Simulation studies on the impact of ACC

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Summary

Most of the car manufacturers worldwide have developed some form of Adaptive Cruise Control (ACC) which are now starting to be available on commercial products. However, little is known about the impact of such systems on safety and traffic flow in various situations.

This paper will present the problem of simulating the behavior of a flow of vehicles where some of them are equipped with ACC. Two simulators have been developed respectively by INRIA and by INRETS to bring some insight into the potential effects of ACC on road throughput. However, many problems with this type of work still remain to be studied.

Introduction

The standard cruise-control which maintains a set speed has been very popular, especially in the United States where long distances are often driven on highways. This technique is nowadays quite difficult to use because of the crowding of the highways. At the same time manual driving is quite stressful in these dense situations. Therefore, there is a demand to improve the driving comfort by regulating the speed of the vehicle in dense situations. The danger of rear-end collision is also a major factor for the introduction of systems which could control the speed of a vehicle with respect to the previous one.

Now, thanks to recent developments in sensor technology (radar or lidar) and control technology for the engine and for the brakes, it is possible to control the speed of a vehicle so that it maintains a safe distance with the previous one automatically. Such systems are generally called “ Adaptive Cruise Control “. However, there are still large differences in the prototype systems which are now under test by the various car manufacturers. Before integrating the system onto standard vehicles, the manufacturers and the public authorities are conducting real life and simulation studies to try to assess the impact of their massive introduction on the roads.

The DIATS program[1] , sponsored by the European Commission, is aimed at studying the impact of various forms of road telematics and in particular the impact of ACC. The French research laboratories INRETS and INRIA have developed new generation of (sub)microscopic traffic simulators which are now used in the DIATS program to asses the impact of a percentage of ACC cars in various circumstances.

Various flavors of ACC

ACC technology relies on sensors which can measure accurately the position and the relative speed of a preceding vehicle. Such measurements are now available from fairly low cost sensor developed specifically for automobile applications. Actually, two types of technologies are competing : one using some form of laser range-finder (usually in the infrared light) and the other using a millimeter wave radar. Although both techniques have their own drawbacks (with inclement weather, with curves or fixed obstacles), they can be used to implement fairly satisfying ACC functions. The sensor data is used by a computer to send commands to the throttle of the engine and in some cases, to the brake system.

However, the concept of a “satisfying” ACC is still unclear since few experiments with standard drivers have been conducted. In particular, should the system simply assist the driver in maintaining “safe” distance in “normal” driving conditions, or should it also take action in case of a sudden stop of the previous vehicle. This later function, often called “collision avoidance” is much harder to implement and may lead to abnormal behavior of the ACC vehicle, not to mention the surrounding ones… So, for the moment, we will restrict our study to the simpler types of ACC which do not implement collision avoidance and limit the deceleration and the jerk to “comfortable” values. The driver stays in charge of emergency situations (although he may be warned by the system). We will also assume that ACC can work at any speed (also called Stop&Go mode) although the first systems will probably not include this function which requires braking control.

We have studied three different ACC algorithms. The first one, given by TRL (Transportation Research Laboratory, England), is based on the Jaguar algorithm and is used in the microscopic simulator SISTM [2]; we called it TRL ACC. The second algorithm is based on research performed in the European Project Prometheus and is used by TNO in their microscopic simulator MIXIC [3] ; we called it TNO ACC. The third algorithm is a more complex algorithm developed and experimented at INRIA (French National Research Institute on Computer Science and Automation) in co-operation with a car manufacturer ; we called it INRIA ACC.

Let us describe these three algorithms:

TRL ACC

$$\Gamma_{TRL\_ACC} = \frac{[K_2(x_t - x_{t-1})/T + K_1(v.t_0 - x_t)]}{M}$$

$$-3\ m.s^{-2} < \Gamma_{TRL\_ACC} < 1\ m.s^{-2}$$

where x_{t-1} and x_t are the inter-vehicle distances in metres in the previous and current epochs, v is the current vehicle speed in m/s, T the epoch length and t_0 the desired headway in seconds. M is the mass of the vehicle (1000 kg); K_1 and K_2 are damping constants (-31.25 $kg.s^{-2}$ and 500 $kg.s^{-1}$).

TNO ACC

$$\Gamma_{TNO\_ACC} = K_s.(x_t - x_{t-1})/T + K_d(x_t - M - v.t_0)$$

$$-5\ m.s^{-2} < \Gamma_{TNO\_ACC} < 3\ m.s^{-2}$$

where x_{t-1} and x_t are the inter-vehicle distances in metres in the previous and current epochs, v is the current vehicle speed in m/s, T the epoch length and t_0 the desired headway in seconds. In this algorithm, a distance of security M is added to the time headway. To compare with a time headway of 1.5 s at 100 Km/h, we use in this algorithm a desired headway t_0 of 1.14 s and a distance of security M of 10 meters. K_s and K_d are damping constants (3.0 s^{-1} and 0.2 s^{-2}).

INRIA ACC

The main objective of this new algorithm is to filter the jerk and to use both approaching and following algorithms. The first algorithm is used to approach the preceding vehicle with a progressive deceleration during a certain time and then a constant deceleration ; the second one is used to follow the preceding vehicle, including a specific reaction to a deceleration of the preceding vehicle.

$$\Gamma_{NEW\_ACC} = MAX(\Gamma_{follow}, \Gamma_{approach})$$

$$-3\ m.s^{-2} < \Gamma_{NEW\_ACC} < 3\ m.s^{-2}$$

$$\text{with } \Gamma_{follow} = K_s.S_r + K_d.(D_r + [1.1.S_r]_{(Sr<0)} - D_c) - [K.(S_r^2/(D_r + 1.1.S_r))]_{(Sr<0)}$$

where D_r is the relative distance to the preceding vehicle, D_c the following *distance* $(M + H.S_{prec})$. The calculation of the following distance differs because the speed taken into account is not the speed of the vehicle, as in the above algorithms, but is instead the speed of the preceding vehicle (S_{prec}). M and H are here calibrated for a shorter headway (M = 5m ; H = 1.2 s). The other constant are K_s = 2.2 s^{-1}; K_d = 0.2 s^{-2} ; K = 2. The specificity is that specific terms are added to the equation when the relative speed is negative ($Sr<0$).

The approaching algorithm is more complex. The objective is to impose, if possible, a constant value to the jerk which should be less than 0.05 $m.s^{-3}$. First, we have to calculate the duration of the progressive deceleration phase as a solution of the following third order polynomial:

$$Jerk.T^3 + 6S_r.T + 12D_r = 0$$

Then we can calculate the value of the acceleration at the beginning and at the end of the progressive deceleration phase:

$$\Gamma_{approach} = S_r / T - Jerk.T / 2$$
$$\Gamma_{final} = S_r / T + Jerk.T / 2$$

If Γ_{final} is less than Γ_{min} (-3 $m.s^{-2}$) then we should use the variable jerk approach. In that case, T is solution of:

$$\Gamma_{final}.T^2 + 2S_r.T + 6D_r = 0$$

Then we can calculate the acceleration as follows:

$$\Gamma_{approach} = 2.S_r / T - \Gamma_{min}$$
$$\Gamma_{final} = \Gamma_{min}$$

As we can see from these three examples that it would be much too simple to consider that an ACC implies a fixed headway and this headway is the only design criteria that we have to evaluate. There are many other design parameters which lead to various acceleration profiles and different vehicular distances. These design parameters have large influences on the comfort, safety and efficiency of the technique with regard to throughput. Our goal is to evaluate these factors.

INRIA Simulator (SSE)

INRIA is not a specialist on transportation technology instead it specializes in software tools and control technology. The SSE simulator has been built with two goals. The first goal is to develop new software tools to program simulators to model the environment and the objects which move in this environment. The second objective is to use this simulator to test vehicle control technologies which are under development for the automotive industry. In particular, we wanted to test if the ACC control techniques developed in the automotive industry lead to safe and comfortable behavior.

SSE is a very detailed driving simulation environment [4], which able us to simulate the following for each vehicle:

- sensors: visual perception of the car driver and various sensors such as radar ;
- decisional model: behaviour of the driver based on psychological requirements ;
- low level motion control: as the decisional model is not able to specify guidance and pedal pressure torque, this model is used as interface between the decisional and the mechanical models ;
- mechanical model: mechanics of the vehicle ;
- geometry of the vehicle.

The ACC algorithms has been integrated in the low level motion control model and has replaced (when active) the longitudinal control of the vehicle performed by the driver.

Simulation Results

To compare the different algorithms, we have a scenario in which the driver is asked to stay in the same lane during the whole simulation. In a four lane highway, we force the four first vehicles driven by a virtual driver to have the same behaviour as follows :

- t = 0s : Initial Speed = 60 Km/h
- t = 30s : change the speed to 40 Km/h
- t = 60s : change the speed to 100 Km/h

The next four vehicles start 200 meters behind the others with an initial speed of 120 Km/h. Three of them are equipped with ACC models unlike the fourth one. The radar characteristics are the same for the three algorithms (angle = 7°, range = 150 m).

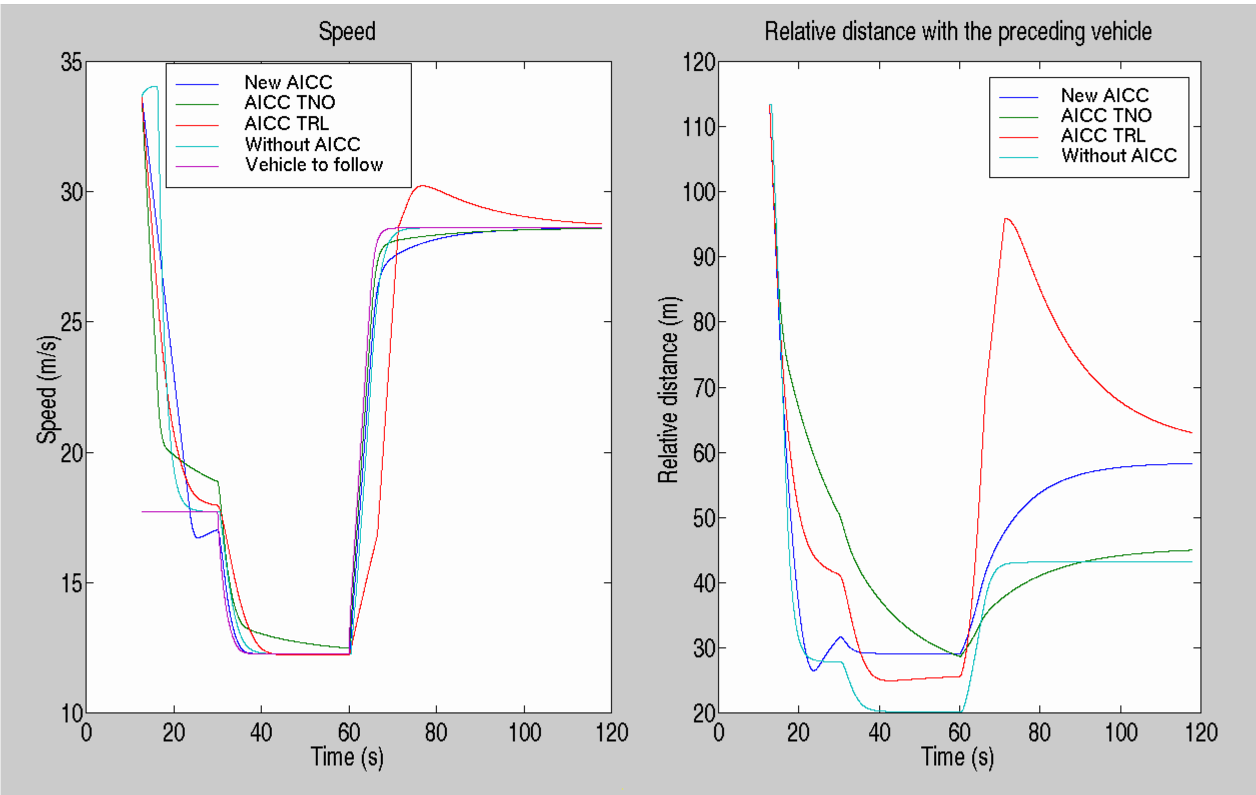


Figure 1: Vehicle speeds and relative distances to the preceding vehicle.

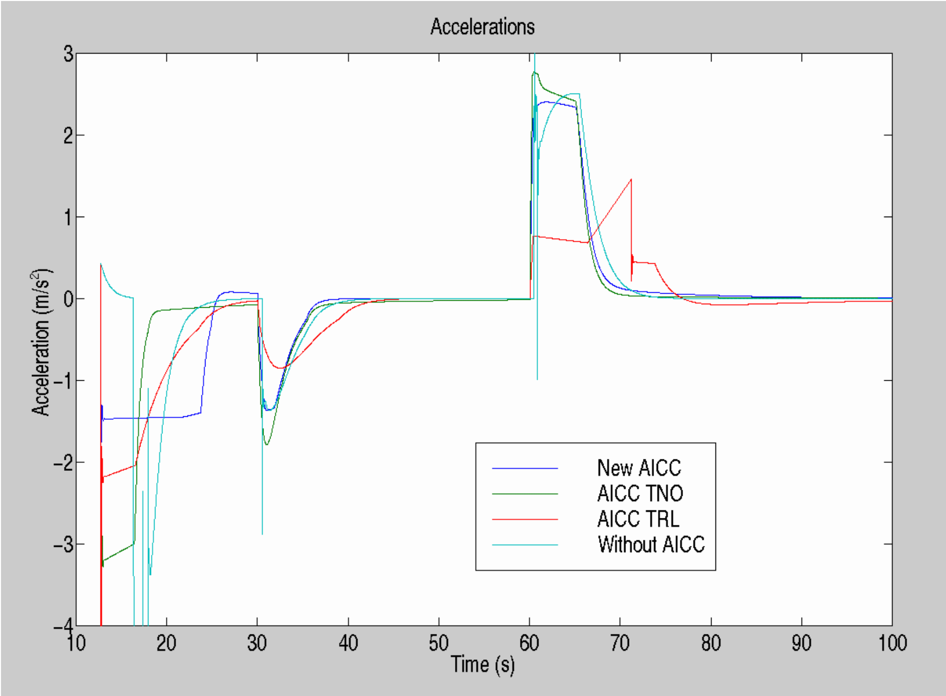


Figure 2: acceleration of the different vehicles.

The reaction of the ACC algorithms are quite different. In the first deceleration phase, the INRIA ACC algorithms (called new AICC in the graph) maintains a less important deceleration during a longest time than the two others algorithms, which is more comfortable for the driver. In the third phase (big acceleration), the TRL algorithm is unable to maintain the relative distance to the preceding vehicle due to the value of its maximal acceleration (1 $m.s^{-2}$), then the ACC is disengaged and the driver takes the control of the vehicle during a short period of twelve seconds.

INRETS Simulator (ARCHISIM)

The aim of the INRETS ARCHISIM project is to provide a realistic simulation of road conditions (infrastructure + traffic), based on individual drivers behaviors in various situations which could involve driving aids, both on-board or not. It is the result of a consideration of the ways in which multi-actor parallel processing could assist in the simulation of a complex system such as road traffic and the psychological analysis of driver activity.

The unique feature of this traffic simulator is that it can include a driving simulator (instrumented cockpit surrounded by videoscreens which display the environment) which allows a human driver to participate in an interactive traffic simulation. Obviously, this simulator can be used in a standalone mode without any human driver.

The aim of the ARCHISIM simulator is to perform “realistic” simulations of road environments (infrastructures + traffic). These simulations include the behavior of individual drivers who are either driving with driving aids or without them. This approach opens various new research areas:

- a better understanding of driving tasks,
- prototyping of new systems,

Our hypothesis is to consider road traffic as a complex system, based on individual behaviors. We consider that it is impossible to apprehend this system globally. Our approach is to consider that the modeling of individual behavior of the various actors of the system and their interaction leads to a good approximation of the global system behavior.

Our problem is then to model these individual behaviors in order to produce a realistic global behavior measured by traffic parameters. This global behavior is not modelled but is derived from the model of the individual behaviors.

ARCHISIM allows in its present state, the real-time modelling of situations involving more than 1,000 units associated with their own “realistic” behaviors. The possibility to include among the units a driving simulator, allows a human to be an actor or a spectator of the simulation. If the driving simulator is used, one must restrict the number of simulated units according to the computing power of the graphic processor. In this fashion, we have a tool to test and evaluate iteratively the behavioral rules integrated in the simulator.

The software architecture is fully open and allows to enter new actors. It is well suited to study new systems. In the scope of the introduction of driving aids (partial or total), ARCHISIM can be used to make impact studies, both at the user level or at the traffic level. This is an original aspect of this tool.

Traffic simulations in the scope of the “Automated Highway”

The missions of the European project DIATS are to study the impact of various scenarios for drivers’aids. In this project, we are interested in studying the impact of these new technologies on the traffic. ACC and anti-collision systems are studied in particular.

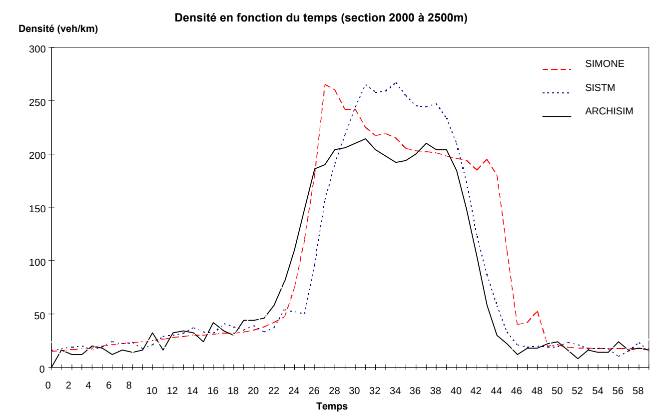
Our approach is to perform these evaluation through simulation with ARCHISIM. A first step consisted in the validation of traffic models independently of the new technologies. This fist step is now finished. The second step is now under way. It consists in the simulation of the introduction at various levels (in %) of ACC techniques in various driving environments (3 or 4 lanes highway, in the presence of entries or exits,…).

Crossed validation

The crossed validation which has been performed with the DIATS partners consists in the simulation of 5 km of a 3 lanes highway reduced to 2 lanes between km 3 and km 4. The traffic starts at 2000 veh/hr during 5 mn, then grow linearly to 4500 veh/hr in 15 mn, stays constant at this level for 5 mn, then decreases linearly to 2000 veh/hr in 15 mn and stays constant at this level for 20 mn. The total simulated time is then one hour.

The reference runs are the macroscopic simulations performed by SIMONE from the University of Hambourg/Harbourg (TUHH) and the microscopic simulation performed by SISTM from the Transportation Research Laboratory (TRL) from the UK. Thes simulators have been validated in turn on many different real sites in Germany and in England.

Figure 3



figure

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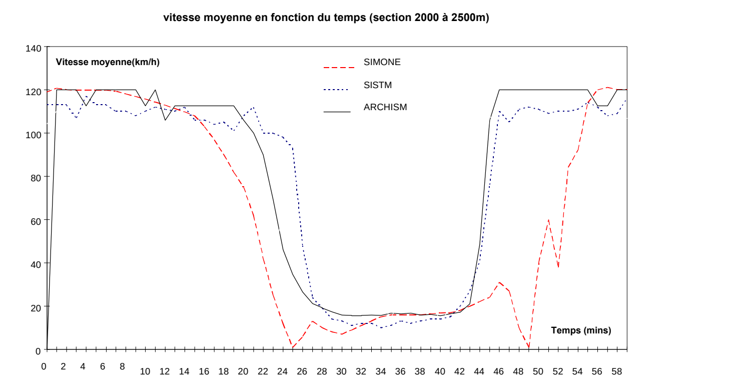
The results shown in figures 3 and 4 show the good coherence of the results obtained from the three different simulators.

Figure 4



Simulation of ACC systems

Although it has been simple to implement the control laws of the three algorithms presented previously, the difficulty has been to simulate realistically the behavior of the drivers who are going to use them. Here we lack a knowledge of user behavior in the presence of such systems for which we have almost no hands-on experience. We can make hypotheses on such behaviors but these hypotheses, from our experience, have a great influence on the results and we may end-up with wrong conclusions.

The problem lies in the very different behavior of a human driver and an ACC system. Human driving is based on the anticipation by the driver on the future situations he may encounter. This anticipation is derived from the perception of what is happening in front and also laterally and in the back of the vehicle one is driving.. It must be noted that often the driver perceives not only the vehicle just ahead but also several ones in front. The headway used by a particular driver are directly dependant on this type of anticipation (and on his response time).

ACC systems do not work on similar types of information and anticipation of future situations. Therefore, its operation in dense situations may not satisfy the driver who may switch it off or change lanes in a very different way in order to avoid unpleasant reactions of the ACC. Since we know very little about these driver behavior, it is premature at the moment to come to any conclusion. Using the simulator, we are now investigating the behavior of users of such systems.

Archisim Output

Conclusion

We have studied in detail the problem of simulating various types of ACC systems. We have come to the conclusion that it is very difficult to evaluate what could be the impact of such systems as long as we do not have any data on the behavior of the drivers who are going to use them. This conclusion implies that it is most important to study, through driving simulators or on the road, these behaviors.

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