

Forward Collision Warning Timing in Near Term Applications

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ABSTRACT

Forward Collision Warning (FCW) is a system intended to warn the driver in order to reduce the number of rear end collisions or reduce the severity of collisions. However, it has the potential to generate driver annoyances and unintended consequences due to high ineffectual (false or unnecessary) alarms with a corresponding reduction in the total system effectiveness. The ineffectual alarm rate is known to be closely associated with the "time to issue warning." This results in a conflicting set of requirements. The earlier the time the warning is issued, the greater probability of reducing the severity of the impact or eliminating it. However, with an earlier warning time there is a greater chance of ineffectual warning, which could result in significant annoyance, frequent complaints and the driver's disengagement of the FCW. Disengaging the FCW eliminates its potential benefits. A shorter warning time may be beneficial; it would reduce ineffectual alarm rates and thus reduce driver's annoyance level, increasing the driver's confidence in the system, which leads to improve overall system efficiency. To use a shorter warning time, its impact needs to be understood.

In this paper an analysis of certain factors affecting the time to issue warnings is presented. A kinematics model is used to simulate variation in driving scenarios and driver characteristics, such as driver reaction time and brake force level. The analysis relies on a stochastic model that uses a set of distributions of driver responses in rear end collision avoidance maneuvers, along with the relation between crash severity/hypothetic fatality rates (HFR), to estimate the impact of the different proposed warning strategies. The study finds that a shorter warning time may be beneficial. The analysis is limited in scope to the simplest, but common, driving scenarios and for the first time quantitatively studies the impact of shorter time to warn.

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INTRODUCTION

The time needed to warn (time-to-warn or warning issuing time) the driver to take action under given circumstances, for example to avoid a collision, and the associated algorithm, have been estimated on theoretical bases and, to some degree, are supported with field studies (naturalistic) or driving simulators [4,5,6,7].

Field research and simulator studies provide some relevant information for developing an understanding of the pre-crash environments and foundation for designing the FCW systems [4, 5, 6, 7]. However, despite this work, insufficient scenarios are collected due to the limited exposures of vehicle types, driver demographics and geographic representations of the field studies as well as the artificial environments in the simulator studies. Theoretical calculations are used for the estimation of TTC and the development of warning algorithms [8]. Burgett et. al. developed a warning algorithm for ACAS (Automatic

Collision Avoidance Systems) in 1998 in which the lead vehicle's deceleration, the relative speed, the spacing distance and the speed level were used to instigate a warning based on two preset calibration parameters: Reaction Time (RT) and maximum braking level (DCmax). Studies using criteria such as TTC and Crash Prevention Boundaries (CPB) have been used to decide the warning issuing time [8, 9]. Other studies have modeled the field data to formulate the associated warning algorithm [10].

One study examined the potential effectiveness of a Pre-Collision System (PCS) that integrates Forward Collision Warning (FCW), Pre-crash Brake Assist (PBA) and autonomous Pre-crash Braking (PB) [9]. The results indicate that PCS might reduce the median velocity variation (ΔV), the number of moderately to fatally injured drivers wearing their seat belt and the number of collisions. However, in the study it is assumed that the system is 100% effective. In the real world the system would not be fully effective, even if the system is sophisticated enough to adjust the warning time

according to road surface conditions complicated by the incremental weather, road surface material, etc. [4]. In addition, the system effectiveness can be compromised due to potential high ineffectual alarm rates. It is not foreseeable, at the current technology level, to achieve complete crash avoidance without introducing system noise (ineffectual alarms).

Consequently, one important issue to be addressed is the rate of ineffectual alarms: The unintended consequence could be reduced benefit. The complexity of the issue and the limitations of the technology indicate a strategy, possibly short term, which utilizes the technology in hand and allows a balance between effectiveness and false alarms, in lieu of an approach that pursues the solution for complex issues impeded by current technologies.

One of the control factors in ineffectual alarm rates is the TTC. TTC is closely tied to, and basically a form of the time headway. In a typical driving situation, when a collision is eminent, the time headways are typically less than 2 seconds and around 1 second. However, current FCW system test procedures (NCAP) require vehicles manufacturers to meet certain specific TTCs [12]. They range between 2.0 seconds to 2.4 seconds. This could result in excessive ineffectual alarms [14]. The headway or TTC observed in the real world is short, and in many cases, seems to be just enough for an attentive driver to avoid accidents [16]. Many researchers suggest much shorter TTCs, typically between 1.2 to 2 seconds [16]. Japanese specifications allow a TTC as small as 1.4 seconds and a minimum of 0.6 seconds [4]. It is believed that if the warning is issued earlier than the driver's expectation for an acceptable warning, it would lead to annoyance. A study conducted by NHTSA shows the impact of ineffectual alarm rates on the driver's behavior; it found that a high percentage (41%) of drivers would turn off the system [7].

There are two warning strategies/philosophies discussed in this paper; one aims to warn for all "possible" collisions. This approach often comes with implicit unrealistically high ineffectual alarm rates, with TTCs longer than perceived as acceptable in real world by many drivers. The other one aims to reduce unnecessary alarms to a technologically possible degree, but at the same time still be able to mitigate the collision.

If the ineffectual alarms can be decreased by reducing the TTC, then there is the potential to improve the overall effectiveness of FCW. Attempts have been made to reduce the effectual alarm rates to a more acceptable level. For example, there are brake assist systems that assume 0.6g braking deceleration level in the warning algorithm, which allows a shorter TTC than when 0.3g is assumed [4]. There is an emphasis in reducing impact speed as the goal of warning systems, if complete avoidance is unachievable [4]. Some designs call for a second system confirmation of crash, e.g. Radar + Camera, before activating the warning/mitigation system [4]. The objective of some collision mitigation systems is to reduce speed.

In this study, to evaluate the effects of a warning system, a simple 2-D mathematical/kinematic model representing a set of pre-crash vehicle dynamic maneuvers was used. Different driving scenarios were studied to explore the potential improvements of warning algorithms in terms of headway/TTC reduction and minimization of the ineffectual alarm rates.

The use of mathematical/kinematic modeling supplements the naturalistic and simulator studies. These models can help address a wider range of kinematic parameters, such as: headways, drivers' pre-crash maneuvers for both lead and follow vehicles, different levels of brake forces applied during the maneuvers, as well as driver and hardware response delay times. The impact of those parameters can be studied individually or in combination. Hypothetically, potential warning strategies can then be developed and tested. In this report, the scope of discussion is limited to TTC reduction as it applies to the three current NCAP test criteria.

Built on the results from the previous study [6], this paper aims to achieve the following objectives:

1. Use the mathematical model to simulate a selected group of potential real world representative scenarios.
2. Use the simulation results in estimating the impact of reduced TTCs on expected fatality or the possible degradation.

ASSUMPTIONS AND METHOD

The model is constructed to include the driver's response to a warning. The distributions of the reaction times and brake levels are used as inputs to the model to simulate the pre-crash scenarios.

The model sensitivity is first examined before running the simulation. The trend in relationship between the crash severity and reduced TTC is then studied. Finally, the calculation of HFR using the speed/fatality relation model proposed by Nusholtz is performed [13].

The simulation uses the distribution of driver brake reaction times developed by Sivak et al. (1982), which has a mean reaction time of 1.21s and a standard deviation of 0.63s [10]. It assumes a log-normal distribution. This distribution has already been used to investigate collision warning responses [11]. In this study, only braking avoidance maneuver is simulated for the sake of simplifications. Not including the steering avoidance actions should have influence on the results, obtaining longer TTCs than necessary (i.e. a conservative estimate).

Figure 1 shows the probability distribution function of driver response times. The driver reaction distribution (Fig. 2) has a median response time of 1.07s [10]. The brake force distribution uses the information from NHTSA's Field Operational Test (FOT) [7] (Fig. 3). Figure 4 shows the statistical distribution curve derived from that study.

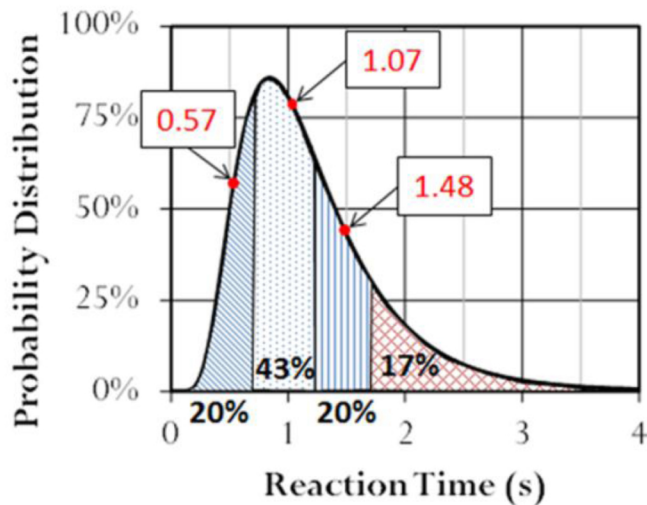


Figure 1. Driver Reaction Time (s) Distribution by Sivak (1982)

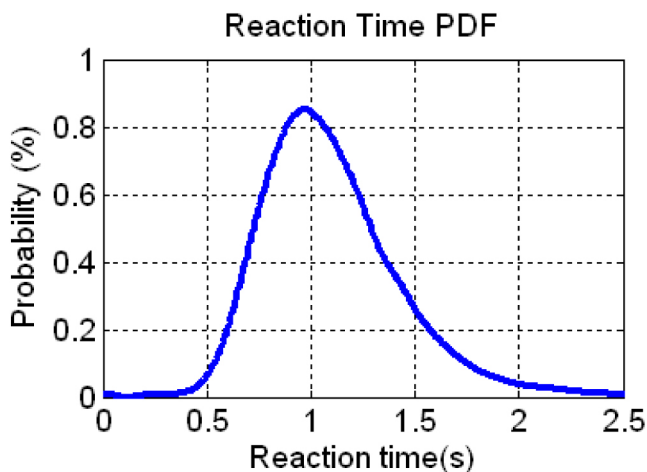


Figure 2. Driver Reaction Time (s) Distribution Used in the Simulations

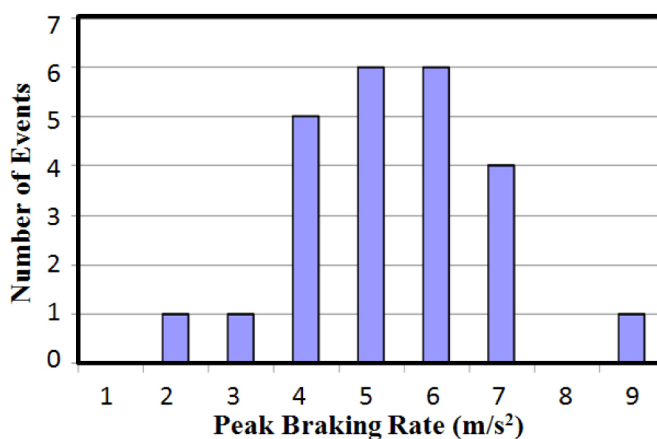


Figure 3. Brake Force Level Distribution from FOT NHTSA (2006)

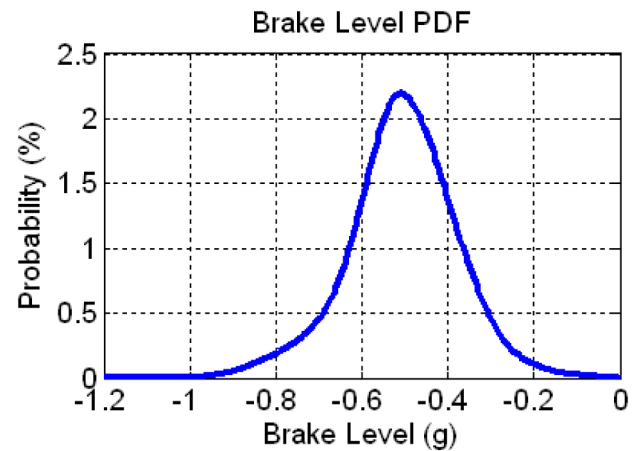


Figure 4. Brake Force Level (g) Distribution Used in the Simulation

The HFRs based on the simulation results are used to evaluate the impact of FCW system's alarm triggering algorithm, or TTCs, where the HFR formula used is:

$$HFR = \tanh(9.7 * 10^{(-8)} * v^{(3.8)}) * 100 \quad (1)$$

Based on the study by Nusholtz et. al. [13]. In (1), V stands for relative velocity, delta-V, in miles per hour. The corresponding relation between the HFR and delta-V is shown in Fig. 5.

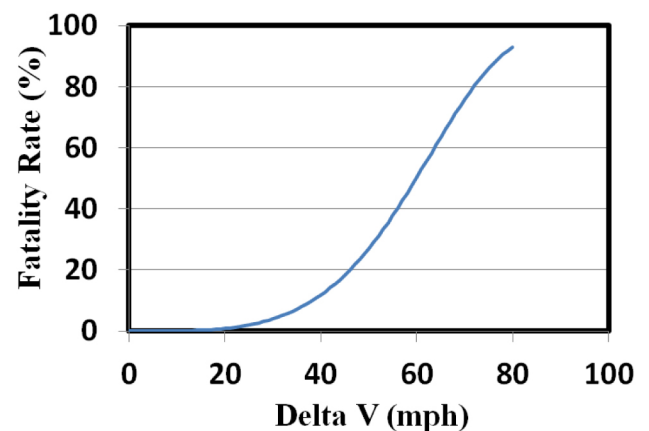


Figure 5. Severe Injury/Fatality Risk for Drivers in Frontal Crashes (11-1) O'clock

In the simulations, the brake force is assumed to ramp up immediately to the peak level once it is applied. On the other hand, the braking time delay is used to account for the driver's reaction and the brake mechanical and system delays. By taking into consideration the distributions of driver (driver reaction time) and system (brake force level) responses, the model improves the accuracy of predictions and the validity of the system performance evaluations, as compared to the earlier study [6].

RESULTS

A. Calculation of Probability of Various Crash Severities (Velocities)

Allowing low speed collision has been found to be a major factor in reducing TTCs [6]. This study focuses on the potential impact of shorter TTCs on the HFR. The HFR is believed to be proportional to the impact velocities, hence crash severity, at the time of contact of the following vehicle with the lead vehicle; the delta-V, as prescribed by Equation 1.

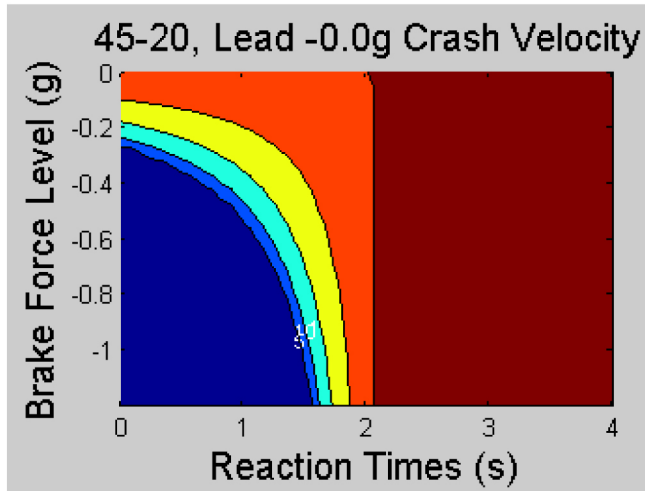


Figure 6. Crash Severity Distribution with Respect to Driver Reaction Times and Brake Force Levels

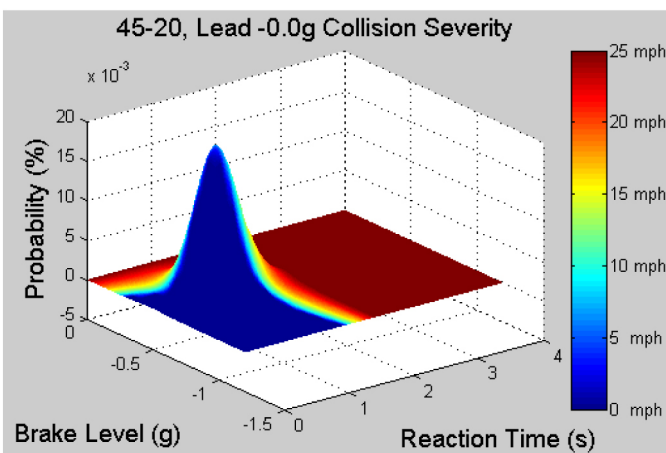


Figure 7. Likelihood of Various Crash Severities w.r.t. Driver Reaction Times and Brake Force for Different Velocities

Figure 6 shows, as an example obtained from the simulations, a color contour plot of resulting impact velocities as a consequence of the driver reaction times and brake force levels for TTC (NHTSA NCAP scenario #2 - lead vehicle velocity 20 mph; follow vehicle velocity 45 mph and

no lead vehicle decelerations). The colors represent the impact velocity for a given reaction time and brake force level, and they are shown in increments of 5 mph. Monte Carlo simulations using randomly chosen brake force levels (Fig. 4) and reaction times (Fig. 2) are run to calculate the crash velocity (severity), which is represented by different colors in Fig. 7. The brake force levels and reaction times were chosen according to their probability curves. The results from the simulation create the probability distribution space of various crash severities corresponding to a combination of different driver reaction times and brake forces. Fig. 8 shows a scatter plot of the entire individual runs projected on a two dimensional plane of probabilities and velocities. The distribution mapping of impact velocities, shown in Fig. 9, is the combined sum of all the runs for a given velocity bin. The cumulative distribution of impact velocities (Fig. 10) is obtained subsequently.

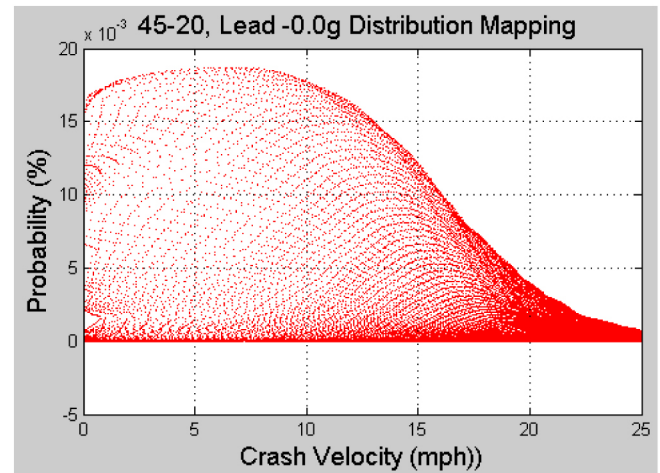


Figure 8. Distribution Mapping of Impact Velocity vs. Probability

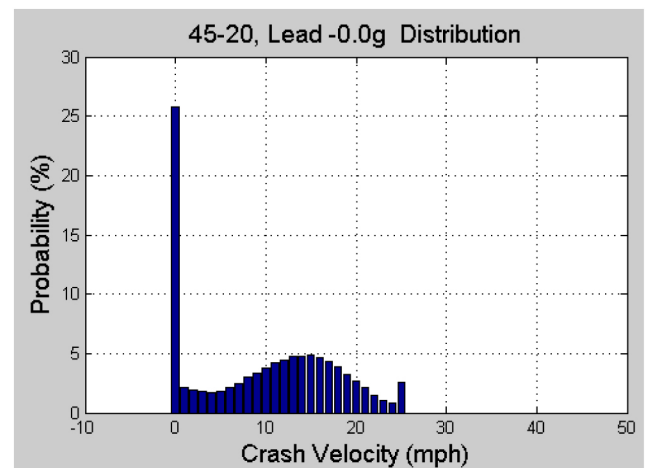


Figure 9. Frequency of Occurrences of Various Impact Velocities