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# Study on the effect of driver reaction times to the collision possibility and evasion ability due to the forward collision warning system using driving simulator

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***Abstract***

36.2 deaths per 100,000 populations, Thailand road deaths that estimated by World Health Organization (WHO) situated Thailand at the second position in the world. The research found that rear-end collision was the most frequently occurring accident in Thailand. The active safety systems are developed to eliminate the driver's errors that cause rear-end collision. The forward collision warning system, which is an active safety system, is designed to warn the driver if the accident is possible and provides needed information to avoid the accident. Time-To-Collision (TTC) is an important variable in the forward collision warning system. TTC directly affects the evasive performance of the vehicle in terms of the delay of the actual TTC. Also, the reaction times of the driver after the warning to the start of the evasive maneuver affect the evasive performance. From previous research, the evasive possibility was simulated using dynamics approach. But, the driver reaction times were not considered in the research. In this research, the driver reaction times were tested using driving simulator with developed forward collision warning system. The forward collision warning system communicated with the driving simulator. The forward collision warning system gets the parameters from the driving simulator then warns the drivers accordingly and the reaction times were collected along with other parameters. The study shows that the driver reaction times were separated into 2 distinct groups, around 0.45 s. from 20-40 km/hr speed and around 0.3 s. from 60-100 km/hr speed that caused by different evasive maneuvers. The evasive ability is significantly affected by the delayed TTC (actual TTC). Therefore, the warning TTC will be more appropriate to be used in the forward collision warning system, if the warning TTC is compensated by the driver reaction times.

***Keywords**:* Driver reaction time, Steering and braking guidance, Driving simulator, Forward collision warning system.

## 1. Introduction

In 2015, Thailand was named as the second position of the world highest road deaths country. World Health Organization (WHO) estimated road deaths of Thailand about 36.2 deaths per 100,000 populations [1]. The most frequent occurring accident in Thailand is rear-end collision [2], which is also causes the most effect on injuries and comprehensive costs [3]. Rear-end collision can be caused by many different reasons (inadequate surveillance, distracted, false assumption, following too closely, fatigue and inadequate evasion) [3]. The reasons that cause the rear-end collision can be also considered altogether as a driver error. To help the drivers eliminate or decrease the driver error, the active safety systems were used [4]. The forward collision warning system is considered as an active safety system. The forward collision warning system will warn the driver if the accident is possible to help the driver avoiding the accident. According to the results of the simulations [5] and the report on the evasive maneuver [3], braking is not enough to prevent the accident in some cases. Steering is also needed to be considered as an evasive maneuver in the system [6], [7] in order to properly guide the drivers.

Steering evasive maneuver is very risky to perform. Inappropriate steering can cause the offset-frontal collision, Fig 1(a), which is much more fatal than the full-frontal collision, Fig 1(b). Geometrical approaches have been used in some researches. But, geometrical approaches do not consider the dynamics behaviors of the vehicles, so the predicted paths could be different from the practical path [8], [9]. Moreover, geometrical predicted paths are easier to perform by the controller. A controller is more active than the drivers to continuously keep the evasive path close to the predicted path. If the drivers are going to perform the steering evasive maneuver, a dynamics approach that consists of vehicle model with driver model will predict the evasive path close to the practical path.

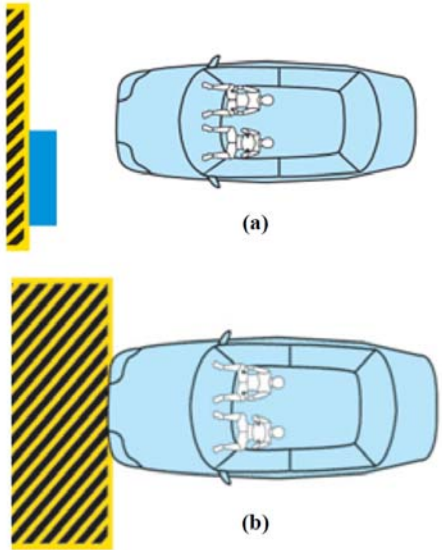


Fig. 1 Types of frontal collision (a) Offset-Frontal Collision (b) Full-Frontal Collision [10]

The dynamics approach can be used to predict the evasive path for the forward collision warning system, but some variables would be considered, such as collision avoiding possibility and warning Time-To-Collision (TTC) [5]. Not only the variables from the dynamics models, the responses of the driver, which directly affect TTC, would be considered as an addition to make the driver start performing evasive maneuver at the desired time.

TTC is an important variable in the forward collision warning system. TTC is used as a warning threshold in the forward collision warning system. Moreover, TTC is also used as a variable to determine if the collision can be avoided. Therefore, TTC directly affects the evasive performance of the vehicle in terms of the delay of the actual TTC. The delayed TTC was the actual TTC that still available for the driver to perform the evasive maneuver.

However, the evasive possibility was simulated using the dynamics approach in previous research [5], the driver reaction times were not considered in the simulation. Therefore, the evasive possibility could be different from the previous research, if the drivers perform the guided evasive maneuver. To observe the drivers responses to the forward collision warning system, the driving simulator was used in this research. The driver reaction time from the simulations could be used for adjusting the forward collision warning more appropriately.

## 2. Simulation Technique

In order to observe the drivers responses, driving simulator was used to simulate the environment. The advantages of using driving simulator are:

- The scenario can be designed and controlled .
- Representing the field test [11],[12]
- The parameters can be collected and sent out for other usages.
- Eliminating the risk of the driver.

The forward collision system was used with the driving simulator. The parameters were sent out from the driving simulator to the forward collision system as the inputs.

### 2.1 Driving Simulator

The simulations were carried out via CARNET Soft driving simulation, Fig. 2. CARNET Soft has very convenient tools for writing scenario script and designing driving course. The parameters are simulated using vehicle model, easily recorded and sent via Ethernet connection to be used in other programs.


Fig. 2 CARNET Soft driving simulation (B) and Forward collision warning program (A).

### 2.2 Forward Collision Warning Conditions

In some cases, the braking evasive maneuver might not enough to prevent the accident. Steering evasive maneuver is needed to perform in order to prevent the accident. To predict evasive paths, path prediction method was included in the forward collision warning. The geometrical approach was used in the path prediction method but this approach leads to the inaccuracy of the evasive paths due to the vehicle dynamic behavior [8], [9]. Vehicle dynamics approach and driver model were used in order to predict more accurate evasive paths [5]. The result of the prediction in terms of vehicle evasive ability due to different relative velocities was shown in Fig. 3.

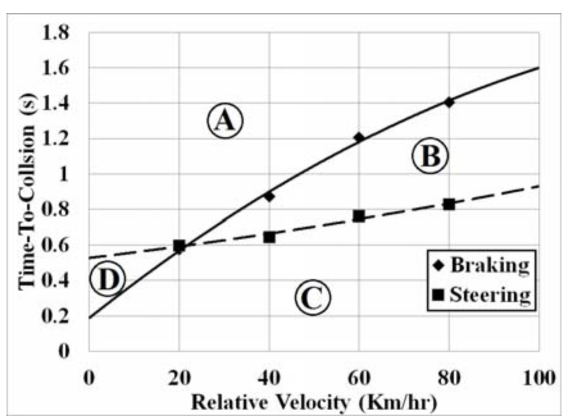


Fig. 3 Minimum TTCs of steering and braking evasive maneuvers

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Fig. 3 shows the minimum TTC that the system needs to warn the drivers. Therefore, the accident will not occur. The graph consists of 2 different lines, minimum TTC for braking evasive maneuver and minimum TTC for steering evasive maneuver. There are 4 different zones in Fig. 3. In each zone, the evasive possibilities are shown in Figs. 4-7.

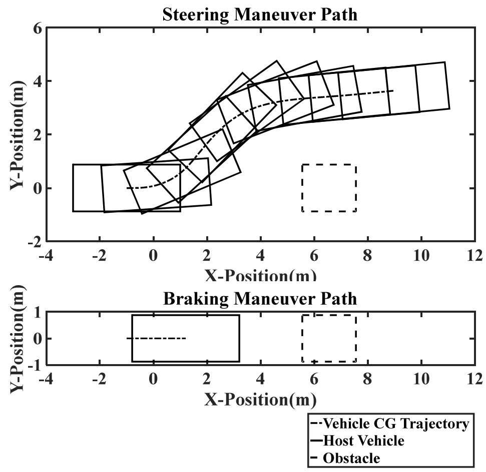


Fig. 4 The predicted steering and braking maneuver paths in zone A

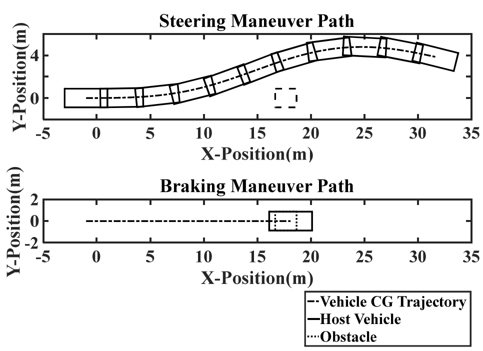


Fig. 5 The predicted steering and braking maneuver paths in zone B

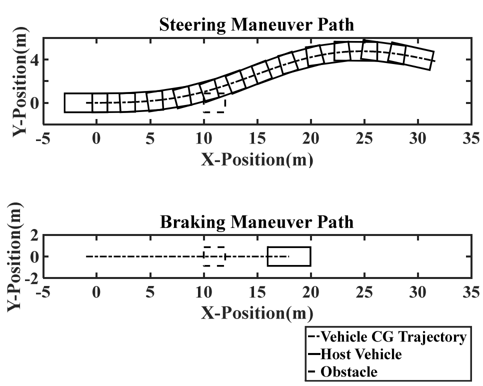


Fig. 6 The predicted steering and braking maneuver paths in zone C

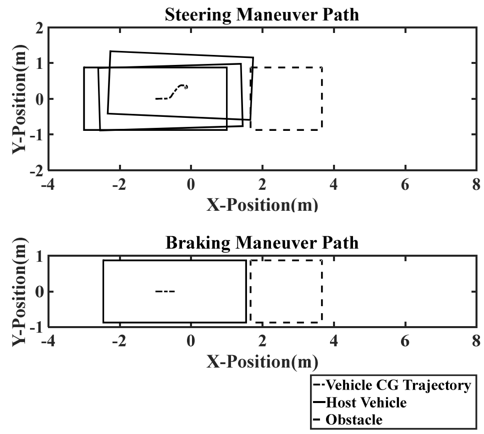


Fig. 7 The predicted steering and braking maneuver paths in zone D

Figs 4-7 show predicted evasive maneuver paths in zone A, B, C and D. Each zone has different obstacle avoiding possibility. In zone A, the vehicle can avoid the obstacle by both steering and braking evasive maneuver. In zone B, the vehicle can avoid the obstacle only by steering. In zone C, the vehicle can not avoid the obstacle by both braking and steering. And in zone D, the vehicle can avoid the obstacle only by braking. The evasive possibilities were summarized and shown in Table. 1.

Table 1 The evasive possibilities of zone A, B, C and D

| Zone | Evasive Possibility | |
|---|---|---|
| | By Braking | By Steering |
| A | Y | Y |
| B | N | Y |
| C | N | N |
| D | Y | N |

As shown in Figs. 3-7, if the forward collision warning system warns the driver at TTC above the minimum line, that evasive maneuver could be possible to prevent the accident. However, the simulations show that the collision could be avoided, the possibility also depends on the response time of the driver, which can be observed in this research.

### 2.3 Parameters

There are 11 parameters recorded in the driving simulator. The real-time data of TTC and velocity are required to be automatically sent out as the inputs of the forward collision warning program. The other parameters were recorded via the data storage method of CARNET soft driving simulation with a time stamp. The parameters were used to determine the position of the vehicle and the evasive timing of the driver. All 11 parameters are shown in Table. 2.

Table 2 The recorded simulation parameters

| Parameters | Unit |
|---|---|
| Longitudinal Velocity | m/s |
| Longitudinal Acceleration | $m/s^2$ |
| Lateral Velocity | m/s |
| Lateral Acceleration | $m/s^2$ |
| Yaw Rate | rad/s |
| Heading Angle | degree |
| Brake Pedal Position | percentage |
| Gas Pedal Position | percentage |
| Steering Wheel Angle | radians |
| Time-To-Collision | second |
| Reaction Time | second |

The reaction time is the duration between the moment that the forward collision warning system warns the driver and the driver performs the maneuver action either braking or steering evasive maneuver.

### 2.4 Simulation Scenario

The participants were asked to drive the vehicle straight along the road from fully stop to the designed velocity. Then, the participants would have to keep the velocity constantly while driving toward a non-moving obstacle, as shown in Fig. 8. When TTC was at 1second, the forward collision warning system will guide the participants to perform an evasive maneuver, either braking or steering evasive maneuvers according to the situation . The participants were asked to perform the evasive maneuver that guided by the forward collision warning system. The parameters shown in Table 1 were collected and analyzed.

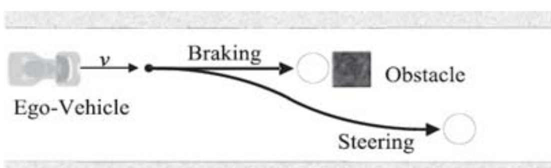


Fig. 8 Simulation Scenario [8]

### 2.5 Participants

Hence, the research did not consider the different factors according to the difference of the participants. Therefore, the participants that chosen have similar attributes. The participants have to reach the requirements that consisted of 1. The participants must have an unexpired driving license. 2. The participants must often drive in the past one month and 3. The driver age has to be between 20-25 years old. There are 10 participants participated in the research.

## 3. Simulation results and discussion

The simulations were carried out in 5 different velocities 20, 40, 60, 80 and 100 km/hr speed by 10 participants

The driver reaction times were recorded during the simulations. The driver reaction time represents how much time the drivers took to react to the forward collision warning system, which shown in Fig 9.

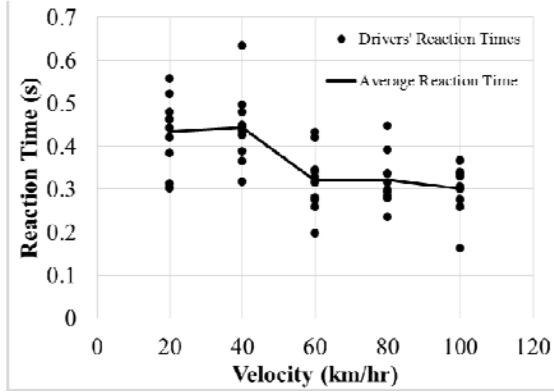


Fig. 9 Driver reaction time in different velocities.

Fig. 9 shows that the driver reaction times have two distinct values, around 0.45 s. from 20-40 km/hr speed and around 0.3 s. from 60-100 km/hr speed. The difference of the driver reaction times was caused by the difference of the evasive maneuvers. On the other hand, the vehicle velocity does not affect the driver reaction time in the same evasive maneuver.

The driver reaction time significantly affects the actual TTC, which is the duration that allows the vehicles to move in order to evade the obstacle. From Fig. 3, minimum TTC lines of both steering and braking represent the ability to avoid the collision. If the warning TTC line is situated above the minimum TTC line the vehicle can avoid the collision with that evasive maneuver. For example, if the warning TTC is 1 second, the vehicle can avoid the collision by braking from 0-46.6 km/hr speed and by steering from 0-113.97 km/hr speed, as shown in Fig. 10.

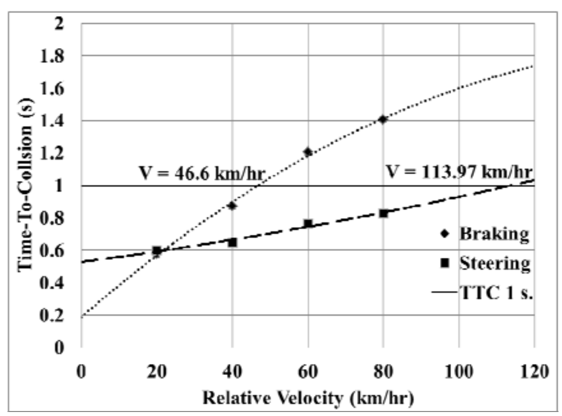


Fig. 10 (a)The vehicle evasive ability using minimum TTC line and warning TTC = 1 s. line.

If warning TTC is 1 second, the actual TTCs that caused by the driver reaction times could be reduced by 30% - 40% from warning TTC. This reduction can drastically change the collision possibility of the vehicles from not possible to possible to collide with the obstacle, as shown in Fig. 11.

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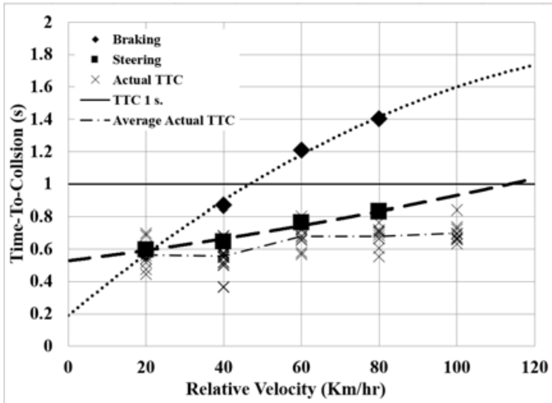


Fig. 11 The vehicle evasive ability using minimum TTC line, warning TTC = 1 s. line and Actual TTC.

Fig 11. shows that the accident occurred almost in every simulation because the average actual TTC line locates in zone C of the graph, which the accident could not be avoided by both evasive maneuvers, as shown in Fig. 6. This was caused by the driver reaction time. The actual TTC can be determined from warning TTC (1 s. in this research) and driver reaction time.

In order to determine the new appropriate warning TTC, the warningTTC can be determined from the ActualTTC and the ReactionTime, as shown in Eq. 2.

$$WarningTTC = ActualTTC + ReactionTime \qquad (2)$$

where the actualTTC is the duration that still available for the driver to perform the evasive maneuver. The warningTTC is the TTC that the system warns the driver. The ReactionTime is the duration between the moment that the forward collision warning system warns the driver and the driver perform the maneuver action, which is measured from the simulations.

In order to allow the drivers to perform the evasive maneuvers at the designed TTC, the warning TTC should be compensated by Eq. 2. The warning TTC has to be increased to 1.5 s. in order to make the actual TTC are about 1 s., as shown in Fig. 12.

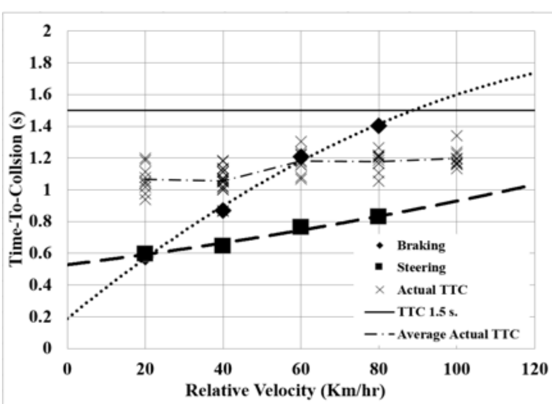


Fig. 12 The vehicle evasive ability using minimum TTC line, warning TTC = 1.5 s. line and Actual TTC.

Using Eq. 2, the actual TTC line in Fig. 12 is increased from the actual TTC line in Fig. 11. Therefore, the steering evasive maneuver can avoid the collision at 20 – 100 km/hr speed. On the other hand, braking evasive maneuver can avoid the collision at 20 km/hr speed to around between 40-60 km/hr speed.

## 4. Conclusion

According to the simulation results and discussions, the conclusion can be summarized as:

- The driver reaction time drastically affects the evasive possibility.
- The warning TTC has to be compensated to be 1.5 s. Therefore, the available duration for performing the evasive maneuver would be 1 s. as designed.
- To determine the maximum velocity that the vehicle can avoid the collision by braking, the simulations should be carried out in a specific evasive maneuver with more velocity variations. There is the evasive maneuver transformation between 40-60 km/hr speed. The velocity variations did not cover the transformation area. Therefore, the maximum velocity that the vehicle can avoid the collision by braking could not be determined.
- The uncertainty of the different driver behaviors was not considered in this research.

The future works should focus on the driver reaction times of both braking and steering evasive maneuver with many velocity variations. The minimum TTCs of braking and steering evasive maneuver can be re-calculated according to the driver reaction times. Therefore, the warning TTC can be determined easily. The uncertainty from the different driver behaviors should also be considered, therefore, the forward collision warning system will be able to warn the drivers more appropriately when the system is used in the real driving situation.

愀 5. Acknowledgement

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