

Driver's Preview Strategy and its Impact on NATO Double Lane Change Maneuver

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ABSTRACT

In this study, a closed-loop driver-vehicle system model is established with ADAMS/CAR. A double lane change maneuver path boundary is setup based on NATO AVTP 03-160W requirement. Multiple choices of driver preview path are derived from optimization of the closed-loop driver-vehicle-road system, where the objective is to successfully pass the double lane change maneuver at a given forward speed without violating the boundary. With the multiple choices of preview path, the vehicle dynamic responses, such as tire patch load, vehicle lateral acceleration, yaw velocity, steering wheel angle and roll angle, will vary associated with each driver's preview path. The relationship between the path clearance and vehicle dynamic responses as well as the forward speeds is further investigated. Finally a methodology to predict the maximum forward speed to successfully pass double lane change is proposed.

INTRODUCTION

The highway safety related to vehicle operation on the road is a complex function of dynamic interactions between the vehicle, the driver and the environment. The safety dynamics of a vehicle directly relates to its directional stability and control limits. The directional control, and thus the safety performance characteristics of vehicles, is strongly influenced by not only various vehicle design and operating factors, but also the driver's interactions with the vehicle. Therefore, a study of driver-vehicle interactions is extremely vital to enhance an understanding of the driver's contributions to the vehicle system performance.

The directional control of a vehicle is realized by the driver based upon the previewed path information and the perception of the vehicle motion under the constraints of

driver's abilities. These include visibility, correction, reaction, and neuromuscular dynamics as illustrated in [Figure 1](#) [1, 2, 3, 4, 5, 6, 7]. The vehicle motion on the road forms a closed-loop system where the driver-as a function of various environmental, vehicle, and driver factors-determine the primary inputs to the vehicle. A study of road vehicle control and safety performance necessitates the directional analysis of the closed-loop driver-vehicle system.

The perception and control characteristics of the driver vary with the individual's skill, perception and reaction abilities, environmental factors and dynamic response of the vehicle. The interactions are highly complex. The stable directional performance of the vehicle is thus a function of control characteristics of both the vehicle and the driver. The driver, in general, contributes to the stable motion by (1) selecting and maintaining the appropriate pathways in the presence of various disturbances (crosswinds, roadway fluctuations, obstacles, etc.) and (2) reducing the path deviations to certain threshold levels in a stable, well damped, and rapidly responding manner. The vehicle, on the other hand, should be designed to achieve (1) superior disturbance rejection abilities, (2) adequate yaw and roll stability limits, and (3) minimal driver's control effort [8].

As an approximation, the vehicle driver may be understood as both the compensator and the estimator, with a time delay, in a common closed-loop control system. The preview effect in conjunction with the perceived motion of the vehicle enables a driver to follow a path within a certain safety margin and to perceive the tracking error in relation with the perceived vehicle path. The tracking error is further applied as the input signal to the driver acting as a compensator to generate a control action in terms of steering, braking or acceleration. The time delay between the driver's perception and reaction (that originates from brain reaction and neuromuscular delay)

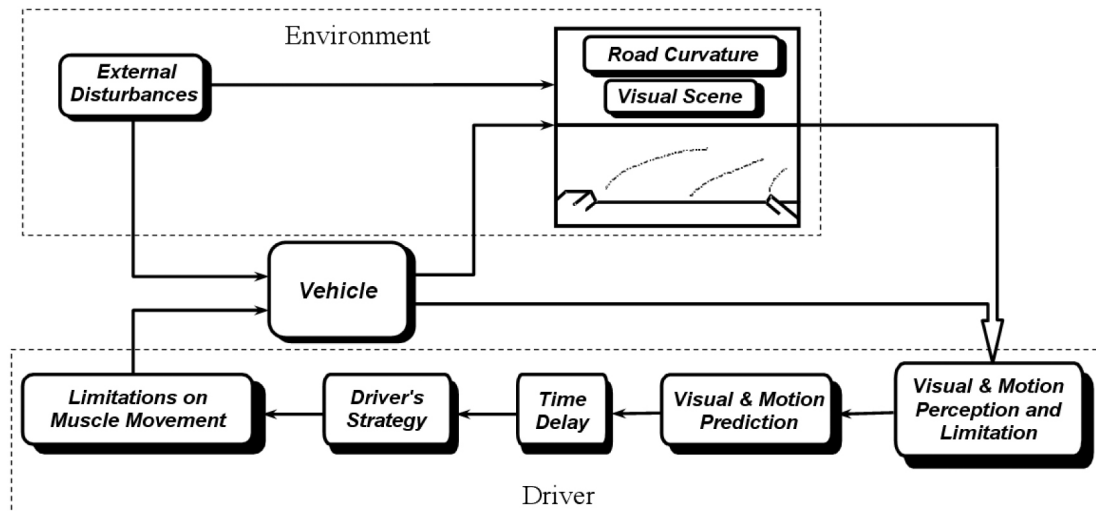


Figure 1. Interaction between the driver, the vehicle and the environment [7].

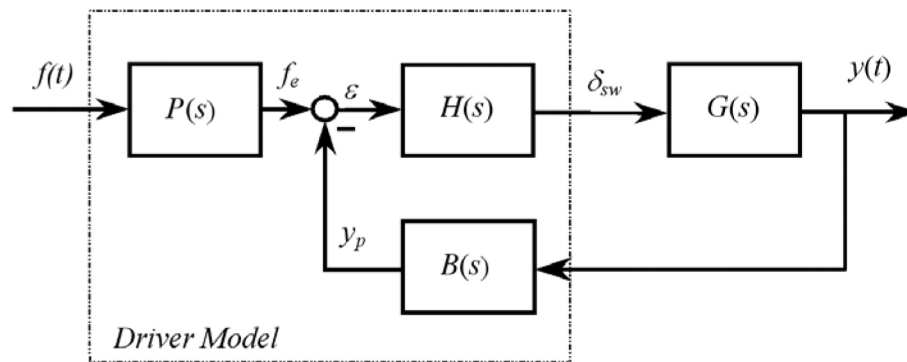


Figure 2. Structure of a preview-tracking model.

ranges from 0.1~0.5s [9, 10, 11, 12]. The primary function of the compensator is to adjust the command signal to the vehicle in both gain and phase while the function of the estimator is to predict the motion of the vehicle. The latter depends upon the driver's experience and skill. The driver's preview strongly depends upon the driver's far-sight and identification abilities and vehicle speed.

The typical structure of a preview-tracking model is illustrated in Figure 2, where $G(s)$ represents vehicle dynamics model with steering wheel angle (δ_{sw}) as input and vehicle state $y(t)$ as output. $f(t)$ is the target lane change path that the driver plan to follow. f_e is the driver's preview path, and y_p is the driver's predicted lateral trace. ε is the difference between the driver's previewed and predicted paths. The driver's control behavior is described by the function $H(s)$, while $P(s)$ represents the preview effect. The feedback function $B(s)$ relates to the path prediction ability of the driver and forms the most vital component of the model. A majority of the driver-vehicle models proposed in the literature use the preview tracking driver models in order to

incorporate the essential preview and prediction effects of the driver [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. These studies have established that the performance of the closed-loop driver-vehicle system is strongly related to the preview time or distance; this is a complex function of the driver physical behavior, maneuvers and tasks, vehicle speeds, road conditions, and vehicle dynamics. A number of measurement techniques based upon restricted and controlled preview distance under various road and speed conditions have been developed [33, 34, 35, 36, 37, 38, 39, 40]. These studies have reported a wide range of preview time ranging from 1.7 to 9.0s, and preview distance ranging from 6.1m to 128m, depending upon the test methods, test objectives, road conditions, vehicle speeds and types of maneuvers.

While considerable discrepancies among the reported results are evident, we can attribute these to varying test methods, conditions and objectives. An examination of the results, however, reveals some very important and significant trends. Under straight-line driving conditions, the preview distance increases nearly linearly with increase in vehicle speed. The

double lane change maneuver. Thus it is difficult to learn the driver's preview strategy from the field test.

Alternatively, in the virtual simulation, the preview path gets entered as a series of points, with the computer employing some polynomial fitting to generate additional intermediate points. How well the virtual driver can follow the preview path depends on the combined capabilities of the simulated vehicle and the simulated driver. For a given vehicle length (L , measured 0.5m above ground, front tire to rear tire) and width (W , measured from tire left hand bulge to right hand tire bulge), the path boundary is defined based on NATO AVTP 03-160W Double Lane Change Test Course specification (Figure 3), whether the vehicle can or cannot pass the boundary at pre-specified forward speed, depending upon the vehicle dynamics and driver's preview strategy, i.e. preview path. From a series of simulations with different preview path selections, one can investigate how the preview path affects the vehicle dynamics responses when negotiating NATO double lane change maneuver.

VEHICLE MODEL DESCRIPTION AND SIMULATION METHOD

The objective of this study is to investigate the behaviour of the vehicle dynamics response during driver's negotiating the NATO double lane change maneuver, so the accuracy of the vehicle model is critical. A prototype vehicle is chosen such that majority of the vehicle model parameters are available. The vehicle is illustrated in Figure 4, where front and rear suspensions are typical short-long arm (SLA) with a front rack-pinion steer system.

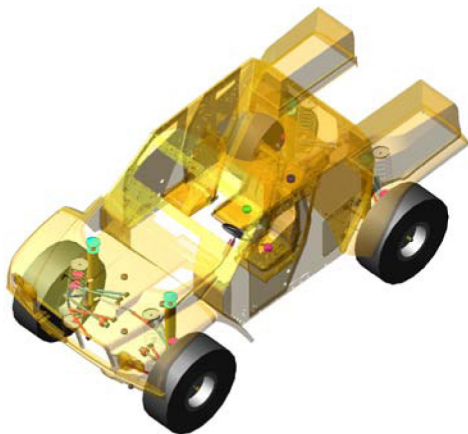


Figure 4. Vehicle model.

The vehicle body is modeled as rigid part and its masses and moments of inertia are derived from the CATIA model. All of the bushings and their forces are assumed to be nonlinear functions of their deflections and linear functions of velocities in the three translational and three rotational directions. All suspension components are represented with

rigid bodies (their flexible mode frequencies being much higher than the concerned road and steering input frequencies). The PAC2002 Tire model [41] is applied to calculate the tire patch forces. The total degrees of freedom of the full vehicle model are 117. The model is first well correlated with the target kinematics and compliance properties before using it for full vehicle simulations.

As previously mentioned, the driver in the double lane change maneuver always tries to drive the vehicle at the fastest speed possible without violating the lane boundaries or lifting a tire. Therefore a driver must learn how to steering the vehicle and adapt the vehicle dynamics. Such a learning process is difficult to describe in the real world but analysts can simulate it with close-loop driver-vehicle system model as previously shown in Figure 2. In this paper, ADAMS/Car [41] driver machine control module is applied to integrate the vehicle for closed-loop driver-vehicle system simulation; the driver's preview distance is assumed to be 50m.

In the driver machine module [41], it is assumed that the driver can accurately learn and follow a linear yaw plane bicycle vehicle system dynamics [42, 43]. Thus, a bicycle model is used to compute the steering control action that should cause the vehicle to follow the previewed path. The simulated vehicle, however, may not exactly follow the previewed path due to 1) the differences between the bicycle model and the simulated vehicle or 2) external factors such as road roughness and aerodynamic disturbances. In order to adapt the actual vehicle nonlinear system dynamics and to drive the vehicle at a given speed within the double lane change boundary, the driver may preview different paths in order to compensate for those differences. The previewed path will generally depend upon a driver's experiences, vehicle speed, and adaptability to the vehicle dynamics. On the other hand, with a given vehicle speed and lane change boundary, there could be many choices of previewed path that lead to successfully completions of the double lane change maneuver-this will yield different vehicle dynamics responses. We must therefore study the potential choices of previewed paths a driver could have to yield successfully passing through the double lane change at maximum possible forward speed.

RESULTS AND DISCUSSIONS

In this section, we will first discuss the simulation results of previewed path choices at a given forward speed of 50mph followed by the prediction of maximum possible speed the driver can successfully pass the double lane change.

CHOICES OF PREVIEWED PATH AT A GIVEN FORWARD SPEED

As previously mentioned, at a given speed, a driver may have multiple choice of the previewed path to pass the double lane