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Two Phase Heavy Truck Acceleration Model

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Abstract

There have been several papers published over the past 25 years regarding the acceleration of heavy trucks, including different loading conditions, drivetrain configurations, and driving techniques. The papers provide a large data set that measures the speed, distance, and time of the vehicles during acceleration testing and present the data in tabular or graphical formats. Although the data as presented can be useful, it can be challenging to pore over all the data to determine the correct set for a specific application in accident reconstruction. As of this paper's date of publication, there are approximately eight relevant papers with a total of 268 acceleration tests performed, spanning many years. This paper reviews all the available published literature and summarizes the relevant data in a comprehensive list of accelerations for different heavy truck configurations, which provides a valuable resource to the accident reconstruction field.

Introduction

This paper intends to summarize and analyze available heavy truck acceleration testing research and develop a tool for estimating heavy truck speeds over time when accelerating from a stop. Heavy trucks are not capable of acceleration values normally seen with passenger vehicles for several reasons, including but not limited to higher gross vehicle weights and gearing limitations. However, current published literature does not provide more than a basic guideline for estimating heavy truck acceleration unless the truck's features and loading configuration are thoroughly identified. It is common in accident reconstruction to have limited information on a vehicle's features and capabilities beyond what a vehicle identification number provides. Heavy trucks have significantly more variation in equipment features and inertial parameters than passenger vehicles, especially relating to gross vehicle weight. These variations can have significant effects on acceleration capabilities, as shown in the following reviewed published literature. However, upon review of the totality of data available through this literature, some trends are present that can assist in estimating heavy truck acceleration for accident reconstruction purposes.

The most detailed and comprehensive source of data for heavy truck acceleration has been provided through literature publishing results of testing performed by Wesley Grimes. Mr. Grimes has been performing heavy truck acceleration testing with a wide variety of tractor brands and features, along with set variations of loading configurations, for over two decades. His research provides the field of accident reconstruction with a wide range of test data for various heavy truck manufacturers' tractors, loading configurations, and even driving styles. Mr. Grimes performed his testing using similar testing methodology in each of his publications, which produced repeatable and consistent results throughout his body of testing. Table 1 summarizes Grimes' test vehicles from six SAE publications [1,2,3,4,5,6].

In addition to the variations in tractor configurations, including engine, transmission, and axle ratio differences, Mr. Grimes also varied the loading of the tractor during testing by hauling either no trailer or trailers with varying payloads. Furthermore, in each series of testing, the tractor driver

TABLE 1 Grimes SAE publications test vehicles summary

SAE Paper No.	Tractor Year, Make & Model	Transmission	Axle Ratio	Trailer
950136	1991 Kenworth T600 / 1994 Kenworth T600	Eaton-Fuller 9-speed MT (1991) 10-speed MT (1994)	3.55 (1991) 3.70 (1994)	48 ft
980366	1994 Kenworth T600B	Eaton-Fuller 9-speed MT	3.55	53 ft
1999-01-0092	1995 Freightliner FLD-120	Eaton-Fuller 10-speed MT	3.73	48 ft
2000-01-0470	2000 Kenworth T2000	Eaton Auto-Shift 10-speed automated manual	3.70	53 ft
2017-01-1418	2016 Kenworth T680	Eaton-Fuller Advantage 10-speed automated manual	2.64	53 ft
2017-01-1426	2016 Freightliner Cascadia	Detroit DT12 12-speed automated manual	2.41	53 ft

utilized alternating driving and/or shifting styles to study the effect of varying driver input on heavy truck acceleration. All these variables were tested over a series of runs with each tractor, loading configuration, and driving style. Test results were recorded by measuring time, speed, and acceleration over a specified distance traveled; test results were published in both tabular and graphical formats. Mr. Grimes' testing produced a rich data set that provides valuable information to the accident reconstruction field.

A 2010 SAE publication on tractor-trailer left turns and lane changes, written by Raymond Merala and Kirsten White, provides acceleration data from video tracking of left turning tractor-trailers [7]. Time and distance data was collected utilizing video footage of turning heavy trucks driving over marks placed on the pavement for tracking purposes. In contrast to Grimes' testing of straight line acceleration, this paper analyzed tractor-trailers performing left turns from a stop through an intersection. The observed turns were classified by turn length and radius along three paths: a short turn (length 50 feet, radius approximately 32 feet), a medium turn (length 60 feet, radius approximately 38 feet) and a wide turn (length 70 feet, radius approximately 45 feet). The only vehicles included in the left turn study were combination vehicles (tractor hauling a semi-trailer), however neither tractor configurations nor payloads were recorded. Results were provided in graphical format, from which data was extracted for analysis purposes.

A 2012 SAE paper, written by Kerry Drew, Sebastian Van Nooten, and Jeffrey Gervais, published testing data for acceleration of tractors equipped with automated transmissions [8]. The testing was performed in the same style as Mr. Grimes' papers, utilizing two tractor configurations tested with two trailer payload configurations and normal and rapid acceleration driving styles. Table 2 summarizes the test vehicles for this paper.

Test results were recorded using a Racelogic VBOX data acquisition system and published in tabular and graphical format.

Several publications were reviewed by the authors but were not included in the data summary and analysis, with varying reasons for exclusion. Gary Long's publication, "Acceleration of Starting Vehicles," was excluded due to containing outdated information from testing performed prior to 1980, and it also comprises reviews of other testing, as opposed to performing testing for the publication [9]. Woodrow Poplin's paper, "Acceleration of Heavy Trucks," was not used because the publication was not subjected to a peer review process [10]. Bellavigna and Gou published a paper investigating vehicle acceleration as it relates to railway crossings; however the data was not provided in a format where it could be extracted per each vehicle or test surface and was not usable in this analysis [11]. SAE publications from James English in 2010 and 2012 were reviewed for acceleration data, but the vehicle types tested are not applicable to this paper's tractor-trailer data analysis [12,13]. Similar to English's papers, Charles Funk's 2012 SAE publication was not used because the test vehicles were not tractor-trailers [14]. A publication from Mehar for European Transport was excluded because only part of the data was relevant to heavy truck acceleration, and the data was not presented in a format where it could be obtained and analyzed [15]. An article in the International Journal of Science and Technology by Yang, et al., was not used because the data was not presented in a manner that allowed extraction and analysis of the heavy truck acceleration data [16]. Finally, an article presented at the 2016 World Conference on Transportation Research by Bokare and Maurya was excluded because the presented data did not include time and therefore could not be combined with the database [17].

The data presented in the selected papers was combined into a single database, including all test runs from every paper, if applicable. This paper reviews data handling required to compare all data sets, presents normalized data including averages of similar configurations, and develops methodology for calculation of heavy truck acceleration for use in the accident reconstruction field.

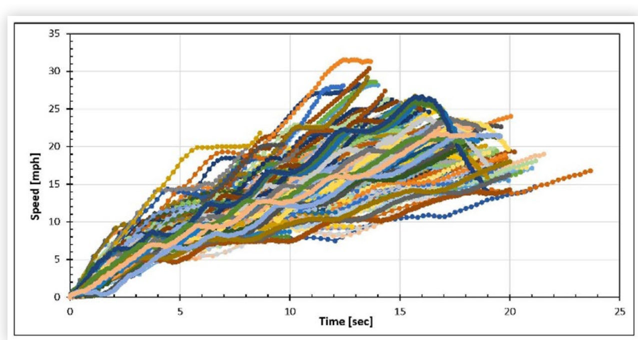
TABLE 2 SAE publication 2012-01-0597 test vehicles summary

SAE Paper No.	Tractor Year, Make & Model	Transmission	Axle Ratio	Trailer
2012-01-0597	2011 Freightliner Cascadia	Eaton-Fuller Autoshift 10-speed automated manual	3.41	53 ft
	2007 Volvo VNL	Eaton-Fuller Autoshift 10-speed automated manual	3.73	53 ft

Data Compilation

The selected heavy truck acceleration publications presented data in either tabular or graphical formats, or both. This data was extracted in its original form from each paper and inserted into a combined database created in Microsoft Excel. All tests recorded time, distance, and speed, and some included measured acceleration data as well. For those that did not include all four measurements, the missing data could be calculated from the provided data using integration over the sample rate of data collection. This compilation resulted in a completed database including time, distance, speed, and acceleration data for each test run from every publication. Figure 1 shows a chart of all individual test runs from the

FIGURE 1 All compiled averaged test runs (speed vs. time)



eight selected papers that were analyzed in this publication, with speed plotted over time.

As seen in the above chart, all the test data for heavy truck acceleration spans up to 24 seconds of recorded data, and final recorded speed varies from approximately 14-32 mph at the end of the test runs. Test runs where acceleration was performed in only a single gear were not considered because gearing limitations stopped acceleration. The data for these test runs was included in the database for the sake of completeness, but these runs were not utilized in the analysis presented in this paper. While this presentation of the totality of the data appears difficult to manage or analyze, the data can be broken down into categories and analysis can be performed using averaged data from each identical set of test runs.

Data Averaging

Heavy truck acceleration data was extracted from many sources with different data collection methods, and in order to accurately compare all the data sets each paper's data were averaged and normalized according to a time scale. All the data sets were first averaged based on test runs with identical configurations (i.e. Kenworth T2000 tractor, half-loaded trailer, rapid acceleration) to reduce the overall size of the data sets. The original data presented in the publications for each test run was averaged based on the existing data scale, which in the case of this example Kenworth T2000 data is in feet because of the method of data capture used by Mr. Grimes. Figure 2 shows the four test runs performed with this tractor-trailer loading configuration with rapid acceleration, and the solid line is the single averaged data from combining the four test runs.

Note that a single averaged data set from one publication was removed from consideration during analysis of heavy truck acceleration. The averaged test runs for automated transmission, empty trailer, and rapid acceleration configurations had a single significant outlier in the data. Figure 3 shows the averaged data sets from the test runs utilizing this configuration.

FIGURE 2 Averaged test run data (Kenworth T2000, automated, half-loaded, rapid)

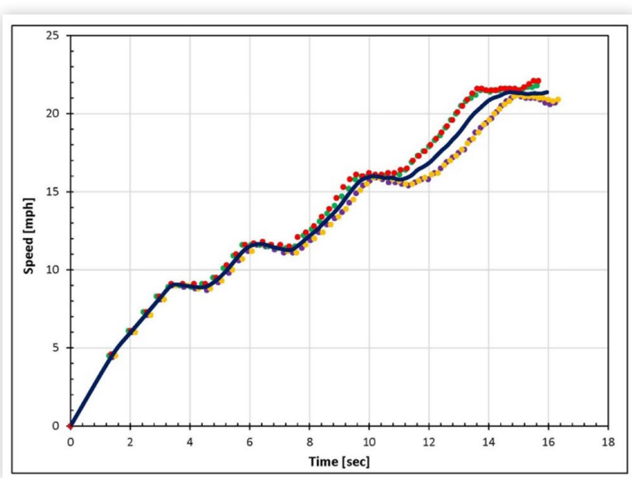
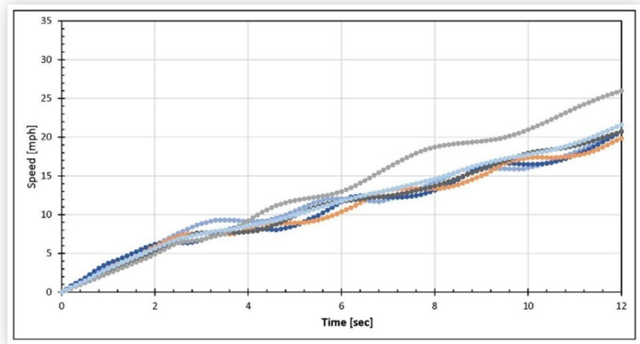


FIGURE 3 Outlier averaged data set (automated transmission, empty trailer, rapid acceleration)



As seen in the chart, the single outlier (grey points) is significantly different than the rest of the runs, and it was removed to prevent skewing of the data. This averaged data set was for the 2016 Freightliner Cascadia tractor, automated transmission, empty trailer, rapid acceleration from SAE Paper 2017-01-1426.

Data Normalization

Then the averaged data was normalized to a tenth of a second time scale, which allowed for direct comparison and analysis between all published data. For example, data presented in Mr. Grimes' papers was collected with a base unit of distance instead of time; the data was normalized to reproduce the data on a time scale with points every tenth of a second instead of the distance scale. Normalization was performed utilizing a modified version of Microsoft Excel's forecast function, which produced a polyline fit that was found to produce the most accurate normalized data when compared to the original data charts. Figure 4 shows a chart of the three types of normalization tested: linear interpolation, Excel's forecast function, and the modified forecast function. As seen in the example data in the chart, the modified forecast provided the most accurate representation of the original data.

Figure 5 is a chart of the averaged runs for automated transmission, half loaded trailer, and rapid shifting from Mr. Grimes' and Mr. Drew's papers, plotted in its original

FIGURE 4 Microsoft Excel Interpolation Comparison

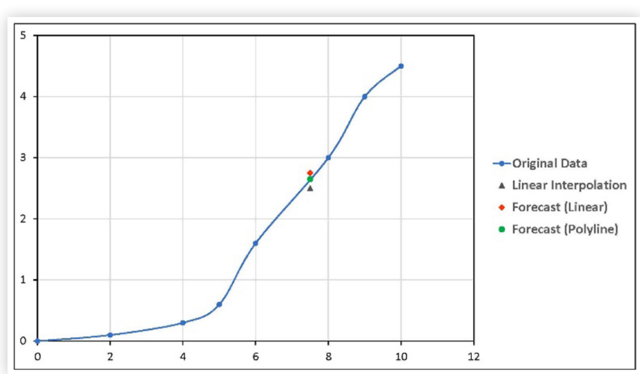


FIGURE 5 Averaged data chart (Automated transmission, half loaded trailer, rapid acceleration)

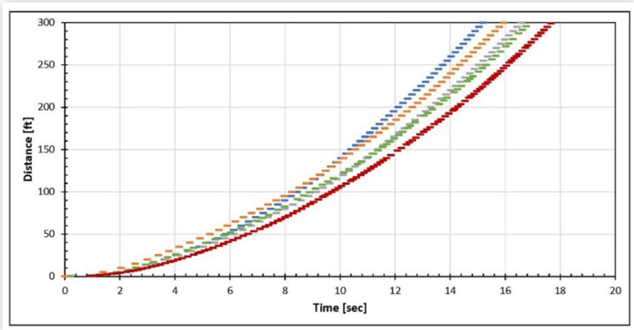
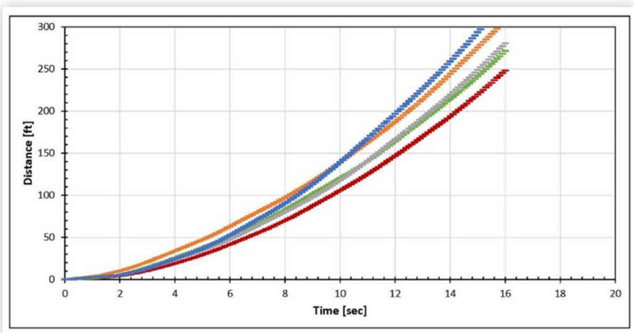


FIGURE 6 Normalized averaged data chart (Automated transmission, half loaded trailer, rapid shifting)



recorded data format. As seen in the chart, the x-axis is in seconds because the recorded data included time at each distance measurement; however it can also be seen that the some of the data sets (blue, orange, grey) are uniformly distributed across the y-axis, which is distance in feet. These data sets were recorded with a base unit of distance, as mentioned previously.

Figure 6 below shows the same data after being normalized through modified forecast and plotted on a tenth of a second time scale.

A comparison of the two charts shows that the original data was not skewed during normalization through modified forecast. The original data was preserved in transformation, however now it is possible to compare all the published data at a resolution of one tenth of a second.

Heavy Truck Acceleration Data and Comparison

Test Configuration Analysis

The eight papers in which the compiled data was published have varying combined weights of the tractor-trailers utilized during testing. Additionally, some of the tests were performed with empty, half loaded, and fully loaded trailers. Table 3 shows a summary of the tractor-trailer weights published in

TABLE 3 SAE publications test vehicles combined weights summary

SAE Paper No.	Tractor Year, Make & Model	Trailer	Tractor & Empty Trailer Weight [lbs]	Tractor & Half Loaded Trailer Weight [lbs]	Tractor & Fully Loaded Trailer Weight [lbs]
950136	1991 Kenworth T600	48 ft van		44,900	
	1994 Kenworth T600 350	48 ft flatbed	31,160		77,660
980366	1994 Kenworth T600B	53 ft van	33,270	56,000	77,240
1999-01-0092	1995 Freightliner FLD-120	48 ft van	32,720	56,760	77,520
2000-01-0470	2000 Kenworth T2000	53 ft van	32,540	50,760	72,360
2017-01-1418	2016 Kenworth T680	53 ft van	32,800	60,800	78,740
2017-01-1426	2016 Freightliner Cascadia	53 ft van	32,620	60,560	78,340
2012-01-0597	2011 Freightliner Cascadia	53 ft van	32,870		66,645
	2007 Volvo VNL	53 ft van	31,402		65,177
Average Tractor-Trailer Combined Weight [lbs]			32,423	54,963	74,210

each paper for reference. All trailers were dry van box trailers at least 48 feet in length, except for the 48 foot flatbed trailer utilized with the 1994 Kenworth in SAE 950136. An average weight for each configuration is calculated at the bottom of the table.

The normalized data was combined in chart format, plotting speed against time for comparison purposes. The speed/time charts have truncated the data at 12 seconds; this was done because beyond 12 seconds some of the original published data was not recorded. Furthermore, averaged data encompassing 12 seconds of acceleration from a stop is typically a sufficient length of time to analyze for accident reconstruction purposes. Although the data presented in this paper is limited to 12 seconds, review of the data shows that the linear trend continues after 12 seconds. Therefore, extrapolation of acceleration beyond 12 seconds can be performed given the linear trend of the data. Figure 7 shows a chart of all the normalized data with speed vs. time; this chart and all charts in this section include an average line overlaid on the normalized data (red line).

Trailer vs. No Trailer Comparison The first significant dividing factor in the data was found to be whether the tractor was hauling a trailer. The tractor without trailer (bobtail) test runs had significantly higher speeds across the 12 second timeframe studied, and as such they were grouped into their own category for acceleration analysis. Figure 8 shows all test runs for bobtail tractors, and Figure 9 shows all test runs for tractors with a trailer, regardless of loading configuration of the trailer. The red line in both figures shows the average of all the displayed test runs.

As seen when comparing the above two charts, the minimum speed of the bobtail tractor test runs after

FIGURE 7 Normalized test data (speed vs. time, 0-12 seconds)

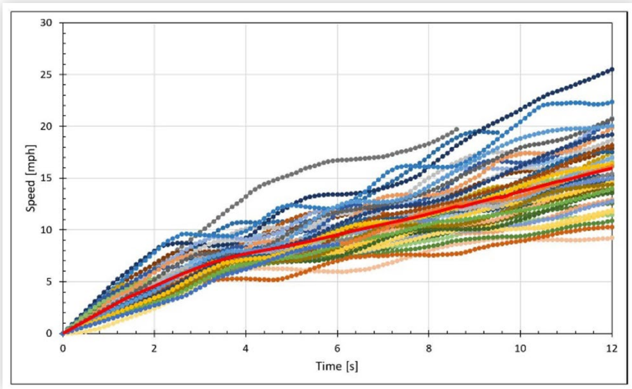


FIGURE 8 All tractor without trailer test runs (bobtail)

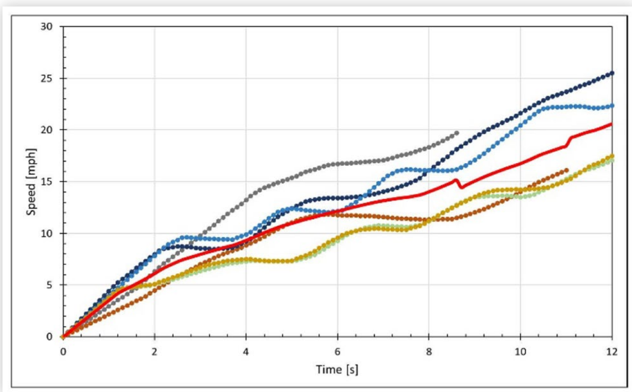
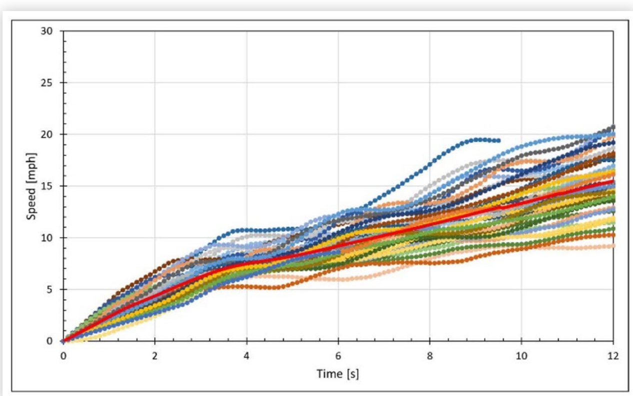


FIGURE 9 All tractors with trailers test runs (all trailer loading configurations)



12 seconds of acceleration was over 17 mph with an average of 21 mph, while the tractor-trailer combinations only achieved at most 20 mph, with the average falling near 15 mph. This shows that the bobtail tractors are able to achieve higher average accelerations than tractor-trailer combinations, which is expected given the difference in gross vehicle weights. For the accident reconstructionist, it is normally possible to determine whether or not the tractor was hauling a trailer when it was involved in a collision. With this simple distinction, a reconstructionist can more accurately estimate the acceleration of the tractor by utilizing the correct data set. The charts in Appendix A show the bobtail tractor average accelerations over the 12 second timeframe, with the 85th percentile range included.

Tractor-Trailer Combinations, Manual vs. Automated Transmissions

Figure 9 shows all test runs performed with tractor-trailer combinations, and the speeds have a wide spread that can be further subdivided in order to draw conclusions for average acceleration calculations. Through review of the test runs of tractor-trailers, it was found that on average the automated transmission tractors achieved higher average accelerations than manual transmission tractors over all trailer loading configurations.

Figure 10 shows all test runs for tractors equipped with manual transmissions and hauling a trailer, and Figure 11 shows all test runs for tractors with automated transmissions hauling a trailer. The red line in both figures shows the average of all the displayed test runs.

As seen in Figure 10, the manual transmission tractor-trailers achieve lower speeds at the end of the timeframe than the automated tractor-trailers: average speed for manual tractors with trailer is approximately 14 mph at 12 seconds,

FIGURE 10 All manual transmission tractors with trailers test runs (all trailer loading configurations)

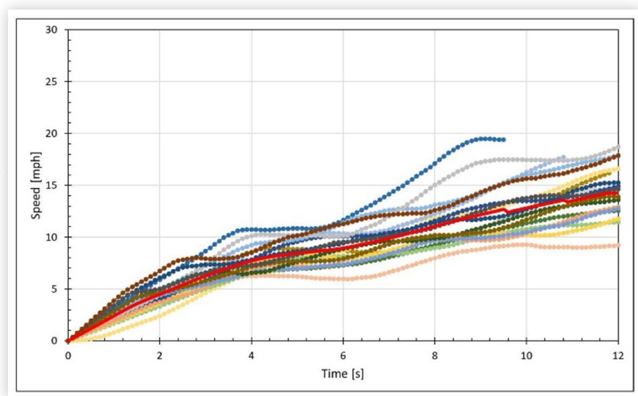
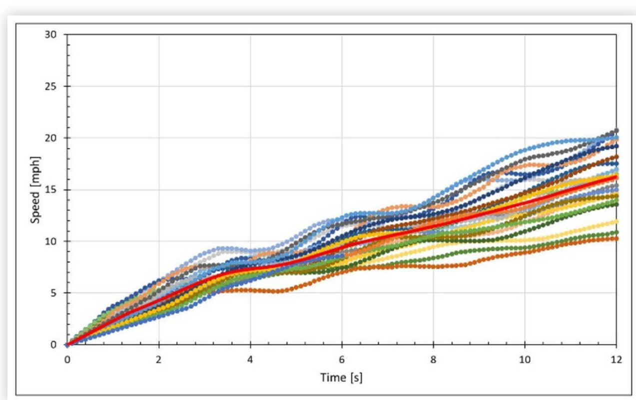


FIGURE 11 All automated transmission tractors with trailers test runs (all trailer loading configurations)



while average speed for automated tractors is 16 mph. An accident reconstructionist can determine the transmission of the tractor through either using the VIN of the tractor, which is typically included in a police report, or a photo of the interior of the cab. When the type of transmission installed in the tractor is known, a more specific acceleration profile can be determined.

Tractor-Trailer Combinations, Manual vs. Automated Transmissions, Individual Trailer Loading Configurations A less commonly known parameter of a tractor-trailer combination involved in a collision is the trailer load weight. This information may not always be available to a reconstructionist when analyzing a collision for many reasons; however, if the loading configuration is available or can be estimated, the acceleration of the tractor-trailer can be further refined.

Manual Transmission; Empty, Half-Loaded or Fully Loaded Trailer. The three loading categories for trailers included in the published acceleration data are empty, half-loaded, and fully loaded trailers. The exact weights associated with these categories varies slightly due to trailer selection and ballast loads, but the three options can be defined as a minimum, average, and maximum loading condition for the trailer. The average gross vehicle weights for each paper's tractor-trailer combinations and loading configurations were calculated earlier. In the previous section it was shown that the transmission type equipped in the tractor is the major defining factor for acceleration of tractor-trailer combinations; this relationship is also relevant when considering trailer load configurations to refine calculations.

Figure 12 shows the averaged test runs of all tractors equipped with manual transmissions and hauling empty trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 16.0 mph.

Figure 13 shows the averaged test runs of all tractors equipped with manual transmissions and hauling half-loaded trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 14.7 mph.

Figure 14 shows the averaged test runs of all tractors equipped with manual transmissions and hauling fully loaded trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 12.8 mph.

FIGURE 12 Manual transmission, empty trailer test runs

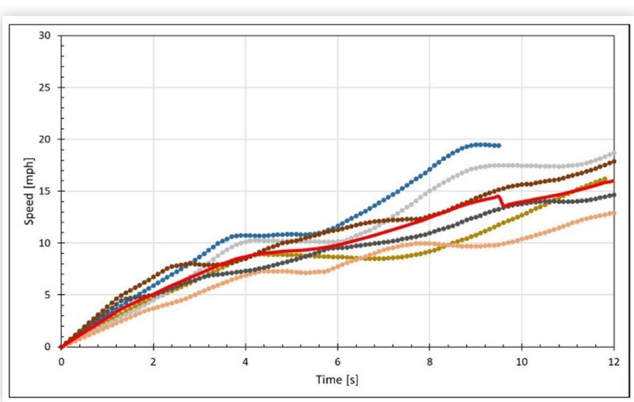


FIGURE 13 Manual transmission, half-loaded trailer test runs

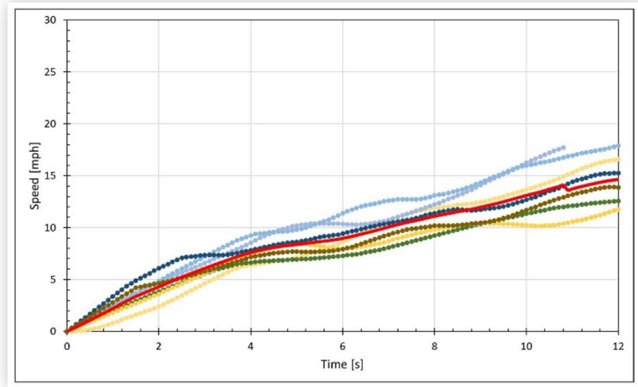
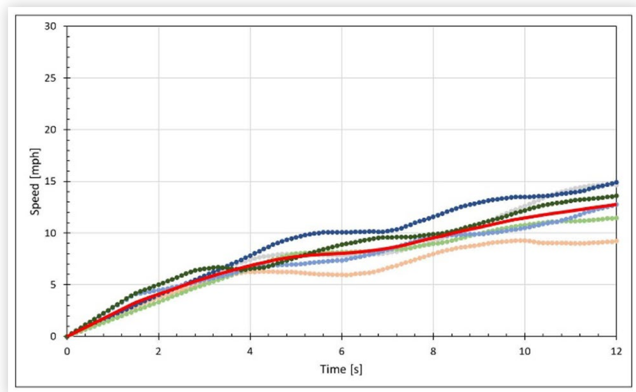


FIGURE 14 Manual transmission, fully loaded trailer test runs



As expected, the tractor-trailer's acceleration capability is reduced with added load to the trailer. If the loading configuration of the trailer is known, or can be estimated to fall into one of the three loading categories (empty, half-loaded, fully loaded), an accident reconstructionist can further refine the acceleration calculations for the tractor-trailer.

Automated Transmission; Empty, Half-Loaded or Fully Loaded Trailer. The speed vs. time charts for automated transmissions with the three loading categories are also presented for comparison to the manual transmission charts above. Figure 15 shows the averaged test runs of all tractors equipped with automated transmissions and hauling empty trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 17.8 mph.

Figure 16 shows the averaged test runs of all tractors equipped with automated transmissions and hauling half-loaded trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 15.7 mph.

FIGURE 15 Automated transmission, empty trailer test runs

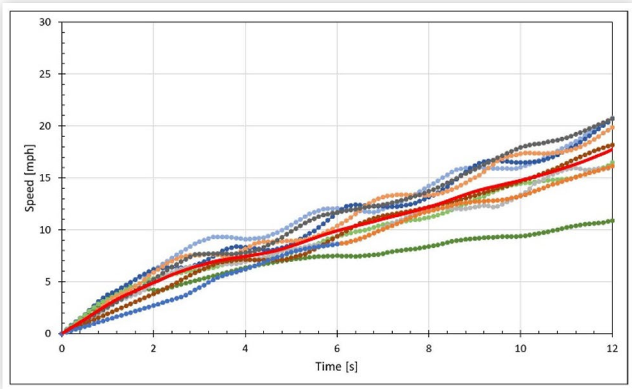


FIGURE 16 Automated transmission, half-loaded trailer test runs

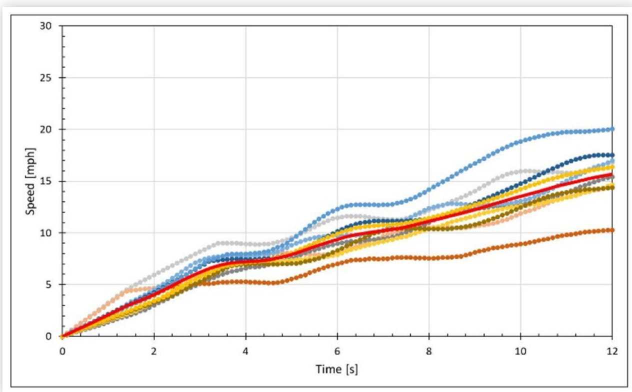
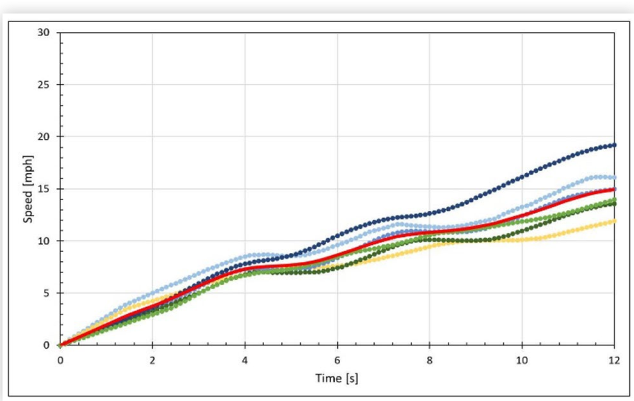


Figure 17 shows the averaged test runs of all tractors equipped with automated transmissions and hauling fully loaded trailers. The red line is the average of the displayed data. The average speed reached after 12 seconds of acceleration for this configuration was 15.0 mph.

Again the acceleration capability is reduced with added load to the trailer. These loading configuration charts with both transmission types show a much larger average difference between comparable test runs with manual and automated transmissions. This reinforces the need to first determine the transmission type when estimating heavy truck acceleration, then refine the estimate through categorizing the trailer load if possible for a narrower range.

FIGURE 17 Automated transmission, fully loaded trailer test runs



Discussion

The above charts extracted from the normalized heavy truck acceleration data present clear trends in tractor configurations and trailer loading conditions that allow for more accurate estimation of acceleration for accident reconstruction purposes. From this compiled data, acceleration can be estimated for any tractor with any trailer configuration with a reasonable degree of certainty. This quantity of data, although subdivided into distinct categories, lends itself to further simplification for accident reconstruction purposes. As seen in the above charts, the average speed line has two linear phases: the first phase of higher acceleration from either 0-3 or 0-4 seconds, and a second lower acceleration phase from 3-12 or 4-12 seconds. The slope of these linear phases in each average speed can be used as average acceleration values for each phase. The phase change time was chosen individually for each data set based on the location of the change in slope of the average line. Each acceleration value also has an 85th percentile range associated with it as an upper and lower bound.

The first category a reconstructionist can define when estimating heavy truck acceleration is whether the tractor is hauling a trailer. Table 4 shows a summary of the average accelerations for all test data, all tractors hauling trailers, and all tractors without trailers (bobtail). Each configuration is defined using the 0-3 second first phase in this comparison.

The next category in which to classify the heavy truck is whether the tractor is equipped with an automated or manual transmission. Table 5 shows a summary of the average accelerations for all tractors hauling trailers, all automated tractor-trailers, and all manual tractor-trailers. Note that the all and automated categories are defined using the 0-3 second first phase, while the manual category uses the 0-4 second first phase.

If it is possible to classify the load of the trailer as either empty, half-loaded, or fully loaded, a reconstructionist can

TABLE 4 Two-phase average acceleration values (trailer vs. no trailer)

Trailer vs. No Trailer			
Configuration	Phase 1		
	Time [sec]	Accel [g]	Range [g]
All	0-3	0.095	± 0.034
All with trailer	0-3	0.095	± 0.028
All without trailer	0-3	0.121	± 0.022

Trailer vs. No Trailer			
Configuration	Phase 2		
	Time [sec]	Accel [g]	Range [g]
All	3-12	0.048	± 0.024
All with trailer	3-12	0.047	± 0.015
All without trailer	3-12	0.064	± 0.011

TABLE 5 Two-phase average acceleration values (automated vs. manual transmission)

Automated vs. Manual Transmission			
Configuration	Phase 1		
	Time [sec]	Accel [g]	Range [g]
All with trailer	0-3	0.095	± 0.028
All Auto with Trailer	0-3	0.094	± 0.028
All Manual with Trailer	0-4	0.088	± 0.022

Automated vs. Manual Transmission			
Configuration	Phase 2		
	Time [sec]	Accel [g]	Range [g]
All with trailer	3-12	0.047	± 0.015
All Auto with Trailer	3-12	0.051	± 0.013
All Manual with Trailer	4-12	0.037	± 0.012

further refine the acceleration numbers. Table 6 shows a summary of the average accelerations for all automated and manual tractor-trailers, with classifications of loading configuration as empty, half-loaded, and fully loaded trailers. Note that the all the manual category uses the 0-4 second first phase, while only the fully loaded automated transmission category uses the 0-4 second first phase.

The two-phase average acceleration model can be used to estimate the acceleration of any tractor-trailer configuration for accident reconstruction purposes. Additionally, the linear trend of the data after 12 seconds of acceleration allows for extrapolation of this acceleration model beyond the charts presented in this paper. Appendix A includes charts of each configuration listed in the above tables including the two-stage

TABLE 6 Two-phase average acceleration values (empty trailer, half-loaded trailer, fully loaded trailer)

Empty, Half-Loaded, and Fully Loaded Trailer			
Configuration	Phase 1		
	Time [sec]	Accel [g]	Range [g]
All Auto with Trailer	0-3	0.094	± 0.028
Auto, Empty Trailer	0-3	0.100	± 0.028
Auto, Half Load Trailer	0-3	0.094	± 0.020
Auto, Full Load Trailer	0-4	0.083	± 0.009
All Manual with Trailer	0-4	0.088	± 0.022
Manual, Empty Trailer	0-4	0.099	± 0.019
Manual, Half Load Trailer	0-4	0.087	± 0.014
Manual, Full Load Trailer	0-4	0.078	± 0.008

Empty, Half-Loaded, and Fully Loaded Trailer			
Configuration	Phase 2		
	Time [sec]	Accel [g]	Range [g]
All Auto with Trailer	3-12	0.051	± 0.013
Auto, Empty Trailer	3-12	0.057	± 0.012
Auto, Half Load Trailer	3-12	0.048	± 0.014
Auto, Full Load Trailer	4-12	0.044	± 0.013
All Manual with Trailer	4-12	0.037	± 0.012
Manual, Empty Trailer	4-12	0.042	± 0.005
Manual, Half Load Trailer	4-12	0.040	± 0.008
Manual, Full Load Trailer	4-12	0.034	± 0.010

FIGURE 18 Two-phase average acceleration values with 85th percentile acceleration range (automated transmission, half-loaded trailer)

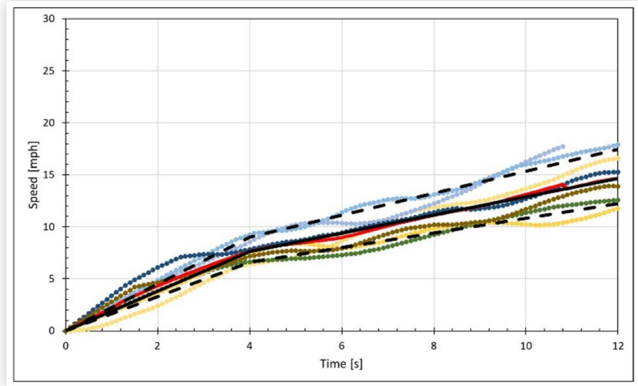
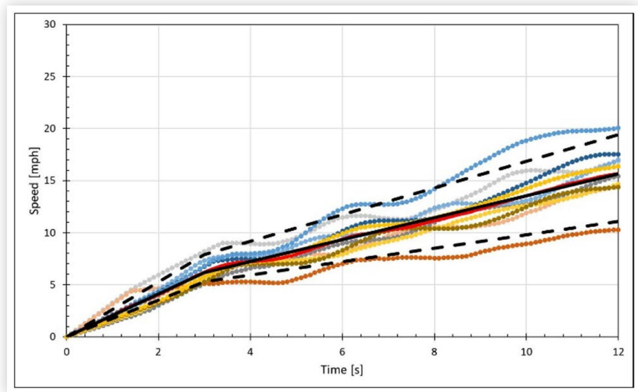


FIGURE 19 Two-phase average acceleration values with 85th percentile acceleration range (manual transmission, half-loaded trailer)



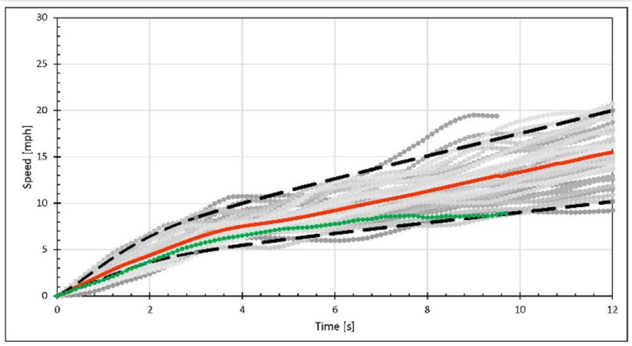
average acceleration, and also plotted with 85th percentile confidence intervals. The 85th percentile values provide a minimum and maximum range for acceleration during each phase. Figure 18 and Figure 19 show two of these charts, which are the averaged data for half-loaded trailer configurations for automated and manual transmissions, respectively. These will likely be the most commonly used configurations given the typically available information for accident reconstructionists.

Appendix B provides a summary table of all the different tractor-trailer configurations broken down into the 3 main sub-categories. The table includes speed data for each tractor-trailer configuration with two-stage acceleration model with 85th percentile confidence interval, which was used to plot the lines in the charts in Appendix A.

Left Turning Acceleration Data

The data provided in the 2010 SAE publication by Merala and White studying left turning tractor-trailers fits within the ranges published in this paper. Figure 20 shows the left-turning trucks data highlighted in a chart showing acceleration data for all heavy trucks hauling trailers.

FIGURE 20 - Left turning heavy trucks acceleration data comparison



As seen in Figure 20, the data from left turning trucks (green) fits within the prescribed ranges for all trucks with trailers published in this paper. The turn lengths defined in the 2010 paper were short radius turns (32-45 feet), and as seen in the above chart the data is on the lower end of the ranges of acceleration. However, all the acceleration data analyzed in this paper is applicable to the acceleration of turning heavy trucks, and this will be further refined by research to be published by these authors next year.

Summary/Conclusions

Accident reconstructionists frequently need to estimate acceleration of a heavy truck from a stop. Heavy trucks typically have much lower acceleration capabilities than a passenger vehicle, and this paper analyzes the available acceleration data and provides a two-stage acceleration model for heavy trucks. Typical passenger vehicles can have an acceleration range from 0.05-0.3 g from a stop, depending on vehicle capabilities and driver input. However, the data published in this paper shows that heavy trucks have a much narrower possible range of acceleration from a stop. This paper shows that the acceleration of a heavy truck from a stop can be estimated from the compiled data for any tractor-trailer configuration, and can be further refined for specific combinations of drivetrain and loading provided additional information is available.

References

1. Proctor, C., Grimes, W., Fournier, D., Rigol, J. et al., "Analysis of Acceleration in Passenger Cars and Heavy Trucks," SAE Technical Paper 950136, 1995, doi:10.4271/950136.
2. Grimes, W. and Dickerson, C., "Low Speed Acceleration of the Kenworth T600 Tractor Truck," SAE Technical Paper 980366, 1998, doi:10.4271/980366.
3. Grimes, W. and Dickerson, C., "Low Speed Acceleration of the Freightliner FLD-120 Tractor Truck," SAE Technical Paper 1999-01-0092, 1999, doi:10.4271/1999-01-0092.
4. Grimes, W. and Dickerson, C., "Low Speed Acceleration of a Kenworth T2000 Tractor-Truck with Autoshift Transmission," SAE Technical Paper 2000-01-0470, 2000, doi:10.4271/2000-01-0470.
5. Grimes, W., Vadnais, T., and Wilcoxson, G., "Acceleration Testing of 2016 Kenworth T680 with Automated Manual Transmission in Auto Mode," SAE Technical Paper 2017-01-1418, 2017, doi:10.4271/2017-01-1418.
6. Grimes, W., Vadnais, T., and Wilcoxson, G., "Acceleration Testing of 2016 Freightliner Cascadia with Automated Manual Transmission in Auto Mode," SAE Technical Paper 2017-01-1426, 2017, doi:10.4271/2017-01-1426.
7. Merala, R. and White, K., "Tractor Semitrailer Left Turns and Lane Changes," SAE Technical Paper 2010-01-0049, 2010, doi:10.4271/2010-01-0049.
8. Drew, K., Van Nooten, S., and Gervais, J., "Low Speed Acceleration of Tractor-Semitrailers Equipped with Automated Transmissions," SAE Technical Paper 2012-01-0597, 2012, doi:10.4271/2012-01-0597.
9. Long, G., "Acceleration Characteristics of Starting Vehicles," in *Transportation Research Board 79th Annual Meeting*, January 2000.
10. Poplin, W., "Acceleration of Heavy Trucks," *W Poplin Engineering LLC*, June 2002.
11. Bellavigna, O. and Gou, M., "Acceleration Performances Testing and Simulation of Various Types of Commercial Vehicles for Railway Crossing Design," SAE Technical Paper 2006-01-3458, 2006, doi:10.4271/2006-01-3458.
12. English, J., Beck, R., and Casteel, D., "Heavy Fire Apparatus Acceleration and Braking Performance," SAE Technical Paper 2010-01-0112, 2010, doi:10.4271/2010-01-0112.
13. English, J. and Beck, R., "Acceleration and Braking Performance of Transit Style Buses," SAE Technical Paper 2012-01-0618, 2012, doi:10.4271/2012-01-0618.
14. Funk, C., Howery, T., Jager, J., and Lee, D., "Acceleration and Braking Performance of School Buses," *SAE Int. J. Commer. Veh.* 5(1), 2012, doi:10.4271/2012-01-0593.
15. Mehar, A., Chandra, S., and Velmurugan, S., "Speed and Acceleration Characteristics of Different Types of Vehicles on Multi-Lane Highways," *European Transport* 55(1):1825-3997, 2013.
16. Yang, G., Xu, H., Wang, Z., and Tian, Z., "Truck Acceleration Behavior Study and Acceleration Lane Length Recommendations for Metered On-Ramps," *International Journal of Transportation Science and Technology* 5(2):93-102, 2016.
17. Bokare, P., and Maurya, A., "Acceleration-Deceleration Behaviour of Various Vehicle Types," in *World Conference on Transport Research*, Shanghai, July 10-15, 2016.

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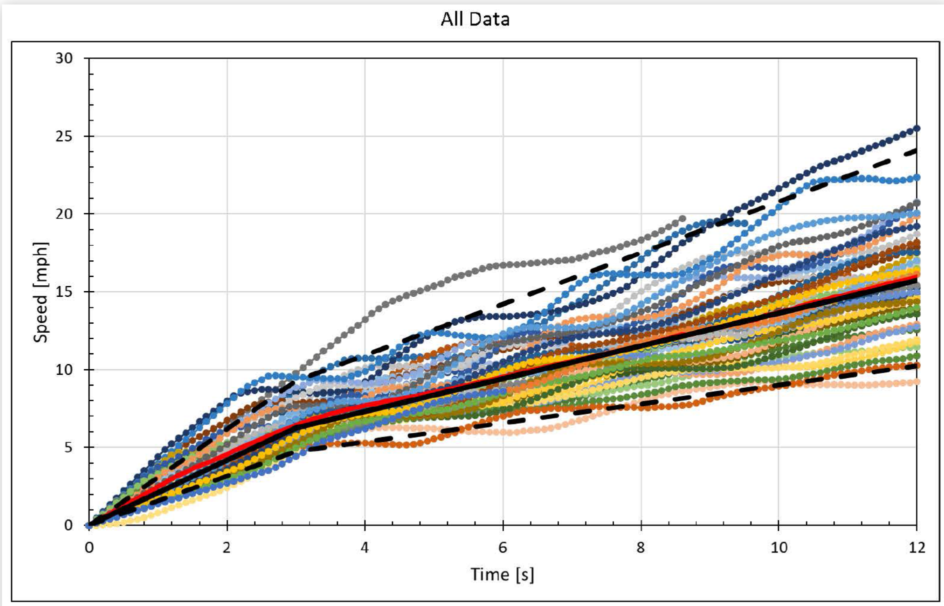
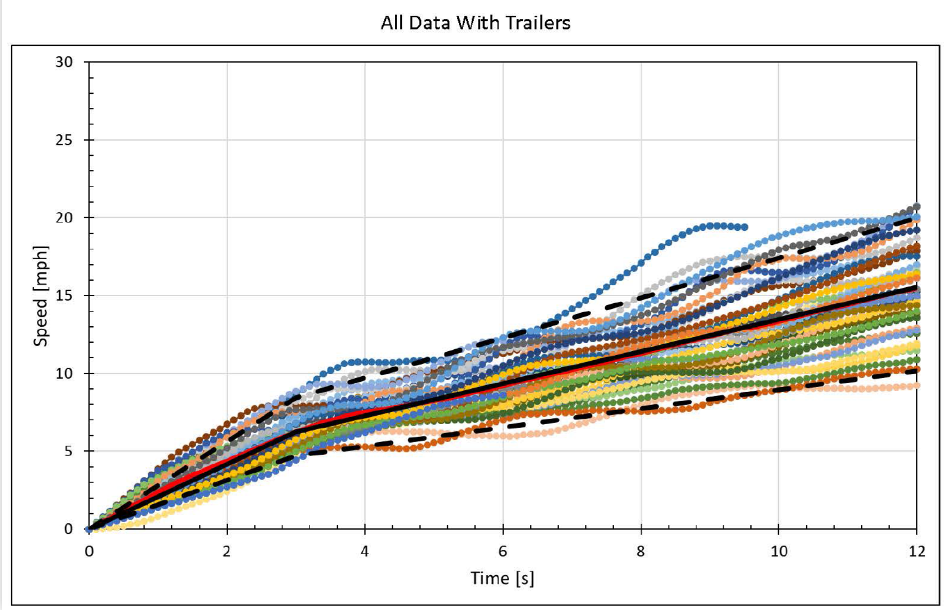
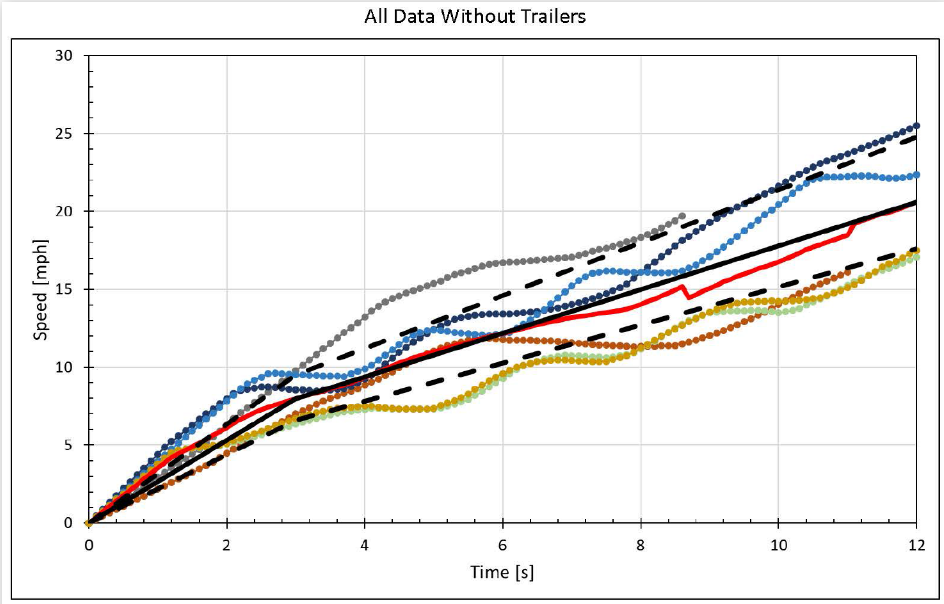
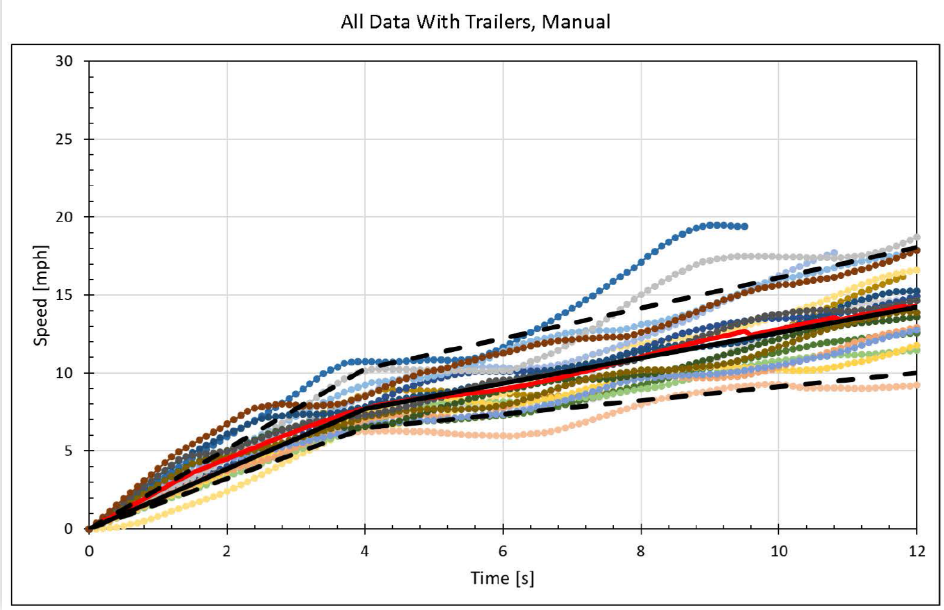
Appendix A

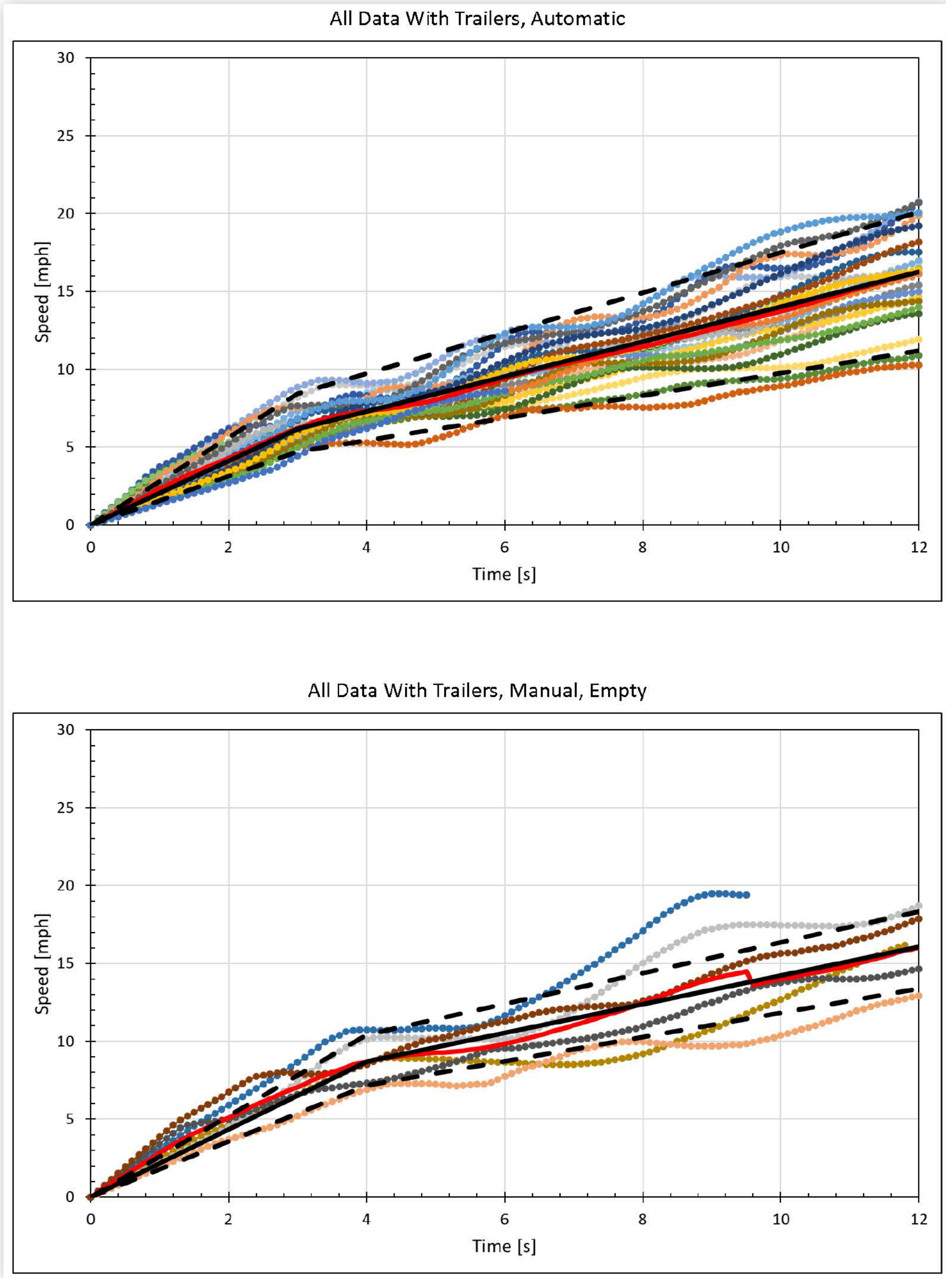
This appendix includes charts of the two-stage acceleration model for each tractor-trailer configuration plotted with 85th percentile confidence interval, overlaid onto the normalized data for the selected subdivision of test configurations.

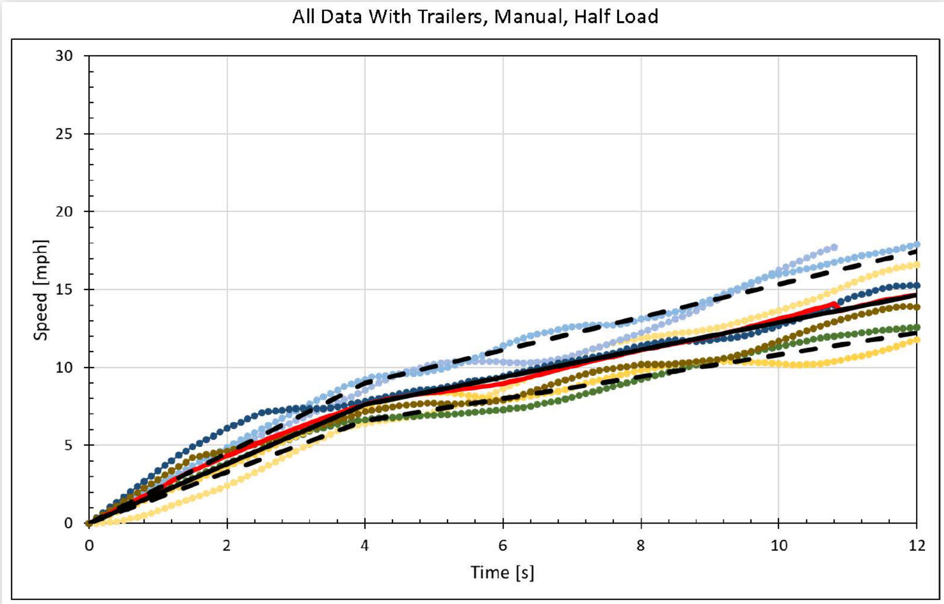


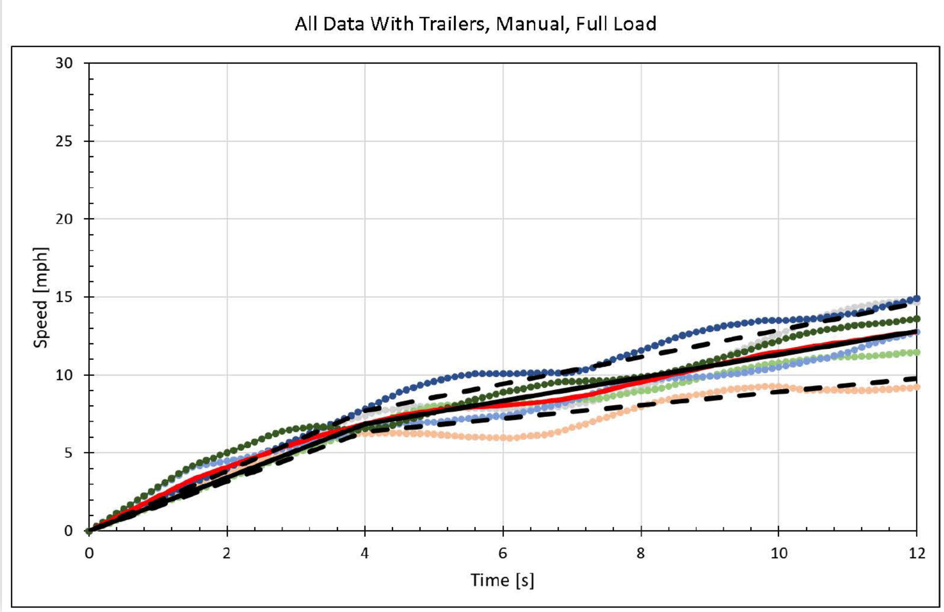


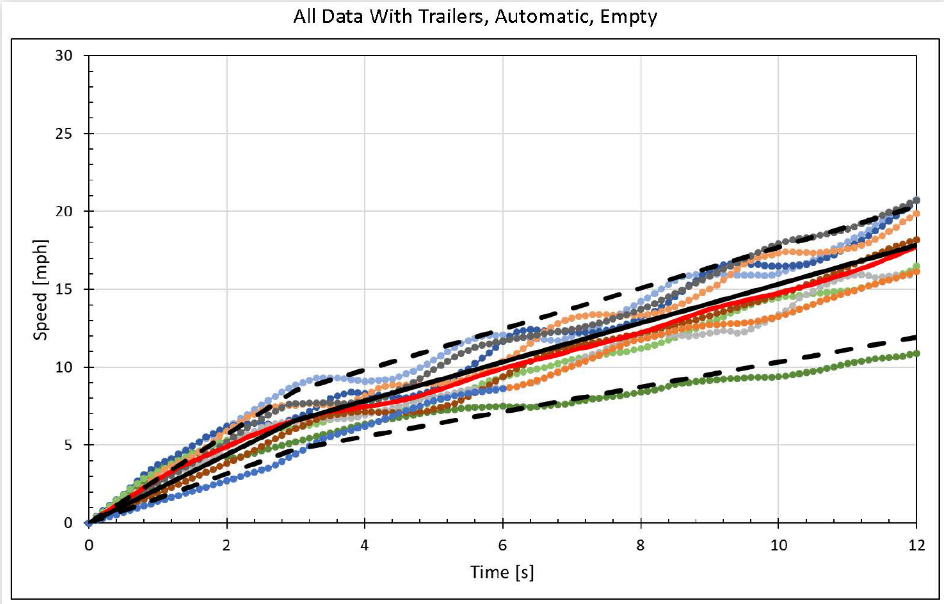

All Data Without Trailers
Speed [mph]
Time [s]
0
5
10
15
20
25
30
0
2
4
6
8
10
12

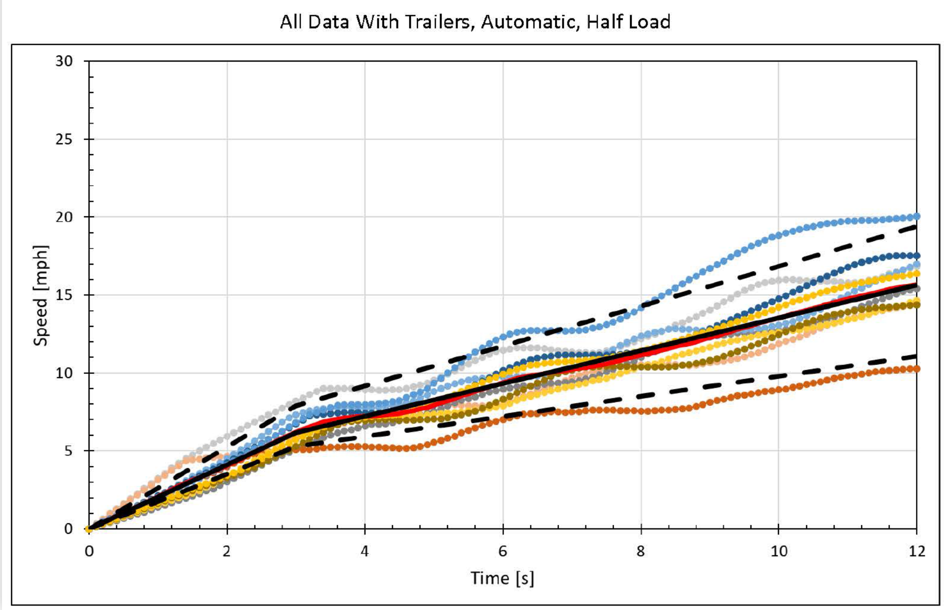

All Data With Trailers, Manual
Speed [mph]
Time [s]
0
5
10
15
20
25
30
0
2
4
6
8
10
12

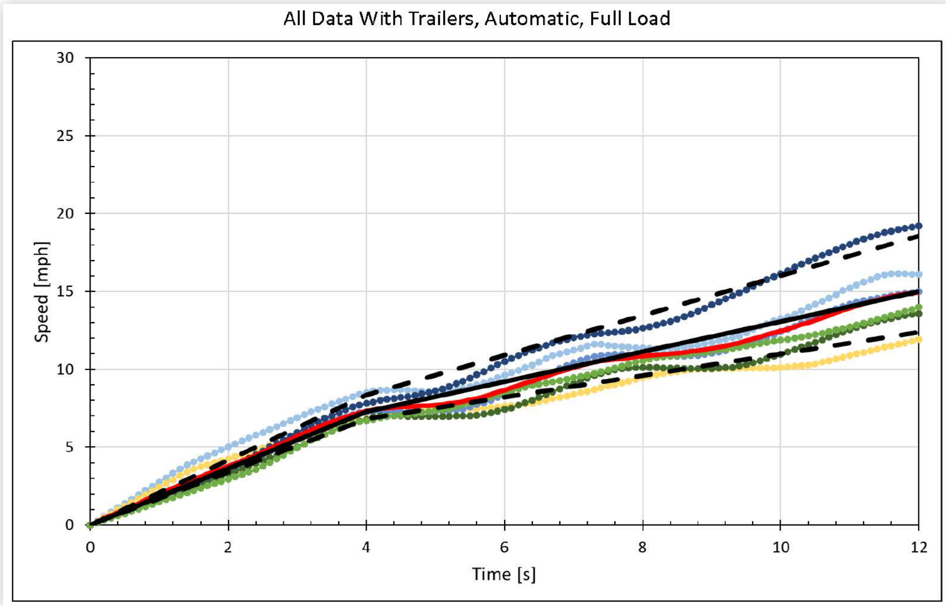

All Data With Trailers, Automatic
Speed [mph]
Time [s]
All Data With Trailers, Manual, Empty
Speed [mph]
Time [s]


All Data With Trailers, Manual, Half Load
Speed [mph]
Time [s]
30
25
20
15
10
5
0
0
2
4
6
8
10
12


All Data With Trailers, Manual, Full Load
Speed [mph]
Time [s]
30
25
20
15
10
5
0
0
2
4
6
8
10
12


All Data With Trailers, Automatic, Empty
Speed [mph]
Time [s]
30
25
20
15
10
5
0
0
2
4
6
8
10
12


All Data With Trailers, Automatic, Half Load
Speed [mph]
Time [s]
30
25
20
15
10
5
0
0
2
4
6
8
10
12


All Data With Trailers, Automatic, Full Load
Speed [mph]
Time [s]
0
5
10
15
20
25
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0
2
4
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10
12

Appendix B

This appendix includes tables of the two-stage acceleration model for each tractor-trailer configuration with 85th percentile confidence interval, which was used to plot the lines in the charts in Appendix A.

Two Phase Acceleration - Trailer vs. No Trailer

Configuration	Phase 1			Phase 2		
	Time [sec]	Accel [g]	Range [g]	Time [sec]	Accel [g]	Range [g]
All	0-3	0.095	± 0.034	3-12	0.048	± 0.024
All with trailer	0-3	0.095	± 0.028	3-12	0.047	± 0.015
All without trailer	0-3	0.121	± 0.022	3-12	0.064	± 0.011

Two Phase Acceleration - Automated vs. Manual Transmission

Configuration	Phase 1			Phase 2		
	Time [sec]	Accel [g]	Range [g]	Time [sec]	Accel [g]	Range [g]
All with trailer	0-3	0.095	± 0.028	3-12	0.047	± 0.015
All Auto with Trailer	0-3	0.094	± 0.028	3-12	0.051	± 0.013
All Manual with Trailer	0-4	0.088	± 0.022	4-12	0.037	± 0.012

Two Phase Acceleration - Empty, Half-Loaded, and Fully Loaded Trailer

Configuration	Phase 1			Phase 2		
	Time [sec]	Accel [g]	Range [g]	Time [sec]	Accel [g]	Range [g]
All Auto with Trailer	0-3	0.094	± 0.028	3-12	0.051	± 0.013
Auto, Empty Trailer	0-3	0.100	± 0.028	3-12	0.057	± 0.012
Auto, Half Load Trailer	0-3	0.094	± 0.020	3-12	0.048	± 0.014
Auto, Full Load Trailer	0-4	0.083	± 0.009	4-12	0.044	± 0.013
All Manual with Trailer	0-4	0.088	± 0.022	4-12	0.037	± 0.012
Manual, Empty Trailer	0-4	0.099	± 0.019	4-12	0.042	± 0.005
Manual, Half Load Trailer	0-4	0.087	± 0.014	4-12	0.040	± 0.008
Manual, Full Load Trailer	0-4	0.078	± 0.008	4-12	0.034	± 0.010

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