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# A Multi-Sensory Cybernetic Driver Model of Stopping Behavior: Comparing Reality Against Simulators with Different Cue-Rendering Fidelities

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**Abstract:** Driver training effectiveness requires assessment of driver performance in order to compare and contrast the impact of different training techniques on the learned control. Human performance can be quantified from different perspectives ranging from aggregate measures to specific model coefficients in order to link observed performance to how the driver achieved this performance through a particular control strategy. A model based approach is needed to understand the pros and cons of different training programs. One important yet often ignored aspect of a model is the cost function that drives behavior adaptation. Here, a model based methodology is proposed that estimates the weights on different terms in the cost function that drivers use to adapt their behavior in order to satisfy their performance needs. Because the driver model includes the effect of the controlled dynamical system as well as any particularities of the training environment, one can use it to quantify the effect of training specific deviations from reality, such as the use of a driving simulator that causes known biases in perception, on behavior. This paper details the methodological approach and discusses it in the context of stopping behavior in reality versus in a driving simulator. The goal with training is to instill the right structural behavior so that only minor adaptations may be needed once applying the learned skill in reality. Because the adopted cost function plays such a large role, much focus should also be given to shaping the cost function that operators employ.



*Keywords:* driving simulator, driver training, system identification, cybernetics, multi-sensory perception.

## 1 INTRODUCTION

Understanding and quantifying the driver as a controller is a requirement for many domains where driving performance and safety are important. Examples are:

- The *design of driver support systems* requires knowledge of how drivers will use these systems in order to reduce the amount of testing required with physical prototypes; i.e. what are the effects of impoverished multi-sensory cue rendering in virtual test environments on perception of relevant vehicle states.
- The *design of dynamic systems* under control of humans requires knowledge of the types of dynamics humans can control well with minimal effort; i.e. what are the limitations on internal model development especially within sensorially impoverished testing environments.
- The *design of driver training environments* requires not only knowledge of cue usage but also knowledge of the impact that a training environment has on the cost function that humans use to shape their control and decision strategy; i.e. what are the effects of training system and environment on perception of performance, risk as well as on the motivation to maintain a high level of attention. risk the design

Knowing whether drivers adopt the same control strategy in the simulator world as in the real world is a necessary condition for effective transfer of training because otherwise the strategy has to be unlearned. The question is: what are the requirements for a driving simulator to assure equivalence in adopted control strategy between simulator and reality? This is a general question that requires much experimentation. In this paper we discuss many of the important elements to consider in the design and evaluation of training environments exemplified with a comparison between stopping in the real world and stopping in a driving simulator.

Driving simulators generally try to recreate the multi-sensory experience that drivers have in the real world such that the experience is representative of reality (Kemeny & Panerai, 2003), unless the simulator is used for entertainment or basic human performance assessment. The goal to construct an experience that is representative of reality has been a rather nebulous one because we are still very limited in characterizing and modeling human experiences in complex environments such as driving. This begs the question: how do we know if our simulator is good-enough to serve as an effective training device?

Our hypothesis is that as long as the elicited control in the simulator is structurally equivalent to that observed in reality, transfer of training from simulator to reality is expected to be positive. By structural equivalence we mean that:

A. The controller structure or the form of the driver model that best characterizes the observed behavior is

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the same in both environments. An example is that if a simple non-linear human control model accurately captures deceleration behavior to a full stop in reality, then the simulator should not require the driver to develop a more complex controller to achieve the same goal.

B. The profile of a control response to a particular event is the same in the simulated and real environment. For example, if a driver in reality decelerates to a full stop with a nearly constant single level of deceleration, then deceleration should not show a multi-modal deceleration profile in the simulator.

C. The performance effort balance is the same in both environments. For example, if a particular behavior such as car following or stopping in the simulator requires much more effort than in reality, then drivers may adopt a different distribution of weights to cost function terms.

The expected order of importance is from A to C in that an error in A is more likely to yield a negative transfer of training than C.

From the literature we know that stopping to a full stop at a specific target location is a difficult task to reproduce accurately in a driving simulator particularly fixed base simulator (Boer et al., 2001). In reality the deceleration profile is generally of the form shown in Fig. 1. Contrast this to the deceleration profile often observed in a fixed base driving simulator (Fig. 2); the profile is multi-modal. The question is: what causes such structurally different behavior in the simulator?

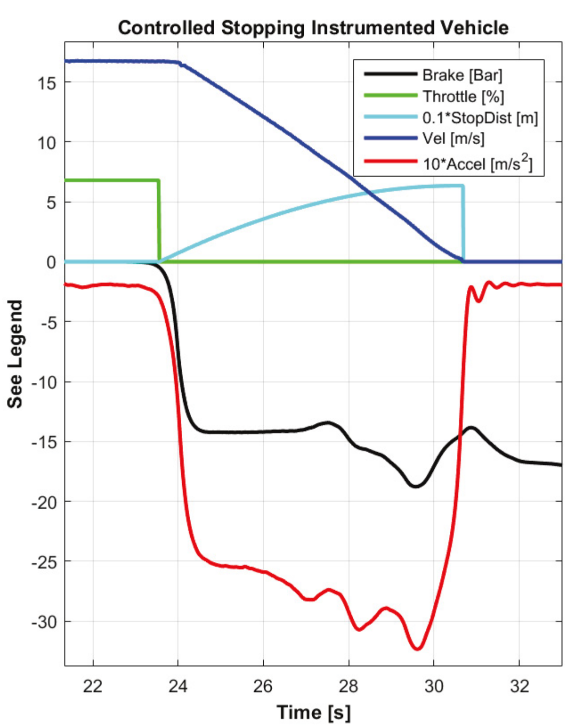


Fig. 1. Typical real world controlled stropping profile with a relatively constant deceleration profile (red).

The interaction between driver and environment is mediated by the fact that the simulator renders a filtered subset of the natural cues that drivers use to control their vehicle. The types of cue filtering that the simulator imposes are three:

1) The simulator introduces a delay caused by the hardware involved in rendering the cue. The graphics pipeline, the motion system, the actuators for torque feedback control on steer and pedals, and the sound system all suffer from delays that range from a few milliseconds to sometimes more than 100 milliseconds. Any delay in a closed loop controller leads to instability under sufficiently demanding high bandwidth control.
2) The simulator also introduces distortions caused by cue rendering hardware limitations. The rendering systems introduce non-linearity and noise into the cues. The visual display system is limited in resolution and contrast. The motion base is limited in excursion. The sound system is limited in its spatial placement of sounds. These distortions increase the variability in control and thus increase the required effort level for a given performance level.
3) The simulator finally applies scaling to some of the cues or simply does not render certain cues. Most visual systems do not render in stereo and do not render motion parallax requiring head tracking. All but the most advanced motion rendering systems present acceleration cues in a scaled version; fixed base simulators do not render any acceleration cues perceptible by the vestibular system.

This means that drivers perceive many cues in delayed, scaled, noisy fashion. The question is: which cues and what levels of distortions are tolerable to assure structurally equivalent control?

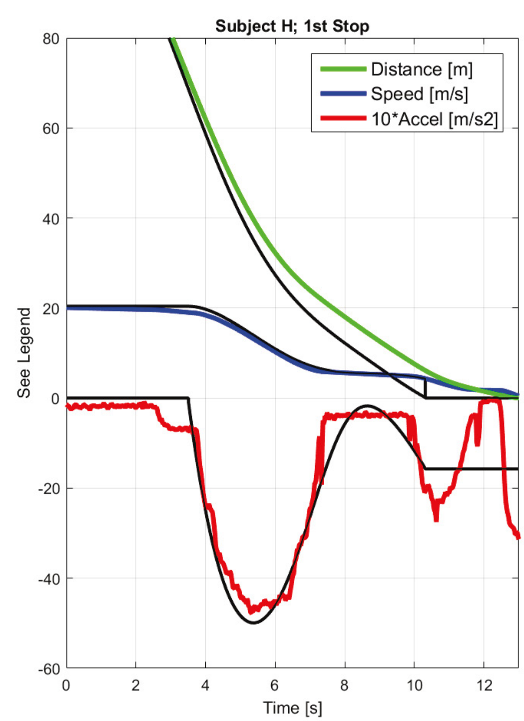


Fig. 2. Characteristic multi-modal deceleration profile (red) of a driver performing a controlled stopping maneuver in a fixed or limited motion driving simulator.