1.0 EXECUTIVE SUMMARY

This report presents the results of the field test portion of the "Development, Evaluation, and Application of Performance-Based Brake Testing Technologies" sponsored by the Federal Highway Administration's (FHWA) Office of Motor Carriers.

Features of Performance-Based Brake Testers

A performance-based brake tester (PBBT) is a device that can assess the braking capabilities of a vehicle through a quantitative measure of either individual wheel brake forces and/or overall vehicle braking performance in a controlled test. The primary benefit of the PBBTs to both the enforcement and the motor carrier communities is that they can provide an objective, consistent, and standard measure of the braking performance of a vehicle, irrespective of the brake type (disk or drum), energy supply (air, hydraulic, electric, or spring), or application method (s-cam, wedge, piston, spring, or lever and cable). PBBTs can rapidly identify weak brakes or underbraked vehicles that are imminent hazards and, hence, should be placed out of service, without requiring an inspector to crawl beneath the vehicle. Current screening is done based on an individual Safety Inspector's knowledge and experience. Actual Commercial Vehicle Safety Alliance (CVSA) Level 1 vehicle inspections take about forty minutes each and involve visual exam for components, measures of push rod travel on air-braked vehicles, and sensory detection of other defects such as air leaks. As such, accurate screening is important because only approximately 12 vehicles a day per inspector can be checked. Focusing on the vehicles most likely to have problems is the key to making sure inspectors' time is well spent. The data from PBBT field tests described in this report revealed that at least 30 and as many as 80 five-axle vehicles per day can be screened for CVSA inspection using one of the PBBT technologies.

Roller Dynamometers (RDs) offer significant diagnostic capabilities, including brake timing, threshold pressures, and rolling resistance assessment. Flat Plate (FP) testers offer the highest throughput and dynamic wheel load measurements. The breakaway torque tester (BTT) can measure brake forces to full air system or hydraulic capacity, irrespective of axle loading. In-ground units of all types of PBBTs can be enhanced to potentially provide certified vehicle weights.

For potential purchasers of a PBBT, such as enforcement agencies, fleets, maintenance shops, or other interested parties, additional detailed information is presented in this report to assist in determining the type of technology or the specific unit that might best suit their requirements.

Field Testing Program Description

Various first and second-generation prototype PBBTs, designed for use on commercial vehicles, have been evaluated. RDs, FP testers, and BTTs were tested in the field at roadside inspections for at least one year by CVSA certified state inspectors. Two additional brake technologies (infrared [IR] brake drum temperature measurement device and an on-board decelerometer) were also investigated,

though less extensively. Ten states participated in the program, each evaluating a particular PBBT. During the field testing, joint inspections consisting of a CVSA Level 4 inspection and a PBBT test were performed on several hundred commercial vehicles.[1] Correlations between the two inspection methods were sought. The participating states, PBBT types, distribution of vehicle types, distribution of brake types, and total brake defects used for correlations in this report are shown in Table 1-1. In addition, input from the fleet/maintenance perspective regarding use and performance of the PBBTs was obtained from several fleets that used a PBBT after the State had completed its evaluation.

Limitations of Performance-Based Brake Testers

PBBTs cannot replace the inspector in finding a number of defects that do not directly affect brake force, such as chafed hoses and thin brake pads. Most PBBTs have limited assessment capability for other than the as-is loading condition, although this limitation can be overcome on RDs by equipping them with artificial axle loading capability. At the time of the field tests, only the BTT has assessment capability for Gross Axle Weight Rating (GAWR) conditions of a lightly loaded vehicle.

One of the physical limitations found for the PBBTs evaluated in this program was that certain low-ground-clearance vehicle configurations could not be tested on portable units without the use of special ramps or platforms. In addition, at the time of the field testing, none of the PBBT technologies could predict braking capability for vehicles with overheated brakes. However, with further development some predictions may be possible. Lastly, portable units were found to have a higher initial cost, higher maintenance costs and a somewhat lower expected reliability than the same units mounted in-ground. This may be partially attributed to the prototypical nature of the units being field tested.

Analysis of Field Data

The field data were analyzed with the primary objective of developing performance-based criteria for identifying weak brakes by comparing the results of the PBBT with those of the CVSA inspection. In the field tests, several tentative criteria for identifying weak brakes were used. These tentative criteria are presented in the next section. Recommendations for pass/fail limits based on these criteria are covered in the main body of this report.

A secondary objective in the evaluation was to determine whether any insurmountable performance or operational limitations of the PBBTs existed, thereby preventing one or more of the technologies from being used in the future for screening or enforcement. No such limitations were found for RDs, FP testers, or the BTT. Since limited data were available for the IR technology assessment, further investigation may be warranted. Preliminary investigation of the IR temperature measurement system indicates that the applicability of this technology is limited to the detection of inoperative brakes

[1] (Note: In the case of this PBBT field test project the CVSA Level 4 (Special Project) inspection was composed of the driver, brake, and tire portion of a CVSA Level 1 inspection.)

or brakes with stroke measurements in excess of 12.7 mm (0.5 inch) beyond the recommended adjustment limit. The on-board decelerometer exhibited limited applicability due to the logistics of test "runway" space limitations, strong dependence of test results on driver skill, and potential damage to deceleration-sensitive cargo. The on-board decelerometer appears to accurately measure braking performance, and will require further evaluation to ensure compliance with all performance braking specifications.

Criteria for Identifying Weak and Defective Brakes by Type of PBBT

Methods for identifying weak or defective brakes, were identified based on initial research. These methods are as follows:

- Roller Dynamometers - A minimum force at a given air pressure for pneumatically braked vehicles (also known as the Vehicle Research and Test Center [VRTC] line.)

- All Types of PBBTs - A minimum ratio of brake force (BF) balance across an axle for any vehicle or brake type.

- All Types of PBBTs - A minimum BF as a function of wheel load (WL) for any vehicle or brake type. This criterion was not part of the initial set of criteria. It was added based on field test results which found that identifying weak brakes on axles where both brakes are nearly equally weak and air pressure could not be measured was not possible with any of the tentative criteria (i.e., either there is no access to the air system or it is a non-air-braked vehicle).

PBBT Criteria for Identifying Out-of-Service Brakes

Draft recommendations for vehicle out-of-service (OOS) criteria to be used in the field testing were developed. Three criteria were suggested:

- A vehicle could be considered OOS if it cannot meet a minimum equivalent deceleration criterion (e.g., if the deceleration is < 0.4g, where g is the acceleration due to gravity [9.8 m/sec^2 or 32.2 ft/sec^2]). This equivalent deceleration can be computed from the sum of all PBBT-measured brake forces divided by the sum of the PBBT-measured axle weight. Additionally, a stopping distance can be predicted (e.g., 12.2 meters from 32.2 km/hr or 40 feet from 20 mph) from this equivalent deceleration; or

- A vehicle could be considered OOS if 20 percent or more of its brakes are found to be defective using one of the above PBBT criteria; or

- A vehicle could be considered OOS based on the results of a PBBT which considers not only the total brake force to vehicle weight ratio, but also includes brake force and/or load distributions. This adds the consideration of braking stability to the minimum stopping distance. Braking stability refers to the ability of a vehicle to maintain travel within its lane during the stop. The data required for development of this criterion are being acquired at the time of this report.

Relevance of PBBT Data to Current Federal Motor Carrier Safety Regulations and CVSA OOS Criteria

Currently, Section 393.52 of the Federal Motor Carrier Safety Regulations, codified under Title 49 of the Code of Federal Regulations (CFR), requires that commercial motor vehicles be capable of stopping within a distance of 12.2 meters from 32.2 km/hr (40 feet from 20 mph). This is equivalent to a 0.4g deceleration when brake lag time is included. The proposed OOS criterion has an equivalent deceleration which can be used to predict stopping distance. The minimum proposed equivalent deceleration of 0.4g for commercial vehicles and the associated stopping distance are consistent with the braking requirements currently found in the 49 CFR 393.52, the National Highway Traffic Safety Administration's (NHTSA) brake performance requirements for new vehicles (49 CFR 571.121 for air braked vehicles, and 49 CFR 571.105 for hydraulic braked vehicles), and suggested by the CVSA's North American Uniform Vehicle OOS Criteria. These proposed criteria are consistent with the stopping distance requirements because they consider what the brakes must do in an interval already reduced by the lag time. The CVSA OOS criteria generally allows up to 20 percent defective brakes per vehicle before a vehicle would be placed out of service, implying a minimum desired brake effectiveness of 80 percent. This results in a minimum 0.4g deceleration since commercial vehicle brakes are designed to provide a force of at least 0.5 GAWR per axle (80% effectiveness x 0.5 GAWR = 0.4 GAWR.) Additionally, it was found that an OOS criterion based on deceleration would be particularly effective for hydraulically braked vehicles, as the current CVSA procedure is somewhat limited in detection of weak or defective hydraulic brakes.

Current requirements under 49 CFR 393.41 and CVSA criteria also cover parking and emergency braking effectiveness, which are difficult to adequately inspect in the field. This study found that parking and emergency brake effectiveness can be quantitatively assessed by the PBBTs. As such, PBBT OOS criteria for parking brake effectiveness are also proposed and are consistent with the existing requirements of 49 CFR 393.41, and its reference to 49 CFR 571.121 which requires that the "parking brakes must hold the vehicle on a 20 percent grade." This requirement implies that the ratio of total parking brake force to total vehicle weight must exceed 0.196. This ratio can be successfully measured by a PBBT.

Statistics from Field Test Data

The overall agreement for individual weak or defective brakes identified by the CVSA inspection and those identified using a PBBT ranged from 53 to 88 percent, depending on the type of PBBT. Such levels of agreement are reasonable considering that the two different techniques assess different factors. The statistics for OOS vehicles using the proposed PBBT criteria as compared with those found during the CVSA inspection are shown in Table 1-2. Many of the vehicles placed out of

service using the CVSA OOS criteria had sufficient stopping capability when their brake forces were evaluated in terms of the proposed PBBT OOS criteria. For example, of the 2,865 trucks inspected during the program for which both a valid PBBT brake test and a CVSA inspection were available, 396 (13.8 percent) were placed out of service by the inspectors under the CVSA North American Uniform Standard for brake-related defects (Type 1 in Table 1-2). Out of these 396 vehicles placed OOS, only 215 would have been placed OOS due to 20 percent or more of their brakes failing a PBBT test (Type 3 in Table 1-2), and only 179 were found by the PBBTs to have an insufficient predicted overall vehicle deceleration (Type 2 in Table 1-2). This means that approximately 50 percent of the vehicles put OOS by the CVSA criteria may have actually had adequate braking capability as judged by measured brake performance. In an earlier FHWA sponsored study by Fancher, et al. (1995)[2], which evaluated the brake adjustment criteria for heavy trucks, a similar percentage of vehicles put OOS by a CVSA inspection were calculated to have had adequate stopping capability.

Conversely, in the present study, a considerably larger number of the 2,865 vehicles examined would have been placed OOS using either the PBBT 20 percent criterion (559) or the proposed minimum 0.4g deceleration criterion (1124). These proposed PBBT OOS criteria require careful consideration and better understanding of the implications of the test results prior to adoption. The final recommendations for PBBT OOS criteria will require additional review of specific individual machine characteristics, and this work is currently underway.

Conclusions from Field Tests

- PBBTs identified weak and defective brakes; however, there is concern that some PBBT results may underestimate brake performance. Detailed analysis that supports this conclusion can be found in the body of the report in Section 8.

- Agreement between the CVSA-certified visual inspection and the PBBT results was in the range of 53% to 88%.

- Screening of vehicles for weak brakes may be done more rapidly using simplified procedures and criteria associated with PBBTs. Test times derived from the field testing might be reduced in actual deployment. In this scenario, joint inspections might be performed only on vehicles that failed field PBBT screening and only a summary printout might be required.

- Reliability and durability of portable prototype units need to be improved over those found during field testing. Specific problem areas have been identified and improvements have been made subsequent to the completion of the field tests.

- Test and calibration procedures need to be developed for use of PBBTs for enforcement.

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[2] "Evaluation of Brake Adjustment Criteria for Heavy Trucks," February 1995 FHWA-MC-94-016.

- Development of a training and certification program will be required for CVSA inspectors prior to use of PBBTs for enforcement.

- Simplified presentation of test results is recommended.

Next Steps in Performance-Based Brake Testing

At present PBBTs can only be used as a screening tool. The PBBTs that passed evaluation in this study have become eligible for the States to purchase with federal MCSAP money. The next step for PBBTs is to use them for enforcement. Several steps are required prior to the use of PBBTs for enforcement. These steps include the development of machine specifications, the development and approval of PBBT calibration and verification procedures, and the establishment of standard test procedures for each type of PBBT. The field test experience with maintenance and repair, calibration requirements, repeatability and reproducibility, and valid test recognition were used for the development of a set of draft machine specifications. These draft specifications are included in Appendix A to the full report. In addition, work is currently underway to change the existing FMCSRs to allow PBBT-measurements to be used for enforcement. The calibration and verification procedures and standard test procedures for each PBBT have yet to be developed. Furthermore, training and certification of CVSA inspectors using PBBTs must be addressed.

Table 1-1. Statistics of Vehicle and Brake Types by State

State		Colorado	Connecticut	Ohio	West Virginia	Maryland	Nevada	Minnesota	Wisconsin	Oregon	Indiana
PBBT Type		Roller Dynamometer				Breakaway Torque Tester		Flat Plate Tester		Infrared	Deceler-ometer

Vendor		Hicklin		Nepean		B & G		Hunter	HEKA	Renstar	Vericom
Vehicle[1]	2	116	126	149	69	89	41	214	13	0	91
Code	3	104	25	45	35	43	13	82	5	0	0
.	2-S1	31	13	11	5	15	7	11	0	2	0
.	3-S2	284	97	264	337	26	41	374	68	30	0
.	3-S1	15	1	7	0	1	0	5	1	1	0
.	Other	30	47	22	19	26	6	16	0	4	0
Total Vehicles		580	309	498	465	200	108	702	87	42	91
Total Brakes		4450	2070	3798	4010	990	786	5254	735	414	364
Air Brakes (S-cam or wedge)		4128	1786	3512	3842	884	634	4772	709	414	88
Brakes with at least 1 primary force-related defect[2]		487	243	596	479	59	81	374	93	41	2
Same as above excluding 1A5B defects		255	115	319	226	20	46	187	34	9	1

[1] Key for Vehicle Codes

2 = 2 axle straight truck or bus
3 = 3 axle straight truck or bus
2-S1 = 2 axle tractor, 1 axle trailer
3-S2 = 3 axle tractor, 2 axle trailer
3-S1 = 3 axle tractor, 1 axle trailer

[2] Primary force-related defects (and the codes used in this report) are defined as:

1A5A Violation for stroke more than 6.35 mm beyond the adjustment limit (FMCSR 396.3a1)
1A5B Violation for stroke from 0 to 6.35 mm beyond the adjustment limit (FMCSR 396.3a1)
1A5C Violation for wedge brake motion greater than 1.59 mm (FMCSR 396.3a1)
1A6A Violation for grease or oil or other contamination of brake linings (FMCSR 393.47)
1A8 Violation for pad does not contact drum (FMCSR 393.48)
1C2 Violation for service brake inoperative (FMCSR 393.48)

Table 1-2. Vehicles placed out of service by CVSA inspections compared with those that would have been put out of service by proposed PBBT OOS criteria

PBBT Type	Manufac/ State	Total Vehi-cles	Types of Out-of-Service Criteria				
			TYPE 1 CVSA-Identified Brake Defects (Current)	**TYPE 2** Vehicles Not Achieving 0.4g Total Vehicle Equivalent Decel[1]	Vehicles Failing Both **Type 1&2** Criteria	**TYPE 3** Vehicles with More Than 20% of Brakes Deemed Inadequate[1,2] by PBBT	Vehicles Failing Both **Type 1&3** Criteria
Breakaway Torque Tester	B & G-MD	144	11 (7.6%)	21 (14.6%)	4 (2.8%)	36 (25.0%)	5 (3.5%)
	B & G-NV	80	22 (27.5%)	13 (16.3%)	2 (2.5%)	10 (12.5%)	2 (2.5%)
Roller Brake Dynamometer	Hicklin-CO	580	71 (12.2%)	139 (24.0%)	28 (4.8%)	86 (14.8%)	44 (7.6%)
	Hicklin-CT	309	37 (12.0%)	209 (67.6%)[3]	24 (7.8%)	61 (19.7%)	24 (7.8%)
	Nepean-OH	498	96 (19.3%)	232 (46.6%)	49 (9.8%)	128 (25.7%)	68 (13.7%)
	Nepean-WV	465	76 (16.3%)	247 (53.1%)	48 (10.3%)	133 (28.6%)	57 (12.3%)
Flat Plate Tester	Hunter-MN	702	72 (10.3%)	234 (33.3%)	19 (2.7%)	44 (6.3%)	4 (0.5%)
	HEKA-WI	87	11 (12.6%)	29 (33.3%)	5 (5.7%)	61 (70%)[3,4]	11 (12.6%)
Totals		2,865	396 (13.8%)	1,124 (39.2%)	179 (6.2%)	559 (19.5%)	215 (7.5%)

1 As determined by PBBTs

[2] PBBT proposed OOS criteria for individual brakes include the following: **1**. Measured brake force below the VRTC line; **2.** Left/right imbalance greater than 30%; and **3.** Insufficient wheel deceleration for individual wheel (less than 0.3 for steer axles and less than 0.4 for the others)

[3] This large number of vehicles failing the proposed PBBT OOS criteria may have resulted from premature test termination or other test system limitation of brake force readings.

[4] HEKA unit still under development at time of report completion.