

Using Vehicular Communication to Support Older Drivers at Road Intersections: A Feasibility Study

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Abstract. More and more people are living to old age, and it is usually a desire among elderly to sustain mobility. Unfortunately, the crash rate of older adults is much larger than for other drivers. Older drivers are also more likely to get serious injuries that lead to disability or death. Therefore, technological contributions for improving traffic safety and preserve mobility of older people are important. One new promising approach is to use traffic safety systems based on vehicular communication, where vehicles exchange warning messages. This paper evaluates the feasibility of using such vehicular communication for supporting older drivers in road intersections, which is the most common accident setting for older drivers. Using a temporal reasoning systems (ECAM) this accident setting is analyzed in depth, and the potential for accident avoidance is quantified, while taking into account several relevant factors such as speed, driver reaction time, and transmission delay for warning messages. The results indicate the high potential of vehicular communication, and highlights requirements on transmission delay.

1. Introduction

Due to societal improvements in health-care, living standards, and socio-economic status, more and more people are living to old age [21]. It is usually a desire among elderly to sustain mobility and continue with their daily activities, such as driving, and thus remain independent [18]. However, statistics show that the crash rate of older adults is considerably larger than that of other drivers [9]. Older drivers are also more likely than other drivers to get serious injuries that lead to disability or death [15]. Therefore there are great opportunities for technological contributions with respect to improving traffic safety while preserving the mobility of older people.

In this paper we focus on a particular accident type of great importance, namely the road intersection accident, which is the most common accident type for drivers of old age [10]. We analyze in depth to what extent traffic safety systems based on vehicular communication can help to avoid this type of accident. Using warning messages sent between nearby vehicles or from base stations located at the side of the road, these safety systems has the potential of overcoming the limitations of safety systems relying only on sensors placed on the vehicle. More specifically, we use a temporal reasoning system (ECAM) for analyzing the impact of information transfer properties (transmission delay of warning messages), driver characteristics (reaction time), and accident scenario characteristics (e.g. speed), on collision avoidance. The results indicate the strong potential of safety systems based on vehicular communication for helping older drivers maintain safe driving in road intersections.

The rest of this paper is structured as follows. In section 2 we analyze older drivers and the accident risks they face. In section 3 we give an overview of traffic safety systems, followed by a detailed description of the road intersection accident scenario in section 4. In section 5 we describe our simulation experiments and present the results. This is followed by a discussion in section 6. In section 7 we describe related work on traffic simulators, and in section 8 we conclude the paper.

2. Older drivers and accidents

Accident statistics reveal that the accident risk for elderly drivers is higher than for other age groups [20]. These statistics indicate that most of the accidents involving older drivers happen in complex traffic situations such as road intersections [4]. People of old age are a highly heterogeneous group. Still, there is general agreement that several functions important for driving behavior tend to degenerate with increased age among older people. These functions are related to cognitive and motor capabilities [4]. Cognitive functions affect a person's intellectual abilities including perception, memory, problem solving ability, space orientation, information management, and attention. Research on driving-related problems has focused on perception, which has been shown to have a strong relationship to accident occurrences [4,19]. In addition, older drivers are slower at handling information when it comes to making difficult decisions. They have difficulties maintaining all the needed information for making decisions due to deterioration in attention and memory. When they act on the information they have gathered, they are slower than what the situation may demand. When it comes to visual perception, it has been found that older people have increased difficulties to perceive impulses from their surroundings. For traffic situations, they have difficulties determining speed and distances. The decay of motor capabilities for older people implies a decrease in movement range, and reaction time [16]. This causes problems for head movements for gathering visual information from the sides, and for handling of pedals, steering wheel, gears, but also for making the coordination work.

To help old people maintain safe driving, it is important to investigate the development of traffic safety systems for accident avoidance.

3. Traffic safety systems

Safety systems can be classified into *passive* and *active* systems [12]. Passive systems, such as anti-lock breaks and seat belts, react to dangerous situations, trying to help the driver avoiding an accident, or reducing the consequences of an accident. However, such passive systems are inherently limited in the sense that they are not designed to hinder a dangerous situation to develop in the first place.

Active systems, such as adaptive cruise control, are designed to proactively prevent vehicles from colliding with each other or with other objects. They collect and analyze information extracted from the local environment surrounding a vehicle, through sensors or video cameras to identify dangers in traffic [1, 3]. The active safety systems act towards avoiding accidents by warning the driver about a potential danger, and can eventually employ automatic actions such as emergency braking. Such systems can be categorized according to the type of support provided to the driver as [11]:

- *Information delivery systems*: These systems present the driver with information that can increase his/her situation awareness and let the driver take the appropriate measures.

- *Automatic control systems:* These systems aim at providing more support to the driver by employing automatic actions. However, attention needs to be given to the transfer of tasks from humans to vehicles, since unknown problems may arise.

Three technologies were mainly considered for implementing active safety systems: radar and laser sensor systems, computer vision, and communication systems [12]. Active safety systems that employ sensors usually use radar and lidar devices (i.e. sensor based on laser) for detecting obstacles that exist around a vehicle and may interfere with its travelling path. Active safety systems that employ computer vision also perform detection of possible dangerous obstacles existing around a vehicle by using stereo cameras. These systems are also employed for monitoring the movement of a vehicle by analyzing its position with regard to road elements such as lane markers. However, relying on data from local sensors or cameras is an inherent drawback of these systems. This severely limits their utility for detecting objects that are not in line of sight, such as vehicles entering an intersection [17]. A potential solution to many of the limitations of such active safety systems is to equip vehicles with communication capabilities, allowing the exchange of safety related information. Using communication, a vehicle can then obtain data about vehicles that are not detected by sensors or computer vision systems. Consequently, the perception of the vehicle is improved and the possibility for the active safety systems installed in it to detect dangers in complex traffic situations is enhanced. For example, two vehicles entering an intersection from perpendicular paths could become aware of each other's presence through communication.

We illustrate in figure 1 an active safety system that employs communication between vehicles. This system integrates in-vehicle sensors (e.g. positioning devices, speedometer) and a communication system that provides information used in traffic analyses. In this example, the vehicles are able to exchange messages that contain safety-related information such as the front seat data of a vehicle (e.g. speed, heading, position) or messages that indicate events in traffic (e.g. accident, traffic jam). The active safety system analyzes this data and the data describing the subject vehicle for determining threats in traffic. For instance, a threat is determined if two vehicles are in danger of crashing at an intersection [17], or if a vehicle is too close to another vehicle [13]. When such dangerous situations are detected, the system reacts by issuing warnings that are presented to the driver.

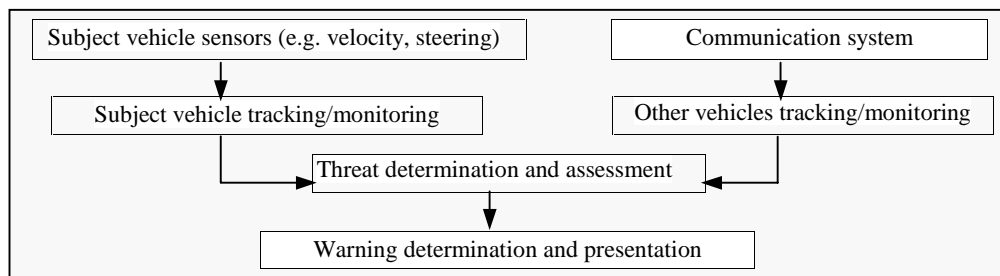


Figure 1 Active safety system using communication.

However, even if vehicular communication is generally thought to have a high potential for supporting active safety systems (e.g. [1, 17]), it may not be effective in all traffic situations. For example, communication may have little impact in helping avoiding lane departure accidents. In our previous work, we have proposed vehicular communication solutions, and analyzed their performance (in terms of message delay, etc). Now, we investigate to what extent these solutions, based on their performance, can help to avoid road intersection accidents involving elderly drivers.

4. Road intersection accidents

Studies have indicated that a large majority of accidents involving elderly drivers take place at intersections [10]. The main difficulties elderly drivers face at intersections are [4, 7, 22]:

- Estimation of a safe gap and the estimation of velocity of other vehicles.
- Fast execution of driving maneuvers (e.g. turning).
- Failure to sense and comprehend traffic signals and signs.
- Inability to perceive and process information about high traffic volumes.

We illustrate in figure 2 an intersection collision involving an elderly driver by the use of an intersection crash with perpendicular path scenario. This type of accident accounts for more than 30% of the total number of accidents that appear each year at intersections [19]. It is also considered to be of very high risk for elderly drivers [20].

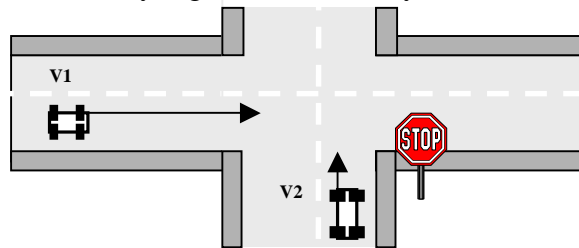


Figure 2 Intersection crash with perpendicular path

The scenario contains two vehicles that approach an intersection. The driver in vehicle V2 is an elderly driver (e.g. over 65) and the driver in V1 is a mid-age driver (e.g. 40-49). Vehicle V1 is travelling on the priority road. Vehicle V2 is initially stopped at the STOP sign and plans to cross the intersection. When V2 starts to cross, its acceleration is low as the elderly driver tends to drive carefully. Let us consider that V2's driver is not able to notice the presence of V1 perhaps because the driver fails to make a correct estimate of V1's distance and velocity. The driver in vehicle V1 is misled by the maneuver of V2 and considers that V2 will not pass the intersection or will pass it in time. At some later time, V1's driver realizes that these assumptions are not valid and intends to brake for stopping. However, due to a small separation distance between vehicles, V1 crashes into V2.

Now, the question is how to avoid this type of accident.

5. Simulation experiments

5.1 Simulation goals and environment

The main goal of our study was to investigate the feasibility of using vehicular communication for supporting older drivers at road intersections. The specific issues that we addressed were:

- Investigate requirements on information transfer that need to be fulfilled by vehicular communication systems.
- Quantify the impact of the accident scenario conditions and information transfer properties on accident avoidance.

In previous work we developed ECAM, a temporal reasoning system for modeling and analyzing accident scenarios [5]. This system constituted the simulation environment that we used within our study for analyzing the possibility of avoiding intersection accidents by the use of communication. A brief description of this system is provided in the following. Details on the design, functionality, and implementation of the system can be found in [5]. ECAM is a formal framework that provides a reasoning engine for studying the time evolution of traffic accidents. It is based on a well-known logical formalism, the Event Calculus [14], and it is implemented using logic programming (i.e. Prolog). This system

gives the possibility of investigating the relations between events that occur in traffic and their possible consequences. It is thus able to model changes that take place when different actions happen in a traffic situation. For performing analyses, the system can be questioned to determine if and when certain traffic conditions related to vehicles involved in a scenario become valid. For instance, we can determine if and when a collision between two vehicles has occurred within a traffic scenario. Further, by modifying different parameters in the scenario (e.g. initial speed of vehicles) or by introducing new actions that modify the development of the scenario (e.g. a heavy braking) we can investigate changes in the scenario behavior. For instance, by performing such analyses we can determine if and how a collision can be avoided.

5.2 Experiments and results

As a case study, we have employed ECAM for studying the intersection accident previously introduced. As mentioned before, our focus has been to evaluate to what extent vehicular communication can help to avoid this accident. Therefore, in our experiments we assumed that an active safety system based on communication is installed in each vehicle. This system can present the driver with warnings about dangers in traffic and can also employ automatic actions if it is set in an automatic mode. Further, we based our investigation on a number of assumptions, which are presented in figure 3.

Assumptions:

- When vehicle V2 starts to cross the intersection a warning message is sent to vehicle V1.
- The active safety system in V1 receives the warning message and reacts to it, either by notifying the driver that V2 has started to cross the intersection, or by braking automatically.
- The driver in V1 reacts to the notification and starts to brake heavily after a driver reaction time has passed (a reaction time of 0 indicates automatic braking).
- The acceleration of V2 when entering the intersection is fixed, and fairly low (i.e. 1.5 m/s^2). This assumption is based on the fact that many older drivers drive slowly, as a compensatory measure for their limited cognitive abilities [10].
- The distance of vehicle V2 from the entry point into the intersection is fixed and is set to 4 meters.
- Vehicle V2 starts crossing the intersection at 1 second after the beginning of the scenario.
- A maximum deceleration of 9 m/s^2 is considered for vehicle V1.
- The width of a road lane is set to 4 meters.

Fig. 3. Assumptions made within the experiments.

The avoidance of the accident between V1 and V2 can be achieved due to the heavy braking maneuver performed by V1 when it receives the warning message sent by V2. Therefore, our interest was to investigate the maximum delay for the warning message sent by V2 that can still assure the accident avoidance. We performed our experiments by varying the scenario conditions and dynamics, represented by the variation of the reaction times of the driver and of the initial speed of vehicle V1. Figure 4 summarizes these independent variables. In our experiments, we have used the *cut-off distance* for V1 as the dependent variable. We defined this parameter as the minimum distance from the entry point into the intersection at which V1 needs to be positioned when V2 issues the warning message, for the collision between V1 and V2 to be avoided.

In figure 5 we present the results obtained by modifying the initial speed of vehicle V1 (i.e. the speed until V1 performs the braking due to the warning message), when we employed a 1.5 seconds reaction time of the driver. We note that we use dotted lines for marking the *accident range* in the figure, which is the distance range where the initial collision between V1 and V2 occurs (i.e. when no active safety system is used). Thus, if V1 is initially situated at distances below and above these dotted lines, the accident will not occur. (Note that the accident range increases in size with increased speed of V1.) Further, by representing the cut-off distance for V1 as a function of V2's warning message delay we

divided the representational space into accident and non-accident areas. Thus, the area above the separating (continuous) curve represents the cases where a collision was avoided, while the area below the curve represents the situations where, in spite of an emergency braking, a collision still occurs.

Independent Variables:

- *Delay of V2's warning message* - varied between 0.6 msec and 2.3 seconds. The values for delay were selected based on realistic results for simulation of communication between vehicles that we obtained in earlier work [5, 6].
- *Speed of V1* – varied between 10 m/s (i.e. 36 km/h) and 25 m/s (i.e. 90 km/h).
- *Driver reaction time (DRT)* – varied between 0 and 3 seconds based on research in collision avoidance (e.g. [13]). We note that a DRT of 0 seconds corresponds to an automatic active safety system. For the overall population, a DRT of 1.5 seconds is an upper limit for simple reactions [13, 8]. However, we have adopted this value as a normal value, since it is known that older people tend to have longer reaction times. A DRT of 3 seconds is an extreme upper bound that rarely occurs in real cases [8].

Fig. 4. Independent variables used within the experiments.

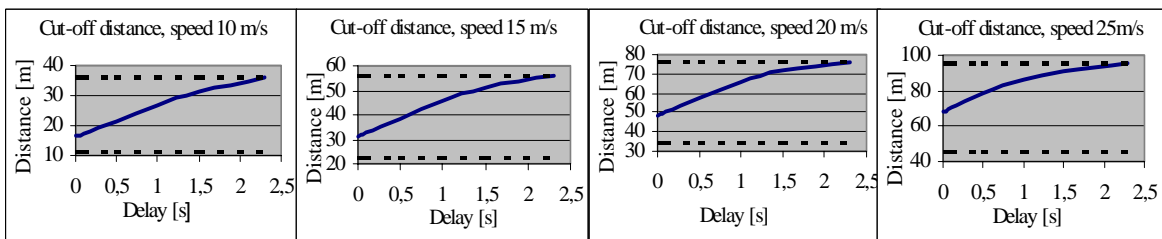


Fig. 5. Cut-off distance as a function of communication delay. Speed values from 10m/s to 25 m/s.

Further, in figure 6 we present the results obtained for using the other two representative values for the driver reaction times (DRT):

- **DRT = 0 seconds.** This corresponds to the active safety system in V1 set to the automatic mode and performing a heavy braking without any delay when the warning message from V2 is received.
- **DRT = 3 seconds.** This is an extreme upper bound that rarely occurs in real cases [8].

The graphs in the figure illustrate the results for an initial speed of V1 of 15 m/s and 20 m/s. Observe that a considerable portion of the accidents in the accident range for DRT of 0 seconds can be avoided due to vehicular communication. On the other hand, with a DRT of 3 seconds, very few accidents can be avoided.

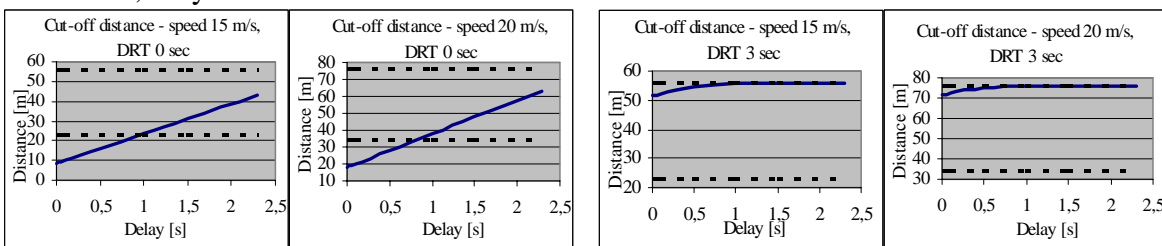


Fig. 6. Cut-off distance and communication delay. Speed values: 15m/s and 20 m/s. DRT: 0 sec and 3 sec.

A peculiarity with the cut-off distance curves for DRT of 0 seconds is that the curve continues below the lower part of the accident range (where accidents are not supposed to happen). The explanation for this is that the automatic braking performed when the warning message arrives actually can lead to accidents if the message is received when V1 is too close to the intersection. If V1 had not started to brake, and continued with normal speed, V1 would have passed the intersection before V2 had entered, and thus the accident would have been avoided.

From the graphs in figure 5 we note that delays above approximately 2.3 seconds mean that no accidents can be avoided. With a DRT of 3 seconds, the corresponding maximum delay is around 1 second. The maximum delay for a DRT of 0 seconds cannot be

determined directly from figure 6, but in further experiments we have determined the maximum delay to be around 3.8 seconds.

6. Discussion

From the experiments we saw that transmission delay has a fairly large influence on collision avoidance. Hence, it is of great importance to minimize the transmission delay. Fortunately, our initial experiments with vehicular communication protocols show that small delays are feasible in many realistic traffic scenarios [5, 6]. However, minimizing delay may not be of much help for people with very long reaction times. In these cases, an automatic system may be the only feasible solution. Still, note that even though an accident may not be entirely avoided, its consequences can be limited due to braking in response to a warning message (e.g. by reducing the speed at collision time).

Traffic safety systems that take automatic action show the best potential for accident avoidance. But such systems need to be more complex than information delivery systems that leave the driver in control. As we saw in the results, automatic braking in response to a warning message may actually introduce an accident. This indicates that further analysis (e.g. continuing the work started in this paper) is needed for the eventual realization of fully dependable automatic active safety systems. Such automatic systems cannot just react to warning messages, but must be deliberative and reason about potential consequences of their actions.

7. Related traffic simulators

A large number of traffic simulators exist. In [2], 57 different simulators are analyzed and compared. The authors conclude that only 3 of the evaluated simulators are event based, “where the states of objects in the network are changed at discrete times in response to events on an event list”. The other simulators work with fixed time steps (typically 1-second intervals). Given the type of analysis we perform in this paper, such coarse-grained analysis with fixed time steps is not appropriate. We need to deduce the exact time at which an accident occurs. Of the three simulators that were event-based, and thus potentially useful for our study, the FLEXSYT-II system makes use of stochastic movement patterns, making it difficult to precisely control the movements of individual vehicles. The SIGSIM system is focused on signal-controlled junctions for the evaluation of signal control policies. Hence, adapting this simulator to our scenario would not have been straightforward. Finally, SIMNET has the purpose of evaluating traffic control strategies in general, and not on analyzing specific accident scenarios. In sum, we believe that the ECAM system complements today’s existing traffic simulators, and will be a valuable tool for future analysis of complex accident scenarios.

8. Concluding remarks

We have investigated the feasibility of using vehicular communication for supporting the avoidance of intersection collisions involving older drivers. Our results indicated the communication to be an effective mean for supporting accident avoidance in many cases.

While the results are promising, it is important to note that our study is early work, and that a number of key steps need to be taken before safety systems based on vehicular communication can become a commercial reality. For example, the question of how a safety system should handle a warning message is crucial. Should the system take action

and brake automatically, or should a warning message be displayed to the driver so that he or she remains in control? Still, researchers tend to agree that vehicular communication is the key to a future with safer traffic, where old people can maintain mobility.

9. References

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