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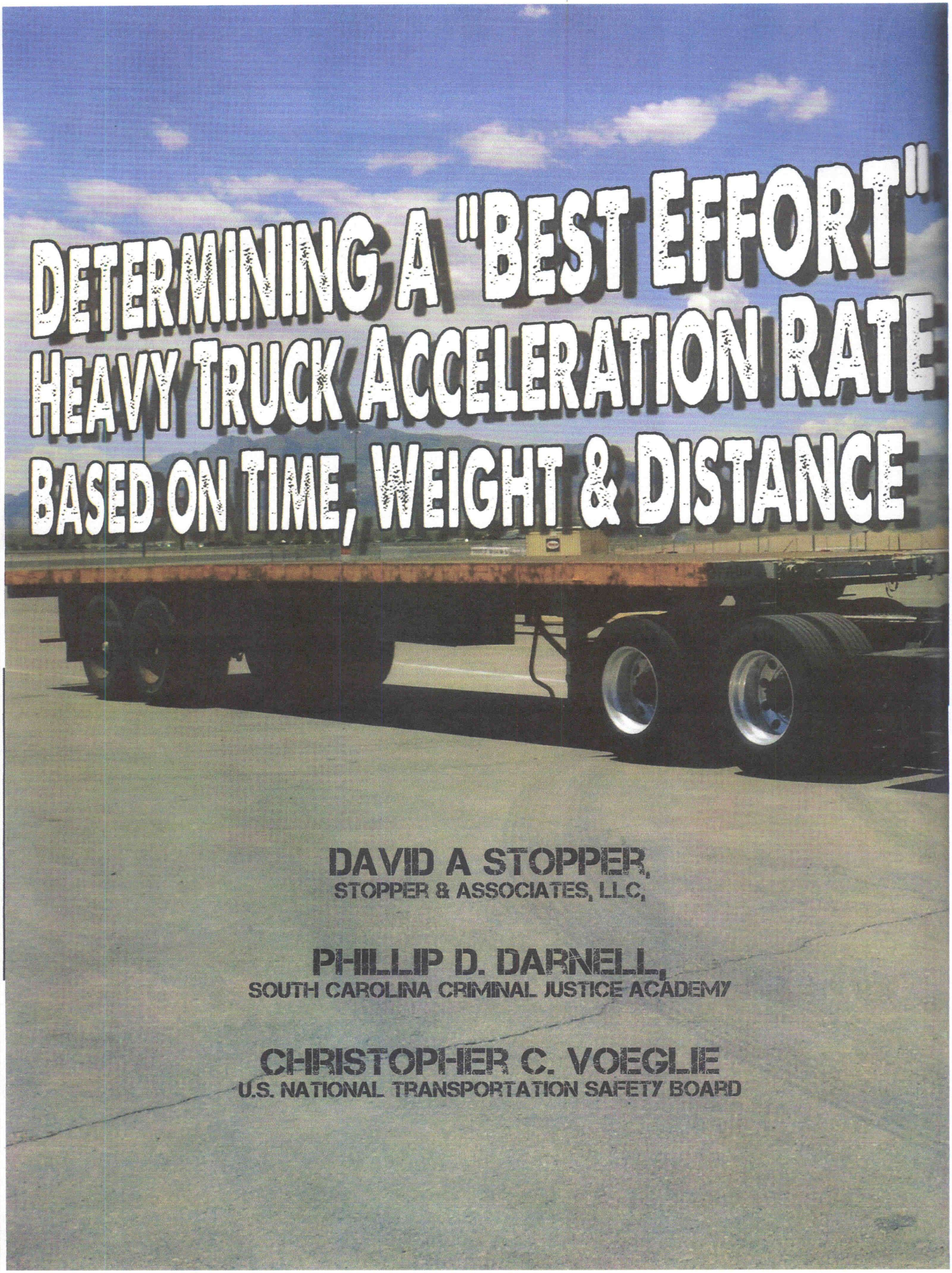

Determining a "Best Effort" Heavy Truck Acceleration Rate Based on Time, Weight & Distance

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Abstract

Many Commercial Motor Vehicle (CMV) incidents and collisions involve developing a reasonable or supportable time for truck tractor semi-trailer combinations to execute turns, cross traffic lanes, or clear intersections during traffic light sequences. This becomes a more critical issue with the ever increasing length of these combination vehicles. Although the most common length of semi-trailer today is 53 feet; there are 57 - 60 foot semi-trailers being used in a growing number of states. This combined with truck tractors with extended wheelbases used to accommodate larger sleeper berths, results in combinations that can reach lengths of over 70 feet. Calculating the acceleration rate of these combination vehicles can play a critical role in conducting a time-distance analysis.

Introduction

Truck engines have evolved significantly since the early 1990's. Modern trucks utilized high torque, low rpm engines to achieve increased life, fuel efficiency and EPA compliance. Typical governed engine speeds have dropped from approximately 2100 rpm to 1600 rpm. Fuel consumption is significantly improved and operating gear range is reduced. "The high level of torque provides better starting and acceleration with excellent gradeability at more fuel efficient engine speeds." [1]

There are various sources of empirical data available to the traffic investigator when considering or developing an acceleration rate for a heavy truck. Additional rates or calculations have been based upon power to weight ratios and testing based on legacy vehicles,[2] computer simulations[3] or tables published by various traffic accident reconstruction manuals.

Because heavy truck acceleration performance is a required consideration during the engineering and design of acceleration or climbing lanes, as well as when considering intersection sight distances, many State highway engineering manuals, the AASHTO Green Book and numerous TRB publications provide various insights to heavy truck acceleration rates.

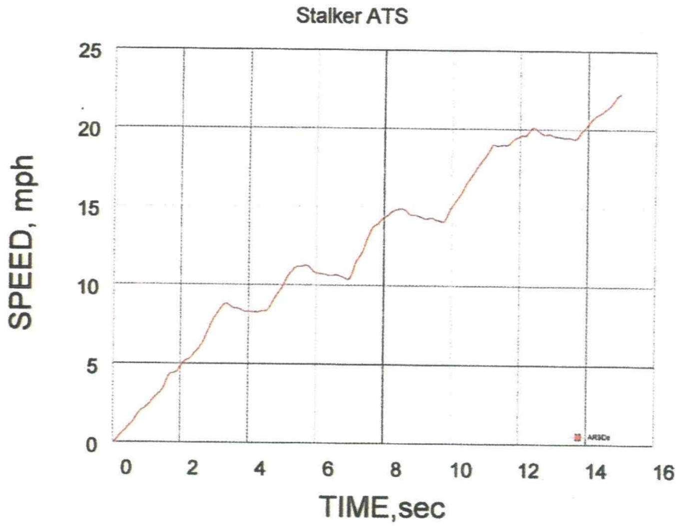

Figure 1

The NWUTI Reconstruction manual provides minimal information regarding medium and heavy truck acceleration rates other than a table of suggested values. The suggested acceleration rates are based on vehicle speed. For example the suggested acceleration values for a loaded heavy truck traveling less than 20-mph is 1.6f/s/s (0.049g), for speeds between 20 and 40 mph the suggested rate is 1.0f/s/s (0.031g) and over 40 mph is 0.03f/s/s (0.0009g).

While these values and methods provide generic values, most available data failed to provide a situationally appropriate, or accurately represent the current advances and variations in today's CMV drive-trains and thus acceleration rates for a given distance at a given weight. Current high torque low rpm CMVs, at lower speeds, experience short bursts of acceleration followed by a brief period of negative acceleration due to gear changes as well as rolling resistance of weight (Figure 1). Heavy CMV driver's rarely use 1st gear when starting in traffic, unless on a grade and under a very heavy load. When empty, they may start in 3rd to 5th gear. Manufacturers' instruction manuals instruct drivers to select a gear that will begin to move the truck from an idle. As the truck begins to move the accelerator while shifting progressively through the gears.

The method for acquisition of the acceleration runs differed to a large degree from most previous methods where speed or time was measured over a given distance from the stopped position, typically 25', 50', 100' or greater distances, and averaged. Through the use of the Stalker® ATS RADAR, continuous data was acquired during the acceleration runs without the need to install instruments on the subject vehicles. The data clearly showed a distinctive "stair step" graphing was acquired identifying shift changes as well as smaller distance increments which could be isolated and recorded on each graph. During accelerations at the time of shifting, the trucks typically experienced no acceleration and sometimes a loss of acceleration from parasitic drag for up to one full second. (Figure 1)

The authors endeavored to collect sufficient data to develop viable acceleration rates which involved many of the factors often missing from the available data sources. The authors wanted to collect acceleration data from a stop, for a known engine and transmission configuration, with a valid total vehicle weight, and with a driver's "best effort" attempt to accelerate as fast as the vehicle was capable. Documenting 12, 24 and 36 ft acceleration rates, as well as the 50, 100 and 200 ft distances, would give a better understanding of how current CMVs could cross travel lanes or enter a roadway and attempt to come up to speed. This resulted in a collection of data not otherwise available within a single source document.

The purpose of this testing was to secure a statistically sufficient sampling of loaded and un-loaded CMVs including truck tractor semi-trailer combinations to provide for a more specific and categorized reference.

The tests were conducted as a cooperative effort between the authors, the South Carolina Criminal Justice Academy and in coordination with the South Carolina State Transport Police.

The tests were conducted in April of 2010, at a fixed scale weigh station along Interstate 26 in South Carolina. The test facility was equipped with a Weigh In Motion (WIM) system as well as a fixed scale. The location was chosen for several reasons including the size and layout of the facility, the number of CMVs traveling through the facility as well as the length and 0%-grade of the acceleration lane as the vehicles exit the scales.

Methodology

The tests were conducted utilizing random selection of CMVs as they passed through the facility. As CMVs passed through the WIM, vehicles were directed to the static scales. Once located on the scales, the driver was interviewed in an effort to obtain information as to the engine manufacturer, horse power and transmission type. The selected vehicle was weighed, and a weight ticket was generated for each CMV tested. The driver was then requested to give "best effort" acceleration from a stop until they passed the data collection station approximately 250 feet ahead.

Various data points were collected for each CMV. Acceleration data was collected utilizing a tripod mounted Stalker® RADAR ATS (Acceleration Tracking System). The Stalker® ATS was located approximately 250 feet from the start point. In addition, two cameras were used to document acceleration runs. The first camera was located perpendicular to the test

vehicle and recorded the first 36 feet of the runs. The additional camera was located at the data collection station facing the test vehicle and recorded the entire length of acceleration runs. Orange 28" traffic cones were placed every 12 feet to provide visual reference points within the video and still photography.

A total of 167 acceleration runs were recorded. The vehicles were grouped into seven weight categories for analysis.

- less than 30,000 lbs,
- 30,000-40,000 pounds
- 40,000-50,000 pounds
- 50,000-60,000 pounds
- 60,000-70,000 pounds
- 70,000-80,000 pounds
- 80,000 pounds and over

Test Results/Analysis

Each of the 167 data sets was examined and 118 of the runs were validated as viable.[4] The resultant data from each run was analyzed in segments. Each run was analyzed from the "Start to 96'" distance in 12' increments. The 12' increments were chosen to represent the width of a typical traffic lane. The 96' distance and the 12' increments were chosen to represent a CMV crossing lanes of travel as it pulls into a roadway or as it starts to proceed across an intersection. Data sets were also selected from the start to 150' and 200' distances to determine the acceleration of a heavy vehicle attempting enter the flow of traffic.

30,000lbs or Less

The group of CMVs weighing 30,000 pounds or less consisted of a variety of different types of vehicles. Some of the vehicles that fell into this category were straight box trucks, bobtail tractors, and unladen truck tractor semi-trailer combinations. These vehicles achieved an average acceleration factor of 0.14g over the first 12' and 24' intervals. Typically there was no gear changes observed during the first 12 feet. The first gear change typically occurred between the 24' and 36' marks. This resulted in the observed higher acceleration factors for the first 24 feet.

CMV transmissions are geared for torque in the lower gears to aid in starting with heavy loads. This results in the quicker initial acceleration, but the gear tops the engine's governed rpm rather quickly. As the vehicle gains momentum, the progressive gear changes have a higher gear ratio resulting in less torque; therefore, the acceleration rate is reduced over time and distance. As expected, the acceleration factor decreased the further the vehicle traveled. The average 200' acceleration factor for this group from the start was 0.10g. See Table 1 for average data for all groups and distances.

30,000-40,000lbs

Analysis of the 30,000 – 40,000 pound group showed how the increased load began to affect acceleration. The addition of an average of almost 13,000 pounds resulted in an acceleration factor of 0.12g for the first 12 feet. The average acceleration factor for the first 24 feet was 0.10g. The first gear change continued to occur between the 24 and 36 foot mark. The overall acceleration factor out to 150' and 200' had dropped to 0.07g.

This trend continued through the remaining weight groups; however, there were some runs that effectively lowered the resultant averages.

A few drivers either missed a shift or shifted significantly slower than that of the entire group. Figure 2 shows an example of a slow shift at the beginning of the run. In addition to eliminating "rolling starts", several runs were considered invalid for the study due to driver distraction or those clearly unwilling to make a "Best effort" acceleration. Outside of those rare instances, the variations could be attributed to driver experience and vehicle condition. There were outliers on the higher

Weight	Average g									
Category / Wavg	12ft	24ft	36ft	48ft	60ft	72ft	84ft	96ft	150ft	200ft
< 30,000 lbs / 22201 lbs	0.14	0.14	0.13	0.12	0.11	0.12	0.12	0.11	0.10	0.10
30k-40k lbs / 35196 lbs	0.12	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.07	0.07
40k-50k lbs / 45216 lbs	0.09	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.06
50k -60k lbs / 55228	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
60k -70k lbs / 65026	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05
70k-80k lbs / 75992	0.08	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
80k + / 108066 lbs	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.04	0.05	0.04
All Runs Combined / 51075 lbs	0.10	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06

Table 1

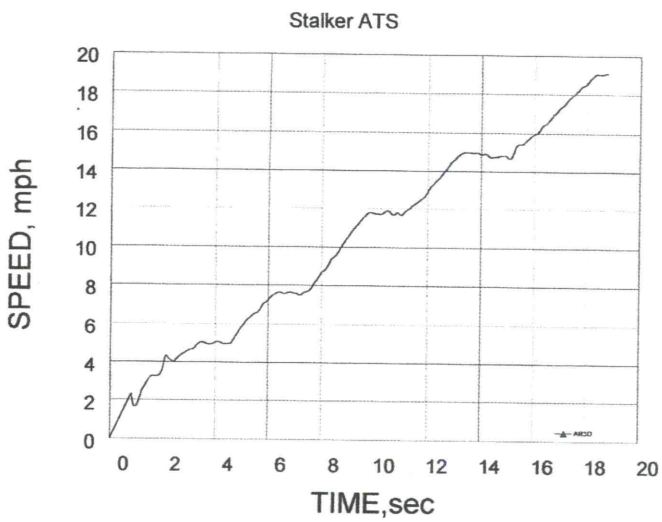

Figure 2

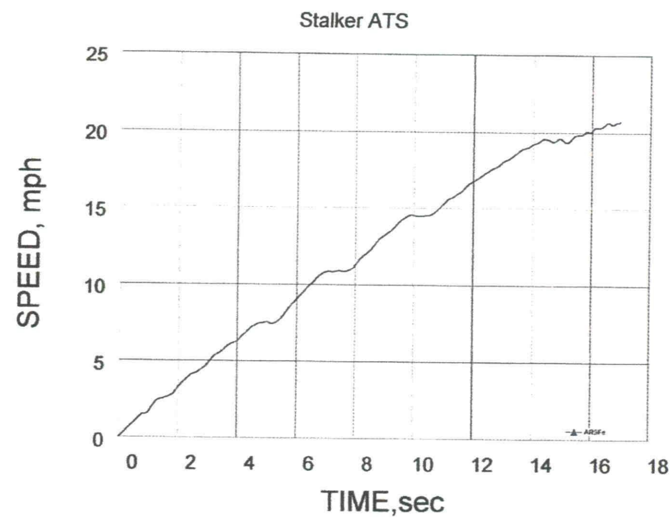

Figure 3

acceleration end that were due to drivers making extremely smooth shifts in CMVs that were more heavily laden. It was determined that in both of the previous examples, that these runs were not considered as invalid, but were viewed as validating the intended "real world" variable of the study.

Discussion

The data was compiled utilizing MS Excel spreadsheet to calculate the acceleration factors. The spreadsheet was designed to round as opposed to truncating the calculations; therefore, the calculations were carried out to the ten-thousandth and then truncated prior to being entered into the tables. It was done in an effort to protect the majority of the data. However, it resulted in a minor difference of the average of all the runs between 150' and 200' feet. The observed difference was that of 0.003g, while standard truncation resulted in 0.07g and 0.06g respectively.

The data was also analyzed from 96 – 200 feet. The average acceleration factor for all of the runs was 0.01g. The highest acceleration factor for set 0.0448g, and the lowest was 0.0038g. There was no correlation between weight, transmission, or vehicle type that was apparent to the authors. This indicates that current CMV transmissions, while able to achieve a substantial initial acceleration rate, cannot accelerate very rapidly once in motion.

The other significant notation should be that in the category of CMVs weighing 80,000 pounds or greater contained only three vehicles. They weighed 80,040, 112,400, and 131,040 pounds. The driver of the 131,040 pound vehicle performed one of the more memorable runs. It was evident to the test team that this was an experienced and skillful driver, as he was extremely smooth through the gears. This specific run is shown in Figure 3.

Smart Shift & Auto Shift Transmissions

Besides weight, an additional sub-category was identified; that was selecting all of the CMVs that were equipped with "Auto Shift" transmissions. Unlike automobile automatic transmissions that typically maintain a light drive train engagement, even at an idle, the heavy truck automatic transmissions shift to a full neutral position when stopped. Manufacturers caution drivers in this regard due to the possibility of backward roll even when the automatic transmission is engaged.

There are two typical heavy truck "Smart Shift" and "Auto Shift" styles. One model still has a clutch but is only used to place the truck tractor in motion. The second style has no clutch and engages as the driver presses on the electronic accelerator pedal. Once in motion, the engine and transmission ECMs monitor engine RPM's and load, resulting in optimum shifting. The transmission operates and shifts in the same manner as a manual transmission. The driver experiences the feel of full shifting but can maintain both hands on the steering wheel and has little need to monitor engine speed.

The "Smart Shift" and "Auto Shift" models allow the driver to switch between manual mode and auto shift mode with the vehicle in motion. A slide switch on the shifter is used to control the manual / auto modes. Progressive manual shifting is controlled by lifting up or pushing down the control arm. On acceleration, the manual mode will hold in the selected gear until the next gear is manually selected.

Similar to a manual heavy truck transmission, downshifting from highway speed will only allow selection of a gear within proper engine RPM range. It is important for a "Smart Shift"/ "Auto Shift" driver to switch to manual mode and select a proper gear before descending steep grades. The "Smart Shift"/ "Auto Shift" will continue to up shift or maintain top gear while descending a steep grade and can accelerate well beyond the governed maximum RPM.

As expected, this category performed better than the traditional manual transmissions. The automatic

Average g for Automatic Transmissions

12ft	24ft	36ft	48ft	60ft	72ft	84ft	96ft	150ft	200ft
0.13	0.12	0.11	0.10	0.09	0.09	0.09	0.09	0.08	0.08

Table 2

transmissions were able to achieve an acceleration factor of 0.13g through the first 12' regardless of vehicle weight. The acceleration factor between the 12' reading and the 200' reading showed a reduction of 0.05g same as that of the manual transmissions. In comparison, the 10 speed transmission averaged a 0.10g for the first 12' and 0.06g for the 200' mark. This was a drop of 0.04g for the entire run.

Due to the growing popularity of "Auto Shift" transmissions in heavy commercial motor vehicles the authors provide this data with the understanding and caution of the limited number of AutoShift samples presented.

Conclusion

The purpose of this testing was to secure a statistically significant sampling of loaded and un-loaded truck tractor semi-trailer acceleration rates given "best effort" accelerations typical of a truck tractor and semi trailer entering traffic. It was the intent of this study to provide a "real world" range of values that the Traffic Investigator can apply with a reasonable degree of certainty. The data indicates that current heavy commercial motor vehicles will typically accelerate quicker during the beginning of acceleration where applying an average value for a longer distance may not be applicable.

Drivers were requested to give a best effort acceleration to replicate a driver intending to clear an intersection or enter traffic as quickly as the vehicle would allow. The vast majority were happy to comply and exhibit their shifting skill. The authors intend to conduct follow up non-alerted acceleration testing. We intend to set up the Stalker® RADAR inside the scale facility, with the antenna monitoring acceleration from the vehicle's rear. We will be able to record weight data but would not gather the engine or transmission data. The authors do not see this as a problem since we did not see a significant difference in that category, except for automatic transmissions during the first 12' to 24' feet of the run.

Related Reading

Motor Truck Engineering Handbook, J. W, Fitch, Society of Automotive Engineers, Warrendale, PA, 1994

Traffic Accident Reconstruction, L.B. Fricke, Northwestern University Traffic Institute, Evanston, IL, 1990

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"JJ" Soto-Diaz - Stopper & Assoc., LLC

References

1 Motor Truck Engineering Handbook, J. W, Fitch, Society of Automotive Engineers, Warrendale, PA, 1994

2 Loaded heavy trucks (60,000 – 80,000 lbs) the power/weight ratio of 0.004 hp/lb – 1988 UMTRI Mechanics of Heavy Duty Trucks.

3 NWUTI Traffic Accident Reconstruction, First Edition, page 78-14

4 Each data set was carefully examined. Although all of the 167 acceleration runs resulted in viable data, the authors strived to reject any potential variants. The only variants observed were those of human error coordinating the start of the recording equipment. This resulted in some rolling starts and although the recorded acceleration data was considered valid, runs which did not indicated a stationary start were excluded.

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