

Development of Representative Regional Delivery Drive Cycles for Heavy-Duty Truck Tractors

Jean-Baptiste Gallo
CALSTART, Inc.

ABSTRACT

Several drive cycles have been developed to describe heavy-duty class 8 truck tractor operations. However, regional delivery operations, consisting of a mix of urban and over-the-road driving using highways to access several delivery/pick-up sites in dense urban areas, have not been well described. With funding from the U.S. Army National Automotive Center, the High-efficiency Truck Users Forum (HTUF) developed two drive cycles in an effort to better describe the full range of Class 8 truck tractor operations, which in total consumed about 30 billion gallons of diesel in the United States in 2010.

This paper describes the rationale for and the process to develop two regional delivery drive cycles: HTUF Regional Delivery #1 and HTUF Regional Delivery #2. These cycles were developed from more than eight months of cumulative data collected on six diesel Class 8 truck tractors operating across North America and representing several types of truck vocations.

The HTUF Regional Delivery drive cycles fill an important gap in understanding and describing the full range of Class 8 truck tractor operations. They characterize regional delivery operations, which are not well described in previous drive cycle development efforts but which represents a meaningful segment of Class 8 truck tractor use. These two drive cycles allow for more effective evaluation of the fuel efficiency and emissions benefits of high-efficiency truck technologies and fuels in this growing segment, such as hybrid electric, plug-in hybrid electric and compressed or liquefied natural gas.

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INTRODUCTION

In the United States, highway vehicles are classified by weight according to eight different categories. At the highest end of the weight scale (Gross Vehicle Weight Rating (GVWR) > 26,001 lbs.) are class 7 and 8 trucks, considered heavy-duty vehicles. The denomination "heavy-duty" covers a wide variety of vehicle vocations: dump trucks, cement trucks, refuse or garbage trucks, transit buses, drayage trucks, beverage delivery vehicles, local delivery vehicles and over-the-road trucks. In 2010, there were over 2.5 million Class 7-8 truck tractors in the U.S. involved in a wide range of vehicle operations, such as drayage, over-the-road, and beverage, local and regional delivery. These trucks logged 175 billion miles and consumed about 30 billion gallons of diesel, representing over 66% of the fuel use for all medium and heavy-duty trucks in 2010 [1].

Therefore, Class 8 truck tractors represent an important target for high-efficiency truck technologies and fuels such as hybrid electric, plug-in hybrid electric and compressed or liquefied natural gas. However, these technologies and fuels are not suited for every truck vocation. For instance, hybrid electric

vehicles provide a higher fuel economy advantage over conventional diesel trucks in dense urban areas and drive cycles with a higher percentage of stops, while compressed natural gas trucks are more suited where natural gas fueling infrastructure can be made available and daily mileage can be maximized.

In order to assess the emissions and fuel economy of a medium or heavy-duty truck, the vehicle is often tested on a chassis dynamometer over a drive or duty cycle that is most representative of its real world use [3]. There are several drive/duty cycles available that describe heavy-duty vehicle operation and are applicable for chassis dynamometer testing:

- The EPA Urban Dynamometer Driving Schedule for heavy-duty vehicles was created in 1983 to represent heavy-duty driving in all US urban areas [4].
- The City Suburban Heavy Vehicle Cycle & Route was derived from two tractors fueled by LNG over six days of operation and 59.5 hours of data logging [4].

- The New York Composite Cycle is representative of actual driving patterns in New York City [5].
- The Heavy Heavy-Duty Diesel Truck schedule was derived from 84 heavy-duty trucks operating in California and involved in a wide range of vehicle activity [3].
- The HTUF Class 8 Urban Delivery Duty Cycle was developed from five beverage delivery truck tractors operating in the Los Angeles region [6].
- The West Virginia University 5-Peak Cycle was designed for general truck chassis testing [5].
- The Drayage Truck Chassis Dynamometer Test Cycle was developed for chassis dynamometer testing of drayage trucks serving the Port of Long Beach and Port of Los Angeles in California [7].
- The Yard Hostler Driving Schedule was developed for use in assessing the emissions and performance of yard hostlers in the Port of Long Beach in California [8].
- The Neighborhood Refuse Truck Cycle and New York City Refuse Driving Cycle were developed for chassis dynamometer testing of refuse trucks [5] [9].
- The Central Business District, Transit Coach Operating Duty Cycle, New York Bus, Manhattan Bus Cycle and Orange County Bus Cycle are chassis dynamometer tests that were based on data collected on urban transit buses [5].
- The Combined International Local and Commuter Cycle is used to evaluate and test the performance of Class 4-6 vehicles, including heavy-duty hybrid electric [10].

Although these drive/duty cycles cover a wide range of heavy-duty vehicle operations, no drive cycle currently exists that describe regional delivery operation of heavy-duty truck tractors. Regional delivery operation involves truck tractors usually based at one specific location and returning to the same location at the end of the work shift. Trucks operate in a mix of urban and over-the-road operations, using highways to access several delivery/pick-up points in urban areas. Given the steady drive for greater efficiency in the trucking sector, and rising competition with rail for longer truck routes, this segment is an increasingly important one for heavy-duty truck tractor use.

In 2010, a working group composed of several major North American Class 8 truck tractor fleets was created by the High-efficiency Truck Users Forum (HTUF). HTUF is a joint project of CALSTART and the U.S. Army National Automotive Center (NAC) to speed the commercialization of high-efficiency trucks such as hybrid electric vehicles. One of the first goals of the HTUF Class 8 Working Group was to better understand and characterize regional delivery operations of heavy-duty truck tractors.

In order to create drive cycles that would better represent regional delivery operation, we first reviewed the class 8 trucking industry to understand how class 8 truck tractors are generally used to help business needs and identify vocations where high-efficiency technologies would work best. Then we

selected six class 8 truck tractors among four different North American fleets representing truck vocations well suited for a successful introduction of high-efficiency technologies. All the trucks were instrumented with data acquisition systems for a period of approximately two months each to collect wide cross-section of route and vehicle data. Next, the data collected was processed and analyzed following standard drive/duty cycle development processes previously used to develop the Heavy Heavy-Duty Diesel Truck schedule [3], the HTUF Class 8 Urban Delivery Duty Cycle [6], the Drayage Truck Chassis Dynamometer Test Cycle [7], the Yard Hostler Driving Schedule [8] and the New York City Refuse Truck Duty Cycle [9]. Then, the analyzed data was combined to create two drive cycles that were assessed to be most representative of regional delivery operations. Lastly, the two drive cycles were compared to existing drive cycles currently used for heavy-duty truck tractor chassis dynamometer testing, to assess their relevance in the panel of heavy-duty drive/duty cycles currently available.

DESCRIPTION OF FLEETS OPERATION

The Class 8 trucking industry covers a wide range of truck operation and business activity. U.S. motor carriers are divided in two major segments: private carriers (representing 53.3% of U.S. motor carriers) and for-hire carriers (representing 31.9%). The remaining motor carriers are mostly owner-operators and owner-drivers [2].

Private carriers are “companies whose primary business is not hauling freight, but who own or lease a fleet in support of their primary business” [2]. Private carriers haul about 33% of total freight tonnage and about 48% of total truck freight tonnage in the US [11]. Among private carriers, food processing and distribution, beverage processing and distribution, wholesale/retail and oil and gas represent the largest sectors of activity. Most private carriers specialize in short-haul shipment, more suited for high-efficiency trucks. For instance, 75% of private fleet deliveries are less than 500 miles with an average haul of 71 miles [12]. Private carrier operation can be described by outbound (direct to customer, direct to distribution center and interplant) and inbound haul [13].

As part of this data collection activity, two tractors were logged in the private carrier segment (Table 1). These two tractors were operated by the largest private carrier in North America. They travelled through a representative range of private carrier operations, with both outbound and inbound operation covered widely, over the course of the several thousand miles of operation logged.

The other major segment, for-hire carriers are “motor carriers that offers freight transportation services to the public” [2]. For-hire carriers haul about 36% of total freight tonnage and about 52% of total truck freight tonnage in the US [11]. For-hire comprises several segments of operation: truckload or TL, less than truckload or LTL and hazardous materials and specialized carriers.

Table 1. Local fleets description

	Fleet 1	Fleet 2	Fleet 3	Fleet 4
State, Country	California, USA	California, USA	Texas, USA	Ontario, Canada
Main Region of Operation	Southern California	Inland Empire	Dallas / Fort Worth	Greater Toronto Area
Carrier Type	Private	Private	For-Hire	For-Hire
Type of Operation	Food Processing & Distribution	Beverage Processing & Distribution	Regional & National Less Than Truckload	Regional & Interregional Less Than Truckload

Several segments were not selected for assessment because their operations were not identified as good first targets for high-efficiency technologies and fuels. Two of those segments were hazardous materials and specialized carriers, which cover a wide variety of specialized activity and truck configuration.

Another segment not selected for assessment was TL, which generally hauls a single shipment, usually between 10,000 and 48,000 lbs. from shipper to customer [12]. Truck operation is generally characterized by longer hauls (usually requiring the use of sleeper cabs), higher average speed and lower number of stops since the truck is serving only one customer per haul. LTL carriers “aggregate smaller shipments from multiple shippers and transport goods to their final destinations by organizing and sometimes reorganizing shipments at terminals as the freight progresses to final destination”. LTL shipments vary widely between 50 and 48,000 lbs. but are generally below 10,000 lbs. [12]. LTL vehicles come mostly in day cab configuration since the shipments they transport travel from customers to terminals where the vehicles return each day. In addition, LTL vehicles can be found in single axle configuration since the shipments are generally below 10,000 lbs. LTL is further separated by different areas of operation: national LTL (average length of haul is 1,200 miles), interregional LTL (average length of haul is 400-750 miles) and regional LTL (average length of haul is less than 300 miles) [14].

As part of this data collection activity, four tractors were logged in the LTL carrier segment (Table 1). These four tractors were operated by two major for-hire carriers in North America. Across the several thousands of miles that they travelled, analysis showed that these four tractors covered a representative range of LTL carrier operations, with both regional and interregional LTL operation covered widely.

Figure 1 below shows the different motor carrier categories and further breaks down the three motor carrier categories in vehicle vocations. The green boxes represent motor carrier categories and vehicle vocations where data was collected for this effort.

Although this data collection activity leaves out important truck vocations, it covers a representative part of the private carrier and LTL segments, which has been identified as a good target for high-efficiency technology because of favorable drive cycles and truck configuration. We estimated that among the top 100 private carriers, about 100,000 tractors and among the top 100

for-hire carriers, about 90,000 tractors were used in 2011 in truck vocations where high-efficiency technologies held the most promise for success [15] [16].

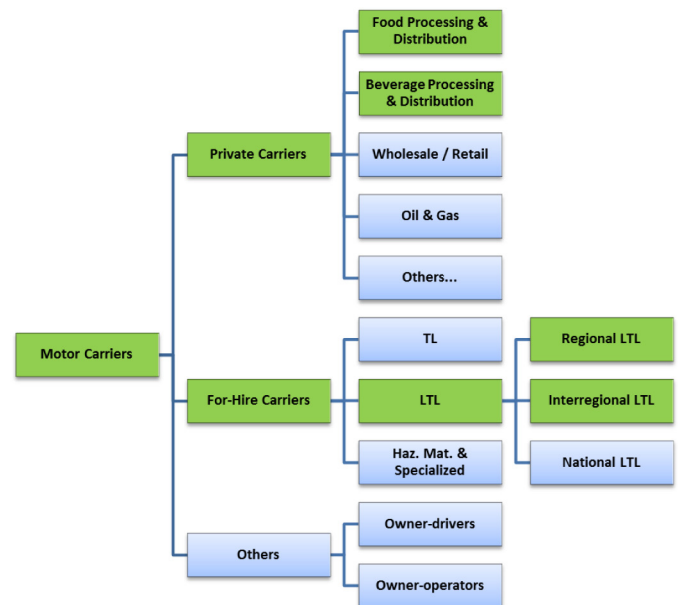


Figure 1. Description of motor carriers by vehicle vocation

DESCRIPTION OF SELECTED VEHICLES

Engine data was collected from six class 8 truck tractors selected among four motor carriers and their respective local fleets (Table 2). The trucks were selected with the assistance of local fleet managers who were asked to identify units with low average speeds and high number of stops, a good target for high-efficiency truck driveline technology such as hybrid electric vehicles.

On some occasions, vehicles selected by the fleet managers had to be replaced by different vehicles that could better accommodate the collection of CAN bus data. Therefore, newer models were preferred and a particular engine manufacturer had to be avoided. The six truck tractors represent three major truck manufacturers and two major engine manufacturers (Figure 2). Engine power ratings ranged from 385 to 425 hp and Gross Vehicle Weight Ratings (GVWR) ranged from 32,000 to 52,000 lbs. Three trucks were equipped with manual transmissions and three with automatic transmissions. Lastly, three trucks were in single axle configuration and three in tandem axle configuration.



Figure 2. A single axle, day cab class 8 truck tractor

Table 2. Tractors description

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Fleet	Fleet 1	Fleet 2	Fleet 3	Fleet 3	Fleet 4	Fleet 4
Chassis Manufacturer	Volvo Trucks N.A.	International	Volvo Trucks N.A	Kenworth	International	International
Model Year	2008	2010	2008	2009	2006	2006
Model	VNM	TranStar 8600 SBA	VNM	T800	TranStar 8600 SBA	TranStar 8600 SBA
Engine Manufacturer	Volvo	Cummins	Cummins	Cummins	Cummins	Cummins
Engine Model	D13-425/1550	ISM10.8 425	ISX11.9 400 ST	ISX11.9 400 ST	ISM10.8 385	ISM10.8 385
Engine Capacity	L6, 12.8L	L6, 10.8L	L6, 11.9L	L6, 11.9L	L6, 10.8L	L6, 10.8L
Power Rating	425 hp	425 hp	400 hp	400 hp	385 hp	385 hp
Torque Rating	1,550 lbs.-ft. @ 1,050 rpm	1,550 lbs.-ft. @ 1,200 rpm	1,450 lbs.-ft. @ 1,200 rpm	1,450 lbs.-ft. @ 1,200 rpm	1,450 lbs.-ft. @ 1,200 rpm	1,450 lbs.-ft. @ 1,200 rpm
Drive Line	4x2	6X4	4x2	4x2	6X4	6X4
Transmission	10 speed manual	Automatic	10 speed manual	10 speed manual	Automatic	Automatic
GVWR	32,350 lbs	52,000 lbs	32,000 lbs	34,700 lbs	52,000 lbs	52,000 lbs

The vehicles pulled a wide variety of trailer configurations: from 24 to 53-foot trailers, with single or 2-axle configurations. Some vehicles also used a double trailer configuration, pulling two 28-foot trailers, with a Gross Combination Weight Rating reaching close to 80,000 lbs. Vehicle loading varied between trucks and business lines. Unit 1 delivered food products and payload ranged from 9,000 to 14,000 lbs. On the other hand, unit 2 delivered beverages with payload ranging from 22,000 to 33,000 lbs. Units 3, 4, 5 and 6 were involved in LTL operation with weight ranging from 5 to 25,000 lbs. per delivery or pickup.

DATA COLLECTION

Vehicle data was collected using ISAAC Instruments data recorders connected to the vehicle CAN bus. Table 3 describes the specifications of the data loggers that were used and Figure 3 shows a sample of the ISAAC Instruments product line.



Figure 3. Isaac Instruments sample product line

The data recorders were mounted behind or next to the driver's seat (Figure 4), with the cables and connectors running behind the seat and under the sill plate to reach the truck J1939 outlet (Figure 5). In addition, a GPS receiver with integrated antenna and a cellular network transceiver were mounted on the lower left corner of the windshield (Figure 4). Prior to collecting in-use