THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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CONSTANT-SPEED FUEL CONSUMPTION TESTING OF HEAVY-DUTY VEHICLES IN INDIA

As policymakers in India deliberate on how best to design a regulation to improve the efficiency of new heavy-duty vehicles (HDVs), one of the most critical issues is what test methods and duty cycles will be utilized to evaluate fuel efficiency performance. Ideally, a regulatory test procedure should test a vehicle, engine, or piece of equipment in a manner that closely matches the expected real-world conditions. That way, regulators, manufacturers, end-users, and society at large can have confidence that the efficiency measured over the regulatory test accurately reflects the efficiency of the vehicle in-use. It is the ICCT's position that an engine standard, coupled with a regulation promoting more fuel-efficient tires, will maximize fuel and emissions benefits most rapidly and put India on the best path forward.[1]

Another testing approach that is garnering attention in the regulatory discussions in India is constant-speed fuel consumption (CSFC) testing. As the name implies, in this test procedure the vehicle is driven on a test track at constant speed. Currently, a subset of HDVs in India is CSFC tested at 40 and 60 kilometers per hour (km/h) as part of the vehicle certification process. Given that this testing already happens and there is a certain familiarity with this procedure, it makes sense to consider CSFC testing to evaluate fuel efficiency performance of HDVs. However, CSFC testing has certain drawbacks: high cost, relatively poor test-to-test repeatability[2] compared to other methods, and inability to influence vehicle's efficiency performance over a wide range of operating conditions.

Simple vehicle simulations can indicate how a vehicle is actually being exercised in the CSFC test. To that end, ICCT analyzed a vehicle based on a popular medium-duty truck in the Indian market. The specifications of the truck are summarized in the following table.

Table 1: Vehicle characteristics for simulation example

Parameter	Description
Engine	Euro III, 5.9 liter, 100kW
Transmission	5 speed manual
Gross vehicle weight (curb weight + payload)	16,200 kg
Aerodynamic drag coefficient*	0.65
Frontal area*	5.9 m^2
Coefficient of rolling resistance*	0.008
Final drive ratio*	6

* Estimates based on manufacturer vehicle specification data and authors' best judgment

As the basis for analysis, we simulated this rigid truck twice: once at 40 km/h and once at 60 km/h. Figure 1 shows the percent of time that the engine spends at various points in its operating range. The time density occurrences are tightly concentrated around two points:

1 Sharpe (2015) Testing methods for heavy-duty vehicle fuel efficiency: trends from regulatory programs around the world and implications for India. http://www.theicct.org/hdv-efficiency-test-procedures-trends-implications-india. Ben Sharpe, "Why heavy-duty engine standards put India on the best path forward," 25 August 2015, http://www.theicct.org/blogs/staff/why-heavy-duty-engine-standards-put-india-best-path-forward

2 Track testing inherently has more test-to-test variability than laboratory-based methods. For reference, see: FPInnoavtions (2013) Testing and Verification Protocol for Engine and Vehicle After-market Devices. http://etvcanada.ca/wp-content/uploads/2013/08/Report-Protcol-EAMDs-Testing-and-Verification.pdf

140 radians per second and 284 newton meters (N-m) for the 40 km/h test and 209 radians/second and 273 N-m for the 60 km/h test. As can be seen, the CSFC test exercises the engine in a limited portion of the operating map. This is not a realistic representation of how vehicles are actually operated. Under normal driving, a vehicle will go through some combination of accelerations, decelerations, stops, starts, idling, and cruising at near-constant speeds. This mix of driving conditions results in varying power demands on the engine. If this truck were tested over a more realistic cycle, we would expect to see the engine spending time in a variety of different speed and load points on its operating map.

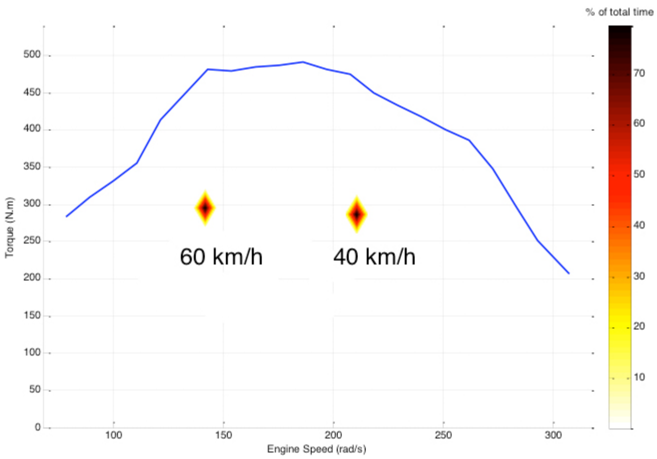

Figure 1: Time density plot for example Indian truck operating at 40 km/h and 60 km/h constant speed

To illustrate this point, we ran the same rigid truck over the Urban Dynamometer Driving Schedule (UDDS). The UDDS is meant to represent city driving for a HDV in the United States, and the speed versus time trace for this cycle is shown in Figure 2. Though the top speeds in the UDDS cycle (between 600 and 800 seconds) may be too high for typical vehicles in India, this example is meant to illustrate that transient testing does a good job of exercising the engine across a reasonable range of operating points, as shown in Figure 3. In the engine speed-load time density plot for this UDDS simulation shown in Figure 3, speed-load combinations extend from the lower left-hand corner (low speed, low load) all the way up to the upper limits of the torque curve and across a number of portions within the map as well.

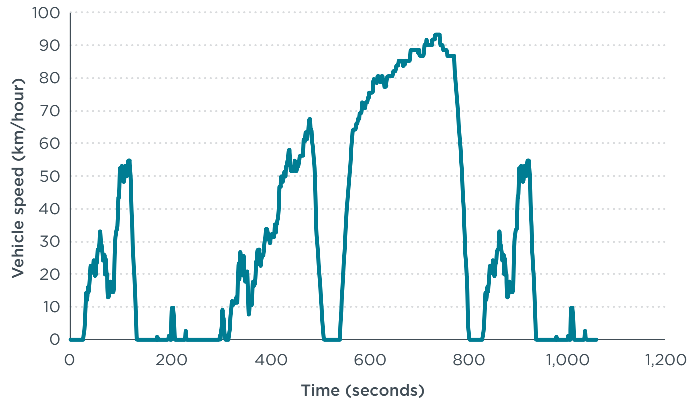

Figure 2: The speed-time trace for the UDDS cycle

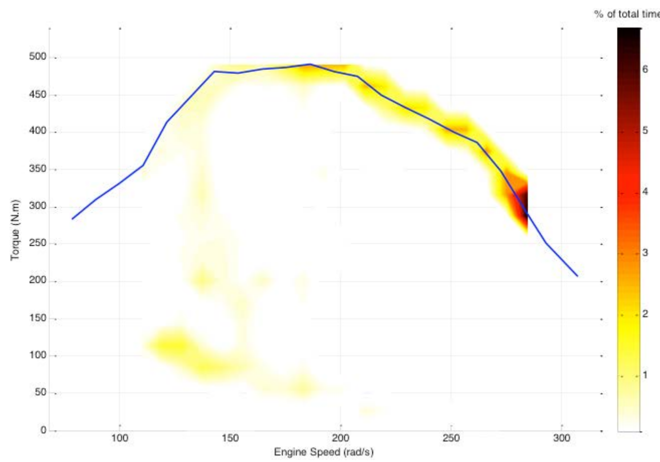

Figure 3: Time density plot for example Indian truck exercised over the Urban Dynamometer Driving Schedule (UDDS) cycle

The ability to test engines over a wide range of operating points is one of the strengths of an engine-based standard. There are transient engine cycles, such as the European Transient Cycle (ETC) and the World Harmonized Transient Cycle (WHTC), which are designed to represent demands on the engine in a vehicle operating in stop-and-go, urban driving conditions. The speed and load points for the WHTC are shown in Figure 4.

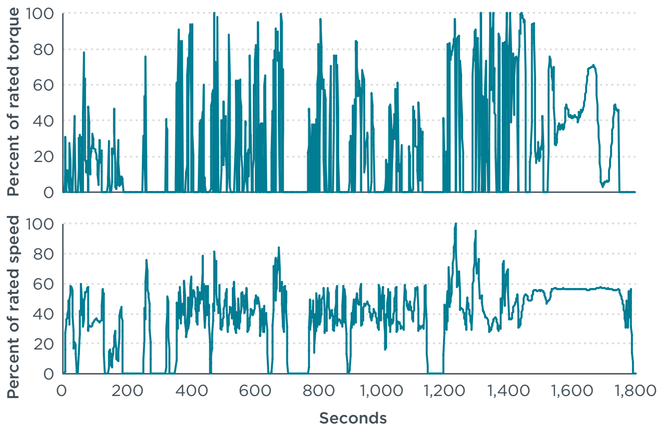

Figure 4: World Harmonized Transient Cycle (WHTC) for heavy-duty engines

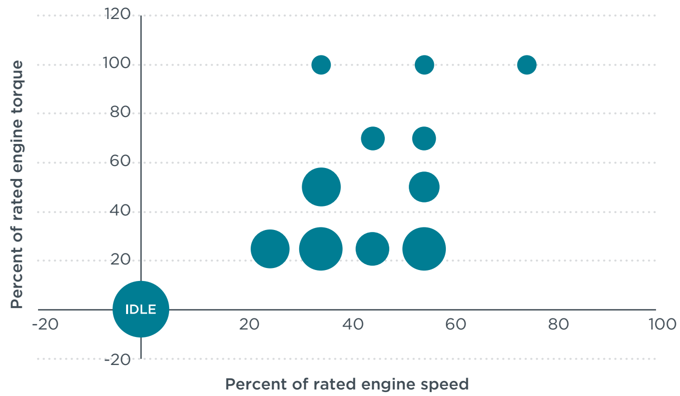

Figure 5: World Harmonized Stationary Cycle (WHSC) for heavy-duty engines

In addition, there are steady-state engine cycles that evaluate the engine at various speed-load points for long durations of time, as if the vehicle were cruising at a constant speed. Figure 5 shows the twelve test points for the World Harmonized Stationary Cycle (WHSC). The size of each of the bubbles represents the weighting factor given to each point in the overall calculated score for the cycle. In contrast to CSFC testing (Figure 1), which only captures one limited point on the engine map, the WHSC—or similar cycles such as the European Stationary Cycle (ESC) or the Supplemental Emission Test (SET)—evaluate the engine at numerous points to simulate the vehicle cruising at a variety of different speed and load conditions.

The overall goal of regulation should be to incentivize manufacturers to design their engines and vehicles to operate efficiently across the range of operating conditions that are typically encountered on the road (i.e., accelerating, decelerating, cruising, idling). Our analysis shows that CSFC testing only exercises the engine at a very tightly bound point on its operating map and does not capture any of the diversity of in-use driving. Engine dynamometer testing offers a more cost-effective and robust way to simulate a broad range of both steady-state and transient conditions.

Engine-based standards coupled with a tire efficiency regulation is ICCT's recommended approach for the first phase of India HDV efficiency standards. Nevertheless, even a CSFC-based efficiency standard, if it were established soon, would be preferable to a long delay in order to design a regulatory program centered around sophisticated vehicle simulation software, which will take many years to develop, validate, and implement.[3] Despite its downsides, efficiency improvements over the CSFC cycles will likely translate to real-world improvements.

3 The European Union, which has been developing a vehicle simulation tool for the past three years, still does not have a fixed date for when a HDV efficiency standard will be adopted. http://ec.europa.eu/clima/policies/transport/vehicles/heavy/index_en.htm