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Avoiding Collision with Oncoming Vehicles when Overtaking

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ABSTRACT – *Many road accident fatalities stem from issues associated with the overtaking maneuver (OM). This study uses an autonomous emergency steering system, to examine OMs in an oncoming vehicle (OV) situation. The generation of the OM was achieved with the use of the trapezoidal acceleration profile (TAP), while taking into account the limits of the tire-road friction coefficient (μ) and maximum lateral jerk (j_{max}). The risk of collision with the OV was measured using a distance margin (dm), which is defined as the distance between the ego vehicle (EV) and OV, at the close of the OM. The results derived from investigations on the effect of the velocity of the OV on the dm, deliver crucial information regarding collision avoidance, during the execution of an OM in an OV situation.*

KEYWORDS: Autonomous emergency steering, collision avoidance, overtaking maneuver, trapezoidal acceleration profile

1. INTRODUCTION

An inadequate overtaking maneuver (OM) can result in a collision with an oncoming vehicle (OV). A head-on collision, with both the ego vehicle (EV) and OV traveling at high speeds, can result in serious injuries, and in a worst-case scenario, fatalities. According to Rahim et al. (2011), 17% of the total road fatalities in Malaysia stem from collisions with an OV, during the execution of an OM.

Several previous investigations delved into the issue of collision avoidance in an OV situation. Levulis et al. (2015) examined the overtaking judgment of human drivers, based on the size of the OV. Isermann et al. (2012) considered the time-to-collision between the EV and OV to investigate the OM. Arikere et al. (2014) delved into the safety benefit associated with propulsion, in terms of reducing the risk of collision with an OV. Kojima and Raksincharoensak (2021) proposed a risk-potential field-based rear-wheel steering control method and evaluated its performance for an OM. Yamada et al. (2022) considered the collision risk for both the obstacle and OV, to solve an optimal overtaking problem. Yang et al. (2023) used fifth-order polynomials to generate the desired overtaking trajectory, and employed model predictive control as well as sliding mode control, to track the desired vehicle path and speed, respectively.

This study examines the issue of collision avoidance with an OV during the OM, by considering a situation in which the OM, performed by the autonomous emergency steering system, strives to avoid collision with a stationary obstacle encountered in the same lane, and an OV travelling in the opposite lane. The desired path for the OM was generated using the trapezoidal acceleration profile (TAP). The distance margin (d_m) (Arikere et al., 2016), which is the longitudinal distance between the EV and OV upon the completion of the OM, was considered, to determine the risk of collision with an OV.

The rest of this paper is organized as follows: Section 2 describes the OM while considering the OV, and the generation of the desired path for the OM using the TAP, Section 3 presents the test outcomes, and Section 4 provides a summary of the findings derived through this investigation.

2. OVERTAKING MANOEUVRE (OM)

A collision avoidance scenario, in which an EV performs an OM to avoid a stationary obstacle, in an OV situation, is depicted in Figure 1. It is assumed that the EV is equipped with an autonomous emergency steering system and performs the OM autonomously. The EV and OV are assumed to be traveling at velocities v_1 and v_2, respectively, and these velocities are assumed to be constant during the OM. The d_m is the longitudinal distance between the EV and OV, at the close of the OM (Arikere et al., 2016). The length of the obstacle is denoted l_{obs}.

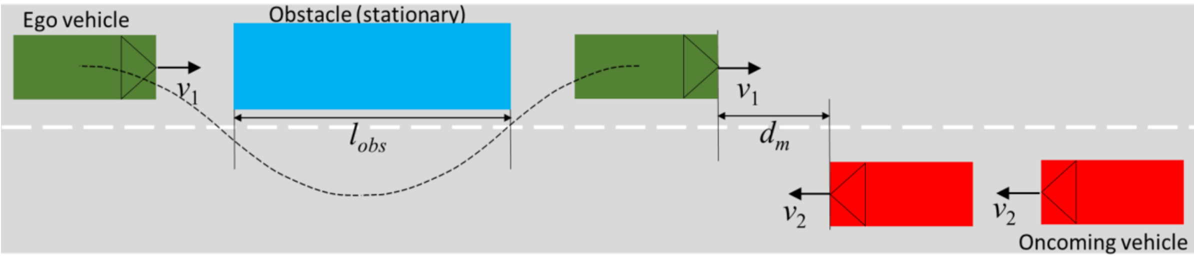

FIGURE 1: The OM that the EV performs in the presence of an OV

Figure 2 portrays the TAP used for the generation of the desired OM path. The blue, red, and green lines represent the maximum lateral jerk (j_{max}), the maximum lateral acceleration (a_{max}), and zero lateral acceleration, respectively. The a_{max} refers to the maximum achievable lateral acceleration, which is specified by the product of the friction coefficient between the tire and the road (μ) and the gravitational acceleration. The j_{max} is limited by the maximum steering rate. Further information with regards to TAP can be acquired by referring to Chee and Tomizuka (1994), and Singh et al. (2021).

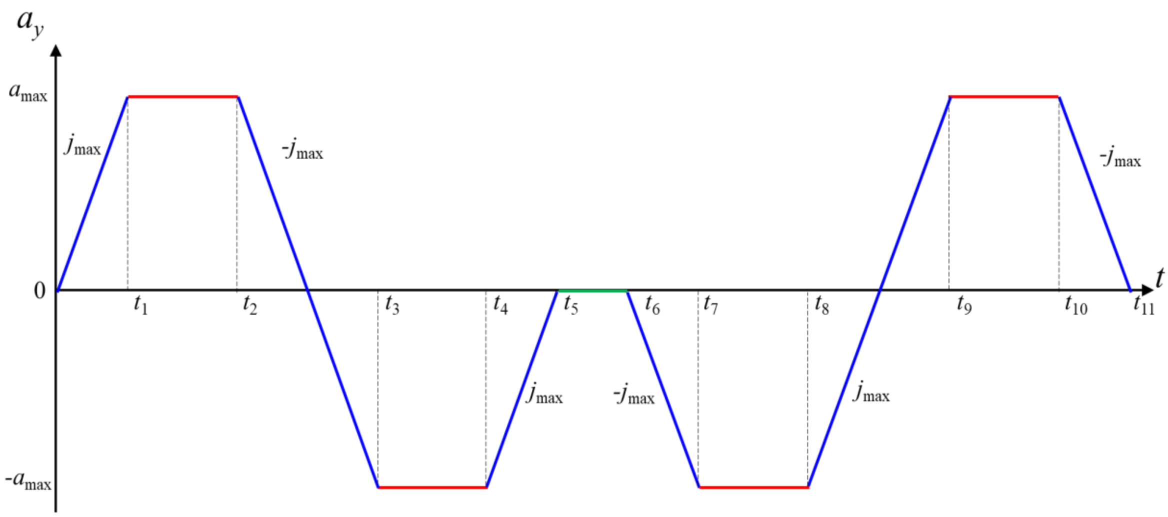

FIGURE 2: The TAP for the OM

3. RESULTS AND DISCUSSION

For this study, a total lateral displacement D of 3.5 m was assumed, for the distance between the middle points of the two lanes. To indicate a vehicle of significant length, the l_{obs} was set as 10 m. A wet road surface is denoted by a μ of 0.5. In keeping with a previous study conducted by Isermann et al. (2008), we assumed a j_{max} of 30 m/s^3 for this investigation. Figure 3 shows the EV path for an OM at different velocities. The blue, red, and green lines represent the EV velocities of 20, 25, and 30 m/s, respectively. As can be gathered from Figure 3, the shortest total longitudinal distance (81.1 m) is achieved when the EV velocity = 20 m/s, while the longest total longitudinal distance (121.7 m) occurs when the EV velocity = 30 m/s. The total longitudinal distance for the OM increased with an increase in EV velocity.

The total longitudinal distance as a function of the j_{max} at different EV velocities is depicted in Figure 4. For a given EV velocity, the total longitudinal distance for the OM decreases with the increase of j_{max}. It is important to note that the j_{max} is constrained by the steering rate. An OM with a higher j_{max} may cause the occupants of the vehicle to endure discomfort. Figure 5 portrays the total longitudinal distance as a function of the μ for different EV velocities. The total longitudinal distance for the OM decreases with an increase of the μ. A contour plot of the total longitudinal distance, presented in Figure 6, indicates that the total longitudinal distance for the OM is shortest when the μ and j_{max} are at their peaks.

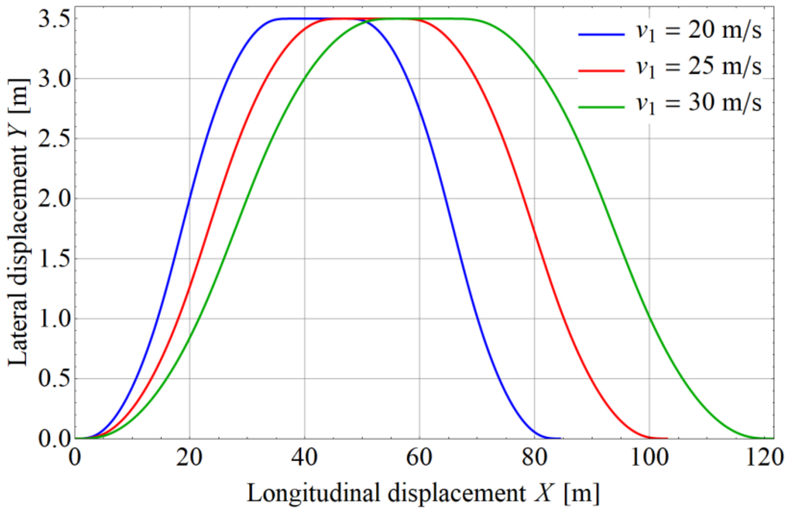

FIGURE 3: The path of the OM, assuming D = 3.5m, μ = 0.5, and j_{max} = 30 m/s^3

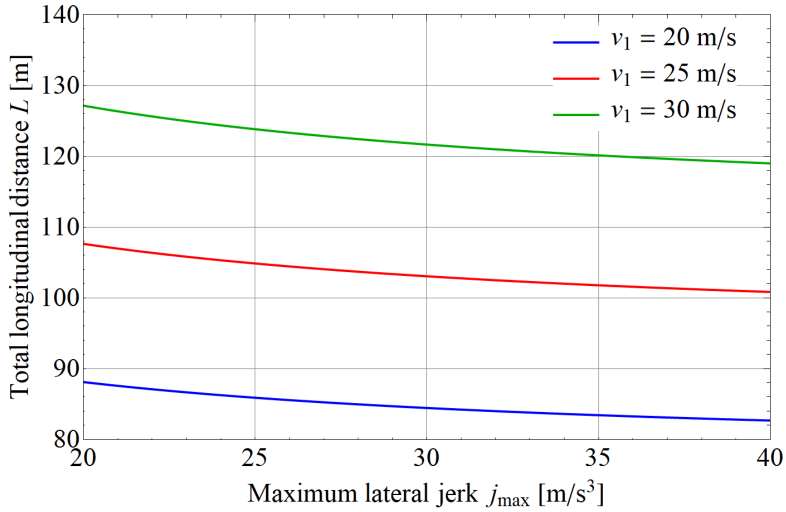

FIGURE 4: The total longitudinal distance that the EV requires to complete the OM as a function of j_{max} at different velocities, assuming D = 3.5 m and μ = 0.5

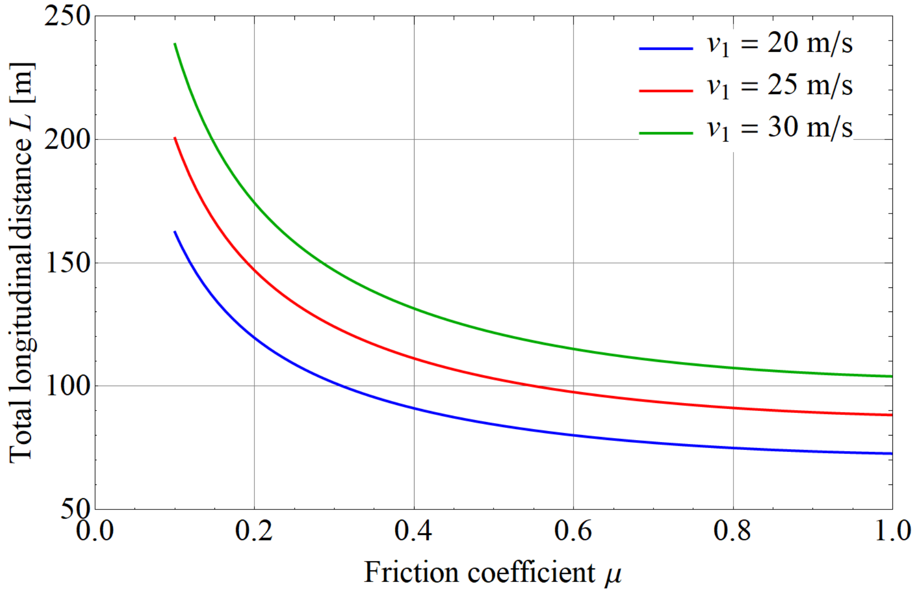

FIGURE 5: The total longitudinal distance that the EV requires to complete the OM as a function of μ at different velocities, assuming D = 3.5 m and j_{max} = 30 m/s^3

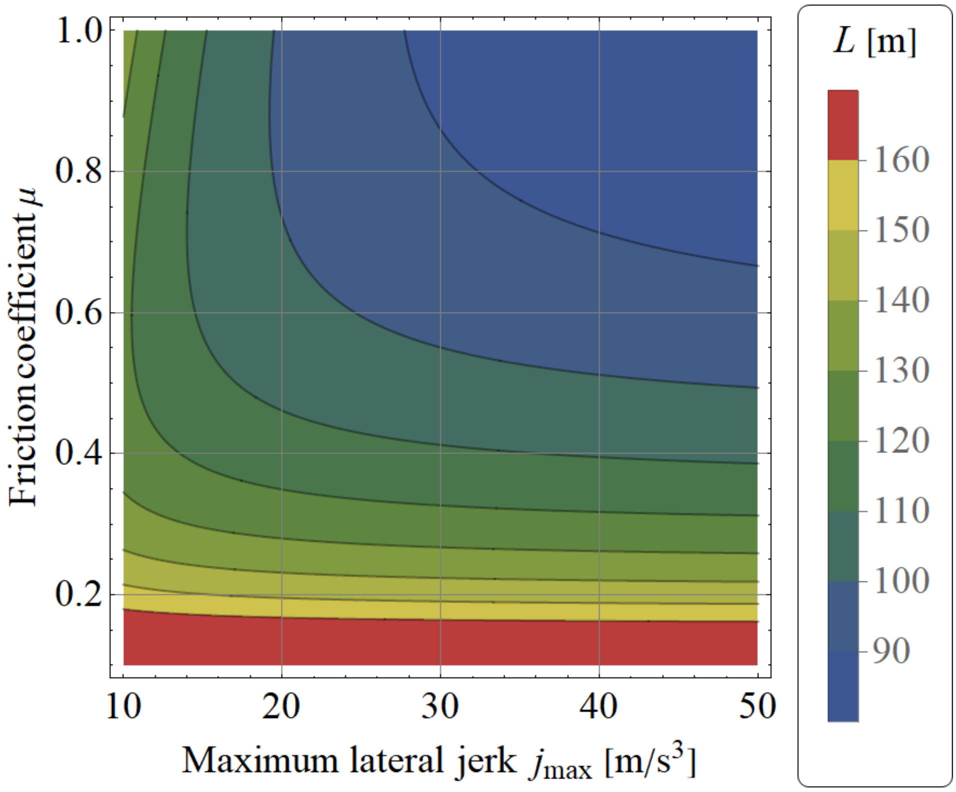

FIGURE 6: A contour plot of the total longitudinal distance that the EV requires to complete the OM, assuming D = 3.5 m

Figures 7, 8, and 9 display the paths taken by the EV and OV to complete the OM, assuming that D = 3.5 m, μ = 0.5, l_{obs} = 10 m, and j_{max} = 30 m/s^3. The d_m between the EV and OV, at the beginning of the OM, was recorded as 245 m. Figure 7 portrays the EV performing an OM at a velocity of 30 m/s, while the OV is traveling in a straight line at a velocity of 20 m/s. The d_m was recorded as 42.450 m. Figure 8 displays the velocities of the EV and OV as 30 and 25 m/s, respectively, with the d_m recorded as 21.974 m. In Figure 9, where the velocities of the EV and OV are similar (30 m/s), the d_m was recorded as

1.699 m. A further increase in the OV velocity reduces the d_m, to consequently increasing the risk of a collision. In a situation where collision with an OV is unavoidable, an autonomous emergency braking system (Singh & Nishihara, 2022) can be employed to reduce the impact velocity, when the EV collides with a stationary obstacle in the current lane. Figure 10 depicts the d_m at three different OV velocities. As the OV velocity increased from 20 to 25 m/s, the d_m was reduced by 48.24%, from 42.450 to 21.974 m. An increase in the OV velocity, from 25 to 30 m/s, further reduced the d_m by 92.27%, from 21.974 to 1.699 m.

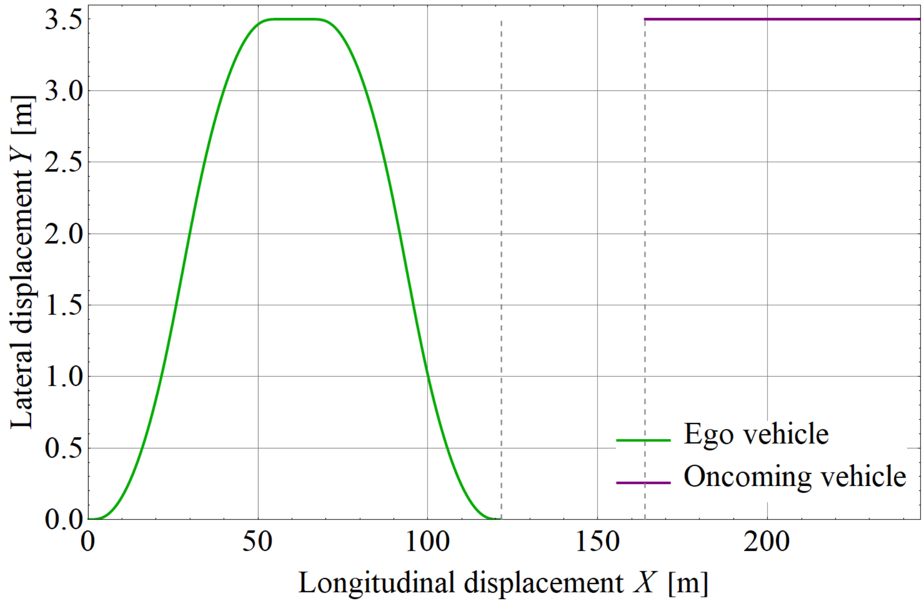

FIGURE 7: The paths of the EV and OV, assuming D = 3.5 m, EV velocity = 30 m/s, and OV velocity = 20 m/s

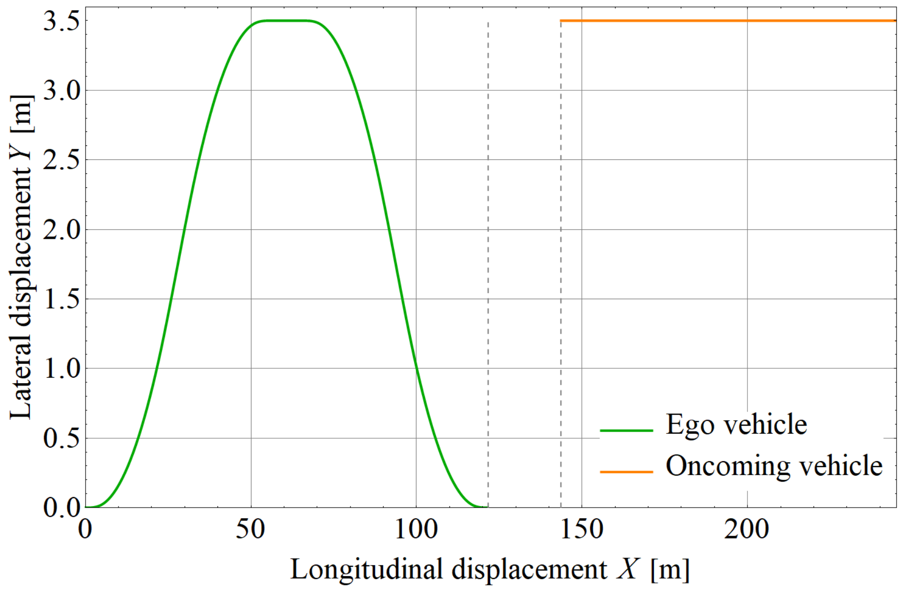

FIGURE 8: The paths of the EV and OV, assuming D = 3.5 m, EV velocity = 30 m/s, and OV velocity = 25 m/s

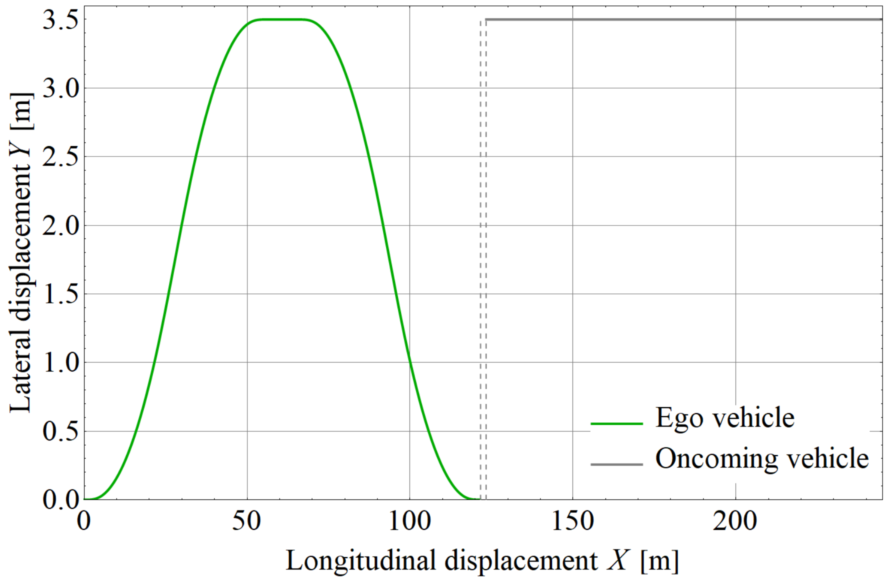

FIGURE 9: The paths of the EV and OV, assuming D = 3.5 m, EV velocity = 30 m/s, and OV velocity = 30 m/s

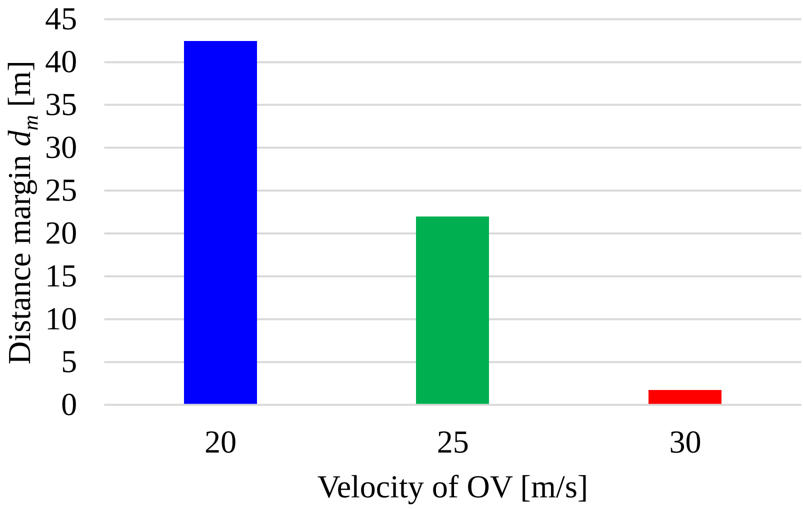

FIGURE 10: The d_m at three different OV velocities

4. CONCLUSION

This study focuses on collision avoidance during an OM, in an OV situation. According to our findings, the shortest total longitudinal distance during the OM occurs when the EV velocity is at its lowest, while the μ and j_{max} are at their highest. For a given μ, j_{max}, and EV velocity, the d_m decreases as the OV velocity increases, indicating an escalation in the risk of collision. Further study could focus on the design of the path-tracking control system using steering to realize the collision avoidance maneuver.

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