

Traffic Jam Alleviation Effect by the Popularization of CACC-equipped Cars

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Abstract—Sag traffic jam has become the biggest problem. We focused attention on the possibility of rate of CACC-equipped cars contributing to the alleviation of the sag traffic jam problem.

I. Introduction

Various types of research and development have been actively conducted in the field of ITS (Intelligent Transport System) from around the 1990s with the view of primarily attaining better automobile traffic conditions. Among others, the traffic jam problem on highways is one of the most serious issues for us to solve in improving the overall automobile traffic conditions. By the spread of ETC (Electronic Toll Collection System), the traffic jam in front of toll gates has become any more a serious problem. On the other hand, the so-called “sag traffic jam” accounts for about 60% of the causes of traffic jams as of the year 2011, and accordingly, this problem has become the biggest issue which needs to be solved in realizing the alleviation of the traffic jam. “Sag” here stands for the point on the road where a downhill slope changes to an uphill slope. The unconscious slowing-down behavior by a driver at that location is propagated to following cars one after another, and that eventually comes to case a big traffic jam.

In the field of ITS, we have such technologies as ACC (Adaptive Cruise Control) that automatically controls acceleration of cars from the information from the car ahead about the car-to-car distance and the relative speed between them, as well as CACC (Cooperative Adaptive Cruise Control) that also takes into account the information about the acceleration of the car ahead in addition to the functions of ACC. In this paper, we focused attention on the possibility of these technologies contributing to the alleviation of the sag traffic jam problem.

As it seems rather difficult for these technologies to spread among people rapidly, we have, as the initial step of our investigation, examined the correlation between the popularization of the above-mentioned technologies and the effect thereof in alleviating the sag traffic jam problem, from the standpoint of the popularization rate of CACC-equipped cars.

II. Following-on driving models for different types of cars

We show hereunder three (3) types of following-on driving models. The first model is for cars equipped with CACC, the second model for cars equipped with ACC, and the third model for cars driven by humans without these technologies. When the location of the car running ahead i is indicated as $x_i(t)$, and the location of following-on car $i+1$ is indicated as $x_{i+1}(t)$, the acceleration of the car $\ddot{x}_{i+1}(t)$ is defined by Formula (1) for cars equipped with CACC, by Formula (2) for cars equipped with ACC, and by Formula (3) for cars driven by humans[1].

Equations:

$$\ddot{x}_{i+1}(t+T_A) = k_1 \frac{\dot{x}_i(t) - \dot{x}_{i+1}(t)}{x_i(t) - x_{i+1}(t)} + k_2 \{\ddot{x}_i(t) - \ddot{x}_{i+1}(t)\} \quad (1)$$

$$\ddot{x}_{i+1}(t+T_A) = k_3 \frac{\dot{x}_i(t) - \dot{x}_{i+1}(t)}{x_i(t) - x_{i+1}(t)} \quad (2)$$

$$\ddot{x}_{i+1}(t+T_H) = k_4 \frac{\dot{x}_i(t) - \dot{x}_{i+1}(t)}{x_i(t) - x_{i+1}(t)} \quad (3)$$

T_A and T_H in Formula (1)~(3) stand for the machine (mechanical) response delay time and the driver’s response delay time, respectively. The signs k_1 , k_2 and k_3 found on the right-hand side item of the equations are the control gains, and k_4 is the reaction sensibility of humans. Hereafter, k ’s are called model parameters in this paper.

III. Study of CACC’s traffic jam alleviation effect by way of simulations

A Simulation environment

The environment for the simulations assumed in this paper is as follows. A convoy of ten (10) cars is moving in a group on a straight-line highway where no overtaking is allowed. An unconscious deceleration of the front-end car occurs at a sag point when it applies the break. Each car is regarded as a dot, and all following cars start decelerating from the situation where they are running at the same speed of 90 km/h, down to the point where the front-end car gets the speed of 75 km/h. Acceleration is assumed to be -2 m/s^2 . The mechanical delay time T_A is assumed to be 0.1 second and the driver’s response delay time T_H is 1.0 second[2].

It is also assumed that the information on the position, speed and acceleration is obtained without any error and that no delay nor error

occurs in the transmission of information.

B Rate of popularization and method of comparison

The rate of popularization is measured by the ratio (percentage) of CACC-equipped cars in a convoy of ten (10) cars. CACC-equipped cars are randomly placed in the convoy and the rest of the cars are all assumed to be human-driven cars. In the case that the car in front is not a CACC-equipped one, the following CACC-equipped car acts like an ACC-equipped car, as it cannot get information from the car in front. For the measurement of the popularization rate, 1,000 times of simulations are conducted. From the (calculated) lowest speed of the following cars, the degree of traffic jam is estimated. Consequently,

C Simulation results

From the preliminary simulations, we have determined the value of the parameter k as follows:

$k_1 = 104.4$; $k_2 = 0.29$; $k_3 = 82.3$; $k_4 = 13.3$. Fig. 1 shows the changing pattern of the speed of each car in a convoy composed of solely human-driven cars. The horizontal axe indicates the passage of time and the vertical axe the speed of each car in the convoy. The far left line shows the speed of the front end car and the next lines show the speed of following cars one after another. From the Figure, we can see that the speed of the following cars gets slower than the car running just in front and the degree of the deceleration gets larger. Thus, we can reasonably judge that this way of propagation of deceleration causes the sag traffic jam problem.

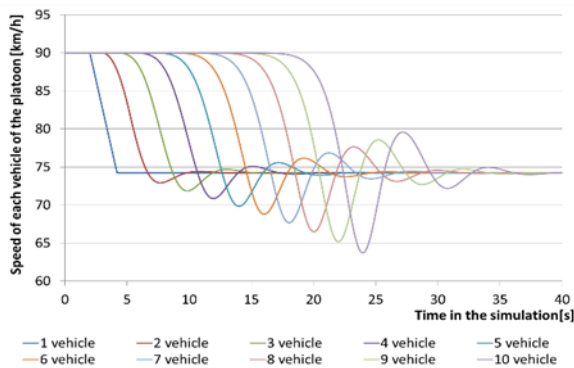


Figure 1: The changing pattern of the speed of each car in a convoy composed of solely human-driven cars

As the next step of our investigation, we replaced human-driven cars with CACC-equipped cars randomly in simulations and examined the correlation between the different rates of popularization of CACC-equipped cars and the changing patterns of deceleration of the following cars. As a result, we confirmed that the larger the ratio of CACC-equipped cars in a convoy is, the smaller becomes the

propagation of the speed changing pattern, and that when the ratio reaches 100%, the propagation of the speed changes becomes null and the sag traffic jam never occurs. Accordingly, we determined from the simulation that the CACC technology is quite effective for the solution of the sag traffic jam problem. Fig. 2 shows the changes in speed of the last car in a convoy for different rates of CACC popularization. The horizontal axe indicates the popularization rate of CACC-equipped cars and the vertical axe the average lowest speed of the last car in a convoy. From the Figure, we can see that the average lowest speed of the last car is almost the same as the speed of the front end car when the CACC popularization rate is 100%. Even with the CACC popularization rate of 30%, we can see that the situation will greatly contribute to the alleviation of the traffic jam problem, compared with the situation where the rate is zero.

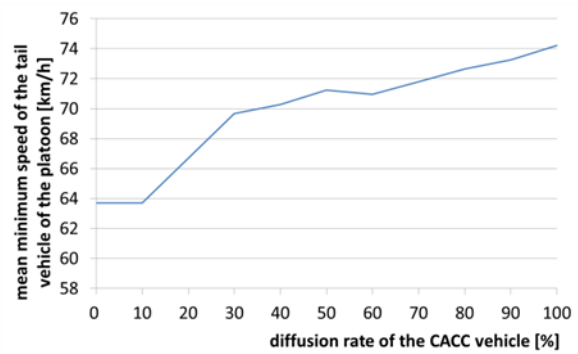


Figure 2: The changes in speed of the last car in a convoy for different rates of CACC popularization

IV. Summary and remaining issues

We judge that the CACC technology has a big potentiality of solving the sag traffic jam problem. We have confirmed that the bigger the popularization rate of CACC-equipped cars is, the larger becomes the effect of traffic jam alleviation. Even with the CACC popularization of 30%, the situation will greatly contribute to the alleviation of the traffic jam problem, compared with the situation where the rate is zero.

As the issues left for us hereafter, it is necessary to investigate the possible impact of the situation where a packet loss or delay in the communication between cars occurs and also to consider errors of measurement devices such as radars.

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