

White paper on
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Background—certification process of automotive control systems in the US

The Office of Vehicle Safety Compliance (OVSC) of NHTSA, Department of Transportation is responsible to ensure compliance of Federal laws, standards and regulations pertinent to vehicle safety. Essentially, OVSC took a **self-certification** process which is very different from the process used in some other countries such as Japan. As stated by OVSC, *“It is the responsibility of a manufacturer of vehicles and/or items of motor vehicle equipment to certify that each motor vehicle and/or equipment item is in full compliance with the minimum performance requirements of all applicable Federal Motor Vehicle Safety Standards (FMVSSs)”* [1].

While control systems have long been incorporated to passenger cars, in the early years their utilization was not mandated per se. For example, stringent fuel economy and emission requirements made the use of engine control units de facto required, but not explicitly. In 2007, the situation changed when NHTSA announced FMVSS 126 [2], requiring all vehicles lighter than 10,000 pounds to be equipped with electronic stability control (ESC) systems starting from model year 2012. This (unusual) requirement is motivated by two major reasons: the traffic casualty statistics shows ESC is extremely effective reducing single-vehicle crashes [3], and its potential to address rollover crashes [4]—a hot button issue in the late 1990’s.

When a control system such as ESC is required on ALL VEHICLES, it becomes the obligation of the government (in particular, NHTSA) to define a clear process on HOW to evaluate its performance. This indeed is the case for FMVSS126. Very briefly, the test procedure is summarized below. The vehicle’s ability to turn is assessed through a “Slowly Increasing Steer Test”, based on which the steering amplitude of the subsequent “Sine-With Dwell” test is determined. The vehicle is then tested at a given speed (50mph), on regular road surface, for a series of Sine-With Dwell maneuvers. The measured signals are processed through specified filters (12-pole phaseless low-pass Butterworth, with a cut-off frequency of 10Hz or 6Hz). Finally, the control performance is judged from the yaw rate amplitude 1.0 second and 1.75 second after “Completion of Steer”. More specifically, the yaw rate values must not exceed 35% and 20%, respectively, of the peak yaw rate value after steering reversal.

While specifying the test condition so specifically helps to ensure the test is repeatable, reliable and can be finished relatively quickly at various sites, it certainly comes with some drawbacks. ESC is frequently triggered when the vehicle is driven on snow/ice but that condition was not tested. In addition, the test condition is for a given speed and specified steering profile, while

the real life scenarios can be a lot diverse and challenging. Some of the values seem to be selected more because they are technically achievable, rather than they better reflect the safety performance of the system.

Autonomous vehicles and the challenges in “control system evaluation”

Over the last several years, there have been many announcements and reports on autonomous vehicles. Many car companies announce they are bringing partially or fully autonomous vehicles to the market. As we speak, the google cars are zipping down the streets in California and attracted a lot of media attention [5]. Aside from the technology challenges associated with the creation of a “level 4” automated vehicle, which according to the definition of NHTSA [6], are vehicles that is capable of “Full Self-Driving Automation”. The question is: if/when a company claims it has solved all the technical challenges, should their autonomous vehicles be permitted to be used as “robo-taxis” for hire by the general public right after they are “certificated” by google engineers? Or they should be certificated by NHTSA? Considering the ground-breaking nature of the technology, and the significant implication to public safety, we firmly believe the later must be insisted by the US government.

It should be remembered that ESC works side-by-side with a human driver, and is by nature a driver-assistance system. Fully autonomous vehicles like the ones Google is contemplating, on the contrary, works completely independently. Therefore, they must be subject to much more careful scrutiny. To ensure their safety, it is without doubt the responsibility of NHTSA and the companies to deploy an evaluation procedure that is much more comprehensive and much more intelligent, to ensure the safety of these autonomous vehicles.

What we need—A Worst-Case evaluation paradigm

Many of the NHTSA test procedures were “standard tests”, i.e., the test conditions are the same for all vehicles. Some of the more recent tests were “customized” to recognize the fact that not all vehicles are created equal. One example is the rollover test, in which case the magnitude of the steering angle and time of reversal of the test maneuvers are customized to recognize the fact not all vehicles have the same steering system gear ratio, tire friction limit, and roll dynamics. We believe that tests for vehicles and vehicle subsystems with a control system not only need to be customized, they should be based on the “worst-case” philosophy. This is because control and management systems have complex behavior because of the control software. Having a standard test is akin to holding an SAT test for students with all problems pre-announced. Students do well in the test but the score may tell very little about how much they really learn. For vehicles with control systems, the “standard test” approach obviously would not work. For autonomous vehicles, “worst-case evaluation” is a must.

So how does the “worst-case” evaluation paradigm work? The “intelligence” that generates the test conditions must generate the “worst case maneuvers” for the target system (e.g., autonomous vehicles, battery management systems) in an iterative fashion. The maneuvers must be within reasonable bound (e.g., 98% hard brake by the lead vehicle, limited charging

and discharging power for a battery and within SOC limits) to explore the weakness of the control system [7]. The performance under the iterative process is a better reflection of the safety performance of the tested vehicle. Generation of “optimal disturbance”, the dual problem of optimal controls, has received relatively little attention in the literature. In [8], a comprehensive process that deploys optimal control theory, game theory, iterative dynamic programming and local numerical search methods such as NOMAD, to search for multiple local optimal (worst-case) solutions. The process can be either based on simulations or hardware-in-loop tests. The process is computation intensive because of the non-convex nature of worst-case problems. Fundamental research for worst-case evaluation methods is important to the evaluation of many vehicle control systems, especially autonomous vehicle control systems.

In our vision, the evaluation process for safety-critical systems, including the control system of autonomous vehicles, must deploy a hybrid testing-simulation based procedure. In the first step, the vehicle is tested to extract key performance measures, useful for developing a model. The worst-case evaluation process then analyzes the model to explore weakness. In the third and last phase, the final vehicle performance is affirmed based on the customized evaluation scenarios, identified by the worst-case evaluation system. We are not in the position to speculate whether the final form is an NHTSA FMVSS, a separate regulation, or a suggested standard. Nevertheless, the proposed “worst-case evaluation paradigm” will provide useful knowledge for NHTSA and mobility companies alike.

Qualification of the Author

Professor Huei Peng has studied the design and evaluation of vehicle control systems for 18 years. He has applied linear-control with preview, game theory, and iterative dynamic programming methods to generate worst-case steering maneuvers for articulated trucks (under the support of DOD), and steering and braking maneuvers for SUVs (under the support of TRW). More recently, he studied the worst-case evaluation methods of integrated chassis control systems using local search numerical method with systematically generated initial conditions. He also has studied the design of a wide range of vehicle control systems, including adaptive cruise control (supported by BMW and Nissan), crosswind stability (Hyundai), Integrated chassis control (GM), hybrid vehicles (GM and Bosch), transmission control (GM), battery management system (DOE), and post-impact stability control (Ford).

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