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NATIONAL TRANSPORTATION RESEARCH CENTER, INCORPORATED
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U14: Field Testing & Analysis of Braking Performance of In-Service Trucks

This project was funded by the NTRCI University Transportation Center under a grant from the U.S. Department of Transportation Research and Innovative Technology Administration (#DTRT06G-0043)

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June, 2009

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **U14: Field Testing & Analysis of Braking Performance of In-Service Trucks**		5. Report Date **June 2009**
		6. Performing Organization Code
7. Author(s) **Steven J. Shaffer and Amy M. Long – Battelle Memorial Institute**		8. Performing Organization Report No.
9. Performing Organization Name and Address **National Transportation Research Center, Inc.** **University Transportation Center** **2360 Cherahala Blvd.** **Knoxville, TN 37932**		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. **DTRT06G-0043**
12. Sponsoring Agency Name and Address **U.S. Department of Transportation** **Research and Innovative Technology Administration** **1200 New Jersey Avenue, SE** **Washington, DC 20590**		13. Type of Report and Period Covered **Final Report March 2008- June 2009**
		14. Sponsoring Agency Code **RITA**

15. Supplementary Notes

16. Abstract

The purpose of this project was to collect a high quality data set to provide a snapshot of the braking capability of a representative sampling of in-service commercial motor vehicles (CMVs) on the road today. This data collection effort is important to safety in that no actual stopping performance data has been collected from in-service vehicles since the implementation of the Commercial Vehicle Safety Alliance (CVSA) visual inspection in the early 1980's. This assessment utilized improved technology, such as GPS systems and a Performance Based Brake Tester (PBBT), to collect data on CMV braking performance.

The data collected in this effort is intended for use in evaluating how current in-service vehicles perform, and how the Level I visual inspection corresponds to actual braking performance. Since there is no regulation of after-market components, including replacement brake pads, visual inspections may not fully assess the ability of a vehicle to stop safely. Industry and regulators alike could use current vehicle performance data in safety applications as they review present design and maintenance practices and regulations.

Industry and government partnered to support this project through direct financial and in-kind contributions. Primary contributors to the project include the Federal Motor Carrier Safety Administration (FMCSA), Commercial Vehicle Safety Alliance (CVSA), Heavy-Duty Brake Manufacturer's Council (HDBMC) and the Tennessee Highway Patrol.

17. Key Word	18. Distribution Statement
braking performance, heavy vehicles, commercial motor vehicles, in-service vehicles, brakes, stopping performance	**No restrictions**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**40**	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Executive Summary

The purpose of this project was to collect a high quality data set to provide a snapshot of the braking capability of a representative sampling of in-service commercial motor vehicles (CMVs). This data collection effort is important to safety in that no actual stopping performance data has been collected from in-service vehicles since the implementation of the Commercial Vehicle Safety Alliance (CVSA) visual inspection in the early 1980s, and it is not known how current in-service vehicles perform, nor whether different methods of brake assessment can be correlated to one another. A key concern for in-service vehicles is that there is no regulation on replacement brake materials, so it is also not known whether degraded brake performance exists as a result of lower quality replacement brake linings, and whether such degradation is unrecognizable through a visual inspection.

In this project, CMV braking capability was assessed using three methods; a 20-mph stopping test, an in-situ brake force measurement using a performance-based brake tester (PBBT), and a visual inspection of the brake components, including push-rod stroke measurements, per the CVSA North American Standard Level I inspection procedure. Stopping distance test data were obtained using a GPS-based data acquisition system, which also recorded the application air pressure via a pressure transducer installed on a Tee-coupling fitted to the control line glad-hand coupling[1]. Three repeat stops were run, with a research team observer riding along to coach the driver on the stops. The best stop from the three was used for comparison. The PBBT was used to measure the individual brake forces and wheel loads on service brakes and parking brakes on each vehicle, also collecting application air using a glad-hand coupling and pressure transducer. The air pressure data will allow for more detailed analyses in the future than was available within the scope of this project. The visual inspection was conducted by a CVSA-certified inspector, according to the CVSA North American Standard (NAS) Inspection Procedure, and used the NAS out-of-service (OOS) Criteria. The CVSA Level I inspection was supplemented by inspection of brake items of interest to the Heavy Duty Brake Manufacturers Council (HDBMC), such as free-stroke measurements, exposed push rod lengths and identification of edge codes on brake linings, if visible.

The project was conducted on behalf of the NTRCI by Battelle, with project direction from a Partnership Advisory Group (PAG), consisting of representatives from: the NTRCI-UTC, the Federal Motor Carrier Safety Administration (FMCSA), the CVSA, the HDBMC, and the Ontario Trucking Association (OTA).

The benchmarks for minimum braking performance are contained in Federal Motor Carrier Safety Regulation (FMCSR) §393.52 in which an in-service CMV over 10,000 lbs gross vehicle weight (GVW), under any condition of loading on which it is found, must be able to stop in less than 40 feet from 20 mph (35 feet for a single-unit truck). FMCSR §393.52 further requires that,

[1] The glad-hand coupling, which connects the control and supply air lines on the tractor to the trailer, is not present on single-unit vehicles. As such, no air pressure signal was available from single-unit trucks or buses.

when measured by a PBBT, the CMV must show a total braking force as a percentage of gross vehicle weight (BF_{tot}/GVW), of at least 43.5 percent. In the CVSA Level I visual inspection, critical components are examined and a vehicle is placed out-of-service if 20 percent or more of the brakes on that vehicle are identified as having a defect, as defined by the NAS. Some defects by themselves, such as mismatched brake adjuster arm lengths on each side of a steer axle, constitute an out-of-service violation.

Data from a total of 82 trucks were collected, coming from two different sets of vehicles. The primary data set was obtained from 59 vehicles whose participation was provided under prior arrangement by cooperative local fleets. This first data collection period took place in two separate month-long blocks during the Summer and Fall of 2008, at the Greene County, Tennessee inspection facility, located at milepost 21, Southbound I-81. The Tennessee Highway Patrol assisted with these tests and conducted the vehicle inspections. A secondary set of data was obtained from 23 randomly selected in-service CMVs, the drivers of which agreed to participate after having the program explained to them. These data were collected during a one week period in the Spring of 2009 at the Gallup, NM inspection facility on Eastbound I-40, milepost 12, with the assistance of the New Mexico Department of Public Safety, Motor Transportation Division.

While the project scope was limited to the management of the test program, collection, compilation and archiving of the data for future detailed analysis, vehicle demographics were characterized and some limited data reduction was completed to provide an overview of the braking capability of the two CMV population sets, and to compare these basic statistics with those collected in the earlier studies, prior to 1983. All the data have been provided to NTRCI.

Of the 82 vehicles tested, 13 were unable to meet the minimum stopping distance requirement, representing about 16 percent of those vehicles tested. Seven of the 82 (8.5 percent) were not able to meet the current minimum PBBT criterion. However, only three of those that failed to meet the minimum PBBT requirements were within the set of those unable to meet the stopping distance requirement. These results imply that the driver can have considerable (negative) influence on the stopping test performance. This also implies that the two different assessment methods may require further consideration if equivalency is desired for regulatory purposes. Additional data analysis, using the application air pressure signal, would be required to quantify the driver influence-effect.

The mean value of stopping distance for the randomly selected vehicle population, at 38.0 feet, was more than three and a half feet greater than that of the cooperative local fleet vehicles, at 34.4 feet. Although the population set was small, the comparison was found to be statistically significant. Similarly, the mean value for BF_{tot}/GVW, as measured by the PBBT was 15 percent lower (worse) for the random in service vehicle population, at 48.0, than that of the cooperative local fleet vehicles at 56.1. These results were not surprising, as it can be expected that most fleets volunteering to provide vehicles for a safety study would likely ensure that the vehicles provided would be well maintained. Indeed, it was discovered that some of the vehicles were being inspected and worked on prior to their dispatch to the test site.

Based on the final three and one-half day data collection period in New Mexico, in which brake performance assessments and visual inspections were conducted on 23 vehicles, this project demonstrated that quality brake performance and condition data could be obtained from up to eight trucks per day, randomly pulled from the traffic stream, if all three test and inspection methods were implemented. It was also determined that data from 15 or more vehicles per day could be obtained if the effort were concentrated on just the instrumented 20-mph stopping tests using the GPS-based data acquisition system, and 40 trucks per day using only the PBBT-based brake assessment.

Chapter 1 – General Overview

Background

Every decade, beginning in the 1940s, an assessment of the braking capability of in-service vehicles was conducted. The original intent was to ensure that highway design and construction, in particular stopping sight distance, was consistent with vehicle braking capabilities. In the 1950s-1980s, the assessment was also used to determine whether any degradation in the braking capability of in-service vehicles had taken place, and whether the minimum brake performance requirements were consistent with changes in speed limits, vehicle design, and cargo capacity. These braking assessments were accomplished via stopping tests conducted from 20-mph, using volunteer vehicles pulled from the traffic stream.

The current project, funded by a Department of Transportation Research and Innovative Technology Administration (DOT-RITA) grant through the NTRCI-UTC in Knoxville, Tennessee, with participation from government and industry, again collected data to assess the braking capability of in-service vehicles. This data collection effort is important to safety in that no actual stopping performance data has been collected since the implementation of the CVSA visual inspection in the early 1980s, and it is not known how current in-service vehicles perform, compared to other vehicle types on the road, or to vehicles in the earlier studies. It is also not known how the CVSA Level I visual inspection corresponds to actual braking performance. Since there is no regulation of after-market components, including replacement brake pads, visual inspections may not fully assess the ability of a vehicle to stop safely. Industry and regulators alike require current vehicle performance data as they review current design and maintenance practices and regulations. In this project the brake performance assessment was restricted to commercial motor vehicles (CMVs) only.

Project Team

National Transportation Research Center, Inc. (NTRCI) – NTRCI was the overall RITA program manager. They coordinated the contractual aspects of the in-kind contributions and monetary support of the project from the relevant members of the Partnership Advisory Group (PAG). NTRCI hosted the PAG review meeting, at which time the initial data set was reviewed, and relevant changes to the protocol were discussed for implementation in the second data collection period. NTRCI provided the V-Box III GPS system that was used for data collection in the 20-mph stopping tests.

Battelle Memorial Institute (Battelle) – Battelle was responsible for the overall conduct of the project. The major tasks included developing a test plan, assembling the vehicle instrumentation and data acquisition suite, coordinating the PAG, identifying, recruiting and developing memoranda of understanding (MOU) with the cooperative local fleets, and coordinating a practice data session and demonstration for these fleets. On the enforcement side, Battelle was responsible for developing an MOU between NTRCI and the Tennessee Highway Patrol and subsequently also with the New Mexico Department of Public Safety. During the test program, Battelle coordinated the schedule for vehicles to report to the Greene County Inspection facility, managed the data collection effort, and compiled the data for distribution to the NTRCI and the PAG representatives. Battelle was also responsible for submitting an article for the NTRCI University Transportation Center (UTC) Newsletter and monthly progress and financial reporting.

The Commercial Vehicle Safety Alliance (CVSA) – The CVSA provided guidance through participation in the PAG, with expertise in the visual inspection procedure. They donated printed safety materials to give to drivers and safety directors. These included brochures on PBBTs, copies of the CVSA North American Standard Level I Inspection Procedure and Out-of-Service Criteria, and drivers pocketbook version copies of the FMCSA Safety Regulations. The CVSA also provided monetary support.

The Federal Motor Carrier Safety Administration (FMCSA) – The FMCSA provided guidance through participation in the PAG, with expertise in implementation of the PBBT test, and assisted with fine-tuning the procedure during the practice data collection run and demonstration. They also provided printed materials for drivers and safety directors. These included laminated drivers visor cards on Brake Inspection and Adjustment and on Safety at Highway-Rail Grade Crossings. The FMCSA also provided monetary support.

The Heavy Duty Brake Manufacturers Council (HDBMC) – The HDBMC provided guidance through participation in the PAG, with expertise on brake components as well as special brake inspections. They assisted on-site with inspection of special brake components and helped teach some of the inspectors how to recognize long-stroke brake chambers, and how to conduct the ABS lamp check. The HDBMC also provided monetary support.

The Ontario Trucking Association / Techni-Com (OTA/Techni-Com) – Provided guidance on special inspection procedures (free-stroke measurement) and copies of two safety handbooks: Practical Airbrake Handbook and Study Guide (ISBN 0-9680607-4-9), and Practical Cargo Securement (ISBN 0-9680607-9-X), for the drivers and safety managers from the cooperative volunteer fleets.

The Tennessee Highway Patrol (THP) – The THP provided the names of potential cooperative fleets to the research team for subsequent recruitment into the test program. The THP provided the facility for the data collection effort during July and September of 2008. THP officers checked the cargo securement prior to accepting a vehicle for testing. They conducted the CVSA Level I visual inspections and provided a copy of the inspection reports to the research team. They also conducted some of the PBBT tests, as they had been previously trained for this, and were willing to do so.

The New Mexico Department of Public Safety, Motor Transportation Division (NMDPS/MTD) – The NMDPS/MTD provided the facility for the data collection effort during

March of 2009. NMDPS/MTD officers checked the cargo securement prior to accepting a vehicle for testing. They conducted the CVSA Level I visual inspections and provided a copy of the inspection reports to the research team.

Project Description

The braking capability of a sampling of in-service commercial motor vehicles (CMVs) was to be assessed through the conduct of four different data collection efforts.

1) 20-mph stopping distance tests
2) Performance-based brake test (PBBT) measurements
3) CVSA Level I visual inspection
4) Special brake component inspection

In the earlier data collection efforts between 1942 and 1983[2,3,4,5,6,7] random vehicles were pulled from the traffic stream in four different States and, if the driver agreed, the 20-mph stopping tests were performed. In the current project, about three-fourths of the vehicles tested were provided on a pre-arranged basis by local cooperative fleets in Tennessee, with the balance being randomly selected from the traffic stream in New Mexico. These latter vehicles, again, were tested only if they agreed to volunteer after having the program explained to them.

---

[2] Brake Performance of Motor Vehicles Selected from the Everyday Traffic, Public Roads Administration, Washington, D.C., February, 1944.

[3] Saal, Carl C. and Petring, F. William, Braking Performance of Motor Vehicles, U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C., 1954.

[4] Stopping Ability of Motor Vehicles Selected from the GeneralTraffic, Public Roads – A Journal of Highway Research, June, 1957, V. 29, No. 8, pp. 177-195.

[5] Tignor, Samuel C., Braking Performance of Motor Vehicles, Public Roads, A Journal of Highway Research, v. 34, n. 4, October 1966, pp. 69-83.

[6] Winter, Paul A., 1974 Brake Performance Levels for Trucks and Passenger Cars, USDOT/FHWA/Bureau of Motor Carrier Safety.

[7] Hargadine, E.O. & Klein, T.M., Brake Performance Levels of Trucks, USCOT/FHWA/BMCS, DTFH61-83-C-00082 Final Report, September 1984.

The need for pre-arranged cooperative fleet participation was necessary due to cargo damage liability concerns. Following up on the recommendations from the THP, as well as independent pursuit of additional cooperative fleets, resulted in MOUs for participation from the following 12 fleets:

Dillard-Smith Construction
Harrison Construction
Huff & Puff Transport
L&D Trucking
Mayfield Dairy
MDS (Morristown Driver Service)
Pilot Travel Centers
Slay[8]
Specialty Transport (Pemberton Truck Lines)
UPS
Wal-Mart Transportation, LLC
Western Express

The total number of vehicles from these fleets were distributed as shown in Figure 1, where it can be seen that 21 of the vehicles were from Wal-Mart. It is well known in the industry that Wal-Mart has a very high level of commitment to good vehicle maintenance, recognized as being among the best. As such, the high percentage of Wal-Mart vehicles, combined with the extra care known to be taken by some of the volunteer local fleets before sending vehicles to the test site may somewhat bias the results. This will be seen in Chapter 3.

[8] A single Slay vehicle was tested at the Richmond, Indiana inspection facility during a demo for the Indiana State Police (ISP).

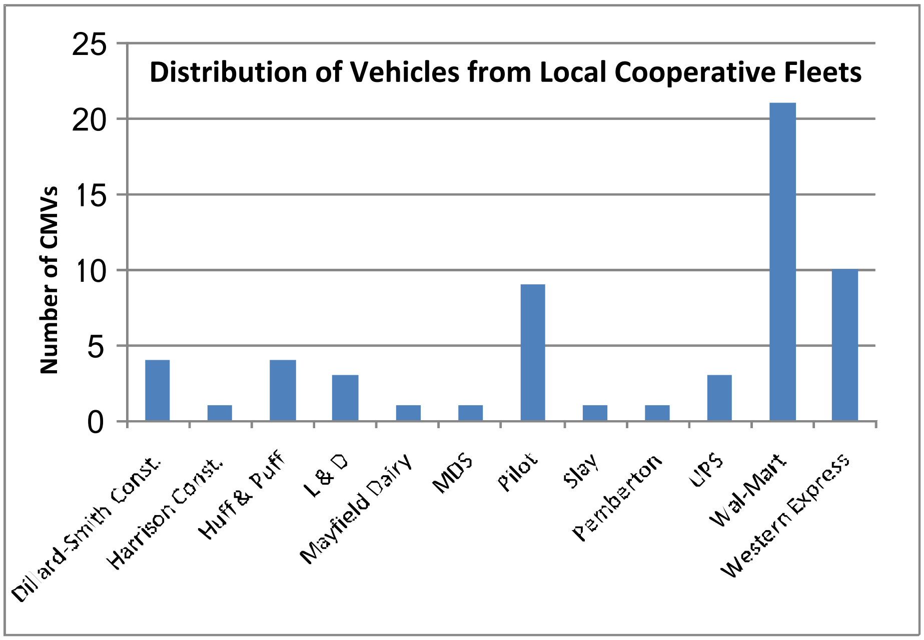


Figure 1. Chart. Distribution of 59 Vehicles from Local Cooperative Fleets Tested in Tennessee.

A final, though abbreviated, data collection period was made possible through additional funding from FMCSA, and followed the PAG recommendation for a more "random" in-service vehicle population. After requests to several other jurisdictions were met with concerns over liability similar to those from Tennessee, New Mexico agreed to participate, and a MOU was developed between NTRCI and the NMDPS/MTD. The testing was completed using their inspection facility near Gallup, NM, and a leased portable PBBT.

Another slight difference from the earlier studies is that drivers in the current study were offered an incentive to participate and compensation for their time. Since the total time for all the stopping tests, PBBT measurements and visual inspections was expected to take up to 90 minutes, it was felt prudent to offer drivers some incentive to participate. The incentive and compensation came in the form of seven different safety publications (see Figure 2), and a $50 pre-paid Visa card. This difference was not expected to affect the data in any way, but was deemed necessary to reflect the current economic and trucking industry conditions.

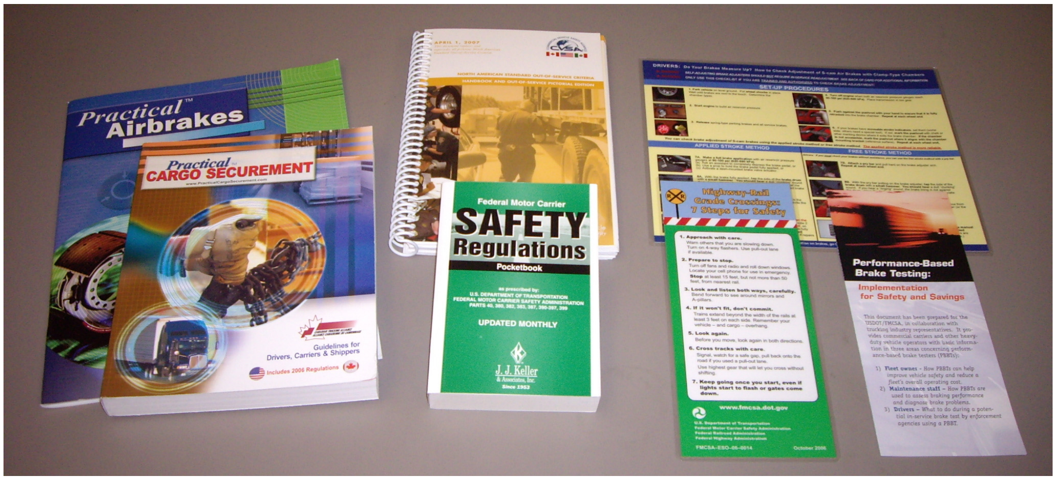


Figure 2. Photograph. Seven Safety Publications Provided to Drivers who Participated in the Braking Study.

After collection and compilation of the data, limited analysis was to be completed under the scope of this effort. Vehicle demographics and the results of a basic statistical analysis of the stopping performance of the population of vehicles tested are covered in this report. The complete data set, consisting of digital files from the stopping tests, PBBT measurements, the results of the visual inspection, and photographs and videos of the vehicles tested, have been collated on a CD and provided to NTRCI, who will distribute copies to the members of the PAG and other interested parties for subsequent detailed analyses, as desired.

Chapter 2 – Data Collection Methodology

This chapter describes each of the data collection methods, and provides an example, along with a brief explanation, of the results from each type of brake assessment method. For the cooperative local fleets, when a vehicle would arrive at the test site, both individual axle weights and gross vehicle weight (GVW) were obtained on the static platform scales. The vehicle then proceeded to the zone for the 20-mph stopping tests, where it was inspected for cargo securement. If the cargo securement was found to be acceptable to all parties, the vehicle was instrumented with the V-Box GPS and data acquisition system (DAQ), and the test protocol was explained to the driver. The brake assessments were obtained in the following order: two or three stops, from 20-mph, PBBT brake force measurements of the service brakes and parking brakes for those axles so equipped, and lastly the visual brake inspection. The layout of the test facility and location of each test is shown in Figure 3. Each separate brake assessment is described in subsequent sections of this Chapter.

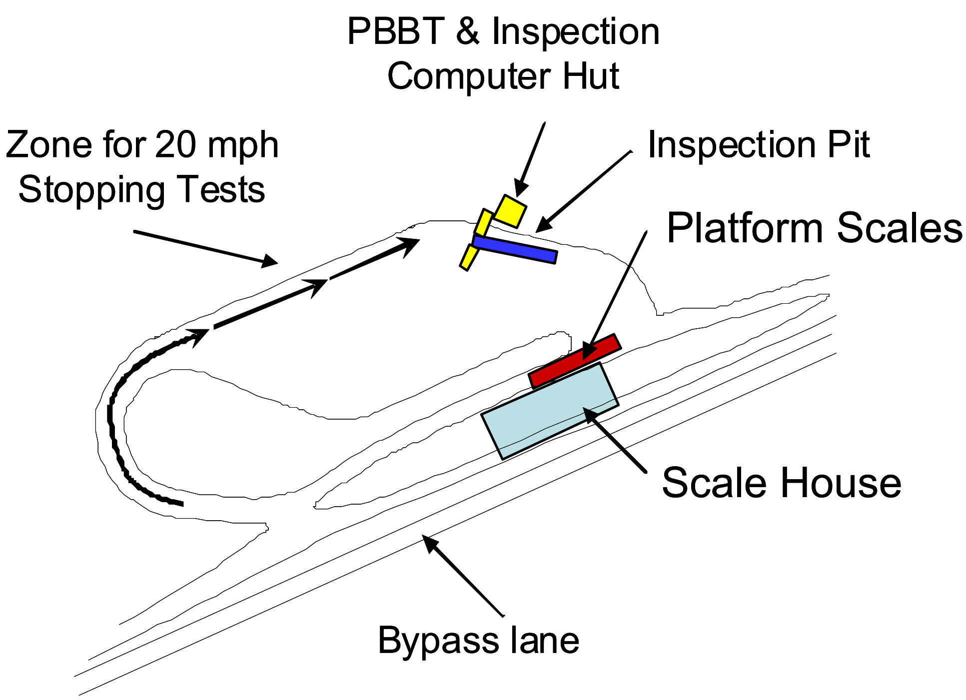


Figure 3. Diagram. Schematic Test Layout at the Grene County, TN Inspection Facility.

20-mph Stopping Test

An important facet of efficiently conducting the 20-mph stopping test is the ability to connect the DAQ and instrumentation to any vehicle, irrespective of the body configuration or bumper style. In the past, an instrumented 5th-wheel-type system has been used, with the trigger (to identify the initiation of the stop) either connected to the brake light switch, or to the brake pedal in the cab. Although this required a significant amount of time and effort for each vehicle, it was considered the most accurate method to obtain the stopping distance – through integration of the directly measured velocity versus time data. With many advanced technologies available today, a number of alternative methods were considered, including electronic decelerometer-based, laser-based and optical measurement systems. In the end, the GPS-based system offered the most advantages, and was selected for use in the program. The GPS-based system provides a position versus time data stream from which the stopping distance can be determined directly. If the data update and acquisition rates are adequately fast, the position data points are sufficiently close and accurate stopping distance can be obtained. The V-box III system has a 100 Hz data update and acquisition rate. At 100 Hz, for 20 mph, this gives a distance between data points of 3.52 inches, which was well within the 6-inch accuracy of the 5th wheel reported in the earlier studies. The accuracy of the GPS-based system decreases as the number of satellites it is accessing decreases, with a minimum of 5 satellites needed, as indicated by the manufacturer. In the current work, it was found that a minimum of seven satellites was best. In most of the tests conducted, eight or more satellites were available.

The accuracy of the V-Box III system was verified through comparison to a calibrated 5th wheel system in tests conducted by Link-Radlinski, Inc., and was found to be within one percent, as shown in Table 1.

Table 1. Comparison of Stopping Distance from 5th Wheel and GPS Systems

Initial Speed (mph)	5th Wheel Distance (ft)	GPS Distance (ft)	% Difference
20.03	31.3	31.16	-0.4
20.23	23.4	23.55	0.6
19.91	21.5	21.54	0.2
20.76	39.8	40.18	1.0
20.13	35.1	34.96	-0.4
22.13	32.0	31.78	-0.7

In the 20-mph stopping data collection effort, a minimum of two stops were conducted. The driver was instructed to conduct a full application hard stop, or panic stop. They were asked to “slam on the brakes”, and to hold their foot down until told to release. If the results were good hard stops in the opinion of the in-cab research team observer, and were nominally identical, this phase of the testing was terminated and the vehicle was sent on to the PBBT test. However, in general the first stop was somewhat tentative and at least three attempts were required to get two good stops. The best (shortest) of the stops was used in the data analysis. An example of the V-Box data is shown in Figure 4. All raw V-Box files are included in the archived data set provided to NTRCI.

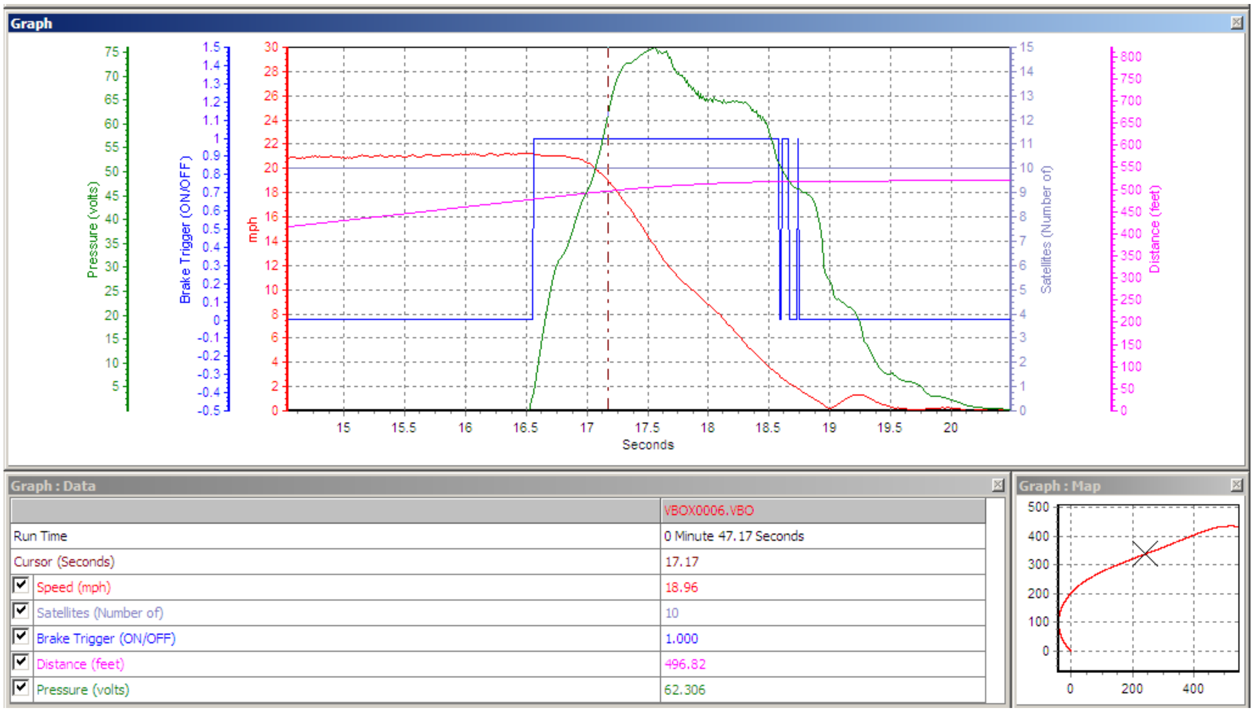


Figure 4. Graph. Example Report from V-Box DAQ of Stopping Distance Test

In the example shown, associated with the Y-axis on the left, the red curve shows the vehicle speed, starting at 21.25 mph and going to zero. The blue curve shows the brake trigger, which is zero when off and one when the driver has his/her foot on the brake pedal. The green shows the pressure transducer signal, in psi, although it is labeled volts. This voltage signal has already had the offset and gain applied in order to convert to psi. A maximum of 75 psi was reached in this test. On the right Y-axis, the light purple curve shows the number of satellites from which signals are being tracked, which in this example is steady at ten. The dark purple shows the vehicle distance, from the time the DAQ was armed and active. The data in the table below the graph show the values for each channel at the position of the cursor, shown as the dashed vertical line at 17.17 seconds, in this example. The red curve in the box in the lower right hand corner shows a bird's eye view of the path of the vehicle during the active data acquisition period, with the red "X" corresponding to the cursor position. Each data file can be viewed and manipulated using the V-Box software, which was included on the data CD.

Although the V-Box display unit had a direct readout of the current vehicle speed, which allowed the in-vehicle observer to signal to the driver when to initiate the hard stop, stops were seldom initiated from exactly 20-mph. However, a correction factor could be applied as long as the stop was initiated from between 18 and 22 mph, in other words, within 10 percent of the target velocity. This "corrected stopping distance", $Dist_{corr}$, is what was recorded. In the example in Figure 4, the actual initial speed was 21.25 mph. The correction formula used was:

$$Dist_{corr} = (V_{20}/V_{meas})^2 \, Dist_{meas}$$

Figure 5. Equation.

Where:

$Dist_{corr}$ is the corrected stopping distance, (in this case, corrected for 20 mph)
V_{20} is the velocity for which the stopping distance is required (in this case, 20 mph, or 32 ft/sec)
V_{meas} is the actual speed at which the stop was initiated
$Dist_{meas}$ is the actual stopping distance measured for the stop initiated from V_{meas}

PBBT Measurements

After the 20 mph stopping tests were completed, the V-Box DAQ and air pressure transducer were removed and the vehicle was staged just in front of the in-ground PBBT. At this point the driver was briefed on the PBBT test and a new pressure transducer, connected to the PBBT's internal DAQ was attached to the same glad-hand coupling. For this brake test the driver was asked to position each axle into the pair of powered rollers and to ensure there was between 90 and 100 psi of air pressure in the reservoirs prior to the start of the test. When the rollers were first started, an initial value of rolling resistance was automatically recorded by the PBBT software, after which the driver was asked to slowly apply his/her brakes over a ten-second period, until the pedal was at the floor. In this way, the maximum available brake force (BF) was measured. The brake force on each individual wheel end was recorded, and the test was terminated either automatically when the brake force exceeded the grip between the roller and the tire (known as lock-up), or when no further increase in brake force was observed over a full wheel revolution, and the PBBT operator stopped the test manually.

The individual wheel loads (WL) were also measured, and the calculated BF/WL was recorded by the PBBT software. As in the stopping test, if the results were not felt to be the best effort (e.g. the driver may not have applied the brakes fully), the test on that axle was repeated. This is the same procedure as used by CVSA inspectors when using a PBBT as part of their inspection, as was the case for the Greene County Inspection facility where the testing took place. This procedure is repeated for each axle. For axles equipped with parking brakes, after the rolling resistance measurement was complete, the driver was asked to apply the parking brake. For these tests the brakes on the non-tested axle were set prior to the start of the rollers to help hold the vehicle in place when the spring brake on the tested axle comes on.

An example of the output from a PBBT assessment is shown in Figure 6, in a simplified summary form, for the whole vehicle. This vehicle, with a measured weight of 59,010 lbs, showed an overall efficiency, or BF_{tot}/GVW, of 54.5 as compared with the minimum requirement per FMCSR 393.52 of 43.5. The individual axle efficiencies are also shown, along with the total brake force for each axle.

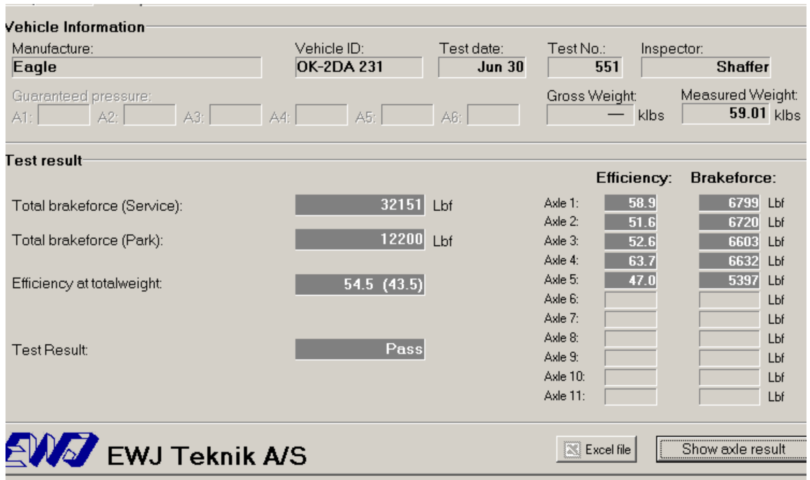


Figure 6. Screen Shot. Example of the Output of a PBBT Assessment for the Whole Vehicle.

Figure 7 shows the individual results for axle four. Note that the left and right side values for drag (rolling resistance), service brake force and weight are shown. The ratio of the latter two is the efficiency. The park brake force for each wheel on this axle is shown. The left-to-right imbalance and maximum air pressure reached are also shown.

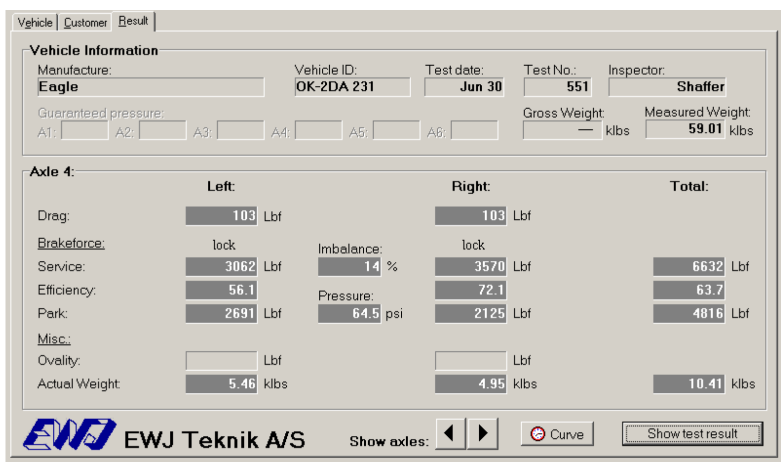


Figure 7. Screen Shot. Results for Axle 4 Individually.

Figure 8 shows an example of the brake force versus time plot for an individual axle from another vehicle. In this case the left brake of axle 5 is clearly weak, and was subsequently found during the visual inspection to be ½-inch beyond the adjustment limit.

The complete time history PBBT files for each axle for all vehicles tested has been archived for this project in the form of an Excel file. These files are part of the archived data set and are available for further analysis.

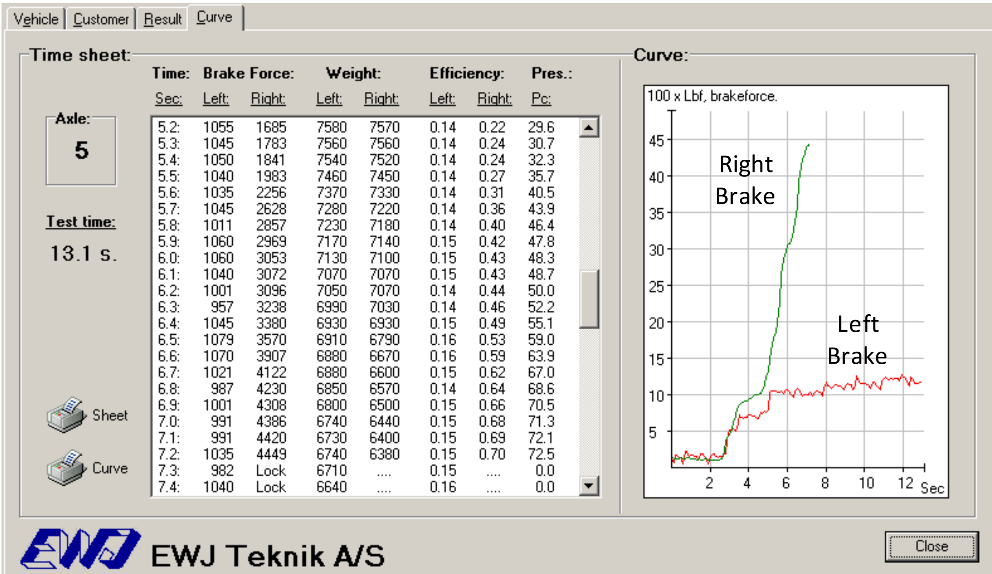


Figure 8. Screen Shot. Example of an Individual Axle Plot from a PBBT Test, Showing a Weak Left Brake.

CVSA Level I Visual Inspection

The North American Standard (NAS) CVSA Level I inspection consists of a 37 step visual inspection of 14 critical items on and underneath a vehicle, as well as an examination of the vehicle registration papers, operator's commercial driver's license (CDL), medical certificate, and driver's record of duty status (log book). The intent of this inspection is to identify any driver violations or vehicle defects which, should any of these be considered so severe as to render the vehicle as an "imminent hazard", enable the driver or vehicle to be placed out of service (OOS) until such time as the defect(s) is repaired.

Of these 14 critical vehicle inspection items, 16 separate OOS criteria are covered under the braking system. One of the key metrics for the brake inspection is the measurement of pushrod stroke. This requires the inspector to mark and measure the movement of a reference position on the push rod at the position when the brakes are fully released and then with the brakes fully applied, from a starting pressure of between 90 and 100 psi. Because of the different types and sizes of brake chambers, a table of recommended adjustment limits is used to determine compliance. Under the CVSA NAS, a vehicle is allowed no more than 20 percent of its brakes to be considered defective (e.g. stroke beyond the recommended adjustment limit) to avoid being placed OOS. Certain defects in and of themselves are considered critical, and can be used to place a vehicle OOS without referring to the 20 percent criteria. Examples of this include mismatched brake chamber or slack adjuster sizes on the left and right side of the steer axle.

Special Brake Inspections

The industry-partner HDBMC representatives from the PAG assisted with the special brake inspections. These included closer inspection of any parking brakes (spring brakes) that showed up as weak on the PBBT test results, measuring the exposed push rod length (to check whether one side of an axle was significantly different than the other), and measuring the push rod free stroke. In the free stroke measurement, the push rod is manually pulled out until the brake pads come in contact with the drum. This was accomplished with the help of a pry tool. The difference between free stroke and applied stroke is that both component deflection and compression of the brake pads occur under the application of 90 to 100 psi, thus leading to a longer stroke. While there is no regulation for free stroke limit, industry practice provides a limit of no more than ¾-inch for free stroke. Also, this is one form of stroke measurement that a driver can conduct by him/herself. It is reasonable to expect a correlation between free stroke and applied stroke, and the data collected in this project can be used in the future to verify this expectation.

Chapter 3 – Comparison of Summary Results from Local Cooperative Fleets and Random In-Service Vehicles

Gross Vehicle Weight Comparisons

Figure 9 shows the distribution of GVWs from all 82 vehicles, the 59 volunteer local cooperative fleet vehicles tested in Tennessee, and the 23 random vehicles tested in New Mexico. Two-thirds of all vehicles exceeded 60,000 lbs GVW, or 75 percent of the legal road limit of 80,000 lbs. The heavier the vehicle, the higher the demands on the brakes to achieve a minimum stopping distance. Between the two groups, 66 percent of the vehicles from the local cooperative fleets exceeded 60,000 lbs compared with 82 percent of the random in-service vehicles.

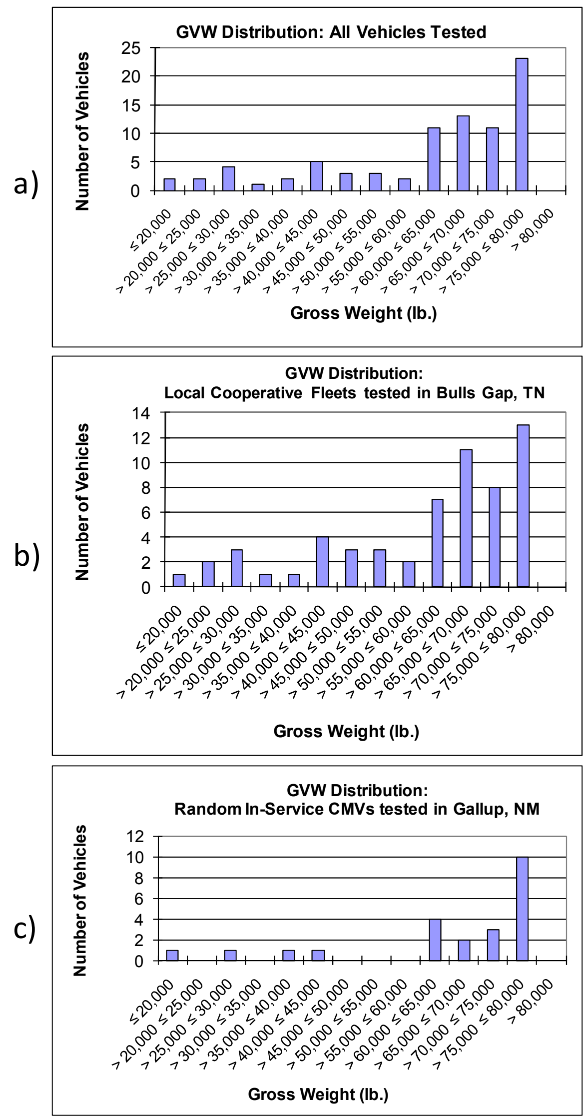


Figure 9. Charts. Distribution of GVW Among a) All Vehicles Tested, b) Local Cooperative Fleet Vehicles, Random In-service CMVs.

Stopping Distance Comparisons

The distribution of stopping distances is shown in Figure 10. It can be seen that the local cooperative fleet vehicles did better (had shorter stopping distances) than the random in-service vehicles, having an average stopping distance of 34.4 feet versus 38 feet, respectively. Seven of the 59 cooperative fleet vehicles did not meet the 40-foot stopping distance requirement, while six of the 21 random vehicles did not. In terms of percentage, 11.9 percent of the cooperative fleet vehicles did not meet the requirement, compared with 28.6 percent of the random in-service vehicles. It is clear that the random in-service vehicles, on average did not perform as well as cooperative volunteer fleets.

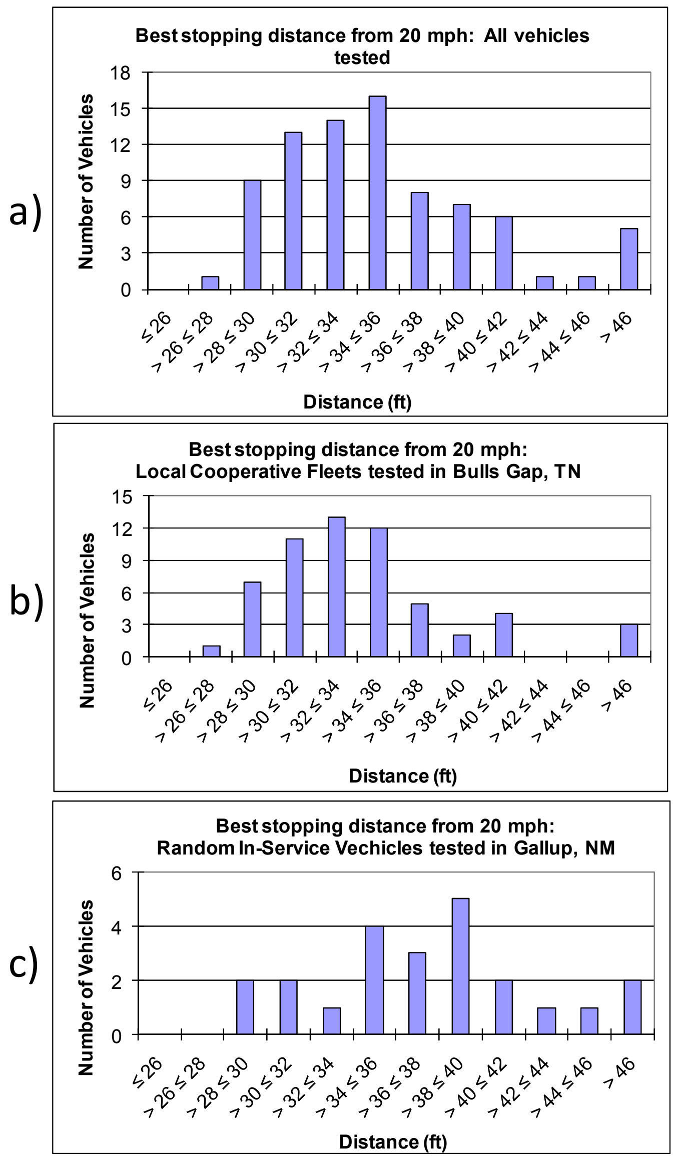


Figure 10. Charts. Distribution of Stopping Distances Among a) All Vehicles Tested, b) Local Cooperative Fleet Vehicles, Random In-service CMVs.

PBBT-measured Braking Performance Comparisons

The distribution of PBBT-measured braking performance is shown in Figure 11. The local cooperative fleet vehicles did better than the random in-service vehicles comparing braking force as a percentage of GVW (BF_{tot}/GVW), with an average of 56.1 versus 48.0, respectively. Two of the 59 cooperative fleet vehicles (3.4 percent) did not meet the minimum required BF_{tot}/GVW of 43.5, while four of the 21 random vehicles (19.0 percent) did not. Again, the random in-service vehicles on average did not perform as well as cooperative volunteer fleets.

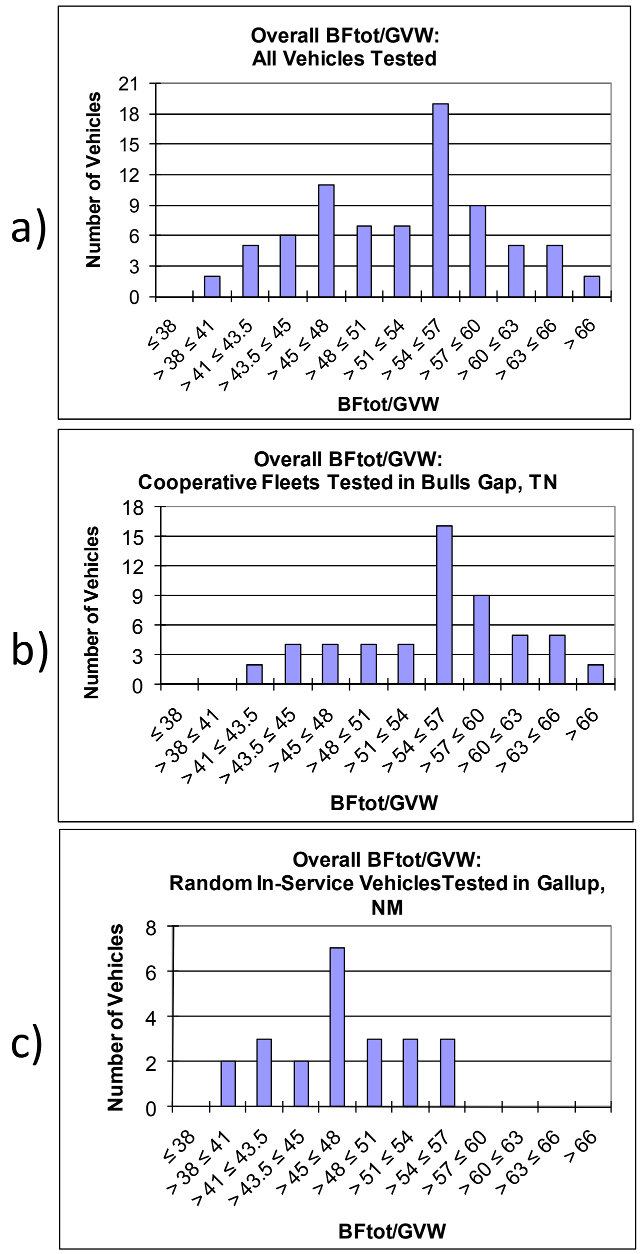


Figure 11. Charts. Distribution of Braking Force as a Percentage of GVW, as Measured by a PBBT Among a) All Vehicles Tested, b) Local Cooperative Fleet Vehicles, Random In-service CMVs.

Discussion of Comparisons

Of the 82 vehicles tested, it was found that 13 were unable to meet the minimum stopping distance requirement. It was also found that seven of the 82 were not able to meet the current minimum PBBT criterion. However, only three of those that failed to meet the minimum PBBT requirements were within the set of those unable to meet the stopping distance requirement. These results imply that the driver can have considerable (negative) influence on the stopping test performance. This also implies that the two different assessment methods may require further consideration if equivalency is desired for regulatory purposes. Equivalency may never be achieved, however, because the PBBT measures maximum brake performance capability, while the stopping distance is a composite measure incorporating the vehicle's foundation brakes' capability, the air system delay time, and the driver's brake pedal input. Additional data analysis, using the application air pressure signal, would be required to quantify the driver influence-effect. Further testing, incorporating air pressure transducers at both the glad hand and brake chambers (or distribution valves), would be required to quantify the air system delay time.

The mean value of stopping distance for the randomly selected vehicle population, at 38.0 feet, was more than three and a half feet greater than that of the cooperative local fleet vehicles, at 34.4 feet. Although the population set was small, the comparison was found to be statistically significant. Similarly, the mean value for BF_{tot}/GVW, as measured by the PBBT was lower (worse) by 15 percent for the random in-service vehicle population, at 48.0, than that of the cooperative local fleet vehicles at 55.5.

These results were not surprising, as it can be expected that most fleets volunteering to provide vehicles for a safety study would likely ensure that the vehicles provided would be well maintained. Indeed, it was discovered that some of the vehicles were being inspected and worked on prior to their dispatch to the test site.

Conclusions from Project

Data collection related to braking performance from CMVs can be efficiently obtained using modern equipment and data acquisition systems. Based on the present study, the following is readily achievable, if only one type of data are desired:

- Stopping test only data can be collected from at least 15 vehicles per day.
- PBBT test only data can be collected from at least 40 vehicles per day.

Random in-service vehicles do not perform as well as pre-arranged vehicles from cooperative fleets.

- One in 3.5 randomly selected in-service CMVs could not meet the required stopping distance of 40 feet from 20 mph.
- One in eight cooperative participating local fleet CMVs could not meet the required stopping distance of 40 feet from 20 mph.
- One in five randomly selected in-service CMVs could not meet the minimum PBBT-measured BF_{tot}/GVW requirement of 43.5 percent.
- One in 30 cooperative participating local fleet CMVs could not meet the minimum PBBT-measured BF_{tot}/GVW requirement of 43.5 percent.
- Limitations on data which are representative of the at-large CMV population can be imposed when using pre-arranged vehicles from cooperative fleets, as these vehicles tend to be better maintained than the average in-service vehicle.

Only three of the seven vehicles that failed to meet the minimum PBBT-based brake performance criteria were among the 14 vehicles unable to meet the minimum stopping distance test. As such:

- Correlations should be sought between the different methods of brake assessment, so that minimum safety requirements and inspection procedures are more uniform across the different methods.
- Further analysis of the data collected in this project is warranted to quantify the driver influence on stopping test results.

Additional data collection, focusing on random in-service vehicles is warranted to obtain a larger population base than the 23 random vehicles tested in this study. A group program, with pre-agreement from States to participate would be most effective.

Chapter 4 – Description of Data Compiled and Archived

For every vehicle tested in this project, the following pieces of data exist, and have been written to a CD for distribution to the PAG:

1) A summary test log, an example of which is shown in Figure 12. The log contains the vehicle axle configuration and description, individual axle weights and GVW, the cargo type and the time of start and stop of all testing and inspections. In the 20-mph stops section, the filename, starting speed, maximum air pressure reached, stopping distance and corrected stopping distance for each 20 mph stopping test. The PBBT section contains the brake force and wheel load values and BF/WL calculation for each axle and for the overall vehicle. The visual inspection section tabulates the free stroke, applied stroke and exposed pushrod length measurements taken during the visual inspection.

2) V-Box files of each stopping test, which can be viewed using the V-box software, as well as Excel files of the same data for specific analysis. A word document containing a graph of the data in each V-Box file is also included.

3) PBBT data files of axle-by-axle measurement for each vehicle have been converted to Excel for further analysis.

4) Photographs and videos of vehicles, as were able to be obtained, and components of interest found during the visual inspection.

A description of the CD directory and instructions for how to navigate through the data can be found in Appendix A.

Date:	10/2/2008						
Time Truck Contacted:	7:33 AM	**Color:**	White	**Truck Mfr:**	Int./ Eagle	**Trailer Mfr:**	Great Dane
		Axle Config:	3-S2			**Trailer Type:**	Box
		Lic. Plate:	OK 2CX720	**Company**	Wal-Mart	**DOT number:**	00063585

Driver Briefed?	Yes		**GVW**	60,360	
Cargo Description	Gen Merchandise		**Axle Weights**		
Driver Agreed?	Yes	**If not, time departed:**	**Axle 1**	11,300	Tandems
			Axle 2	13,520	25,700
			Axle 3	12,180	
Cargo Securement Check by THP	Not done		**Axle 4**	12,320	23,360
Concur by HDBMC	-		**Axle 5**	11,040	
Concur by Research Staff	-	**If not OK, Time departed:**	**Axle 6**		

20-mph Stops

Time of first run: (vehicle instrumentation completed)	7:53 AM	Speed	Max. Air Press	Distance	Corrected Dist.*	Notes
1st Stop Filename:	051	20.0	84.0	33.5	**33.6**	Good stop, but let off pedal a bit
2nd Stop Filename	052	19.8	102.0	32.4	**32.9**	Good stop, but let off pedal a bit
3rd Stop Filename	053	19.4	102.0	31.0	**33.5**	
Time of completion:	8:01 AM					

* The distance calculated from exactly 20 mph stop

$$CorrectedDist = Dist*\left(\frac{20}{OriginalSpeed}\right)^2$$

PBBT Test

Time of first axle in rollers: 8:07 AM

VIN Tractor	2HSCNASR84C081836					
VIN Trailer	1GRAA06296G339758	**Year of mfctr:**	**Tractor**	2003	**Trailer**	2005

	Left			Right					
	BF (lbf)	**WL (klb)**	**BF/WL**	**BF (lbf)**	**WL (klb)**	**BF/WL**	**Lift Axle?**	**Left Parking BF**	**Right Parking BF**
Axle 1	2730	5740	0.48	3004	5530	0.54		N/A	N/A
Axle 2	2676	6250	0.40	3016	6600	.046		3140	3204
Axle 3	2460	7160	0.41	2974	5220	0.57		N/A	N/A
Axle 4	3540	5320	0.67	3126	3560	0.88		2628	2696
Axle 5	3643	5100	0.71	4005	428/0	0.74		2598	2911
Axle 6									

Time pulled off of PBBT and Printout completed: 8:24 AM

Overall Vehicle BF_{tot}/GVW: 57.4

Visual Inspection

Time of start: 8:30 AM

	Apply Stroke		Exposed Push Rod Length		Free Stroke		Chamber Size (L = long stroke)		Edge Code	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Axle 1	1.25	1.25	2.25	2.25	1.00	0.50	20L	20L		
Axle 2	1.50	1.50	2.25	2.50	0.50	0.50	30L	30L		
Axle 3	1.50	1.25	2.50	2.50	0.50	0.75	30L	30L		
Axle 4	1.25	1.50	7.00	2.00	0.75	0.50	30	30		
Axle 5	1.25	1.25	7.00	7.00	0.75	0.75	30	30		
Axle 6										

Time Completed: 8:50 Lots of discussion

Figure 12. Chart. Example of Summary Data Log for Each Vehicle Tested in this Program.

Chapter 5 – Recommendations for Possible Additional Analyses

Although the scope of the project was limited to the collection of the data, and did not permit detailed analyses beyond that presented above, many additional useful comparisons are possible. This section provides some recommendations for analyses to be done with the available data.

Comparison with Earlier Studies

This modest data collection effort is the first after a 25 year hiatus, of a series of stopping tests that took place approximately every 10 years since the 1940s. The performance of the current set of vehicles can be compared with that of the vehicles tested in years past. As an example, we have extracted the data from the 1983 study reported by Hargadine and Klein, in which they show both the 1983 and 1974 data, and have compared it with our data from the first two collection blocks, taken in Tennessee. As shown in Figure 13, the modern vehicles from the local cooperative volunteer fleets did slightly better than their predecessors, which were random in-service vehicles. The same analysis could be done for the random in-service vehicles tested in this project, keeping in mind that the sample size is rather small.

AVERAGE STOPPING DISTANCE (feet)
DETERMINED BY SHORTEST STOPPING DISTANCE

VEHICLE CONFIGURATION	FMCSR Req. (20 mph)	1974	1984	Percentage Change
Single Unit Truck				
2-axle, <=10,000 lbs.	25	25.6	27.6	8 *
2-axle, >10,000 lbs.	35	32.7	34.7	6 *
3-axle	35	39.3	36.4	-7 *
Tractor-Semi Combination				
2-S1	40	35.8	38.1	6 *
2-S2	40	36.4	35.7	-2
3-S2+	40	38.4	38.9	1
Truck-Trailer Combination	40	42.5	39.9	-6 *
Double Bottom Trailer	40	43.8	45.6	4

Note: * means the absolute difference from the 1974 stopping distance was statistically significant at the a = .10 level of significance, two-tailed test (See Appendix A).

Average Stopping Distance (ft.) Determined by Shortest Stopping Distance (2008/2009)						
Vehicle Configuration	Avg. Best Stopping Dist (ft)	Requirements (from 20 mph)	Stopping Dist. Sample Size	Avg. PBBT BF_{tot}/GVW	PBBT Requirements	PBBT Sample Size
Single Unit Truck						
2-axle, <= 10,000 lbs.						
2-axle, > 10,000 lbs.	32.1	< 35 ft.	1	54.2	> 43.5	1
3-axle	34	< 35 ft.	5	69	> 43.5	4
Tractor-Semi Combination						
2-S1						
2-S2	33.8	< 40 ft.	1	54	> 43.5	1
3-S2	35	< 40 ft.	51	55	> 43.5	49

Figure 13. Chart. Comparison of 1983 Stopping Distance Data with that Collected in the First Two Blocks of this Study.

Normalization of Stopping Distance by Air Pressure

As was discussed in Chapter 3, the influence of the driver on the stopping distance tests can be considerable. The collected air pressure data can be used to determine whether the driver was giving a full application, as well as how long it took for the pressure to fully build (at least to the glad hand connection) from the time the brake pedal was pressed.

Calculation of Deceleration

Although the V-Box output available on the in-cab instrument board, which was recorded on the data log sheet, showed only the measured and corrected stopping distance, and air pressure, the stored position versus time data can be used to obtain velocity versus time, the slope of which can be used to obtain decelerations.

Correlation of Free Stroke with Applied Stroke

Because measurement of applied stroke requires marking of a reference position on the push rod, and then someone or something to press and hold the brakes for a measurement of the change in position of this mark, it is nearly impossible for a single individual, such as a mechanic or the driver, to make such a measurement him/herself. The free stroke measurement is conducted with a single manual pull of the push rod, which can be done by an individual using a pry tool. As such, if a correlation exists between the free stroke measurement and the applied stroke measurement, an opportunity exists for development of additional regulatory and/or inspection criteria to help improve highway safety.

Additional Data Collection

The total sample set from the local cooperative fleets was limited by the ability to stage the arrival of the vehicles, as well as many circumstances beyond the control of the research program. Due to Hurricane Ike[9], vehicle availability was limited from several of the fleets in the second data collection block. Wal-Mart had a local distribution center nearby, so most days at least one Wal-Mart vehicle could be tested. On average only two to three vehicles per day were tested in Tennessee. In New Mexico, where there was virtually a constant stream of vehicles available from which to seek participation, it took no more than ten to fifteen minutes to find a driver to agree to participate. On the most productive day of the project, a total of eight vehicles were tested over a 10 hour period, an average of 75 minutes each. Given that the data collection was comprised of three different brake assessments (stopping tests, PBBT, visual inspection), it is clear that many more stopping tests only could be accomplished in a day.

[9] From September 5-8, 2008, Hurricane Ike caused extensive damage and knocked power out in a wide area from Galveston Texas up through the Ohio Valley and into Canada. As such, two of the participating fleets were occupied with the cleanup and recovery efforts for several weeks afterwards, namely Pilot and Dillard-Smith Construction.

A cursory examination of the average time from first contact of the driver, weighing the vehicle, inspecting the cargo for securement, instrumenting the vehicle and completing the three stopping tests only, found this to be less than 20 minutes. As such, even with 15 minutes to find the next vehicle, it is expected that a minimum of 2 vehicles per hour can be tested, or 16 vehicles in an eight-hour shift. Similarly, examination of the PBBT times indicated an average of between 10 and 12 minutes, including data entry and hook-up of the air pressure transducer, so that at least 40 vehicles per day could have their brakes tested using a PBBT.

If the FMCSA, National Highway Safety Administration (NHTSA) or the National Transportation Safety Board (NTSB) were interested in obtaining data from several hundred vehicles, the example set by the testing done in New Mexico could be used to estimate the level of effort required to collect such data. In principle, testing could take place in several States simultaneously if separate DAQ systems were available. For example, stopping test data from over one thousand vehicles could be collected in a four week period with testing conducted at four different sites,

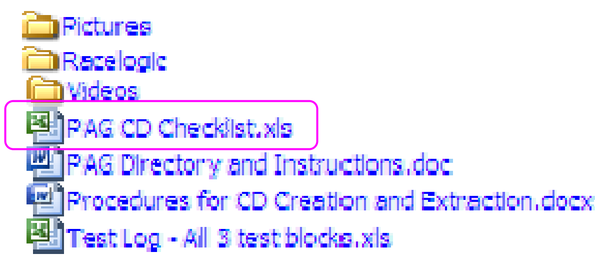
Appendix A – Description of, and Navigation through the Data CD Directory

The PAG Directory and Instructions, found on CD 1, is intended to help the user quickly find specific information on these two CD's containing in-service commercial motor vehicle (CMV) braking test data collected at the I-81 S weigh station, mile marker 21, in Bulls Gap, Tennessee in 2008, and the I-40 E/B Gallup POE station in Gallup, New Mexico in 2009. (The directory screen shots were created using Microsoft Office 2003, and may look slightly different in Office 2007.)

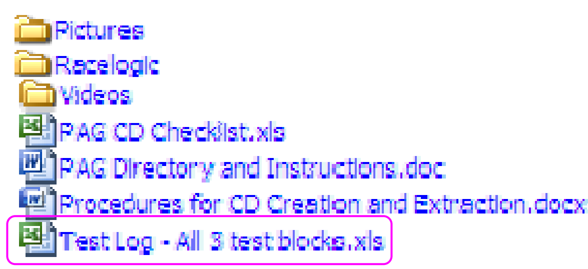
Sections discussed in this directory include:

- **1) Viewing Summary Data, Videos, and Photos**
- **2) Manually Viewing Raw Data**
- **3) Viewing Stopping Test Data using VBox Software**
- **4) Utilizing the links within the "Test Log – All 3 test blocks" excel file**

The "PAG CD Checklist" (highlighted below), found on both CD 1 and 2, is a quick overview of the available raw data, videos and photos for each test. The blue links within this file open the raw data folder for each test **only on CD 2**.

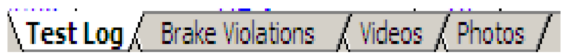


1) **Viewing Summary Data, Videos, and Photos:** Open the "Test Log – All 3 test blocks" excel file. The test log excel file on both CD 1 and 2 is the same, but the links are connected to different data on each CD (Refer to section 4).

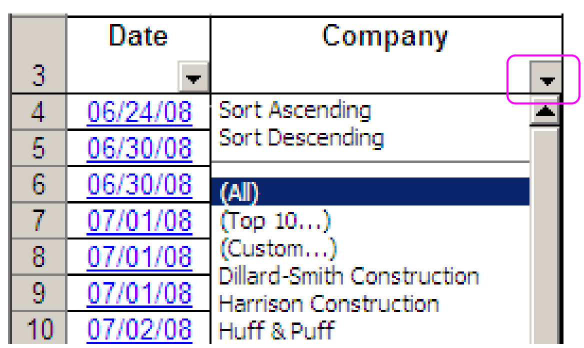


a. There are four tabs which assist in navigating to the desired data:

   i. Test Log
   ii. Brake Violations
   iii. Videos
   iv. Photos



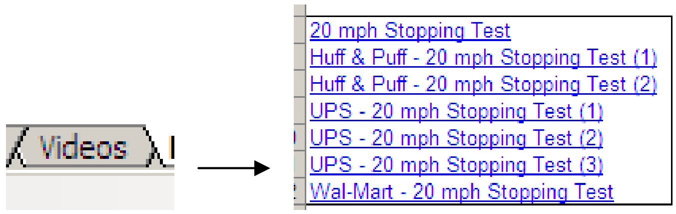
b. Test Log Tab
   i. Includes all data recorded for each test
   ii. Clicking on the blue links opens the raw data for a particular test (Refer to point two for opening the raw data manually)
   iii. Sort the test log using the auto filter in the lower right corner on the column headings.
      1. Choose "Sort Ascending", "Sort Descending", "(Top 10…)", "(Custom…)" to sort within a range, or choose to sort by specific data in the column
      2. Choose "(All)" to display all of the data again after sorting
         a. Another option to display all data is to click the "Data" tab → Filter → Show All



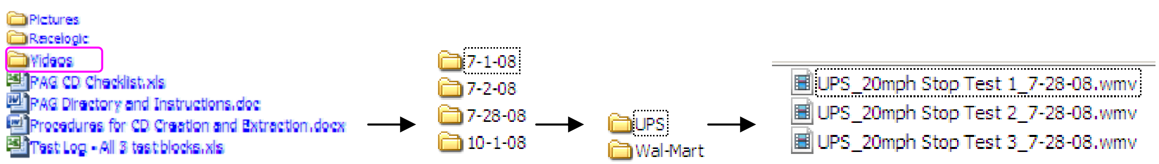
c. Brake Violations Tab
   i. Includes brake violations noted in the vehicle examination report
   ii. Identifies vehicles that did not meet the requirements for the 20 mph stopping test and/or the Performance Based Brake Test (PBBT)

d. Videos: There are two methods for viewing videos taken during testing.
   i. Click on the "Videos" tab in the Test Log excel file

1. Click on a blue link to watch a video for a particular test



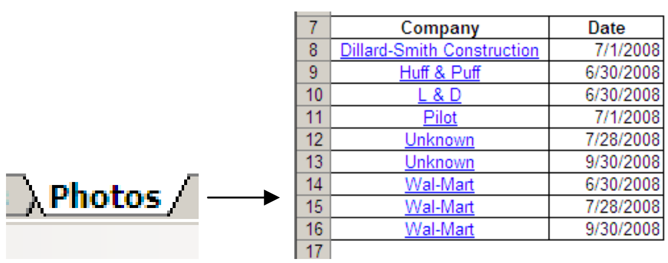
ii. Click on the “Videos” folder and select the pertinent folders and videos.



e. Photos: There are three methods for accessing pictures taken during testing.

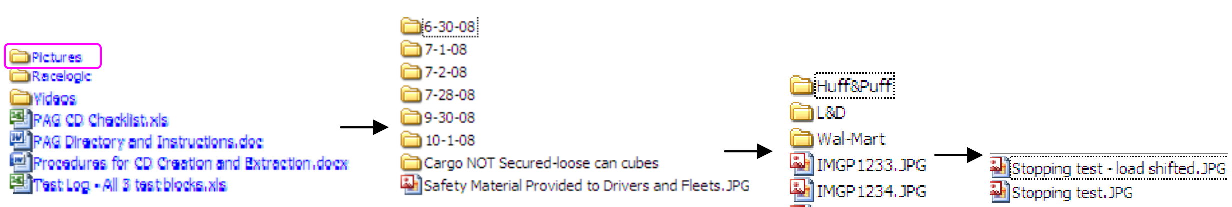
i. Click on the “Photos” tab in the Test Log excel file

1. Click on the blue link to see the pictures for a particular test



7	Company	Date
8	Dillard-Smith Construction	7/1/2008
9	Huff & Puff	6/30/2008
10	L & D	6/30/2008
11	Pilot	7/1/2008
12	Unknown	7/28/2008
13	Unknown	9/30/2008
14	Wal-Mart	6/30/2008
15	Wal-Mart	7/28/2008
16	Wal-Mart	9/30/2008
17		

ii. Click on the “Pictures” folder and select the desired folders or pictures.

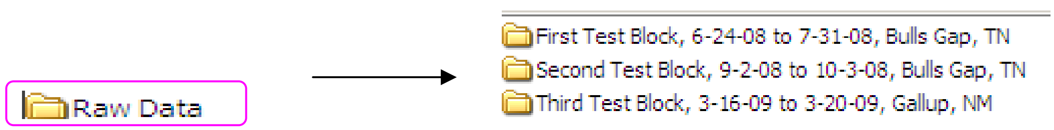


iii. Pictures are also organized by date in the individual raw data folders discussed in section two of this directory.

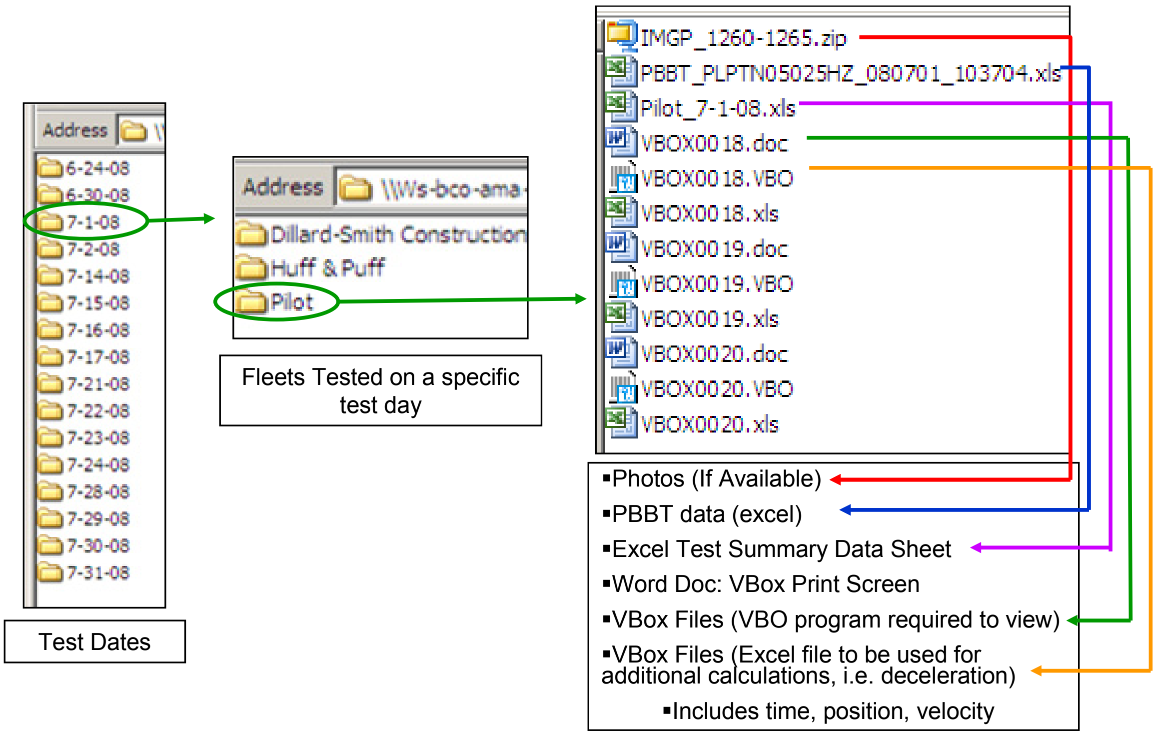
2) **Manually Viewing Raw Data:** The raw data are organized on CD 2 in folders by the date the test was conducted. There are two methods for obtaining the raw data. If you don't use the blue links in the "Test Log – All 3 test blocks" file, use method b.

a. Click on the links in the test log on CD 1 (discussed in point 1b), which automatically connects each test to its raw data.

b. Open the "Raw Data" folder on CD 2, and select the appropriate folder containing the raw data for each test conducted during the indicated time frame.



i. Each test block folder is organized by the day of testing, and then company tested. The figure below also shows all the possible data gathered for one test vehicle available on CD 2.

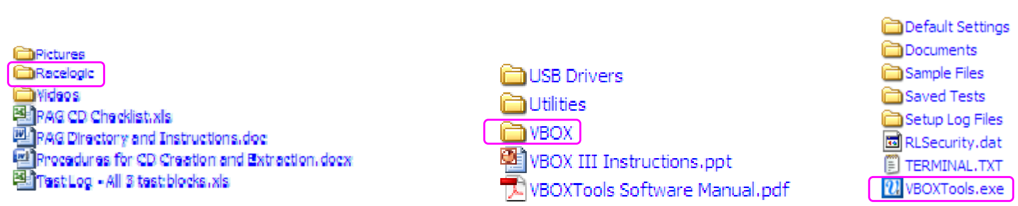


3) Viewing Stopping Test Data using VBox Software

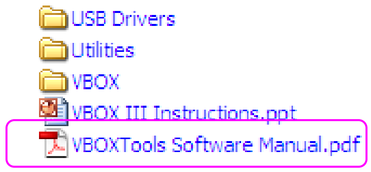
a. The stopping test data was recorded using a Racelogic VBox III GPS data acquisition system. The software is provided in the Racelogic folder on CD 1.

   i. Double click VBOXTools.exe file to open

      1. Click "Register Later" to open the software



b. View the "VBOX III Instructions" or "VBOXTools Software Manual" for an explanation on how to view the data in a .VBO file



c. The file “Procedures for CD Creation and Extraction” also contain a brief overview on how to view files using the VBoxTools software.

4) Utilizing the links within the “Test Log – All 3 test blocks” excel file

a. The excel file “Test Log – All 3 test blocks” is exactly the same on CD 1 and 2

i. The “Test Log” and “Brake Violations” tabs (discussed in sections 1b and 1c of this directory) contain links to the raw data for use on **CD 2.**

ii. The “Videos” and “Photos” tabs contain links to videos and pictures for use on **CD 1.**