Overtaking Trajectory Assessment Utilizing Data from Driving Simulator

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Extended Abstract

Introduction and Problem Statement

The provision of passing maneuvers is regarded a key safety priority during the geometric and operational design of two lane rural roads. Accidents associated with failure during the passing process, such as head-on collisions between the passing and the opposing vehicle, or collisions between the passing and the passed vehicle driving in the same direction, are reported as mostly severe (e.g. 1, 2, 3, 4).

Passing is permissible on specific road areas (passing zones). The locations with passing zones strongly depend on the provision of at least minimum sight distance [passing sight distance (PSD)]. PSD is the distance that drivers must be able to see along the road ahead to safely and efficiently initiate and complete passing maneuvers of slower vehicles on two lane rural roads using the lane normally reserved for opposing traffic (5). Road sections with limited passing opportunities besides safety impose also operational degradation.

The most effective means to enhance safety and operational considerations during the passing process is to provide additional passing lanes, or at least protected passing zones through the provision of continuous 3-lane cross-section. On steep grades, such auxiliary lane configurations, known as climbing lanes, besides facilitating the passing of slow-moving heavy vehicles are used to mitigate congestion and prevent delays. As far as vehicle passing on level grades is concerned, the well-known 2+1 road sections solution is utilized. However, such road layouts are not possible for every road environment due to economic, topographical or environmental protection constraints (6).

Safety during the passing process can be violated by many means. Besides operational constraints imposed from traffic volumes and/or traffic composition, the impact of short passing zones, although not extensively validated by accident data seems to be very important in terms of smooth vs violent return of the passing vehicle to the through lane. A recent study (7), showed that in short passing zones, 92% of passing maneuvers ended beyond the passing zone, compared to 21% of longer passing zones (over 300 m). A similar research revealed that the proportion of forced and violent returns for 270m long passing zone was 10%, and it increased to 45% at 200m long passing zone (8). Another issue of concern is that in many research studies (e.g. 9, 10) the speeds of passing vehicles were found to be over the posted speed limit.

As a result, roadways with limited passing opportunities might motivate certain drivers to make risky passing attempts either late in a passing zone or on a portion of the road not intended for passing and therefore seem mostly critical (10).

On the other hand, drivers' misjudgment seems also a critical consideration. A recent study reported that 30% of accidents during passing attempts were observed even in road sections with adequate PSDs (11).

The continuous evolution of autonomous driving seems encouraging in terms of regulating human errors and improving safety, especially during complex maneuvers that include lane changing. The technological advancements provided by connected vehicles (CVs) and autonomous vehicles (AVs) are paving the way for a more "tailored" interaction between vehicle(s) and road environment. At present, vehicles equipped with Level 2 automation (partial automation) as defined by the society of automotive engineers [SAE, (12)] are already in the market, although mainly their contribution is limited to controlled conditions such as rather smooth geometric design (13).

The facilitation of the passing process is currently addressed in the literature through a number of geometric lane changing algorithms, which, however, refer to more advanced vehicle automation.

A detailed evaluation of existing approaches and methodologies for the motion planning of autonomous on-road driving which consists of finding a path, searching for the safest maneuver and determining the most feasible trajectory, is given through Katrakazas et al. (14).

In general, such trajectory algorithms consist of various geometric curves for which the lane changing paths can be either static or dynamic (15). The dynamic lane changing trajectories are more sophisticated since they have the advantage of adjusting their geometry in real time due to speed variations of the involved vehicles and thus support the examined vehicle to maintain safe distances.

Among the most widely utilized lane-changing trajectory curve is the polynomial trajectory curve; initially proposed by Nelson (16). In other research studies either cubic polynomial trajectory curves were used (17, 18), or quadratic Bessel curves (19), or trapezoidal curves (20) mainly for representing the acceleration curve of lane changing, or even spiral curves (21).

A comparison among four types of geometric lane changing algorithms; namely, circular trajectory curve, cosine trajectory curve, polynomial trajectory curve and trapezoidal acceleration curve, revealed that the latter algorithm describes better the lane-changing process of automated vehicles (22).

The present paper aims to investigate the vehicle's passing paths under acceleration mode from the road-engineering point of view, with special emphasis on the two pairs of consecutive reverse curved sections at the beginning and ending phase of the manoeuver respectively. The authors by examining these curved paths intend to quantify their trajectories, define potential safety violation imposed from the vehicle acceleration performance, and consequently deliver accurate passing paths.

The assessment is based on a driving simulator experiment as well as a vehicle dynamics model. The authors on one hand intend to determine the geometry of the curved passing paths and the respective critical parameters, such as headway and lateral distances (driving simulator), and on the other to assess their implementation potential in terms of safety by examining conflict points and defining vehicle critical acceleration performance (vehicles dynamic model).

The analysis, besides the above-mentioned parameters, includes the initial speed of the passing vehicle at the beginning of the process, the point along the path where the passing vehicle reaches and maintains thereafter the posted speed of the roadway, as well as individual driver characteristics i.e. gender and age.

In view of the deployment of advanced driver assistance systems (ADAS) in the near future, the results of the research may serve as a preliminary approach for addressing more accurately the passing process and thus standardizing vehicle passing paths more accurately.

Methodology

The analysis is part of a broader assessment where besides accelerated passing maneuvers, flyover overtaking was examined as well. Therefore, free flow conditions were assumed, where the passing maneuvers were performed on tangent sections of a two lane rural road. Although the passing process includes the contribution of three vehicles; namely the passing vehicle, the passed vehicle and the opposing vehicle, in the simulation experiment the opposing vehicle was ignored. The present paper addresses accelerated passing maneuvers.

The authors, aiming to determine realistic passing paths, performed a driving simulator experiment in order to quantify the trajectories of the curved paths during the passing maneuver, the results of which were used to feed the vehicles dynamic model for addressing potential critical safety concerns due to the examined vehicle's accelerated performance.

Passing maneuvers comprise of 3 phases (Figure 1); in Phase 1 the vehicle is assumed to move gradually from the original driving lane to the opposing lane, in Phase 2 the vehicle travels along the opposing lane, and in Phase 3 the vehicle returns once more gradually to the original lane. For Phase 1 and Phase 3, the optimal trajectory algorithm is to obtain a trajectory curve starting from the centerline of the current position (lane) to the centerline of the target lane (15).

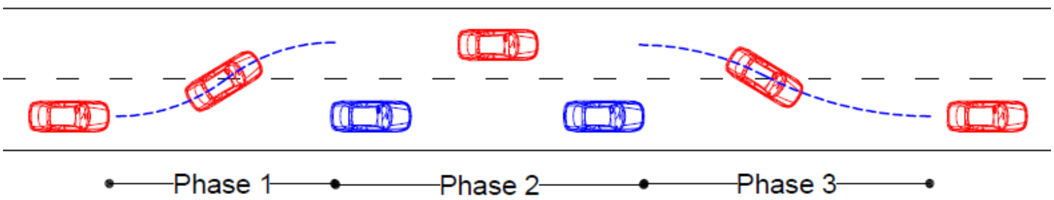

Figure 1. Phases during Passing Manoeuvers.

The two involved vehicles have different motion characteristics, where the following criteria - assumptions were applied:

- the speed of both vehicles never exceeds the posted speed of the roadway
- passing maneuvers under 2 different posted speed values were examined; namely, 70km/h and 90km/h
- the motion of the passed vehicle is under steady state conditions with a speed value 20km/h below the posted speed of the roadway
- the passing vehicle's motion during the passing process is under acceleration mode; however, it's initial speed value at the starting phase is set equal to the relevant speed of the passed vehicle and increasing continuously until the roadway's posted speed is reached from which point beyond steady state conditions apply

The experiment was implemented at the driving simulator of the Department of Transportation Planning and Engineering of NTUA. The driving simulator is a motion base quarter-cab manufactured by the FOERST Company. The simulator consists of 3 LCD wide screens 40'' (full HD: 1920x1080pixels), driving position and support motion base. The dimensions at a full development are 230x180cm, while the base width is 78cm and the total field of view is 170 degrees.

The simulated driving task entailed driving along a 3.5km approximately two lane rural road (2x4.00m wide), consisting of both tangents and curves, for which the participants were asked to drive 3 times including one lap for warming up and getting acquainted with the driving environment. For each of the remaining runs, a different posted speed was implemented (70km/h and 90km/h), where the speed of the preceding vehicle was constantly set 20km/h below (50km/h and 70km/h respectively). For every run, the duration of which was approximately 3min, the participants were able to perform between 2 and 3 accelerated passing maneuvers.

In view of the present analysis, the participants were asked to comply with the posted speed value and perform accelerated passing maneuvers only on tangents. Moreover, they were instructed to approach the impeding vehicles, maintain their speed for a certain amount of time, and pass when comfortable.

The geometry of the vehicle trajectories during the passing process was defined by drawing the azimuth diagram (23), utilizing the x and z coordinates of the vehicle path. The azimuth diagram, through regression analysis, defines the angular change rate of the vehicle path along with the driven distance, thus enabling the definition of core design elements (tangents, circular arcs and spiral lengths).

A number of critical parameters were determined from the simulator experiment and include the quantification of the passing consecutive curves, the lateral distance at the points where the headway between the passing and the impeding vehicles is eliminated, as well as headway and lateral distances. The analysis was performed for the median (50%) values of the boxplot output data.

Discussion and Conclusions

The paper delivers a safe and realistic representation of the passing process on tangent road sections, where the actual capacity of the passing vehicle to perform passing maneuvers was examined from certain perspectives.

The assessment is based on a driving simulator experiment. The curved paths were determined for two different and mostly typical posted speed values (70km/h and 90km/h), where the impeding (passed) vehicle was assumed to travel under steady state conditions (20km/h below the respective posted speed values).

A number of critical parameters were determined from the simulator experiment and include the quantification of the passing consecutive curves, the lateral distance at the point where the headway distance between the passing and the impeding vehicles is eliminated during acceleration mode in Phase 1, as well as headway and lateral distances. The analysis was performed for the median (50%) values of the boxplot output data. It must be stressed that this approach although not supported by advanced modeling, seems to deliver reasonable outputs. For example, the headway distances are very close to a similar research based on video recordings (25).

Nevertheless, there seems to be a number of issues that require further investigation. Among them stands the assessment of the above-mentioned lateral clearance point, especially during Phase 1 of the passing maneuver.

Another critical concern, in terms of safety is the quantification of the acceleration rates under various vehicle horse-power utilizations and pavement frictions values.

The human factor during the acceleration process might impose additional restrictions and consequently, affect vehicle's safety performance. Therefore, a wider sample of participants in terms of gender but mostly age is necessary, since in the present analysis only young drivers were involved. An interesting, however, finding among female participants was the fact that the passing curved paths were determined approximately 8% more abrupt. A reasonable explanation may be the fact that the speeds of the male drivers were always higher.

The investigation of more speed values between the involved vehicles and more speed differences between the impeding vehicle and the roadway's posted speed, without necessarily assuming its motion under steady state conditions, seems also very challenging. However, as far as steady state conditions of the impeding vehicle are concerned, a speed difference value of at least 20km/h below the posted speed is reported as a common approach in current practice (26,27). Short speed differences (<20km/h) between the impeding vehicle and the posted speed value result to excessive PSDs (28). A related issue of great importance to be further assessed for such cases, is the potential impact on the roadway's operational level, since unless the vehicle to be passed further decreases it's speed, the roadway is subject to perform below the designed level of service.

Therefore, in terms of vehicle automation, the present analysis addresses mainly cases where only the passing vehicle can be automated (the impeding vehicle conventional). For the above 20km/h speed difference, the research is an opening paradigm of how the passing process can be standardized and therefore deployed in existing ADAS. At present time, this effort is at preliminary stage since the speed of the passed vehicle was considered constant but also traffic conditions were assumed ideal.

Consequently, there is a need for recording in more detail actual passing maneuvers either through instrumented vehicles or through high accuracy devices (lidar, etc.).

An imminent challenge is to further improve the described methodology by enabling more sophisticated communication between vehicles (V2V) or between vehicles and road environment (V2I) and thus enable the utilization of guidance during the passing process in an advanced vehicle automation levels environment. During such an effort, cases of unforeseen situations that might cancel the passing process should be also addressed. Such cases, among others, include the capability of obstacles detection on the roadway through cameras with deep learning process as well as tire – road friction assessment due to harsh weather conditions.

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