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Abstract: Many new technologies using ITS have been developed in order to reduce traffic accidents. Adaptive Cruise Control system (ACC) is one of such ITS. The impacts of ACC installation on traffic accident within traffic flow has not been evaluated because of difficulty evaluating accident occurrence with respect to complexity of interaction between vehicles with and without ACC. Thus, the approach was developed to estimate traffic accident occurrence after installation of ACC by using a micro traffic simulation model which was basically modified by adding a function of perception-response process. In this approach, traffic accident occurrence was access by detecting conflict on the simulation. In addition, the evaluation method was developed by using proposed safety indicator. To evaluate the influence market penetration of ACC, many cases with different installation rate of ACC were simulated by using the proposed approach and relationship between installation rate and safety indicator was analyzed.

Key Words: Adaptive Cruise Control system, Micro traffic simulation, Traffic safety indicator

1. INTRODUCTION

Many new technologies using ITS have been developed in order to reduce traffic accidents as well as relief traffic congestion. ACC is one of such ITS which help to avoid rear-end collision by maintaining headway distance and has been in widespread use gradually in Japan. At the early stage of ACC promotion, it is expected that mixture of vehicles with and without ACC on traffic flow might be a trigger increasing a vehicle cutting in traffic stream because a vehicle with ACC intents to keep wide headway. Therefore, it is necessary to evaluate the
impact of ACC on traffic accident occurrence. However, until now, the impact of introduction of ACC on reduction of collision has been evaluated through the test using a single vehicle or a driving simulator. To analyze ACC’s impacts on traffic flow have never been examined because the evaluation approach with respect to the variables of a normal vehicle’s acceleration and breaking rules and ACC vehicle’s automatic adaptation rule in a traffic flow. Thus, this study proposed an approach to evaluate the impact of ACC installation on traffic safety by using a micro traffic simulation model that can represent a driving behavior of individual vehicle. The proposed model was developed by adding a function of perception-response process and then detected the conflicts or near miss situation that means potential accident between vehicles occurred on the existing micro traffic simulation. In addition the evaluation method was proposed by using traffic safety indicator which represents conflicts instead of actual traffic accidents occurrence. Many cases with different installation rate of ACC were simulated by using the proposed approach and relationship between installation rate and safety indicator was analyzed.

2. LITERATURE REVIEW

2.1 Existing Evaluation Approach

New technologies using ITS could be evaluated by using a real vehicle test, driving simulator and micro traffic simulation. By using the real vehicle test, a single vehicle based on actual driving behavior on real road network could be evaluated (Mizutani, 2007 etc). It is hardly evaluate the impact to other vehicle on the traffic flow. It is possible to develop road environment artificially within a driving simulator so that the impact in various traffic situations based on real driving behavior could be evaluated by using a driving simulator, but the impact to other vehicle on the traffic flow could not be evaluated (Shimizu et al. 2006). On the other hand, a micro traffic simulation can be use to estimate the impact to traffic flow such as traffic flow rate or queue length and might be used for evaluation. U.S. DOT developed Surrogate Safety Assessment Model (SSAM) which is combining existing micro traffic simulation and automated conflict analysis (2009). However the vehicle behavior of existing micro traffic simulation is uniformed behavior based on car following model so that traffic accident or dangerous situation could not be occurred in the simulation. Because of this, the impact of any ITS installation on traffic safety can’t be evaluated by using a micro traffic simulation. There are several attempts to develop an approach by combined driving simulator and a micro traffic simulator (Hasegawa, 2007 etc). However it has not been used wildly because it needs large scale equipments.

2.2 Evaluation of Adaptive Cruise Control

The evaluation of ACC installation was attempted by some existing researches. Fukuda et al. (2007) have reported that ACC contributes to prevent the speed degradation on road sag. Suzuki et al. (2004) have examined that ACC is effective for reducing the travel time when setting headway time is about 1.0 sec. On the other hand, Miderhoud et al. (1999) mentioned that ACC contributes to decrease the traffic flow rate when setting headway time of ACC is longer than actual traffic flow. Thus an impact of ACC is showed different results by the reproducibility of model and parameter setting of ACC.

Several researches have been done to evaluate an impact of ACC installation on traffic safety within traffic flow. Minderhoud et al. (2001) have reported that dangerous situation increases by ACC installation. Nevertheless the used micro traffic simulation by his study could not express driver error and characteristics of driver. Thus the result may be different from real
situation. There has been no evaluation approach which can evaluate an impact of new technologies using ITS on the traffic flow from the view point of traffic safety.

The impact of ACC to traffic flow could be evaluated using a micro traffic simulation in the various traffic situations. However, traffic accident can’t be occurred in micro traffic simulation because vehicle behavior is usually uniformity in most of a micro traffic simulation model. Thus the developing evaluation process of an impact of ACC to traffic safety is important to discuss spread process and control technique of ACC.

3. DEVELOPMENT OF MICRO TRAFFIC SIMULATION MODEL

3.1 Following Behavior for Non ACC Vehicle

Since the vehicle velocity of existing micro traffic simulation used to be calculated based upon a car following model from current velocity, position and acceleration rate of leading vehicle and following vehicle, all vehicle in a micro traffic simulation model used to be control in same manner. Actually, vehicle behavior is controlled by perception-response process of a driver and a traffic accident happens by error or misses on perception-response process. ACC contributes to traffic safety by preventing occurrence of the error or missed. Thus this study basically modified the existing micro simulation model by adding a function of perception-response process.

In this study, Xing’s model (Xing, 2008) which is a car following model including perception-response process in Gipps model (Gipps, 1981) was employed. The perception-response process consists of three factors which are visual expansion rate, change of distance and Instantaneous time gap. The visual expansion rate is calculated from vehicle width, relative speed and headway distance. The change of distance is simply the difference between the current headway distance and the headway distance at the previous scanning interval. The instantaneous time gap is derived by dividing current headway distance by subject vehicle’s instantaneous speed. At each scanning interval of driver, the following questions are checked.

1. True or False: visual expansion rate $\theta$ exceeds the threshold $C_{\theta}$.

2. True or False: change of distance exceeds the threshold $C_D$.

3. True or False: gap time outside of $[(1-E_g) t_g', (1+E_g) t_g']$.

$E_g$ = time gap error; $t_g'$ = driver’s desired following gap time;

If all answers are false, the vehicle can’t perceive changing velocity of front vehicle. Thus the vehicle keeps previous acceleration or deceleration. When neither of these checking results is true, the vehicle can perceive changing velocity of front vehicle. Then the vehicle calculates a new acceleration by Gipps model. Gipps model is shown in Equation 1-3.

$$V_{n(t+t_g)} = min\left[\frac{V_n^a}{(t+t_g)}, \frac{V_n^b}{(t+t_g)}\right]$$

(1)

$$V_n^{a} (t+t_g) = V_n(t) + 2.5a_n t_g \left(1 - \frac{V_n(t)}{V_{n_{max}}^t}\right) \sqrt{0.025 + \frac{V_n(t)}{V_{n_{max}}}^t}$$

(2)
\[ V_n^{b(t+t_g)} = -t_g b_n + \sqrt{t_g^2 b_n^2 + b_n \left\{ 2(x_{n-1(t)} - x_n(t) - S_0) - t_g V_n(t) + \frac{V_{n-1}^2}{\hat{b}_{n-1}} \right\}} \]  

where,
- \( t_g \): Reaction time,
- \( a_n \): Maximum comfortable acceleration rate for vehicle \( n \),
- \( b_n \): Maximum comfortable braking rate for vehicle \( n \),
- \( x_n, x_{n-1} \): Position of vehicle \( n \) and \( n-1 \), respectively,
- \( \hat{b}_{n-1} \): \( n \)th driver’s estimation for \( n-1 \)th vehicle maximum comfortable braking rate,
- \( V_n^{\text{max}} \): Desired free flow speed of vehicle \( n \),
- \( S_0 \): Headway distance at standstill.

Behavior of one front vehicle is considered in Xing’s model. However, actually a driver perceives not only changing velocity of one front vehicle but also some vehicles in the front. Therefore in this study, the above perception processes by visual expansion rate and change distance are expanded to second vehicle in the front when following conditions are satisfied. The conditions are set such as shown in Figure 1 from the result of research by Suzuki (Suzuki, 2009).

1. Following vehicle is passenger car, first vehicle in the front is passenger car and second vehicle in the front is truck.
2. Following vehicle is truck and first vehicle in the front is passenger car.

If the following vehicle perceives the breaking of second vehicle in the front, the following vehicle will break in advance. The chart of simulation model for non ACC vehicle is shown in Figure 2.

![Figure 1 Condition of perceiving second vehicle in the front](image-url)
3.2 Following Behavior of ACC Vehicle
The specifications of ACC are slightly different by automobile companies. However their fundamental functions are almost the same. ACC fundamental functions can be explained as follows.

- Driving with constant speed if there is not front vehicle ahead.
- Maintain the headway distance set at appropriate level.
- If speed of a front vehicle is slower than setting speed, ACC decelerates speed.
- Follow a front vehicle to maintain the setting headway and adjust change of a front vehicle.
- If a front vehicle changes a lane, accelerate and continue constant running.

We developed an algorithm for ACC based on above specification such shown in Figure 3. In this study, we evaluate high speed ACC. When the velocity of ACC vehicle is faster than 45km/h, the vehicle will behave as ACC vehicle and when the velocity is under than 45km/h, it will behave as non ACC vehicle. When headway distance with leading vehicle is less than 100m, ACC vehicle consider behavior of front vehicle at any time. On the other hand, it does not consider behavior of second vehicle in the front at any condition. The velocity of ACC vehicle is decided by Gipps model. Maximum acceleration rate and deceleration rate of ACC vehicle set 2.0 m/s² and -2.5 m/s² that are fixed by Japanese Industrial Standards. Reaction time is fixed 0.3 second as system reaction time.
4. TRAFFIC SAFETY INDICATOR

Traffic safety measures such as improvement of intersections usually are evaluated by comparing a number of traffic accidents. However traffic accident is probabilistic incident and it takes long time for collecting traffic accident data. On the other hand, according to Heinrich’s law, the constant ratio between fatal accident, light accident and near-accident (conflict incident) is 1:29:300. The existing studies (Motoda, 1992) also showed interrelation between conflict incident and revealed traffic accident. Therefore, in this study, conflict incident is used as indicator instead of revealed traffic accident for evaluating the safety impact of ACC in traffic flow.

4.1 Review of Proposed Traffic Safety Indicators

The traffic safety indicators were suggested to define the conflict incident by the existing researches. These indicators are classified 4 type indicators according to a definition as shown in Figure 4 and Table 1.

The indicators that are defined from time to collision include TTC (Hayward, 1972), TTC$^{-1}$ (Suzuki, 2002), TTC$_{2nd}$ (Barber, 1998), PTTC (Wakabayashi et al., 2003), TET (Michiel et al., 2001) and TIT (Michiel et al., 2001). These indicators show the remaining time before collision to leading vehicle in case of keeping current velocity and acceleration rate. Above all, TTC is used for safety evaluation in some studies because it is simple and clarity. Nevertheless when relative velocity of leading vehicle and following vehicle is 0, these indicators can’t be calculated.

The indicators that are defined from relative distance of leading vehicle and following vehicle when leading vehicle breaks suddenly include S-Stop (Difference of space distance and stopping distance) (Japan Society of Traffic Engineers, 2005), PICUD (Iida et al., 2001), PSD (Allen, 1978) and MTC (Kitajima et al., 2009). PSD and MTC can’t be calculated when...
velocity of following vehicle is 0. On the other hand, S-Stop and PICUD can be calculated in any situation.

The indicators that are defined from deceleration rate include ODCA (Hiraoka et al., 2008), PDCA (Hiraoka et al., 2008), DR (Deceleration rate) and $a_t^2$ (Noda et al., 1995). ODCA and PDCA show deceleration rate for avoiding collision when front vehicle breaks suddenly. $a_t^2$ shows dispersion of acceleration during unit time in unit road section. These indicators are calculated by complicated formula. Thus analysis of dangerous situation is difficult.

KdB (Isaji et al., 2006) and PE (Suzuki et al., 2004) are classified in other indicators. KdB shows changing rate of square measure of leading vehicle. PE shows potential collision energy. KdB can’t be calculated when relative velocity is 0. PE can’t be decided dangerous threshold value.

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Figure 4 Definition of variable

Table 1 Traffic safety indicators

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<th>Classification</th>
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4.2 Proposal of Evaluation Method by Using Traffic Safety Indicator

For this study, S-Stop is used as traffic safety indicator. S-Stop is defined by difference of space distance and stopping distance as shown in equation (4) and Figure 5. Space distance can be calculated by sum of difference between leading vehicle and following vehicle and breaking distance of a leading vehicle. Stop distance can be calculated by sum of break reaction distance and breaking distance of a following vehicle. S-Stop shows comparative freeze position of a following vehicle and a leading vehicle when a leading vehicle brakes suddenly and then a following vehicle also breaks to avoid collision. Negative value of S-Stop means happening of collision due to a flowing vehicle can’t avoid colliding with a leading vehicle in sudden brake. As this described, calculation formula and dangerous threshold value are simple and clarity.
where,

\[ S \text{− Stop} = \left( \frac{v_1^2}{2\mu g} + d_2 \right) - \left( V_2 \Delta t + \frac{v_2^2}{2\mu g} \right) \]  \hspace{1cm} (4)

\[ \text{S; Space Distance,} \]
\[ \text{Stop; Stop Distance,} \]
\[ v_1; \text{Velocity of following vehicle,} \]
\[ v_2; \text{Velocity of leading vehicle,} \]
\[ \mu; \text{Friction coefficient,} \]
\[ g; \text{Gravity acceleration,} \]
\[ d_2; \text{Distance between leading vehicle and following vehicle,} \]
\[ \Delta t; \text{Reaction time.} \]

In this study, an evaluation method which can evaluate safety of traffic flow is needed. In existing study, safety of traffic flow was evaluated by number of non-safety vehicles that were defined by traffic safety indicator. In case of S-Stop, when S-Stop is under 0m, non-safety vehicle can be defined. However this evaluation method can’t consider dangerous degree and length of dangerous time. Therefore this study proposes new evaluation method. This method evaluates safety of traffic flow by total value of time integrated value gap between S-Stop and dangerous threshold value (Time Integrated S-Stop; T-I-S-Stop) as shown by equation (5) and Figure 6. This method can consider dangerous degree and length of dangerous time. In this study the existing method and the new method are observed depending on ACC installation rate in a traffic flow.

\[ T - I - S - \text{Stop} = \int_0^T \{ TH - (S - \text{Stop}) \} dt \]  \hspace{1cm} (5)
where

\[ T; \text{ Time,} \]
\[ \text{TH}; \text{ Threshold value.} \]

Figure 6 For Example of safety evaluation by using T-I-S-Stop

5. EVALUATION OF ACC BY USING MICRO TRAFFIC SIMULATION

5.1 Setting Parameters

To evaluate an impact within traffic flow after widespread use of ACC, Paramics as micro traffic simulation was used basically and following behavior of vehicle was put. Vehicle’s lane changing behavior was depended on initial setting of Paramics.

The simulation patterns are 9 patterns by ACC installation rate which are 0%, 25%, 50%, 75%, 80%, 85%, 90%, 95%, and 100%. Each pattern was calculated 20 times. The network is straight road of 5km that has three lanes. Traffic flow rate is 2,000 vehicles / hour. Mix rate of truck is 20%. Simulation time is 30 min. Time step is 0.1 sec. Following parameters in models were set randomly based by following vehicle data* and Japanese Industrial Standard.

\[ P; \text{ Passenger vehicle, T; Truck,} \]
\[ C_\theta; \text{ The threshold, normal distribution } N(0.058, 0.00867), \]
\[ C_D; \text{ The threshold, normal distribution } N(0.036, 0.08), \]
\[ E_g; \text{ Time gap error, normal distribution } N(0.095, 0.071) \text{ sec,} \]
\[ t_g'; \text{ Reaction time of ACC, 1.5 sec,} \]
\[ t_g; \text{ Reaction time, lognormal distribution } P: N(1.08, 0.43) \text{ sec, T: N}(0.92, 0.51) \text{ sec,} \]
\[ a; \text{ Maximum comfortable acceleration rate, normal distribution } P: N(2.6, 0.57) \text{ m/s}^2, \text{ T: N}(2.0, 0.25) \text{ m/s}^2, \]
\[ b; \text{ Maximum comfortable breaking rate, normal distribution } P: N(3.5, 1.11) \text{ m/s}^2, \text{ T: N}(3.1, 0.85) \text{ m/s}^2, \]
\[ v_{\text{max}}; \text{ Desired free flow speed, normal distribution } N(27.3, 4.42) \text{ m/s,} \]
\[ \hat{b}; \text{ Estimation maximum comfortable braking rate, } P: N(3.5, 1.11) \text{ m/s}^2, \text{ T: N}(3.1, 0.85) \text{ m/s}^2, \]
\[ S_\delta; \text{ Headway distance at standstill, normal distribution, } P: N(4.6, 1.65) \text{ m, T: N}(4.5, 1.65) \text{ m,} \]

Setting speed of ACC vehicle; normal distribution N (27.3, 4.42) m/s, (maximum speed is 27.8 m/s),

Reaction time of ACC; 0.3 sec.
5.2 Results of Simulation

The results of simulation are shown in Figure 7–11. These figures show average value by bar graph and maximum/minimum value by line segment. X-axis means installation rate of ACC.

The number of non-safety vehicle is shown in Figure 7. The non-safety vehicle is defined by the vehicle that S-Stop is less than 0m. The number of non-safety vehicle decreased as ACC installation rate rise. The non-safety vehicle was consisted mostly. However there are little non-safety vehicles of ACC vehicle. The rate of non-safety vehicle to all vehicles is shown in Figure 8. The rate of non-safety vehicle to all vehicles decreased as ACC rate raised. The rate of non-safety vehicle to all non ACC vehicles showed around 20% each ACC installation rate. The rate of non-safety vehicle to all ACC vehicles showed around 1% each ACC installation rate. The non-safety vehicle on traffic flow decreased. Therefore ACC vehicle contributed safety on traffic flow. However ACC vehicle did not contribute to decrease non-safety vehicle of non ACC vehicle.

The average of T-I-S-Stop per all vehicle is shown in Figure 9. T-I-S-Stop of all vehicles decreased as ACC rate rise. It was consisted mostly by non ACC vehicles. The average of T-I-S-Stop per one all non-safety vehicle is shown in Figure 10. The averages were 40-80 msec each ACC rate expect 100%. On the other hand, it dramatically decreased to about 4 msec in 100% rate. Thus non ACC vehicle strongly influenced to T-I-S-Stop. T-I-S-Stop by vehicle type per one non-safety vehicle showed same trend with rate of non-safety vehicle. ACC vehicle contributed to decrease T-I-S-Stop on traffic flow from these results.

The maximum value of S-Stop of all vehicles is shown in Figure 11. Here, the S-Stop changed to absolute value for analysis. The maximum value of S-Stop decreased as ACC installation rate rise. Maximum value of S-Stop of non ACC vehicle decreased as ACC installation rate rise. Thus the probability of seriously accident by non ACC vehicle decreased. Maximum value of S-Stop of ACC vehicle was less than non ACC vehicle. However it showed 3-10 m. ACC vehicle also generated instantaneous dangerous situation.

These results are summarized as follows. Increase of ACC vehicle contributed traffic safety on traffic flow. The safety of non ACC vehicle and ACC vehicle did not increase respectively on the mixing traffic flow. In addition the probability of seriously accident by non ACC vehicle decreased by increase of ACC vehicle. However ACC vehicle was not complete safety vehicle. ACC vehicle also generated instantaneous dangerous situation. When the recorded data was examined, it was realized that the dangerous situations were happened by cutting vehicle. However the lengths of dangerous situation time were very short (about 0.3 sec) because ACC vehicle kept safety headway distance soon. Thus it do not seriously influence to safety of traffic flow.
Figure 7 Number of non-safety vehicle

Figure 8 Rate of non-safety vehicle

Figure 9 Average of T-I-S-Stop per all vehicle
In this study, an approach to evaluate the impact of ACC introduction on traffic safety using a micro traffic simulation model was proposed in this study. In the developed model, perception process of first and second vehicle in the front was described so as to simulate driver's behavior. The simulation model was consisted by Paramics as the micro traffic simulation and behavior of with/without ACC was rewritten by API. The existing traffic safety indicators were reviewed. The indicators were classified 4 type indicators according to a definition. As result S-Stop was selected for traffic safety indicator in this study. In addition the evaluation method by using S-Stop which represents conflicts instead of actual traffic accidents occurrence was proposed. This method can consider dangerous degree and length of dangerous time. In this study existing method and new method were observed depending on ACC installation rate in a traffic flow. Finally many cases with different installation rate of ACC were simulated by using the proposed approach and relationship between installation rate and safety indicator was analyzed. The parameters were set randomly based by following vehicle data. As a result of simulation, we could identify that this simulation model can
evaluate the safety impact of ACC. Increase of ACC vehicle contributed traffic safety on traffic flow. The safety of non ACC vehicle and ACC vehicle did not decrease respectively on the mixing traffic flow. In addition the seriously conflict by non ACC vehicle decreased by increase of ACC vehicle. However ACC vehicle was not complete safety vehicle. ACC vehicle also generated instantaneous dangerous situation by cutting vehicle. However the lengths of dangerous situation time were very short. Thus it don’t seriously influence to safety of traffic flow. As the future issue, developed evaluation approach will be applied to real traffic flow on Tokyo metropolitan expressway. In addition the various transportation systems will be evaluated.

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