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Fuel economy testing of autonomous vehicles

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A R T I C L E I N F O

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A B S T R A C T

Environmental pollution and energy use in the light-duty transportation sector are currently regulated through fuel economy and emissions standards, which typically assess quantity of pollutants emitted and volume of fuel used per distance driven. In the United States, fuel economy testing consists of a vehicle on a treadmill, while a trained driver follows a fixed drive cycle. By design, the current standardized fuel economy testing system neglects differences in how individuals drive their vehicles on the road. As autonomous vehicle (AV) technology is introduced, more aspects of driving are shifted into functions of decisions made by the vehicle, rather than the human driver. Yet the current fuel economy testing procedure does not have a mechanism to evaluate the impacts of AV technology on fuel economy ratings, and subsequent regulations such as Corporate Average Fuel Economy targets. This paper develops a method to incorporate the impacts of AV technology within the bounds of current fuel economy test, and simulates a range of automated following drive cycles to estimate changes in fuel economy. The results show that AV following algorithms designed without considering efficiency can degrade fuel economy by up to 3%, while efficiency-focused control strategies may equal or slightly exceed the existing EPA fuel economy test results, by up to 10%. This suggests the need for a new near-term approach in fuel economy testing to account for connected and autonomous vehicles. As AV technology improves and adoption increases in the future, a further reimagining of drive cycles and testing is required.

1. Introduction

Management of environmental pollution and energy use in the light-duty transportation sector is currently regulated through fuel economy and emissions standards. In the United States (U.S.), Japan, and the European Union these standards are in the form of quantity of pollutants emitted and volume of fuel used per distance driven (Atabani et al., 2011). Compliance with these standards is evaluated via a standardized fuel economy and emissions test. The U.S. test consists of a vehicle on a treadmill, while a trained driver follows a fixed velocity schedule, or drive cycle (EPA, n.d. A). During the test all effluent from the tailpipe is tested for pollutant levels, and carbon dioxide levels are used to estimate fuel usage (EPA, n.d. A). This is done for five different types of drive cycles, to simulate different conditions (EPA, n.d. B). The results from each test are then aggregated to ascertain if the vehicle is complying with emissions standards. In addition, the tests are weighted four separate ways to determine fuel efficiency with respect to required standards and reporting to the consumer in the form of highway, city, and combined fuel efficiency (EPA, n.d. B). This system allows for a standardized method to compare all passenger vehicles in the U.S. market, streamlining the regulatory process.

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By design, the current standardized fuel economy testing system neglects differences in how individuals actually drive their vehicles on the road. As autonomous vehicle (AV) technology is introduced, more aspects of driving are shifted into functions of decisions made by the vehicle, rather than the human driver. Yet the current fuel economy testing procedure does not have a direct mechanism to evaluate the impacts of AV technology on fuel economy ratings. Autonomous and partially autonomous vehicle technology has advanced greatly over the past several years, with adaptive cruise control (ACC) with lane assist systems already reaching the market, and more advanced technologies have been announced for the coming years. While these systems may allow vehicle manufacturers to optimize their partially-autonomous vehicle control systems for fuel efficiency, these systems will not affect vehicle fuel economy ratings unless they are included in fuel economy testing. Hence, manufacturer incentives will not be aligned with improving fuel economy. Without inclusion into fuel economy ratings, autonomous technology will not help manufacturers meet their required Corporate Average Fuel Economy (CAFE) targets and manufacturers cannot advertise the increased vehicle fuel efficiency. Under such incentives, manufacturers are likely to make vehicle control decisions that increase vehicle desirability at the cost of fuel efficiency. Currently, the National Transportation Safety Board is considering if certain partially-autonomous technologies should be included as standard vehicle features for safety reasons (Mlot, 2015). Requiring autonomous technologies on new vehicles for safety reasons would enhance the importance of understanding their impacts on vehicle fuel economy.

The EPA has addressed similar issues of emerging technologies through ‘‘off-cycle technology credits” for CAFE standards, and is likely to continue this practice for autonomous technology (EPA and NHTSA, 2010). A manufacturer may petition for an increase in a vehicle's CAFE fuel economy rating if it can demonstrate the current two-cycle test does not capture some fuel efficiency gains that ‘‘new and innovative technologies” provide (EPA and NHTSA, 2010). There are three potential challenges if this approach is used for autonomous vehicle technology. First, off-cycle technology credits only apply to new and non-standard technologies. Once other manufacturers begin to adopt them, as has already happened for many early autonomous features, they are no longer eligible. Second, the process is non-standardized. A manufacturer must submit a testing and validation method, which has to be granted preliminary approval, and go through a public review process. In addition, the EPA will not certify the method or results (EPA and NHTSA, 2010), meaning that these technologies may not be tested equivalently across manufacturers. The final challenge is that this will only apply for CAFE standards and not fuel economy ratings that inform the consumer (EPA and NHTSA, 2010). Hence a manufacturer still cannot reflect the impacts of this technology in its fuel economy stickers and may face restrictions when trying to advertise any fuel economy benefits to consumers.

As autonomous vehicle technologies become more prevalent, the current drive cycle system should be expanded to include drive cycles for autonomous and partially autonomous vehicles. This paper makes a contribution to the literature by demonstrating a method to incorporate autonomous following drive cycles into the existing EPA testing regimen. This method was developed primarily for near-term conditions, where the majority of traffic is comprised of conventionally-driven vehicles. This method would allow the current dynamometer testing to continue, while accounting for the introduction of AV technologies. This approach was tested on a range of possible drive behaviors, modeling different priorities that a vehicle manufacturer may wish to pursue to obtain new testing drive cycles. The fuel consumption resulting from these drive cycles were then simulated on a variety of vehicles using the Virginia Tech Comprehensive Fuel Consumption Model (Edwardes and Rakha, 2014; Park et al., 2013; Rakha et al., 2011; Saerens et al., 2013), and then compared. While the ultimate procedure adopted by EPA will have to comply with regulatory requirements, the methods outlined here demonstrate the need for a new approach and provide a starting point for discussion in the near-term. As AV technology improves and adoption increases in the future, a further reimagining of drive cycles and testing is required. This paper is organized as follows. First, the current drive cycles used for fuel economy testing are discussed. This is followed by a review of current literature and a description of the proposed addition to the current test. Next the ACC behavior used for testing is described and the fuel consumption model discussed. Finally, the results are discussed and their sensitivity to assumptions is tested.

1.1. Current drive cycles

Currently the EPA requires five separate drive cycles for passenger vehicle fuel economy testing. These are the Urban, Highway, High Speed, Air Conditioning, and Cold Temperature tests. While the first three are permitted to be tested in any temperature between 68 °F and 86 °F, the latter two must be done at 95 °F with the air conditioning on and 20 °F, respectively (EPA, n.d. B). The results of these cycles are then weighted in four different ways to find the emissions rate, urban and freeway fuel economies and combined fuel economy. This research uses the urban (FTP) and highway (HWFET) drive cycles, as the basis for the new autonomous drive cycles.

The urban drive cycle (FTP) simulates typical travel through a city with stops and acceleration changes, while the freeway drive cycle (HWFET) simulates smoother freeway travel and makes no complete stops until the end of the test. Figs. 1 and 2 show the velocity schedules for the FTP and HWFET drive cycles respectively, while Table 1 summarizes some of the test details. Also worth noting is that the FTP calls for a cold engine start. This is important as the engine typically operates at its highest efficiency after warming up (EPA, n.d. B).

1.2. Previous research

Rakha et al. developed the Virginia Tech Comprehensive Power-Based Fuel Consumption Model (Rakha et al., 2011). This model was produced in response to two problems found with other available fuel consumption models. The first is that