

Impact of Driver's Steer Control on Truck-Trailer Combination when Negotiating NATO Double Lane Change Maneuver

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ABSTRACT

In this study, a closed-loop driver-truck-trailer system model is established with ADAMS/Car. A double lane change maneuver (DLCM) path boundary is set up based on the NATO AVTP 03-160W requirement. The best driver preview path at a given speed to pass the DLCM is derived from optimization of the closed-loop driver-vehicle-road system, where the objective is to successfully pass the DLCM at the given forward speed. This must be done without violating the maneuver boundary, lifting any tires off the ground, as well as staying within the Driver's steering effort limit. Depending upon the Driver's control strategy, which is reflected by the formulation of the optimal objective, the dynamic responses of the truck-trailer combination will vary. Two extreme conditions are discussed in this study: full and no consideration of trailer, respectively, when negotiating the DLCM. The vehicle responses and Driver's preview paths under these two conditions are further compared to demonstrate the impact of Driver's skills and lane change control strategy on DLCM.

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INTRODUCTION

Vehicle driving is a common yet highly complex task that involves dynamic execution of multiple critical subtasks [1], including steering, accelerating, braking and possibly the shifting clutch on a manual transmission; sometimes also including the related controls such as turn signals, headlights, and windshield wipers. In the same situation, drivers with different behaviors and skills may demonstrate different execution patterns of these tasks. Alternately, the same driver may behave differently when driving different vehicles, such as a single unit vehicle or a truck with a trailer [2, 3, and 4]. It is thus extremely important for automotive engineers and designers of vehicle active safety systems to understand and simulate human driving behavior accurately.

Lane change crashes represent approximately 10% of the 6.3 million crashes that occur annually [5]. In addition, lane-change events are closely related to rear end crashes, which account for approximately 25% of the total crash population each year. Learning lane-change maneuvers can help identify opportunities for crash avoidance countermeasures and provide a framework in which crash countermeasures should be evaluated. The process of making a lane change requires major skill elements to be simultaneously undertaken and coordinated. These fundamental skills include scanning the vehicle's surroundings in the rear-view and side-view mirrors at appropriate times and controlling both the direction and

speed of the vehicle [6], and more importantly, correctly previewing the path to ensure performing the lane change maneuver without rollover and violating the path boundary formed by other vehicles in the same and other lanes.

Widely used driver-vehicle system models involve three function blocks: (i) preview; (ii) prediction; and (iii) compensation, as illustrated in Figure 1. The preview function is highly dependent upon the driver's visual cues and path decision process, where the preview time is the key parameter that affects the driver's steering strategy and thus the closed-loop driver-vehicle system performance. Extensive experimental studies on single unit vehicle have established that the driver's preview time varies between 0.5 and 9.0 s, depending upon the vehicle speed, maneuver severity, and driver's experience and habits [7, 8]. The prediction block reflects the driver's biological activity in assessing and predicting the instantaneous vehicle motions, such as lateral position, orientation, and lateral acceleration. The prediction ability of the driver is a complex function of the driver's experience, skill and the vehicle dynamics. The third block, compensatory function, depends upon the driver's physical and biological conditions. The driver's reaction time and neuromuscular delay reflect the driver's physical limitations due to driver's brain and limb muscle, which are reported within the range of 0.1-0.5s [9]. The biological factors of the compensatory function are simply referred to as the

compensatory gain and equalization function. The gain and equalization function differ widely from one task to another and may vary substantially with time due to the driver's experience accumulation and adaptation to the vehicle system.

Many studies on single unit vehicles have reported the values of the compensatory gain (steer wheel angle change in radian per meter of vehicle CG lateral displacement offset), equalization lead and lag time constants, vary from 0.001 to 0.12rad/m, 0.01 to 5.0s and 0.01 to 20.0s, respectively [9, 10].

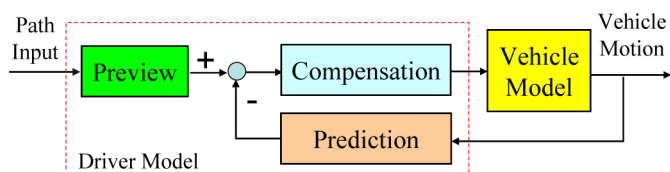


Figure 1. General structure of a driver/vehicle system.

The Driver's preview behavior may be studied using two general approaches: (i) experimental perceptual studies; and (ii) theoretical investigations. The experimental studies, usually performed in a driving simulator by constraining some channels of perceptions, can effectively identify most significant motion sensors under different constraints. Alternatively, the theoretical approach tends to identify the vehicle motions that must be sensed, and commands required to achieve satisfactory path tracking. This modeling approach, however, does not lead to a unique solution. Further considerations thus must be given to the Driver's ability to perceive or sense, the vehicle motion and input quantities, and to the nature of the operations required on the sensed quantities in closing the driver/vehicle system loop. Furthermore, the influence of the preview and prediction on the driver-articulated vehicle system performance can be studied using theoretical approach. Under path tracking and evasive maneuvers, however, the driver control actions do not rely upon single feedback variable.

A heavy vehicle driver, with higher skill level and experience, specifically relies upon various motion cues arising from the dynamic response of the vehicle combination. Such motion cues may arise from the yaw rates, lateral accelerations and roll angles of the vehicle units. The significance of such motion cues, however, requires study of driver-vehicle models based upon multi-feedback loop structure. Compared with driving a single-unit vehicle, driving a vehicle with a trailer requires different maneuvers to successfully negotiate a lane change maneuver; and the driver of a truck & trailer has considerably less room for margin of error; the vehicle with trailer is much less maneuverable and nimble than the single unit vehicle without a trailer; and it's critical that the driver always needs to compensate for the added vehicle length and the dynamic interactions between truck and trailer when changing lanes. Fundamentally, all these differences will affect the Driver's

preview control, i.e. how to adapt his/her preview path such that they can take the appropriate steering, accelerating, and braking control actions to negotiate successfully the lane change maneuver. Unfortunately, it is extremely difficult in practice to accurately measure a real Driver's preview path, thus in this study, the Driver's preview paths with and without considering the trailer are respectively solved through closed-loop driver/vehicle system model simulations and optimizations on a NATO double lane change (DLC) maneuver at a given speed. The resultant Driver's preview path, steering angle/torque and other vehicle dynamic responses are further compared to learn how the trailer will impact the Driver's steering control during negotiating double lane change maneuver.

DOUBLE LANE CHANGE MANEUVER

The DLC test is commonly adopted because it correlates well with the fact that the more controllable and secure a vehicle is when pushed to its handling limits, the better chance the vehicle occupants will avoid an accident in emergency situations. When an obstacle is in the way, swerving around it quickly can cause the vehicle to go out of control and result in a vehicle rollover or obstacle impact. This can happen due to the compromising nature of vehicles in general (such as tradeoffs between performance handling and ride comfort). In the DLC maneuver, rollovers are more common on vehicles with high center of gravity (CG) than vehicles with low CG, especially if swerving abruptly. An inexperienced driver may not know how fast the vehicle he/she is driving can negotiate the lane change without rollover. Alternatively, a driver at a proving ground may not know how to control the steering wheel effectively at a given speed so that he/she does not violate the DLC boundary specified with the pylons as shown in [Figure 2](#) [11]. Furthermore, a driver experienced only in single unit vehicle may need to learn adapting himself/herself to the truck with trailer combination.

In an early stage of vehicle development, modeling and simulation engineers often employ double- and single-lane change maneuvers to evaluate a vehicle's transient handling dynamics. In such events, the lane boundaries are given with a few specified pylons. The locations of these pylons are dependent upon the vehicle length and width (NATO double lane change AVTP-03-160W for example). Evaluation of the vehicle's dynamic capabilities involves finding (and demonstrating) the maximum speed at which the vehicle can navigate through the course 1) without violating the lane boundaries and 2) without any tire normal force going to zero (lifting off the ground). A course boundary violation is defined as any part of the tire sidewall or vehicle corners that crosses over a boundary. The higher the speed at which the vehicle can pass the event successfully (no boundary violations and no zero tire normal forces), the better the evaluation of the vehicle's transient dynamics.

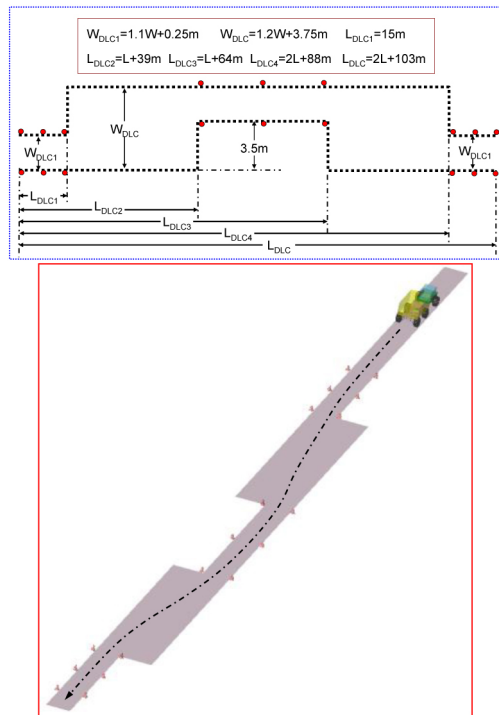


Figure 2. NATO (AVTP 03-160W) lane change test course definition and boundary (W : vehicle width, L : vehicle length).

Inherently, the lane-change maneuvers are closed-loop events. The driver does not simply give standard, predefined control inputs to the vehicle and evaluate the response. Instead, the driver must adapt the inputs in order to achieve the objective, i.e. in order to successfully negotiate the course. In the real world, experienced drivers can quickly learn the handling limits of the vehicle while operating under their control and can often leverage their knowledge (from previous maneuvers) to select the proper inputs. In the virtual world, a simulated driver attempts to maneuver the vehicle through the digital proving ground. Models of the virtual driver continue to improve; however, the human brain is an extremely complex system and the full “knowledge” of an experienced driver cannot be captured in the digital model. The simulation engineer cannot simply tell the virtual driver to avoid the cones and stay within the boundaries; rather, the engineer must generate a preview path that the virtual driver then attempts to follow. Due to vehicle nonlinear dynamics, tire-road interactions, and the complexity of the maneuver, the simulated vehicle trajectory never follows the previewed path. Furthermore, it is almost impossible for a real human driver to tell what exactly the preview path was used during negotiating 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 2). Whether the vehicle can or cannot pass the boundary at a pre-specified forward speed depends 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 the DLC.

Figure 3 summarizes this simulation process, where the target vehicle forward speed is given as a constant, which serves as the vehicle longitudinal control objective achieved by modulating the accelerator or brake pedal travel; the truck and trailer tracking points in this study are chosen as the extreme outer points of a tire sidewall middle and lower edge as shown in Figure 4. The clearance is defined as the minimum lateral distance between the truck and trailer tracking points and the path boundary for all four and/or six corners, depending upon whether or not the trailer is considered. Based on the assumed driver preview path, the virtual driver control model [12] modulates the steering wheel angle to yield the required vehicle response, and the objective for the virtual driver is to ensure the vehicle stays within the lane change boundary and has no tire lift-off at the given forward speed. Therefore, different driver preview paths will yield different vehicle responses, steering wheel angle and torque. Furthermore, if the driver considers or doesn't consider the trailer violating the path boundary and trailer tire lift-off, the resultant steering wheel angle will be different as can be seen in later discussion. This might be associated with the Driver's skill or experiences driving the vehicle with trailer.

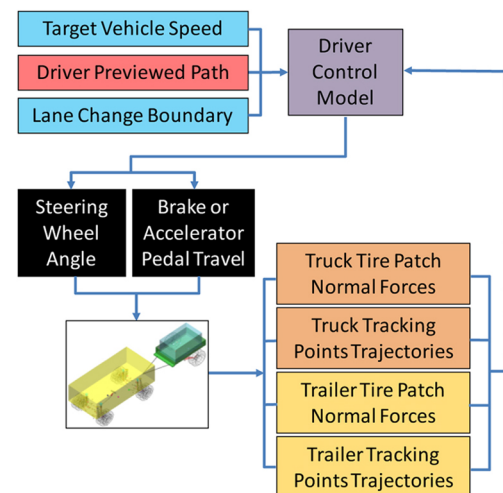


Figure 3. Closed-loop driver/vehicle/road interactions.