can view the flashing green of the pedestrian signal and anticipate an imminent change in the timing of the vehicle signal. This means that the vehicle's movement is affected by providing any signal information, even in actual situations.

4. Estimating the reduction of CO_2 emissions caused by providing information using microscopic simulation

By using VISSIM, a microscopic traffic simulation tool, we estimated the reduction in the CO_2 emissions caused by providing the information to drivers. We first reproduced the observed movements of vehicles approaching the signalized intersection using VISSIM, and then simulated vehicle movements under the conditions where information is provided. Three different information patterns were provided in the simulation.

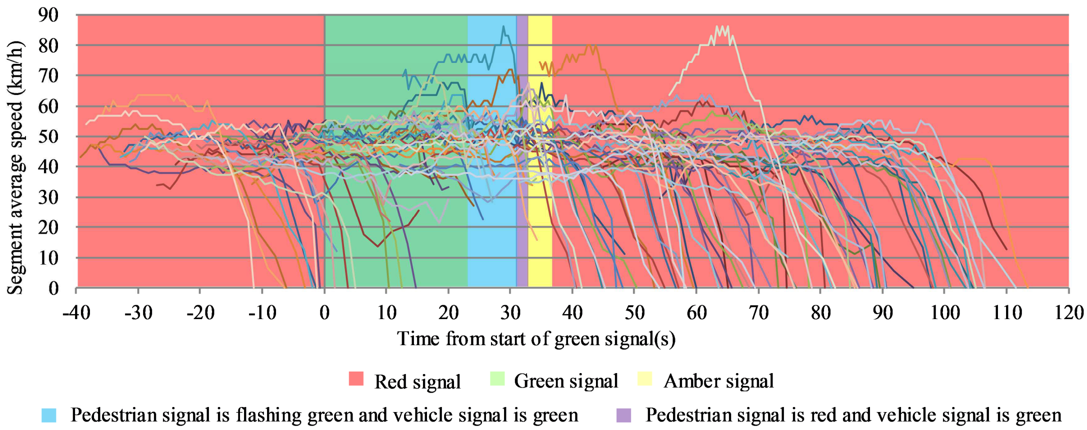

Fig. 6. Changes of segment average speed for each vehicle at the Shiyakusyo-Higashi-Intersection

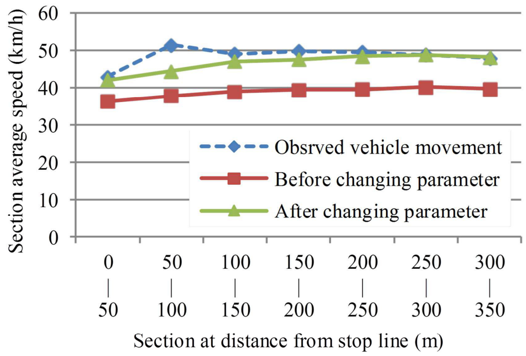

Fig. 7. Simulated vehicle average speed before and after changing parameter

Table 2. Correlation coefficient and RMSE before and after parameter change

	Changing Parameter	
	Before	After
Correlation coefficient	0.827	0.939
RMSE	8.233	2.455

We evaluated each environment by comparing the calculated the amount of CO_2 emissions in that environment with the case in which no information was provided.

4.1. Reproducing observed vehicle movements using microscopic simulator

When configuring the vehicle movement within VISSIM, some parameters were changed in order to accurately reproduce the observed vehicle movements. Fig. 7 shows the average vehicle speeds calculated from the simulation results before and after the parameter were changed. The average vehicle speed after the parameter change is closer to the observed average speed than the speed before the change. From the correlation coefficient and the root-mean-square error (RMSE) between the observed and simulated vehicle average speeds shown in Table 2, we also found that the reproducibility was improved after the parameters were changed.

4.2. Construction of information provision environment

Fig. 8 shows the vehicle movements for different patterns of provided information. The information regarding the recommended speed is assumed to have been provided to the driver, and consequently, the driver reduces

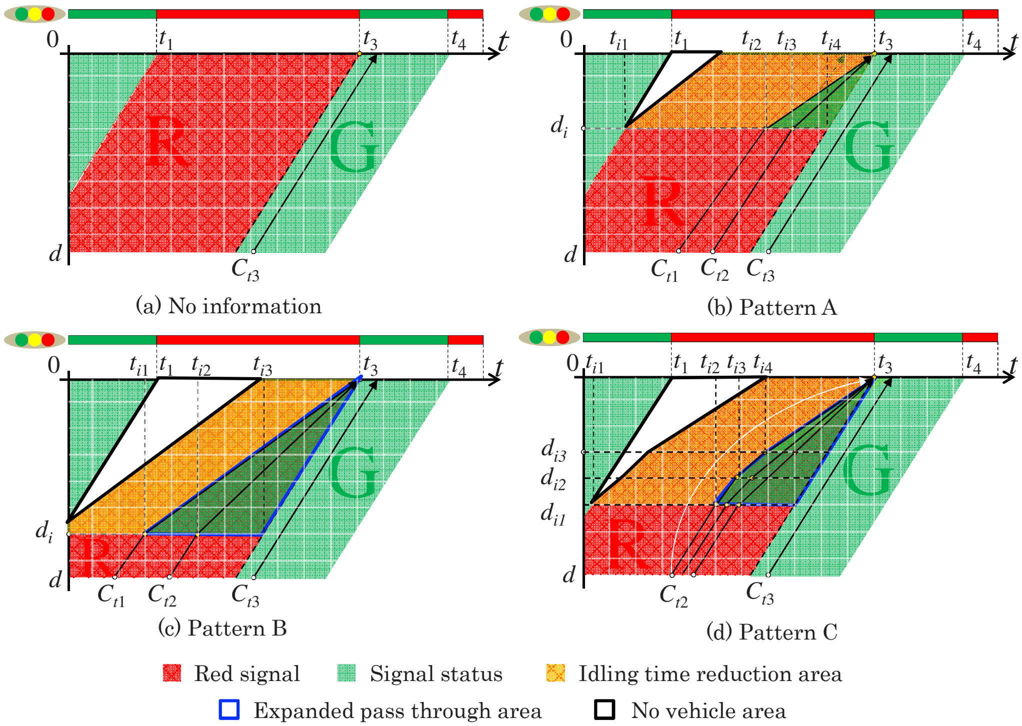

Fig. 8. Patterns of information provision; (a) No providing information, (b) Pattern A, (c) Pattern B and (d) Pattern C

speed in the simulation. The horizontal axis of these figures shows the time and the vertical axis shows the distance from the signalized intersection. The color bar on the top of the figure shows the signal state. In this study, for convenience, an amber signal is considered to be the same as a red signal so that vehicles stop when the signal is amber. Therefore, only red and green bars appear alternately on that color bar. The background color shows the signal state when the vehicle running at the distance d arrives at the intersection with a constant speed. In actual situations, the driver may not necessarily follow the recommended speed so the vehicle speeds may vary widely and the vehicle movements are expected to vary for each vehicle. However, for simplicity, in this study we assume the following three conditions:

i. A vehicle runs at a constant speed as long as no information is provided,
ii. All vehicles follow the recommended speed directives provided to drivers,
iii. A vehicle starts to change speed immediately after receiving the recommended speed.

Fig. 8 (a) shows the vehicle movements when no information is provided to drivers. The black oblique lines with an arrow in the figure illustrate the vehicle movements approaching a signalized intersection. When the vehicle C_{t2} reaches a distance d from the intersection, the signal ahead is red at that time. Because of the assumption that the vehicle speed is constant, the signal has already changed to green when the vehicle reaches the intersection. Therefore, C_{t2} passes through the intersection without stopping. On the other hand, the vehicle C_{t1} reaches a distance d from the intersection when the signal ahead is green, but when it reaches the intersection, the signal has already changed to red. Therefore, C_{t1} stops at the intersection at a red signal.

Fig. 8 (b) illustrates pattern A for which the information was provided. In this pattern, when the vehicles reach d_i at a time from t_{i1} to t_{i4}, the system provides the deceleration information with the recommended speed to a

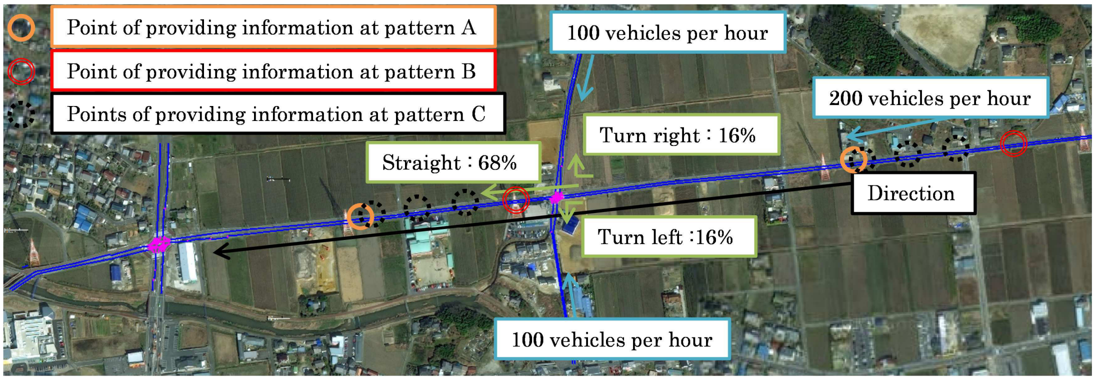

Fig. 9. Setting of microscopic simulation

driver. If the driver follows the recommended information, C_{t1} and C_{t2} reach the intersection with any delays. As a result, C_{t1} and C_{t2} are able to pass through the intersection without stopping. The area in which it is possible to pass through the intersection without stopping is expanded by providing the information (In Fig. 8, the expanded area is surrounded by blue lines). The size of the expanded passing area depends on the deceleration speed provided. The more is the vehicle reduction in speed, the larger is the expanded area.

If the system provides the information of a slower speed to the vehicle at d_i, more vehicles are able to pass through the intersection without stopping. However, driving at lower speeds may lead to congestion. For this reason, it is necessary to appropriately set a minimum speed (V_{min}). In this study, the system provides the recommended speed information to the vehicles at d_i from time t_{i2} to t_{i4}. The system provides only the deceleration information to the vehicles at d_i from the time t_{i1} to t_{i2}. These vehicles cannot pass through the intersection. However, by reducing those vehicles' speeds, it is possible to delay the arrival time of the vehicles at the intersection and to reduce the idling time. The area with the orange background color in the figure indicates the area in which the idling time can be reduced. The vehicle C_{t3} is present in the area in which it is possible to pass through the intersection while maintaining the current speed. Therefore, the system does not provide any information to C_{t3}. There is no vehicle within the white background area as long as the vehicles follow the provided information.

Fig. 8 (c) illustrates pattern B. In this pattern, the system provides the information to a vehicle earlier than in the case of pattern A. In fact, the areas in which it is possible to pass through the intersection (dark green area) and where there is no vehicle (white area) are larger than those of the pattern A.

Fig. 8 (d) shows pattern C. In this pattern, both the deceleration information and the recommended speed are provided using three steps. Vehicles decelerate at distances d_{i1}, d_{i2}, and d_{i3} from the intersection in pattern C. The decelerating speeds are defined as V_{i1}, V_{i2}, and V_{i3} at d_{i1}, d_{i2}, and d_{i3}, respectively, where $V_{i1} > V_{i2} > V_{i3}$. In this case, vehicles are able to gradually decelerate.

The information provision point (d_i) and the minimum speed (V_{min}) are set up based on the observations of vehicle movements. In pattern A, d_i and V_{min} are 250 m and 30 km/h, respectively. In pattern B, d_i is 416 m and V_{min} is 30 km/h. In pattern C, d_{i1}, d_{i2}, and d_{i3} are 333 m, 291 m, and 250 m, respectively, and V_{i1}, V_{i2}, and V_{i3} are 40 km/h, 35 km/h, and 30km/h, respectively.

4.3. Setting of microscopic simulation

Fig. 9 shows the section that was studied in the microscopic simulation, where parameters such as the traffic volumes in each direction, the rate of left turns, and the rate of right turns are also shown. These parameters were set based on the observations that were made at the same section. The information is provided to drivers at points drawn by a circle in Fig. 9. To reproduce the observed traffic conditions, the maximum speed was set to 50 km/h.

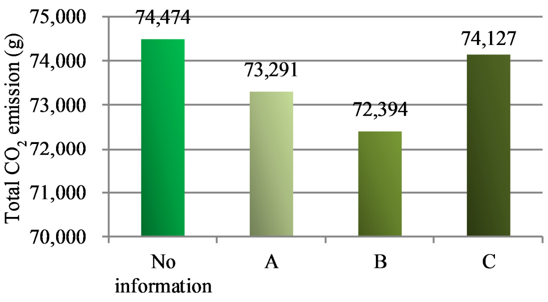

Fig. 10. CO_2 emission for different patterns of providing information

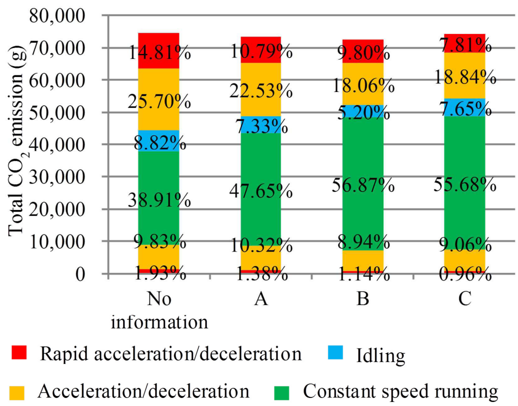

Fig. 11. CO_2 emission by types of vehicle behavior

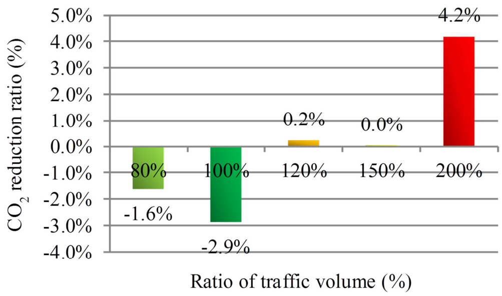

Fig. 12. CO_2 reduction ratio of pattern B to no information

4.4. Simulation result

Fig. 10 shows the average amount of CO_2 emissions calculated from the simulation results for each pattern of provided information. All of the information patterns can reduce the CO_2 emissions compared with the no information case. The extent of CO_2 reduction obtained using patterns A, B, and C are 1,183 g-CO_2, 2,080 g-CO_2, and 347 g-CO_2, respectively. We therefore deduced that the CO_2 emissions are reduced by a greater extent when the deceleration information is provided earlier. The effect of the CO_2 reduction caused by pattern C is lower than that obtained for other patterns. Because the deceleration information is provided in three steps in pattern C, we believe that unnecessary vehicle movements occurring during deceleration cause the increase the CO_2 emission.

Fig. 11 shows the amount of CO_2 emissions according to the type of vehicle behavior for each pattern. When any information is provided, the proportion of CO_2 emissions from vehicles running at constant speed increases. Contrarily, the proportions of CO_2 emissions at idling time and rapid acceleration/deceleration decrease. Accordingly, it can be seen that by providing the information, the traffic flows becomes smoother.

Fig. 12 shows the change in the ratio of the amount of CO_2 emissions due to pattern B to the amount when no information is provided as the traffic volume is changed. From this figure, there is a large reduction in the CO_2 emissions when the traffic volume is small. However, in the case of a high traffic volume, it was found that the CO_2 reduction effect disappeared. We considered that the slower vehicles following the provided deceleration information cause traffic congestion in the case involving a higher traffic volume.

5. Conclusion

In this study, we first observed actual vehicle movements around signalized intersections. A total of 137 samples were selected for an intersection without a pedestrian signal and 105 samples were selected for one with a pedestrian signal, and all samples were analyzed. The continuous average speeds of each vehicle for the observed section were calculated for both intersections. The average speeds formed wavy plots at the intersection without the pedestrian signal. This shows that a red signal causes the average speed to decrease and a green signal causes it to increase. On the other hand, the wavy shape of the average speeds for the case with the pedestrian signal is less clearer than the shape without the pedestrian signal. We considered that vehicle movements may have changed when the pedestrian signal was flashing green. Based on this fact, by providing appropriate signal information, we would be able to improve vehicle movements.

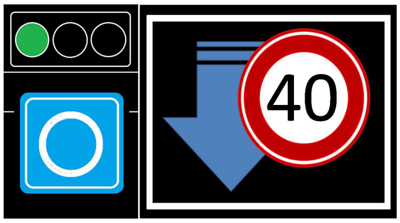

Fig. 13. Example of providing information by driving simulator

To estimate the CO_2 reduction effect of the information provision system, which informs a driver to accelerate/decelerate or recommends a given speed, we simulated the traffic flows under the information provision environment based on the observed vehicle movements. The results showed that by providing information, the CO_2 emissions from vehicles were reduced. Moreover, it is found that when the information is provided more quickly to a driver, the CO_2 reduction effect appears to increase. In our results, the maximum CO_2 reduction was 2,080 g-CO_2 for a traffic environment that emitted 74,474 g-CO_2 when no information was provided. However, it was also shown that there is a possibility that the CO_2 emissions will increase when the traffic flow increases.

We are currently constructing a prototype to observe the effect of providing information to a driver using the driving simulator UC-win/Road. Fig. 13 shows an example of the information provided displayed on a section of the monitor of the driving simulator. In the case where a driver is able to pass through the intersection by reducing the speed, the system provides the recommended speed information, as shown as Fig. 13. We aim to complete construction of such a driving simulator prototype to verify the effect on the driving behavior when the information is provided. The results of this verification will be reported in a separate paper.

For future works, there is a need to implement additional microscopic traffic simulations at other types of intersections with different patterns of information provided in order to understand the general influence of the information provided on vehicle movements and CO_2 emission reductions. It is also necessary to develop a driving simulator that observes the driving behavior under conditions where many types of information are provided and finds the optimal design in which the information should be displayed considering the traffic conditions and driver attributes.

Acknowledgements

This study has been supported by JSPS KAKENHI Grant Number 24560650.

References

Farah, H., Koutsopoulos, H. N., Saifuzzaman, M., Kölbl, R., Fuchs, S., & Bankosegger, D. (2012). Evaluation of the effect of cooperative infrastructure-to-vehicle systems on driver behavior. *Transportation Research Part C, 21(1)*, 42-56.

Iwata, Y., Otake, H., & Takagi, M. (2012). Results from Simulation Evaluation of Green Wave Advisory System. *Proceeding of 19th ITS world Congress, Austria*, CD-ROM.

Limanond, T., Prabjabok, P., & Tippayawong, K. (2010). Exploring impacts of countdown timers on traffic operations and driving behavior at a signalized intersection in Bangkok. *Transport Policy, 17*, 420-427.

Lum, K. M., & Halim. H. (2006). A before-and-after study on green signal countdown device installation. *Transportation Research Part F, 9(1)*, 29 - 41.

Miyata, K., & Yoshii, T. (2001). Analysis of driver's Reaction at Boundary Time of Signal Phases. *Proceedings of infrastructure planning, 24*, CD-ROM, in Japanese.