A Time Gap Interval for Safe Following Distance (TGFD) in Avoiding Car Collision in Wireless Vehicular Networks (VANET) Environment

Suzi Iryanti Fadilah, Azizul Rahman Mohd Shariff

School of Computer Sciences
Universiti Sains Malaysia
Penang, Malaysia

suziiryanti@yahoo.com, azizul@cs.usm.my

Abstract—Driving is an intense and dynamic cooperation between human and vehicles. Drivers control the vehicle directly or supervise the situation according to information displayed on the instrument panel. Different from the time-headway and traditional braking models, this paper aims to propose a new safety indicator called time gap interval for safe following distance (TGFD) which incorporates vehicle dynamics and driver behavior factors that includes the time component to broadcast and propagate suitable safety messages in vehicular ad hoc network (VANET) environment. This simulation-based safety indicator could analyze the capability of a vehicle in a car-following situation to safely stop without hitting the vehicle in front when an emergency brake is applied by considering the proper reaction time of the driver of the following. Results from this simulation study indicate that the TGFD is more comprehensive safety indicator for safety analysis.

Keywords—Time Gap, Safe Distance, Collision Avoidance, VANET

I. INTRODUCTION

All Vehicular Ad-Hoc Networking (VANET) is an important component of Intelligent Transportation System (ITS), which provides an infrastructure based framework for most vehicle-to-vehicle communication applications. The development of VANETs for ITS can most significantly enhance driving safety and support the traditional traffic management functions. VANET is a wireless communication networks that do not require any fixed infrastructure, and support cooperative driving among communicating cars on the road. Vehicles act as communication nodes and relays, forming dynamic vehicular networks together with other near-by vehicles on the road and highways. In the recent years, vehicular networking has gained a lot of popularity among the industry and academic research community and is seem to be the most valuable concept for improving efficiency and safety for future transportations. VANET have grown out of the need to support the growing number of wireless products that can now be used in vehicles. Over the last few years, we have witnessed many research efforts that have investigated various issues due to the crucial role they are expected to play in ITS. In fact, various VANET projects have been executed by various governments, industries, and academic institutions around the world in the last decade or so. One of the primary goals of implementing technology in the ITS domain is to improve safety by reducing risk, with the intended consequence of minimizing accidents. The short term goal of this endeavor is to detect high risk situations and alert the operator of the vehicle in an appropriate manner.

It has been oriented that supporting vehicle-to-vehicle and vehicle-to-infrastructure communications with a Vehicular Ad-Hoc Network (VANET) can improve road safety and increase transportation efficiency. Among the candidate applications of VANETs, cooperative collision avoidance (CCA) is important safety applications of vehicular ad-hoc networks (VANETs). This system has attracted considerable interest as it can significantly improve road safety. Since road safety has now been identified as a major problem in public health and is increasingly seen to be a development issue relevant to the achievement of the worldwide development goals, instead of being treated as just a secondary aspect of transport policy. Despite the best efforts of research and development carried out in the automotive industry, car collisions are a worsening global disaster destroying lives and livelihoods, and the good solution of road injury prevention is a must. Rear-end collision is one of the main types of car collision. It is particularly important to prevent rear-end collisions and determine time gap interval of safety distance to the following vehicle. Safety distance is determined by many factors, such as dynamic vehicle state, location context, environmental context and human context:

i. The dynamic vehicle state can be described as the dynamic properties of the vehicle requirement in the local environment to determine safety risk. The vehicle parameters such as speed, acceleration and heading determine the future possible motion of the vehicle. The vehicle state can also include measures of the vehicle control inputs such as the state of the accelerator and brake pedals.

ii. The location of the vehicle is a major factor in determining whether the current vehicle state
constitutes “high risk” behavior. The road location could be described as a residential road, highway, etc, and the area location could be described as a parking lot, intersection, petrol station, etc. The expectations for safe vehicle behavior changes depending on the high level understanding of this location context.

iii. Environmental Context: The environmental conditions can alter the dynamic properties of the vehicle (traction), and the ability to detect threats due to rain, dust, fog, etc.

iv. Human Context: The ability of a driver to operate a vehicle depends on many complex factors including skill, fatigue, experience and many others. The determining of safety risk would be improved by being able to quantify these factors, though many are practically unobservable.

On the other hand, high traffic growth and an increasing level of motorization is something to be expected in a developing country like Malaysia. Traffic congestion, road accidents and environmental degradation are the challenges that come with this phenomenon. Probably one of the most issues to be addressed currently is traffic accidents and fatalities and Malaysia is known to have a significantly high accident fatality rate in comparison to the developed countries. Thus in this paper we focus on active safety applications.

The term “active” and “passive” are important terms in the world of automotive safety. Passive safety refers to the features that help to protect vehicle occupants during and after crash which belong components such as seat belts, airbag and physical structure of the vehicle. While the term of active safety is refer to technology in assisting in the prevention of a crash which includes braking system, collision warning and avoidance. Since deploying and testing VANETs involves high cost and intensive labor, simulation is a useful alternative prior to actual implementation.

The research and application development in vehicular ad hoc networks (VANETs) have been driven by the Dedicated Short Range Communication (DSRC) technology or IEEE 802.11p designed to help drivers to travel more safely and to reduce the number of fatalities due to road accidents. The IEEE 802.11p MAC uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and some concepts from the Enhanced Distributed Channel Access (EDCA). The intelligent road infrastructure while equipping the new generation vehicles with various kinds of on-board sensors, and V2V (vehicle to vehicle) and V2R (vehicle to roadside) communication capability will allow large-scale sensing, decision, and control actions in support of these objectives. Communication-based active safety is viewed as the next logical step towards proactive safety systems. These systems provide an extended information horizon to warn the driver or the vehicle systems of potentially dangerous situations in much early phase.

The DSRC is licensed at 5.9GHz with 75MHz spectrum which is divided into seven 10MHz channels and 5MHz guard band. The control channel (CCH) will be used for safety applications while the other six channels, called service channels, will be used for infotainment or commercial applications to make this technology more cost effective. Vehicles will synchronize the switching between the CCH and one or more of the service channels (SCH), hence safety related messages will not be missed or lost. The synchronization interval (SI) contains a control channel interval (CCI) followed by a service channel interval (SCI). Increasing the CCI will enhance the reliability of safety applications and challenge the coexistence of both safety and non-safety applications on the DSRC.

In this paper, IVC (inter vehicle communication) is taken into consideration where vehicles will be equipped with sensors and GPS systems to collect information about their position, speed, acceleration and direction to be broadcasted to all vehicles within their range. These status messages should be broadcasted periodically in every CCI. In IEEE 802.11p, the serious problem in collision warning applications are where all vehicles behind the accident have
to receive the warning message successfully in a short time to avoid chain collisions.

**Vehicle Communication (VC)**
- VC promises safer roads,
- ... more efficient driving.

---

Figure 3. The concept of VANET technology

This problem motivates us to propose an analytical model for assessing the DSRC reliability and delay taking into account in VANET. More specifically, the probability of successfully receiving the status messages from all vehicles around the tagged vehicle, the probability of receiving the safety (or emergency) messages from all vehicles up to a certain distance behind the accident scene, and the delay for that safety messages to reach their intended recipients will be studied assuming unsaturated conditions. Besides, even all vehicles are equipped with brake lamps which are meant to warn following vehicle on the activation of brakes by the front driver. However they suffer of two problems. The first one is that the lamp gives no quantification; it does not tell if the driver is pushing lightly or strongly the pedal. The second one is visibility; in the case of fog it is possible that a driver sees the brake lamps of the front vehicle when it is too late to avoid a crash. Moreover, with usual brake lamps human reaction times cumulate, increasing the risk of chain collisions. Besides the safety application should broadcast warning messages when the entity of the deceleration is over a certain threshold. The proposed model is built based on a new mobility model that takes into account the vehicle’s follow-on safety rule to accurately derive the relationship between vehicles’ dynamic and driver behavior. It is shown that the current specifications of the DSRC may lead to severe performance degradation in dense and high mobility conditions. Therefore, a new analytical model is introduced to increase the system’s reliability in terms of the probability of packet’s successful reception and time delay of emergency messages in a harsh vehicular environment.

Lots of works have been done to reduce the collision possibilities with wireless communications help. In our work, we class these researches into two categories: one for avoiding collisions by designing proper protocols for warning messages dissemination; another focusing on alleviating collisions by wireless signal transmission but with research emphasis on vehicles’ movement features, collision scenarios, road or weather conditions, and drivers’ subjective reasons. For studies with emphasis on vehicles’ moment features, an influential work is from Brackstone and McDonald [1] who had elaborately analyzed the car-following model especially for safety applications. Although they just discussed the movement characteristics in single-lane case during car following process and did not refer to the term of safety distance, their work actually suggested that modelling safety distance is an important way to guarantee driving safety in car-following scenarios [2].

Based on safety distance, warning messages could be disseminated in advance to alert drivers for possible collisions. The latest published research results by Werling et al. [3] suggested an ICS (Inevitable Collision States) and PCS (Probabilistic Collision States) based driving safety assessment strategies for single road lanes. Their work considered the collision probability of the investigated vehicle and the collision avoidance behaviour of the other vehicles at the same time. The authors also just discussed the case of single lane and their evaluation results showed the relevance of this safety assessment approach which allows to reduce computation time by using slower re-planning cycles and to avoid unnecessary maneuvers caused by no conservative safety assessment. Adell et al.[4] investigated the effectiveness of an assistance system for keeping safe speed and distance and showed positive effects of this system in terms of fewer alarm situations, shorter alarm lengths, shorter reaction times, increased headway, and better interactions with drivers. Even their work did not give the statistical analysis to safety distance and relied on feedbacks from drivers and logged driving data to output suggested results, they provided a powerful evidence for the necessity to introduce safety distance into driving assistance.

Kannan et al. [5] proposed an Intelligent Driver Assistance System (IDAS) which focuses on generating the alert messages based on the context aware parameters such as driving situations, vehicle dynamics, driver activity, and environment. In IDAS, an adaptive cruise control system is embedded for alerting driver to reduce speed and maintain safe distance between vehicles and passengers. This system retrieves related driving and environment data by embedded sensors and returns the corresponding suggested actions based on previous collected relevant statistics. Therefore, their work is built on expert database and did not give the general statistical expressions to safety distance. Biral et al. [6] proposed a driver-support system that helps to maintain the correct speed and inter vehicle distances with respect to lane curvature and other vehicles ahead. This work mainly focused on the warning maneuvers for drivers by comparing their behaviours to suggest system actions. Besides, they just took the different situations of the leading vehicles into account and did not consider the relative movement status between the front and the back cars.

Wu et al. [7] analyzed the SD for avoiding collisions when the leading car encounters obstacles or some emergency. However, they did not take the different movement status of the following car and traffic efficiency into consideration. Besides, the safety distance when the
leading car drives normally, that is, without emergency or obstacles ahead, was not considered. Luo et al. [8] proposed the traditional braking model which derived the safe distance considering the influences from vehicular mechanical braking ability and relative velocity. But, they assumed the following car drives with a constant speed and did not discuss the scenario when the leading car suddenly stops. Ayres et al. [9] and Touran et al. [10] introduced the classical time-headway model. This model is based on the abstracted real test data from highway vehicles and uses the real-time distance between vehicles’ heads as the metric to enhance driving safety. Although simulation results showed this work to be very effective in highway, its reliability is somehow weak because the authors mainly focused on traffic efficiency and did not consider the case where large velocity difference occurs between neighboring vehicles. Thereupon, the calculated safety distance is smaller and not enough to guarantee safety.

One observation made regarding the parameters considered in most of the simulation models and safety indicators that have been proposed is that certain parameters which may have a direct impact on vehicle braking performance, hence the ability to safely stop in car following situation, have not been explicitly considered. Although a few researches were working on stopping time, there was no detail on stopping distance and stopping time in a vehicle following situation to further understand the subject not only from the driver visual input perspective but also from vehicle dynamics capability perspective. At any given time, human, vehicular, and environmental influences and events conspire to affect crash risk. Crash causation studies consistently show, however, that vehicle and environmental factors are less significant than human factors. Human factors involved in crashes can be subdivided in various ways. The most common critical errors made by drivers, whether they are heavy vehicle drivers or other involved drivers, appear to be save time gap misjudgments, which is driver follow to closely and over confidence in their ability to stop the truck before crash. The consciousness of the minimum safe time gap is very crucial for heavy vehicle drivers to prevent collision with the vehicle in front. Therefore, in order to prevent front-end and rear-end collision, this paper attempts to propose a new safety indicator, named time gap interval for safe following distance (TGFD) which incorporates the vehicle dynamics and driver behavior factors.

III. TGFD MODEL

![Figure 4. The difference between time gap and time headway](Image)

To examine car-following safety in this research, we analyzed the time gap instead of the time headway, because

\[ RT = T_p + T_d + T_{ap} \]
To introduce our TGFD model, we will first explore the movement features of vehicles especially when braking. Based on the analysis to the vehicular moving procedure for car following model, a safe following distance could be divided into 5 stages as shown in figure 5 above. \( T_p \) indicates the perception time. Its average value is 0.9 s [11] in general. In this period, the driver finds that an emergency situation has happened ahead and is ready to take immediate actions, decision time \( T_d \). Here, we also assume that it includes a little mechanical coordination time for braking preparation, application time \( T_{ap} \). \( T_b \) is a broadcast time to periodic deliver status of vehicle from time to time to the other nodes. \( T_{pr} \) denotes the message propagation delay, which indicates the average needed time for warning messages is transmitted to the destination. Then, supposing the back car it will not brake until receiving the warning messages from the leading car. The extended reaction time-gap in VANET given by

\[
T_g = \{T_b + T_p + T_d + T_{ap} + T_{pr}\}
\]

where, time-gap, \( T_g \) is proportional to Speed of vehicle \( V_{ij} \):

\[
T_g \propto V_{ij}
\]

where, \( i = \alpha, \beta, \ldots N \) is type of vehicles

Broadcast time delay, \( T_b \):

\[
T_b = T_h + \frac{S}{R}
\]

where Time broadcast is time to transmit a safety message of size \( S \) in bits, at a data rate, \( R \), in b/s, including \( T_h \) which summarizes the time interval between frames (AIFS), the time to transmit the PHY layer convergence procedure (PLCP) preamble and header, and the contention window (CW):

\[
T_{pr} = (T_{rc} - T_{tr}) + \Delta T
\]

where \( T_{rc} \) is the success time-stamps of message reception and the success \( T_{tr} \) message transmission, and \( \Delta T \) is the minimum time interval necessary to connect a couple of vehicles traveling at speed \( v \) [m/s] and separated at distance, \( D \) (m):

\[
\Delta T = \frac{\Delta D}{\Delta v}
\]

Time application, \( T_{ap} \) (application brake time) [13]:

\[
T_{ap} = 0.02321v - 0.08785
\]

Where, \( T_{ap} \) is a braking time for passenger car in second and \( v \) is a vehicles’ speed.

Time perception, \( T_p \) and Time decision, \( T_d \):

McGee et. al. [14] reported that perception time and time decision is the sum of eye movement time, fixation on the hazard time delay, recognition time delay and muscle response delay time. They found that for the 85th percentile of drivers, eye movement delay was 0.09 seconds, fixation delay time was 0.20 seconds, recognition delay time was 0.50 seconds, decision time 0.85 seconds, muscle response delay was 0.31 seconds. But systems such as cooperative collision avoidance (CCA) and cooperative collision warning (CCW) in VANET could improves road safety by allowing hazardous conditions to be detected sooner than using human perception.

\[
\text{Figure 6. The concept of TGFD}
\]

The value of proposed TGFD model (Equation 4) as illustrated in figure 6 above is obtained from Equation (1) (2) (3) and being extended by considering the braking time (time application, \( T_{ap} \)) of the following vehicle \( (V_i) \) and the leading car \( (V_{i+1}) \) as well as the time factors of time perception, time decision, time broadcast and time propagation in VANET environment. Different compositions of leader-follower pairs, say for example in the case of truck following-car, will affect the TGFD value due to different in braking performance and capability. Similarly, the following vehicle driver’s physical
and mental condition will affect the perception and time
decision of driver. Besides time broadcast delay and time
propagation delay also being influence by density of
network and mobility of vehicles, hence affecting the TGFD
(Equation 4).

\[
TGFD = T_b + T_p + T_d + (T_{ap,i} - T_{ap,i+1}) + T_{pr}
\]  

(4)

Numerous factors influence this time factors analytical
model. It can be influenced directly by factors related to
vehicle, road and delay because of error during time
broadcast and time propagation in VANET environment.
Some of these factors are; vehicle type, speed, whether and
road condition. If the approaching rate is negative (i.e.,
leading vehicle is travelling faster than its follower), then
the vehicles are automatically increasing their gap, so the
TGFD remains disabled. If instead the approaching rate is
positive, the TGFD must compute the safety gap to
determine if a vehicle is too close to its leader. A wise
TGFD definition could consider the successful collision
avoidance the relationship crash probability and time gap
below (Equation 5)

\[
Pr (\text{crashes}) = \frac{e^{5.755 - 4.126x}}{1 + e^{5.745 - 4.126x}}, \text{ where } x = \text{TGFD}
\]  

(5)

IV. RESULTS

We have developed a VANET simulation environment
using the network simulation tool NS2 to support the novel
IEEE 802.11p technology. We integrated this with the
VANET specific Wave Short Message Protocol (WSMP)
based on a simplified model of the Wave communications
standard selected the most representative parameters for
VANETs, and then we defined and simulated a basic
scenario. Finally, by varying the selected parameters, we
generated and simulated more scenarios. The results
obtained from the simulations allow us to draw some
important preliminary conclusions. The Wave model
contains one Control Channel (CCH) and one Service
Channel (SCH) interface with total channel duration of
100 ms with 50 ms per channel that switch periodically at
50 ms intervals. In this study, NS2 in cygwin software
has been used to generate braking time data for
vehicles under various vehicle types, and speed
conditions. For experimental investigation, we modeled an
urban scenario using the road traffic simulator SUMO.
Since the aim of the study is to develop a model that can
reflect an actual vehicle following situation, it is
important to develop more realistic simulated following
vehicle model. Simulation was carried out under the
assumption that the vehicle has reached a steady state
condition and stay on the road at a constant speed
before the brakes are applied. Using equation (3) (4)
and (5), the respective values of TGFD can be determined
for the different composition of follower-leader pair
travelling at various speeds. As would be expected the
TGFD varies for the different combinations of following
vehicle type and travel speed.

V. CONCLUSION

A new safety indicator, time gap for following distance
(TGFD) is proposed for use in safety analysis in
VANET environment. The concept of TGFD introduced
in this paper incorporates elements from vehicle (vehicle
type, speed etc.), and driver (physical abilities, psychological
factors etc). It has been established that vehicle braking
performance is of utmost importance in relation to
vehicle stopping time, hence it has to be incorporated
into the safety indicator. Thus, the TGFD is determined by
considering the vehicle braking time (for both leading and
following vehicle in a vehicle-following situation), time
factors in VANET environment and driver behavior. The
simulation data show that this safety indicator would provide
a more realistic depiction of the real traffic situation for
safety analysis. As a future direction to this work we would
like to integrate into the VANET clustering approach and
dissemination of safety message in vehicular ad hoc. In
summary, to generate vehicle clusters, a lot of clustering
schemes are proposed considering the inherent characteristic
of VANETs. The general purpose is that each driver must
keep sufficient distance between his/her vehicle and the vehicle in front in order to avoid an accident if the car in front stops suddenly or reduces speed. This rule does not always come with specific distances that must be observed, such as the required minimum distance or time between the vehicles. Still, most countries encounter problems with enforcement. Thus in future, this model could be enhanced to enforce driver to follow safe distance to prevent collision.

ACKNOWLEDGMENT
The authors would like to acknowledge Universiti Sains Malaysia (USM) for supporting this work under USM Short term Grant Scheme No. 304/PKOMP/6313023.

REFERENCES