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EVALUATION OF BRAKE ADJUSTMENT CRITERIA FOR HEAVY TRUCKS

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16. Abstract

This report presents analyses, findings and recommendations concerning the brake adjustment criteria of the North American Uniform Driver-Vehicle Inspection Criteria for heavy trucks.

The study involved interviews with Motor Carrier Safety Assistance Program (MCSAP) inspectors, mechanical analyses of the influence of brake adjustment on stopping capability, statistical analyses of brake inspection data, combined statistical and mechanical analyses of the current brake adjustment criteria, and development of a procedure for estimating or predicting brake adjustment intervals.

The key statistical results are derived primarily from a set of 2,146 brake inspections performed by the National Transportation Safety Board. The data indicate 936 of the 2,146 vehicles (with S-cam brakes) were placed out of service for brake adjustment. Of the 936 vehicles placed out of service, 480 vehicles had braking capability that was greater than 80 percent of what the braking capability would have been if the brakes were fully adjusted. These 480 vehicles represent "false positive" cases.

The study presents recommendations for changes to the brake adjustment criteria in order to reduce the percentage of "false positives" during roadside inspections and a procedure motor carriers can use to estimate brake adjustment intervals.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

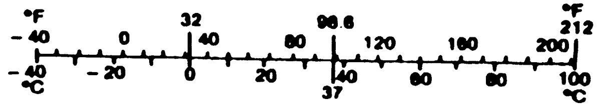
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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EXECUTIVE SUMMARY

This report presents analyses, findings and recommendations concerning the brake adjustment criteria of the North American Uniform Driver-Vehicle Inspection Criteria for heavy trucks.

The objectives of the study were to:

(1) Evaluate the technical adequacy of the brake adjustment portion of the out-of-service (OOS) criteria;

(2) Make recommendations for revisions to either the OOS criteria or the Federal Motor Carrier Safety Regulations to make them uniform, technically sound, practical, and appropriate;

(3) Develop guidelines on brake inspection and maintenance, with particular emphasis on brake adjustment for use by drivers, mechanics, and motor carriers;

(4) Determine what effect vehicle use has on brake adjustment, and;

(5) Determine how often brakes require adjustment for various types of vehicles and various types of operations.

The study focuses on S-cam brakes used on heavy trucks. Since results from Motor Carrier Safety Assistance Program (MCSAP) and National Transportation Safety Board (NTSB) inspections indicate that 20 to 40 percent of the heavy trucks inspected have brake adjustment violations at the OOS level, it is important to evaluate the brake adjustment criteria and inspection procedures.

The study was conducted in two parts. Part 1 included interviews with MCSAP inspectors in eight States (Michigan, Wisconsin, New York, Maine, Oregon, Utah, California, and Georgia), mechanical analyses for relating stopping capability of vehicles to brake adjustment levels, and statistical analyses associating operational and vehicle factors with brake adjustment violations. Part 2 included a combined mechanical and statistical analysis for evaluating the technical adequacy and uniformity of the out-of-service criteria, statistical modeling and analysis of the NTSB inspection data, and development of a procedure for determining an appropriate period between brake adjustments for heavy vehicles equipped with manual slack adjusters.

The statistical results of inspection data are derived primarily from more than 2,100 detailed NTSB roadside inspections of vehicles with S-cam brakes. The data indicated that 936 out of 2,146 vehicles inspected failed the OOS brake adjustment criteria. Of the 936 vehicles that failed the 20-percent rule because of brake adjustment, 480 had a computed braking capability greater than 80-percent of the braking capability that would be available if the vehicle had all of its brakes fully adjusted. The 480 vehicles could therefore be considered "false positives." (None of the vehicles that passed the brake adjustment criteria had a computed braking capability less than 80 percent of the braking capability for the fully-adjusted condition.) This report presents two alternative methods to evaluate brake adjustment levels on heavy vehicles to reduce the false positives currently associated with the use of the 20-percent rule on brake adjustment.

The first alternative is the "demerit" method. The demerit method involves a graphical procedure for estimating the braking capability for each of the brakes on a vehicle relative to that of a fully adjusted brake. The braking capability for each of the brakes is represented as a brake adjustment factor. Brake adjustment factors for various states of adjustment are determined such that given the pushrod travel, the corresponding adjustment factor can be selected from a table of adjustment factors. Using the individual brake adjustment factors, a composite brake adjustment factor for the vehicle is computed.

The second alternative is the "brakeability" method. Brakeability is an analytical method for computing the influence of brake adjustment on braking capability as a percentage of the vehicle's braking capability with fully adjusted brakes. Using the same basic physical principles as those employed in the demerit method, the brakeability method provides a more accurate prediction or estimate of the braking capability of the vehicle.

The advantages and disadvantages of these methods are discussed, with the net result being that brakeability is the most uniform, technically sound, and appropriate approach. The main disadvantage of the brakeability method relates to the calculation that needs to be performed in order to evaluate the braking ability of the vehicle. In the context of a roadside inspection, the brakeability calculations would need to be performed on a computer. The inspectors would have to enter the pushrod stroke measurements, brake chamber sizes and slack adjuster lengths into the computer program. The use of the computer would enable the inspectors to determine unsafe brake adjustment conditions more accurately than the current criteria while retaining useful brake inspection data which is generally not recorded during roadside inspections.

One possible approach to implementing an alternative method to evaluate brake adjustment may be to use the current system as a screening tool. Calculations would not be performed on every vehicle inspected but only those that failed under the current brake adjustment criteria. The alternative procedure could be applied to ensure that the vehicle was not a "false positive." This approach could increase the practicality of using a slightly more complicated brake adjustment criteria.

With regard to the frequency with which brakes need to be adjusted, the report contains information on how service factors such as retarders, short haul versus long haul, terrain (mountainous versus level) and loading (fully laden versus lightly loaded) influence the time/distance interval between brake adjustments. An examination of field data on the amount of vehicle service between brake relinings is used, along with the amount of brake wear involved in going from a fully adjusted brake to the readjustment point, to estimate the amount of service between brake adjustments. Based upon an initial estimate of the period between brake adjustments, an iterative experimental procedure is developed for determining the time/distance interval between brake adjustments. This procedure can be used by motor carriers that are having difficulty keeping the brakes on their vehicles properly adjusted.

1.0 INTRODUCTION

1.1 Background

This report presents analyses, findings and recommendations concerning the brake adjustment criteria of the North American Uniform Driver-Vehicle Inspection Criteria [1] for heavy trucks. In 1989 these criteria were used in the inspection of more than 1 million trucks in States participating in the Motor Carrier Safety Assistance Program (MCSAP). In these inspections, 41-percent of the heavy vehicles were placed out-of-service. Of the out-of-service vehicles, 54.6 percent were placed out-of-service for brake system defects. The most frequently cited brake problem was brake adjustment [2].

An overriding concern regarding the brake adjustment problems with heavy trucks is that the current "system" or procedure for ensuring well maintained brakes is not adequate. Perhaps the brake systems themselves cannot be adequately maintained given the pressures involved with being cost effective in the trucking industry. Another possibility might be that brake adjustment has not been adequately accounted for in the motor carriers' maintenance schedules. Furthermore, the ability to check brake adjustment is hindered because pushrods are not always readily accessible for measurement. Although the lack of accessibility has always hampered efforts to keep brakes properly adjusted, it may have become an even greater problem in recent years given changes in the design of trucks, the trucking industry, and the demands on the driver.

Recently published Federal regulations on automatic brake adjusters and brake adjustment indicators should help to improve the problem of brake adjustment on heavy trucks. The use of automatic brake adjusters will reduce the frequency with which brakes are out-of-adjustment while the use of brake adjustment indicators will help to make the detection of out-of-adjustment brakes much easier for drivers.

In the current environment in which many heavy trucks are placed out-of-service because of out-of-adjustment brakes, the objectives of this project are highly relevant. This study contributes to an improved system for monitoring and maintaining proper brake adjustment on heavy trucks.

1.2 Summary of the OOS Brake Adjustment Criteria

The North American Uniform Driver-Vehicle Inspection Criteria includes a "20-percent rule" for brake defects. The rule covers certain mechanical defects (e.g., loose, broken or missing components, air leaks, etc.) and brake adjustment. Under the 20-percent rule a vehicle is to be placed out-of-service if "the number of defective brakes is equal to or greater than 20 percent of the brakes on the vehicle or combination." In the case of a combination vehicle, the brakes on all of the units in the combination (truck-tractor, semitrailer, converter dollies, etc.) are used in the application of the rule. Generally two brakes are required for each axle (one brake at each axle end) of the vehicle or combination. A five-axle tractor-semitrailer combination would have a total of ten brakes and two defective brakes would place the combination out-of-service.

The brake adjustment criteria place each brake on the vehicle or combination into one of three categories with respect to the number of defective brakes:

(1) not defective

(2) 1/2 of a defective brake (at the readjustment limit or less than 1/4 inch

beyond the readjustment limit), and

(3) one defective brake (1/4 inch or more beyond the readjustment limit).

For the purposes of this report, the discussion of the 20-percent rule relates to brake adjustment only. Considering only the brake adjustment criteria, the following are considered as **one** defective brake:

(1) One brake at 1/4 inch or more beyond the readjustment limit.

(2) Any two brakes at the readjustment limit or less than 1/4 inch beyond the readjustment limit.

A table of readjustment limits for different types and sizes of brake chambers is provided in the inspection criteria. The readjustment limits are 80 percent of the maximum stoke for the chambers listed. The inspection procedure includes instructions to bring reservoir pressure to between 90 and 100 psi, turn the engine off and then fully apply the brakes when measuring brake adjustment.

A review of minutes of the Commercial Vehicle Safety Alliance meetings suggests that the reasoning behind the current system of defining defective brakes under the brake adjustment criteria is based on estimating the influence of brake adjustment on the stopping capability of the vehicle being inspected. The intention is that vehicles lacking sufficient stopping capability (because of improper brake adjustment) such that they are likely to cause an accident or contribute to the loss of control of the vehicle by the driver should be placed out-of-service.

2.0 Project Methodology

2.1 Methodology

The study was conducted in two parts. Part 1 included interviews with MCSAP inspectors in eight States (Michigan, Wisconsin, New York, Maine, Oregon, Utah, California, and Georgia), mechanical analyses for relating stopping capability of vehicles to brake adjustment levels, statistical analyses associating operational and vehicle factors with brake adjustment violations, and combined mechanical and statistical analysis for evaluating the technical adequacy and uniformity of the out-of-service criteria. Part 2 included statistical modeling and an analysis of the NTSB inspection data, combined statistical and mechanical analysis of an alternative method for evaluating brake adjustment, and development of a procedure motor carriers can use for determining an appropriate period between brake adjustments for heavy vehicles equipped with manual slack adjusters.

The approach used in this study involves a combination of mechanical principles, experimental findings, and data from field inspections and investigations. Some of the work is based primarily upon mechanical analyses, and some involves statistical treatment of data gathered during inspections. In this sense, the examination of the brake adjustment criteria employs a multidisciplinary approach in which (a) the mechanical aspects of brake system performance are used to relate stopping distance to "patterns of adjustment levels" and (b) statistical associations between "key factors" and brake adjustment levels are used to infer relationships between those key factors and stopping capability. The goal of the analyses (both statistical and mechanical) is to provide a sound quantitative basis for confirming or changing the current out-of-service brake adjustment criteria.

The term "key factors" pertains to matters like vehicle configuration (number of trailers and number of axles), type of trucking operation (seasonal, for-hire, heavily-laden vehicles, etc.), the use of leased units, the use of the trailer brake valve, company policies with regard to brake maintenance (training, procedures for determining readjustment cycles, and responsibilities in the organization), the use of special equipment (retarders, automatic slack adjusters, brake adjustment indicators, etc.) severity of service (frequency of severe braking, downhill operation, or stop-and-go delivery), etc. In the context of this study, "key factors" mean any of the above plus other factors that can be determined to be associated with brakes being out-of-adjustment (particularly at the out-of-service level) during roadside inspections.

The term "patterns of adjustment levels" means the amount of static stroke at each brake (by unit, axle, and side). Mechanical analyses were performed to relate various patterns of adjustment levels to predicted measures of braking performance. However, with regard to relating patterns of adjustment levels to key factors, the Oregon, Wisconsin and NTSB databases of inspection reports were explored to find any associations. The associations obtained by examining the inspection data do not contain the deterministic rigor of mechanical analyses, but rely rather on using statistical techniques to interpret the available data. Given the distinctions made here, the patterns of adjustment are useful for evaluating the technical adequacy of the out-of-service criteria. The key factors were intended to support the second part of the study in connection with associating the characteristics of trucking operations with the likelihood that vehicles will have brakes that are out-of-adjustment.

2.2 Methodology of Part 1

2.2.1 Interviews with MCSAP Inspectors

The interviews were aimed at identifying (a) problems with the current out-of-service criteria, (b) aspects of the brake out-of-service criteria that require further research, and (c) recommended changes in the brake out-of-service criteria. Seven questions were used in the interview process:

- How is brake adjustment inspected?
- How do you record brake adjustment in relation to the vehicle being inspected? Cover factors such as the number of brakes out-of-adjustment, the degree to which the brakes are out-of-adjustment, and the distribution of stroke from brake to brake around the vehicle.
- What do you know about vehicles with brakes out-of-adjustment?
- What do you think might be done to improve highway safety through better brake-adjustment and brake inspection procedures?
- What are your views on the out-of-service criteria for brakes?
- How often do brakes need to be adjusted?
- Have we missed something of importance and relevance?

An interview outline was developed to provide an orderly structure so that the interviews would be conducted efficiently, and to ensure that appropriate topics were treated in a logical order. The outline included follow-up questions to many of the general questions.

Once the interview plan was finalized (see Appendix A), copies were furnished to the inspectors ten days prior to the interview to allow them a chance to familiarize themselves with the nature of the questions and subjects to be discussed during the interview. The inspectors were allowed to gather pertinent materials and references on the subjects to be discussed. All of the interviews were conducted at the inspector's facility. The first two interviews included having the inspectors explain and demonstrate how they performed inspections using vehicles that were stopped for inspection (see Appendix B). Inspection forms used in each of the eight States were reviewed (see Appendix C).

The interviews provided practical information and informed opinions regarding topics related to the seven questions listed on the previous page. The practical and pragmatic information gathered during the interviews combined with the examination of the findings of pertinent previous studies (see Appendix D) contributed to the development of an analysis plan that involved both mechanical and statistical analyses.

Specifically, the interviews with the inspectors provided a better understanding and practical perspectives on brake adjustment procedures and equipment. They have shown that the inspectors have a general understanding of the relationship between brake adjustment levels, lining condition, drum condition, and pneumatic timing (and the influences of brake valves) on stopping performance. However, this is not a quantitative understanding. The inspectors have a qualitative feel for the elements of a satisfactory braking system. Their training, study, and experience appears to have provided them with the knowledge needed to measure and judge the quality of air brake systems.

2.2.2 Literature Review

The study included a review and evaluation of recent studies on braking performance and the influence of brake adjustment on the braking performance of heavy vehicles. In addition to pertinent references on the characteristics and components of air brake systems, the review emphasized data and results in reports from the Federal Highway Administration and the National Highway Traffic Safety Administration, specifically FHWA's report on "Brake Performance Levels of Trucks" [3] and NHTSA's report on "The Effect of Brake Adjustment on Braking Performance" [4]. Based upon the information derived form the literature review and the knowledge and experience of the researchers conducting this study, two documents were written to provide an evaluation of data and procedures available for investigating brake adjustment, the out-of-service criteria, and braking performance. (See appendices E and F.)

2.2.3 Mechanical Analyses of Stopping Capability

The method described in this section is an extension of the work presented by Mark Flick in "The Effect of Brake Adjustment on Braking Performance"[4]. Mr. Flick's study includes dynamometer testing of brakes, vehicle tests, and calculations of braking performance. The results of that study provided the fundamental information used here to account for the influences of static stroke and brake temperature. (Appendix F contains a complete review of Mr. Flick's work and a presentation of the type of data available for use in mechanical analyses.)

The primary difference between Mr. Flick's work and the work performed in this study is that Flick developed an empirical model for making calculations of the influence of static stroke and temperature on stopping distance, and this study involved the development of a theoretical-empirical model. The theoretical-empirical model is based upon mechanical modeling of the physical phenomena occurring in the braking system. Coefficients, describing pertinent mechanical properties of the brakes, are evaluated to match experimental data.

Many of the concepts presented later in this report are based on an understanding of occurrences associated with the operation of brake chambers when brakes are out-of-adjustment. The following discussion uses a series of four questions to help outline or describe basic concepts involved in determining the influence of brake adjustment on stopping capability, particularly stopping distance.

First, to provide an overview, consider the question: Where does the stroke go? The pushrod in the brake chamber moves in response to an increase in air pressure in the brake chamber. As indicated in Figure 1 (taken from reference [5]), the brake shoes contact the drum at 5 or 10 psi. This typically corresponds to approximately 0.5 inches of stroke for a well-adjusted brake. As the brake lining wears, the stroke at which the shoes touch the drum will increase. If the brake is not adjusted the increase in stroke will continue until the brake no longer provides effective braking action.

Once the linings touch the drum, the stroke increases by about an inch as the air pressure increases to 100 psi. As shown in Figure 1, this would account for the stroke being 1.5 inches when the brakes are cool. Due to drum expansion, more stroke is needed at higher brake temperatures. Stroke can increase by about 0.1 inches per 100°F. The range of temperature from approximately 200°F to 700°F in Figure 1 corresponds to an increase of approximately 0.5 inches of stroke. At elevated temperatures, even a well-adjusted brake may be at the readjustment limit of 2 inches for the example given in Figure 1. For the poorly-adjusted brake in Figure 1, the pushrod would "bottom-out" in the brake chamber and there would be no reserve stroke at elevated temperatures. The additional clearance due to lining wear or misadjustment of the poorly adjusted brake can cause the brake to bottom-out at high pressures.

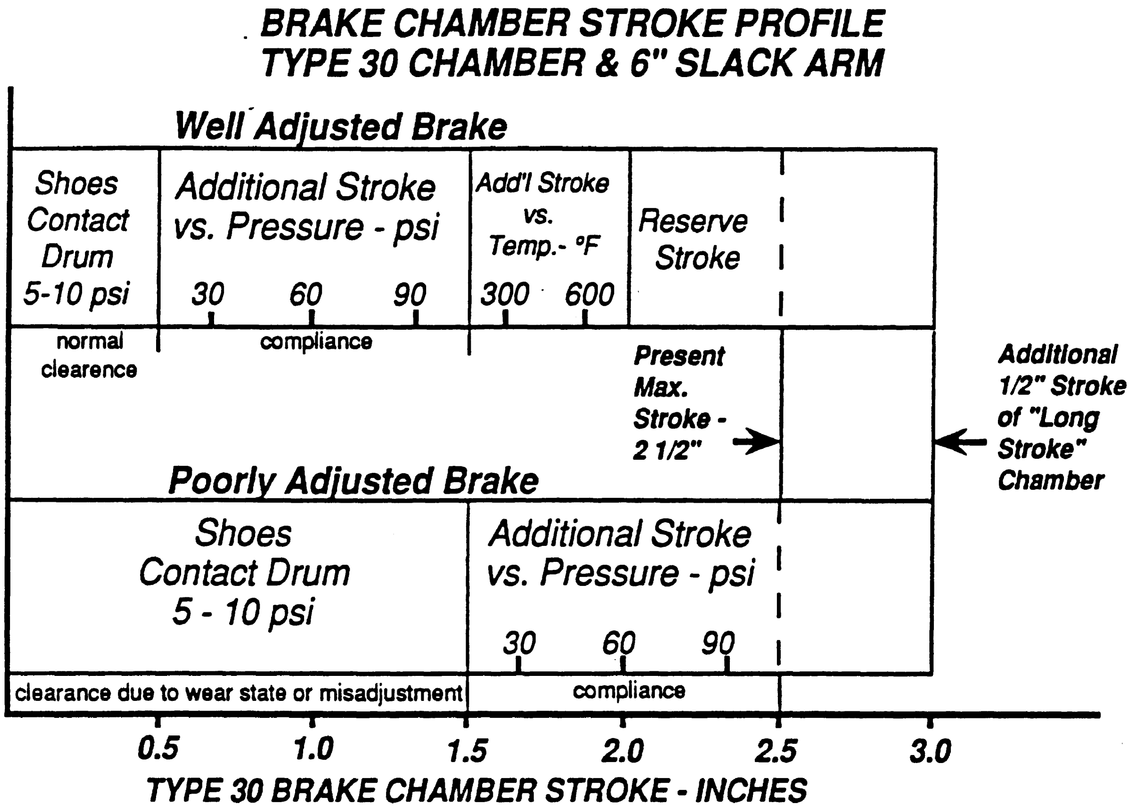


Figure 1. Profile of stroke consumption

Up to this point, the discussion has covered the following phenomena (a) the "pushout pressure" for the linings to touch the drum, (b) the compliance of the linings, shoes, etc. when the linings touch the drum and the application pressure increases, and; (c) drum expansion due to temperature.

To further develop these concepts, a quantitative approach is used to answer the question: How does a brake chamber work? To aid in answering this question, Figure 2 illustrates (a) the output force characteristics of an air chamber (the actuation force on the pushrod as a function of stroke and pressure) and (b) an "operating line" representing the relationship between actuating force and stroke due to compliances in the brake and its actuating mechanism. The mechanical advantage, due to the S-cam and the slack adjuster length, is included in this representation of the compliance. In the example shown in Figure 2, the brake is poorly adjusted. The brake has an initial "slack" of 2.0 inches (the pushrod must travel 2.0 inches in order for the linings to contact the drum). In this example the temperature rise is about 250°F resulting in about 0.25 inches of slack stroke. At 100 psi the simultaneous solution, satisfying both the chamber characteristics and the relationship determined by the operating line, is an actuating force of about 1,700 pounds.

The 1,700 pound force is approximately equivalent to the actuating force attainable at 60 psi if the initial slack had been around 0.75 inches of stroke instead of 2.0 inches. For the example given in Figure 2, there has been a reduction of approximately 60 percent in the actuating-force capability for the brake compared to the fully-adjusted condition. This reduction is due to the amount of overall slack which determines where the lining first makes contact with the drum, and hence where the operating line starts in Figure 2.

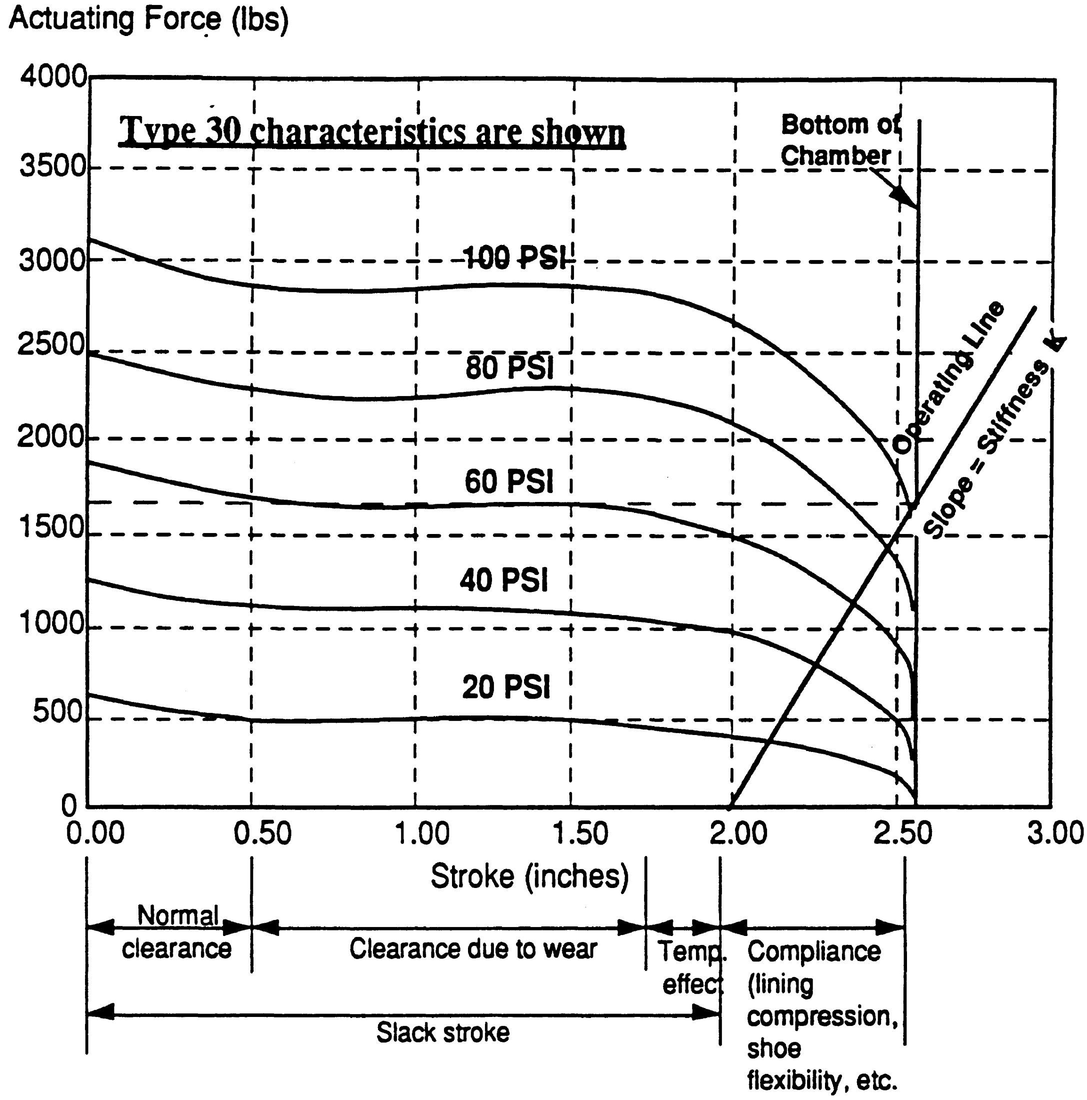


Figure 2. Operating line superimposed on brake chamber characteristic curves

Given the above quantitative information, the next question is: How are these conditions represented? A mechanical model for representing the conditions associated with the onset of bottoming-out of the pushrod in the brake chamber and the compliances in the brake was used in the study. As illustrated at the top of Figure 3, the model consists of three elements:

(1) a pushrod with an actuating force equal to the chamber pressure, P_C, times the chamber area, A_C, and the return springs,

(2) a non-linear bottoming effect represented by a stroke at which this effect starts,

S_C, and non-linear stiffness that increases as stroke, S, increases beyond S_C, and

(3) a "lining model" which represents the operating line introduced in Figure 2 and consists of the overall slack S_L, and the stiffness, K_L. (The overall slack, S_L, is the amount of stroke needed for the lining to touch the drum.)

Since the overall slack, S_L, changes with temperature during stopping the model has two inputs - the chamber pressure, and that component of S_L that changes with temperature. The pushrod stroke in combination with the stiffness for the lining and the chamber (as indicated in Figure 3) produces two forces - F_C, the bottoming force of the chamber, and F_L, the actuating force on the lining. The output of the model is the actuating force F_L.

Since the model contains non-linear elements and the overall slack, S_L, changes during a stop, the calculation of the actuating force, F_L, is dependent on a series of calculations. This series or sequence of calculations is indicated by the arrows and dashed lines in the graph at the bottom of Figure 3. At a given instant the slack, S_L, can be computed from the temperature and the thermal properties of the drum. This means that the relationship between the total force ($F_C + F_L$) and the stroke, S, is known. Given the value of the total force on the pushrod (the product of air pressure in the brake chamber, P_C, and the area of the chamber, A_C), the total-force function can be used to solve for S. (That is, $P_C A_C = F_C + F_L$.) Once the stroke, S, is determined the lining model can be used to calculate F_L, the actuating force that is effective in producing brake torque. This series of calculations is illustrated in Figure 3 for a situation in which $S > S_C > S_L$.

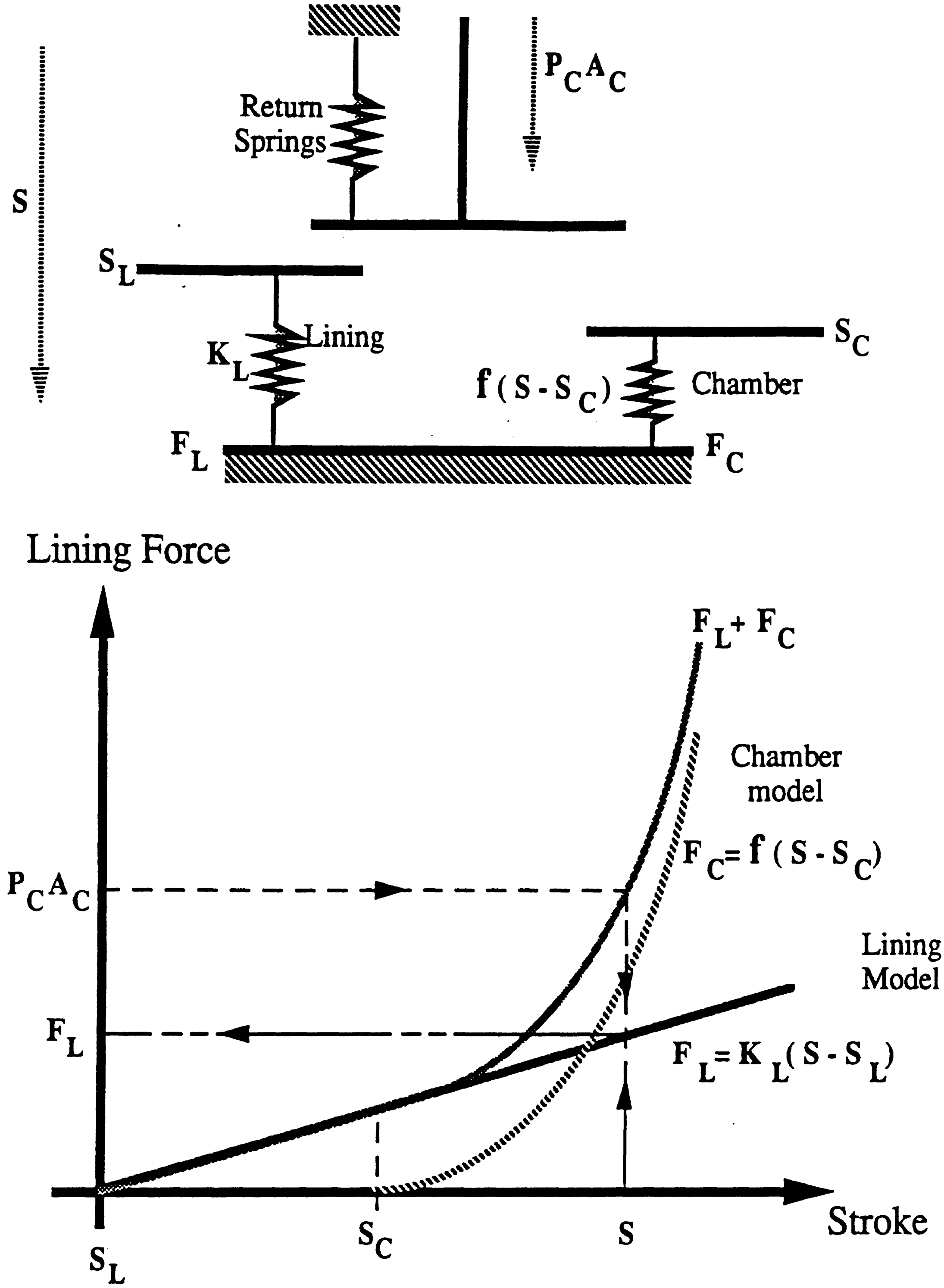


Figure 3. Mechanical model of the brake chamber

The final question considered is: How are the models of individual brakes incorporated into a method for predicting stopping distance? In that regard the model described above may be embedded into a method for calculating stopping distance. The method includes computations of (a) the chamber pressure for each brake, (b) the brake torques due to the actuating forces on the linings of each brake, (c) the temperature rise at each brake, and (d) deceleration, velocity, stopping distance of the vehicle as indicated in Figure 4. Figure 4 illustrates how these separate computations fit together to represent braking on a high coefficient of friction surface. In this case the stopping capability may be predicted for any pressure that is below the pressure that will cause a wheel to lock. In particular, this type of calculation can be used to predict the influences of various patterns of brake adjustment levels on the stopping capability of a heavy truck loaded to its maximum weight capacity, W.

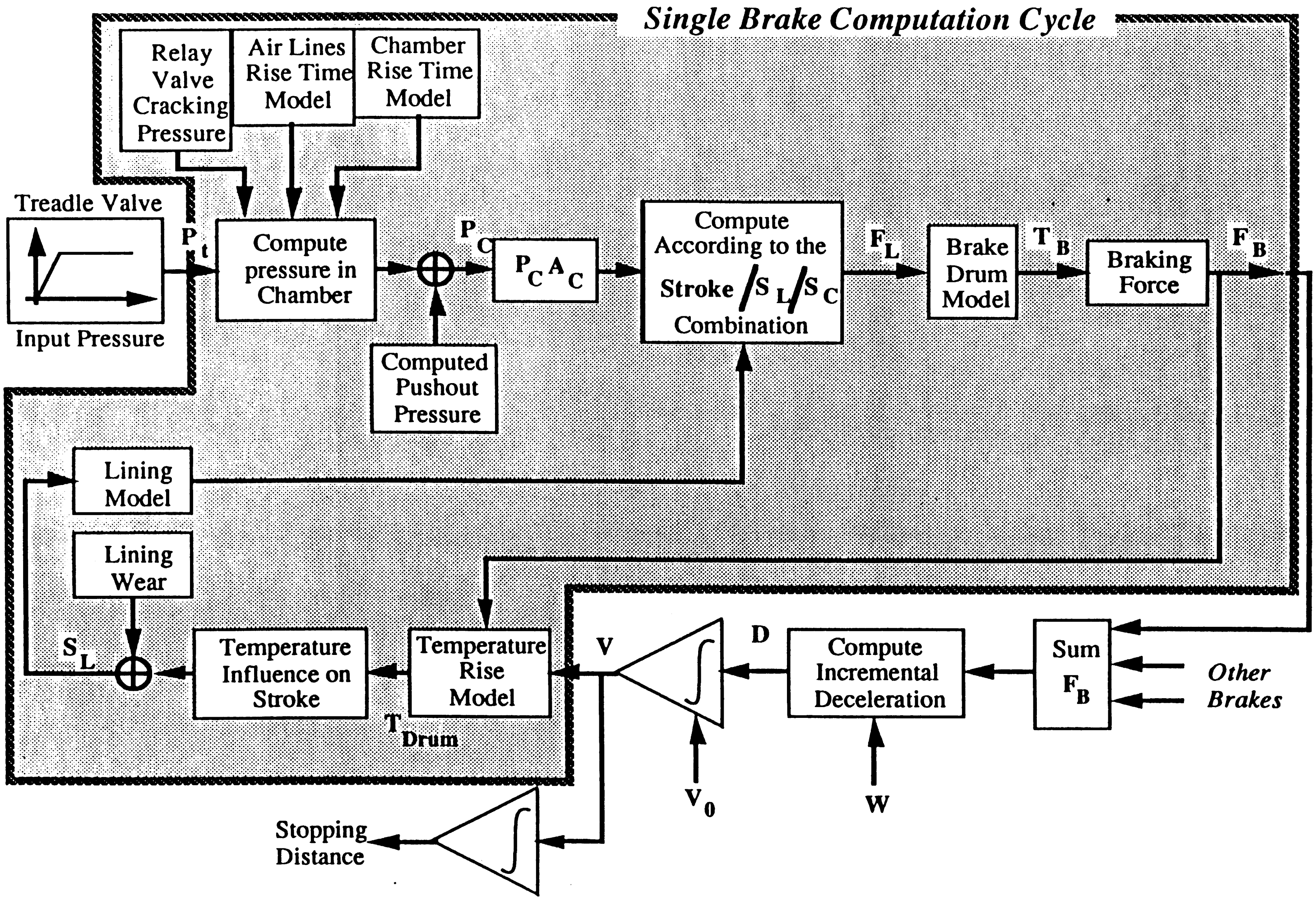


Figure 4. Calculation of stopping capability

2.2.4 Mechanical Analyses of Brake Adjustment

Two methods were developed to evaluate brake adjustment levels on heavy trucks. The "demerit" and "brakeability" methods are based on the assumption that the components of the brake system (e.g., brake chambers, slack adjusters, etc.) are appropriate and in working order. Both methods are aimed at estimating the amount of loss of braking capability due to improper adjustment of the brakes. They address the question: what portion of the braking capacity is available (at the adjustment levels observed during the inspection) compared to the braking capacity available when the brakes are fully adjusted? A computed value of 1.0 represents a truck with fully adjusted brakes. If, for example, either the brakeability or the demerit value for a certain truck is 0.75, the truck has lost 25 percent of its original stopping capability. A primary difference between the brakeability and demerit methods is the accuracy with which the calculation takes into account the physics involved in the operation of the brakes. Another difference is that the demerit method has less resolution because it uses a single brake adjustment factor for a range of stroke increment. The brakeability method uses stroke continuously and represents the components of the brake system more rigorously.

2.2.4.1 Demerit Method

The idea behind the demerit method is to assign brake adjustment factors to various ranges of brake adjustment. These factors are used to estimate changes in stopping capability for any given pattern of brake adjustment levels. In this context vehicles might be placed out-of-service if the estimated increase in stopping distance was 20 percent. The brake demerits would be associated with the influences of adjustment level on the brake's torque capability, and vehicles would be placed out-of-service based on their loss in stopping capability. The basic idea behind the method for determining the desired brake adjustment factors for various ranges of brake adjustment is based on examining brake chamber characteristics.

Example

A brake has a cold-static stroke of 2-1/8 inches at 80 psi (a situation that would be represented as 0.5 defective brakes in the current 20-percent rule). As illustrated in Figure 5 (shown by the lines with arrows), the adjustment factor for this brake would be determined by the following considerations:

(1) The slack stroke must be determined. The slack stroke is the total distance the pushrod must travel in order for the linings to come into contact with the brake drum. (This is the distance that would be measured by pulling on the slack adjuster arm (by hand or by using a pry bar) when the brake is cold.) The following steps are used to determine the slack stroke:

• locate the static stroke, 2.125 inches, on the horizontal axis and following a vertical line to the 80 psi curve.

• proceed down an operating line from the 80 psi curve to the fully-adjusted-cold static stroke on the horizontal axis.

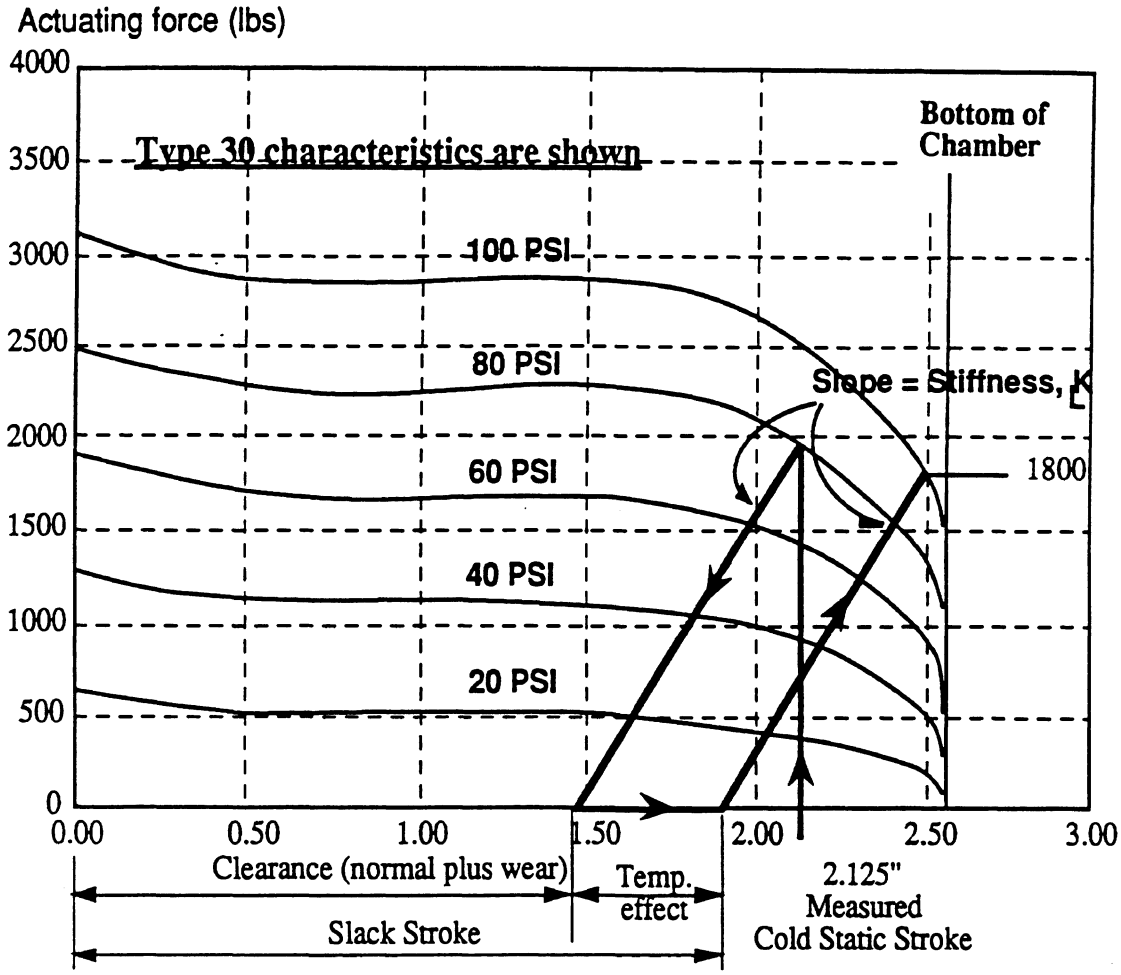
• make allowance for increased stroke due to a brake temperature factor and other factors due to dynamic stroke. In this case a brake temperature of 400°F, which amounts to an increase of 0.4 inches of slack stroke, is used plus 0.1 inch of dynamic stroke increase. (Slack stroke increases approximately 0.1 inches per 100°F.)

(2) The actuating force capability is determined by proceeding up a parallel-operating line starting from the slack stroke up to the 100 psi characteristic curve for the brake chamber. This is the pushrod force that would be available for actuating the brake in a full-treadle brake application at 400°F. The actuating force capability for this example is 1,800 psi.

(3) The actuating force for a fully-adjusted brake is determined by locating the corresponding value on the 100 psi curve. With 1.50 inches representing the fully-adjusted Type 30 brake chamber, the actuating force in this example is 2,850 psi.

(4) Brake Adjustment Factor = $F_{capability}/F_{ref}$ = 1,800/2850 = 0.632

Net Result: The braking force for a brake with a static stroke of 2-1/8 inch (measured at 80 psi) is 63% of the braking force for the fully adjusted brake.



$$\frac{F}{F_{ref}} = \frac{1800}{2850} = 0.632 \quad \Longrightarrow$$

Net Result : 63% of the fully adjusted braking force for a cold static stroke of 2.125 inches measured at 80 psi.

Figure 5. Determination of a brake adjustment factor

To illustrate the ideas underlying the demerit method, the following discussion applies the procedure illustrated graphically in Figure 5 to situations representing various states of brake adjustment.

Table 1 provides the results of carrying out this process for different ranges of cold-static stroke measurements. The ranges of stroke measurement have been chosen to provide a simplified means of accounting for the brake adjustment situations discussed earlier in this report. For example, a brake close to the readjustment limit has an adjustment factor equal to 0.77 and a brake that is backed-off has an adjustment factor equal to zero. Relating the demerit method to the current 20-percent rule, the brake adjustment factors for the 1/2 defective brake case (a brake that is at the readjustment limit or less than 1/4 inch beyond the readjustment limit) and the 1 defective brake case (a brake that is 1/4 inch or more beyond the readjustment limit) are 0.63 and 0.30 respectively. (Please recognize that different results will be obtained when brake chambers with characteristics that differ from those given in Figure 5 are used. Also, different results will be obtained if the static stroke is measured at 90 psi or some other pressure instead of at 80 psi.)

Table 1. Brake adjustment factors

Range of cold-static strokes, S, with respect to the readjustment limit, RL	Brake adjustment factor representing the braking capability relative to a full-treadle application of the fully-adjusted brake at 400°F
"Fully-adjusted" stroke, S	1.0
RL-1/8-inch ≤ S < RL	0.77
RL ≤ S < RL+1/4-inch	0.63
RL+1/4-inch < S < RL+1/2-inch*	0.30
RL+1/2-inch* ≤ S	0.0

* Use 1/2-inch for Type 30 brake chambers. Use the bottoming out distance - 1/8-inch for other types of brake chambers.

In the situation explained by Table 1, if all of a vehicle's brakes were close to the readjustment limit, the vehicle would be capable of approximately 77 percent of the braking capability available when all of its brakes are perfectly adjusted. This is basically consistent with the idea that the vehicle's adjustment level is deemed to be unsafe when the braking capability is 80 percent or less of that with fully adjusted brakes.

Differences in the type of brake chamber (e.g., Type 16, Type 24, etc.) must be taken into account because they each have different torque capabilities in the fully-adjusted state and each have different readjustment limits. A table similar to table 1 would be used for each type of brake chamber.

A common situation is that steering axle brakes have approximately 50 percent of the torque capabilities of rear brakes. Also, when slack adjuster lengths and brake chamber sizes on the non-steering axle brakes of the tractor differ from the trailer brakes, the "AL" factor (the brake chamber area (e.g., area of a Type 30 chamber = 30 square inches) times the effective length of the slack adjuster) needs to be included in the procedure.

The following example, presented in Table 2, illustrates the calculation of the braking capability for a 3-axle (6-brake) truck. In this example four of the brakes are fully adjusted, one rear brake has a cold-static stroke of RL+1/8 inch, and one brake has a cold-static stroke of RL+3/8 inch. When the relative AL is not taken into account, the braking capability is 0.82. With the relative AL, the braking capability is 0.79. Looking at the relative torque column in Table 2, the total relative torque for this vehicle with all brakes fully adjusted would be 5. This total takes into account that the steering axle brakes (brake numbers 1 and 2) have approximately half the torque of the other brakes on the vehicle. Under the current 20-percent rule this truck would be placed out-of-service (1.5 defective brakes out of the six brakes on the vehicle is approximately 25 percent defective brakes).

Table 2. Example of the calculation of stopping capability

Brake Number	Adjustment Levels	Adjustment Factors	Relative AL	Relative Torque
1	Fully adjusted	1.0	0.5	0.5
2	Fully adjusted	1.0	0.5	0.5
3	Fully adjusted	1.0	1.0	1.0
4	Fully adjusted	1.0	1.0	1.0
5	RL+1/8-inch	0.63	1.0	0.63
6	RL+3/8-inch	0.30	1.0	0.30
TOTALS		4.93	5.0	3.93
Adjustment factor for the vehicle		4.93/6 = 0.82		3.93/5 = 0.79

The demerit method as presented in Table 1 and applied in Table 2, utilizes 5 discrete divisions for the cold-static strokes. Referring to Figure 5, once the stroke measurement gets beyond the readjustment limit, the available pushrod force values start to decline rapidly and demonstrate a high level of sensitivity to stroke. The stroke region between the readjustment limit and the bottoming-out point of the chamber is shown in the last two divisions in Table 1. This means that there are only two brake adjustment factors allocated to that sensitive region of the brake chamber's operative stroke. It stands to reason that a more refined sectioning of that region, and subsequently more brake adjustment factors, will improve the accuracy of the demerit method.

Using the results of the brakeability method (discussed in section 2.2.4.2) as a basis for comparison, more stroke divisions or sections were introduced into the demerit method. In addition to addressing the brake adjustment factors, the concepts involved with the AL factor were re-examined. When using techniques such as the demerit method or the brakeability method, each brake is considered individually, and then weighted to evaluate the braking capability of the truck as a whole. As shown in Table 2, the relative AL factor has been used as a weighting parameter in the demerit method.

The brakeability method uses an assumed axle load as the weighting parameter. Using axle loads, a 5-axle tractor-semitrailer combination has a maximum allowable gross combination weight of 80,000 lbs: 12,000 lbs on the front axle, and 34,000 lbs on each of the two tandem axles. The benefit of using axle weights is two-fold: the inspection process is simplified because the slack adjuster length does not need to be measured; and a sounder basis for comparing the demerit and brakeability methods is provided.

Calculations comparing the demerit method (using the AL weighting factor) and the brakeability method (using the axle load weighting factor) indicated that the differences between the methods are small. Therefore, the brake adjustment factors in the demerit method are weighted by axle loads instead of by the AL factor.

Table 3 introduces an additional stroke zone in that region of the brake chamber's operative stroke that is most sensitive to brake adjustment. The table also provides modified values for the brake adjustment factors. The modified values are based upon an empirical fit to the results of brakeability computations for the 21,460 brakes inspected by NTSB[6]. (The results of fitting the demerit results to the brakeability results are illustrated and discussed later in conjunction with Figures 14 and 15 in chapter 4.) Since the brakeability results are the best prediction available for estimating stopping capability, the modified values assure a more accurate estimate of the braking capability of the vehicle if the demerit method is used.

Table 3. Modified brake adjustment factors

Range of cold-static strokes, S, with respect to the readjustment limit, RL	Brake adjustment factor representing the braking capability relative to a full-treadle application of the fully-adjusted brake at 400°F
"Fully-adjusted" stroke, S	1.0
RL-1/8-inch ≤ S < RL	0.77
RL ≤ S < RL+1/4-inch	0.70
RL+1/4-inch < S < RL+1/2-inch*	0.55
RL+1/2-inch* ≤ S < Bottom-out	0.40
S = Bottom-out	0.0

* Use 1/2-inch for Type 30 brake chambers. Use the bottoming out distance - 1/8-inch for other types of brake chambers. For example, the bottom-out distance for a type 20 chamber is about 2 3/8 inches.

The next variant of the demerit method included 8 discrete divisions or stroke zones. Five of the divisions are in the region of the pushrod travel that is most sensitive to brake adjustment. Each 1/8-inch was considered as a division. The appropriate brake adjustment factors used with each division are presented in Table 4. The reason for going from Table 3 to Table 4 was to obtain a better fit to the brakeability results for the 21,460 brakes measured in the NTSB study [6]. The point of discussing the evolution of the brake adjustment factors in the demerit method is to indicate that the final set of factors in Table 4 represents as good an approximation to the brakeability results as we were able to achieve. At least theoretically, the results from the demerit method should (on the average) produce results comparable to those produced by the brakeability method. Furthermore, if stroke is measured with no more resolution of 1/8 inch, results from the demerit method can be expected to be quite similar to those produced by brakeability calculations. (The brakeability computations have the flexibility to account for specific variations in brake system hardware that may take place or become popular in the future. If that happens, the adjustment factors used in the demerit method should be revised to take these changes into account. As was done in this study, brakeability computations for a representative sample of the truck fleet could be used to revise the values of the brake adjustment factors used in the demerit method.)

Table 4. Brake adjustment factors for eight divisions

Range of cold-static strokes, S, with respect to the readjustment limit, RL	Brake adjustment factor representing the braking capability relative to a full-treadle application of the fully-adjusted brake at 400°F
"Fully-adjusted" stroke, S	1.0
RL-1/8-inch ≤ S < RL	0.77
RL ≤ S < RL+1/8-inch	0.70
RL+1/8-inch ≤ S < RL+1/4-inch	0.65
RL+1/4-inch ≤ S < RL+3/8-inch	0.60
RL+3/8 < S < RL+1/2-inch*	0.55
RL+1/2-inch* ≤ S < bottom-out	0.40
Bottom-out point ≤ S	0.0

* Use 1/2-inch for Type 30 brake chambers. Use the bottoming out distance - 1/8-inch for other types of brake chambers.

2.2.4.2 Brakeability Method

The brakeability method is aimed at obtaining a value that represents the relative braking ability of the truck as a whole. Conceptually, this method is an enhancement of the demerit method. Both methods involve an evaluation of the percentage change in stopping capability of a truck due to its brake adjustment status, but the brakeability involves more complicated calculations and yields more accurate results.

The concepts illustrated in Figure 5 and used in the explanation of the demerit method, also serve as the basis for understanding the brakeability method. Where the demerit method uses brake adjustment factors for certain ranges of stroke to approximate the degradation of braking capacity, the brakeability method employs algebraic calculations involving locally linearized equations and intersecting points to obtain more accurate results.

Looking at the model illustrated in Figure 3, the slope of the operating line represents the stiffness of the braking system (symbolized by K_L in Figure 6). This stiffness is determined by the following parameters: the effective length of the slack adjuster; the torsional stiffness of the cam shaft, the effective radius of the cam; the flexibility of the brake shoes and their pivot points; the radius and width of the brake drum; and the stiffness of the lining. Experimenting with the model in Figure 3, two representative values for the slope of the operating line can be obtained. These stiffness values -1,620 lbs/inch for front brakes and 3,120 lbs/inch for rear brakes - were determined to have sufficient accuracy to match the influence of brake pressure on stroke as illustrated in Figure 1. As the length of the slack adjuster is implicitly included in the stiffness, certain lengths of slack adjusters were assumed to be used with certain brake chambers However, that assumption does not impose any restriction on the accuracy of the brakeability method since the slope of the operating line is modified in the calculations when a slack adjuster length found during the inspection differs from the assumed length.

Depending upon the temperature increase selected for the analysis, the slack stroke is increased 0.1 inches per 100°F for a typical 16.5 inch drum. (Clearly other drum expansion factors can be used in the analysis.)

For each brake, the actuating force can be determined by using the appropriate chamber-data table. This is done by using the measured stroke and the pressure at which the inspection was performed, and looking up the corresponding actuating force. With the assumed slope (1,620 lbs/in or 3,120 lbs/in according to the location), once that force-stroke point is established (1 in Figure 6), the equation for the line can be determined and the slack stroke (2 in Figure 6) can be computed. To account for the temperature effect on the stroke, the equation for a parallel line is computed. An additional look-up and interpolation process is used to determine point 3 in Figure 6, and subsequently the available actuating force. The brakeability of the individual brake is determined by the ratio between the resultant actuating force and the maximum actuating force that can be generated by the particular chamber.

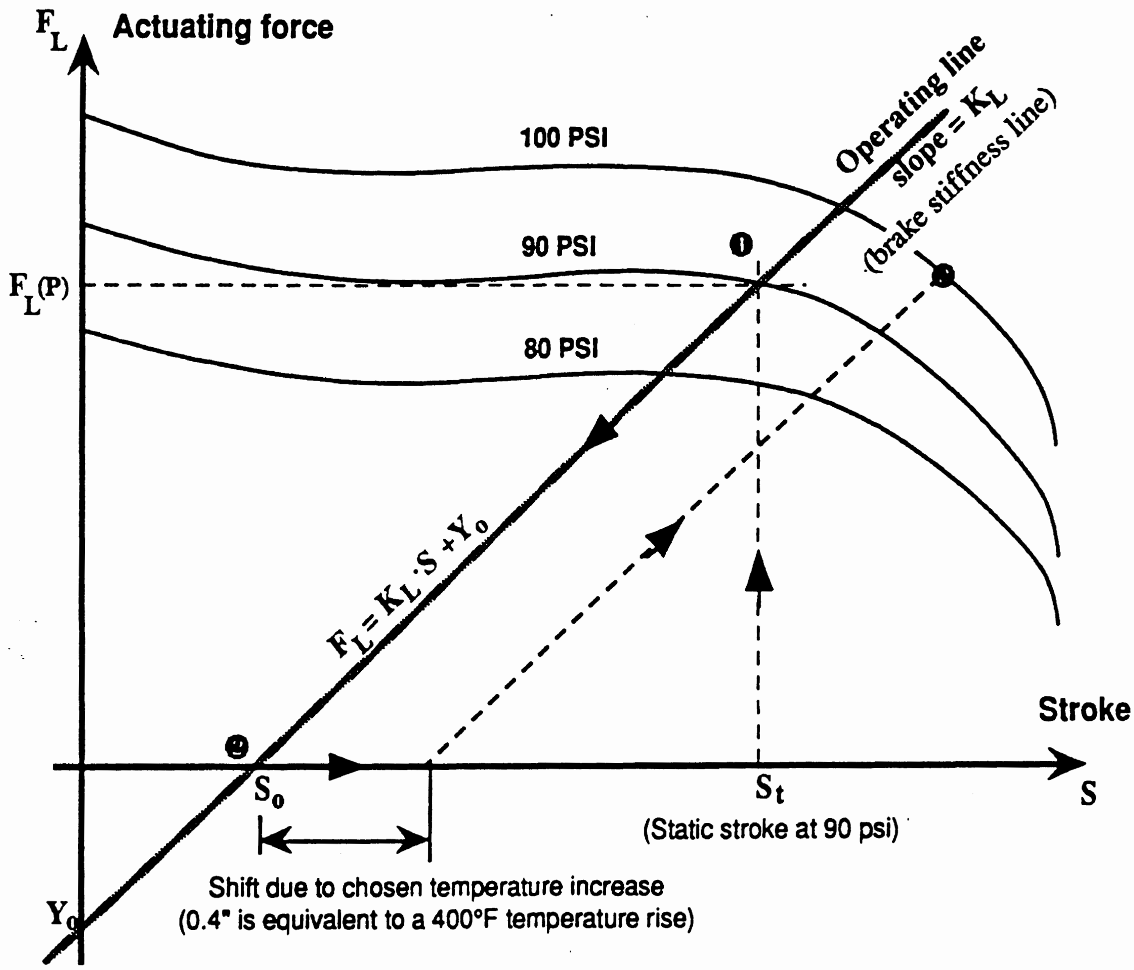


Figure 6. Determination of the operating line's equation

After the brakeability of each brake is determined, the total brakeability of the truck is calculated. This is done by using a weighting factor, axle loads - The more weight the axle carries, the more significant its brake adjustment status will be in the evaluation of the overall brakeability. For a typical 5-axle tractor-semitrailer, the front axle is assumed to carry 12,000 lbs, 6,000 lbs per brake. The tandem axles are assumed to carry 34,000 lbs, or 8,500 lbs per brake. The total weighted calculation of the brakeability is shown in equation (1).

$$\eta_t = \frac{\sum_{i=1}^{\#\text{of brakes}} \eta_i \cdot \overline{W}_i}{80{,}000} \qquad (1)$$

where:

η_t is the total brakeability of the truck

η_i is the brakeability of an individual brake

$\overline{W}_i$ is the individual wheel load (6000 lb for front wheels, 8500 lb for rear ones)

2.2.5 Associations of Brake Adjustment Levels With Vehicle and Operation Characteristics

To study the associations between brake adjustment levels and different vehicle configurations and different types of carrier operations, State inspection data was reviewed. The review of computerized data identified only two States, Oregon and Wisconsin, with data elements that appeared to provide sufficient information to assist in the study. Information recorded during roadside inspection were obtained on magnetic tape. The data were converted into an appropriate format for analysis by the OSIRIS database program on the University of Michigan mainframe computer. In addition to the State inspection data, detailed brake inspection data were obtained from the National Transportation Safety Board (NTSB).

2.2.5.1 Oregon Data

The Oregon data contained 20,233 inspection records. The data covered all inspections of interstate and intrastate trucks performed by the State in 1989. The records include trucks without violations, trucks with brake violations, and trucks with other violations. The records describe the carriers' operating authority and the configuration of the truck. The configuration is described in a series of fields for up to six units (tractor, semitrailer, etc.). Each unit is characterized in terms of the unit type, Commercial Vehicle Safety Alliance (CVSA) inspection decal, vehicle make, state of registration, and whether the vehicle was placed out-of-service.

The records also describe individual brake violations. Each record identifies the unit with the violation, the type of unit, and whether the violation put the unit out-of-service. The brake violation codes include: defective brakes exceeded 20 percent; brake adjustment; pushrod (on steering axle); slack adjuster (on steering axle), and; no steering axle brakes. A number of other codes describe brake violations not related to adjustment. Only brakes with violations have records.

The configuration of the vehicle can be determined from the combination of units identified. For each configuration, the violation codes can be located by unit number. However, the database does not include actual pushrod measurements and violations cannot be located with regard to the specific axles or axle ends.

Of the 20,233 vehicles inspected, 22.1% had no violations, 45.7% had brake violations, and 32.1% had violations that did not include brake-related violations. Overall, 34.4% of the trucks inspected were placed out-of-service with brake violations responsible for 80% of the out-of-service vehicles. Focusing on the 45.7% (9,250 vehicles) that had one or more brake violations, 59.6% of these vehicles were placed out-of-service. There was a total of 29,021 brake violations on the 9,250 vehicles having one or more brake violations. The trucks with brake violations averaged approximately three brake violations per vehicle. Approximately two-thirds of the brake violations were for adjustment.

2.2.5.2 Wisconsin Data

The Wisconsin data covers 4,156 trucks, each with one or more brake violations, for a total of 8,725 violations. The Wisconsin data only covers vehicles with violations. Wisconsin inspects both intrastate and interstate trucks and a code in the database distinguishes between the two. Truck configuration is identified and coding is used to identify the location of each brake violation in terms of the unit number, the axle number, and the axle end (left or right). Thus, the available information is adequate to determine the distribution of violations by unit of the vehicle, and by axle location on each unit.

In addition, the file includes certain information on the nature of the brake violation. In identifying the nature of the brake violation, there are codes for: pushrod travel exceeds 1.75 inches; pushrod travel exceeds 2 inches; no pushrod movement when the brake is applied; pushrod travel is improper, and; difference in pushrod travel left/right (L/R) exceeds 1/2 inch.

Of the 4,156 vehicles with brake violations, 65% (2,721) were placed out-of-service. (It could not be determined if the brake violations alone were sufficient to place the vehicle out-of-service.) The data show that 3,558 of the inspected vehicles had just one unit with brake violations. Also, 55.2% of the truck tractors had brake violations compared to 42% of the semitrailers and trailers with brake violations. The average number of brake violations per truck was 2.1 compared to 3.1 from the Oregon data.

2.2.5.3 NTSB Data

Most of the NTSB data were collected in roadside inspections performed between March and December 1990. During that period, the NTSB inspected brakes on 1,520 trucks in five States: Florida, Illinois, Oregon, Pennsylvania, and Texas. After the data collection was complete and an analysis performed, additional data was gathered to verify the first round of data collection and to test alternative brake inspection procedures. The supplemental round of data collection on 823 vehicles occurred between April and July 1992 at sites in Michigan, Oregon, Pennsylvania, and Texas. Both sets of data (a total of 2,343 vehicle inspections) were analyzed for this report.

The NTSB selected trucks for inspection by randomly picking trucks entering weigh stations, such that every Nth five-axle combination vehicle was chosen (N was chosen to keep the inspection teams continuously busy without tying up the flow of vehicles). Truck configurations included straight trucks pulling one trailer, and tractors with one or two trailers. The teams collected data primarily related to the brake system. Data included company type and size, the make and model year of all units, trailer body type, brake type, chamber size, pushrod stroke measurement for each brake, whether or not the vehicle was equipped with a retarder or limiting valves, and several other brake-related items.

Data collection sites were on interstate and off-interstate roads in order to get a good representation of the types of vehicles in use. Table 5 shows the number of interstate and off-interstate inspections per State.

Table 5. Number of trucks inspected by state and road type

State	Interstate	Off Interstate	Total
Florida	185	107	292
Illinois	197	151	348
Oregon	148	92	240
Pennsylvania	220	152	372
Texas	160	108	268
subtotal	910	610	1,520
supplementary data			
Michigan	48	0	48
Oregon	125	130	255
Pennsylvania	145	115	260
Texas	140	120	260
subtotal	458	365	823
total	1,368	975	2,343

Though it is not possible to determine in a rigorous manner the extent to which the population of trucks included in the NTSB inspection is representative of the national population, there do not appear to be any obvious biases in the sampling procedure or in the sample itself. Distributions from the NTSB brake adjustment sample were compared with distributions from the 1987 Truck Inventory and Use Survey (TIUS) conducted by the Bureau of the Census. Only a limited number of comparisons were possible. Nevertheless the NTSB sample reasonably matches the national population in the TIUS on some important variables. These variables included trailer cargo body type and tractor model year. For-hire carriers were somewhat over-represented in the NTSB data compared to TIUS, as were conventional truck tractors. However, the cab type and the private/for-hire distinction were not found to be associated with brake adjustment problems.

Overall, the NTSB teams found very high levels of brake violations. Of the 2,343 vehicles inspected, 1,408 (60.1 percent) were placed out-of-service for brakes and other violations. (Although the NTSB teams focused on brake violations, they responded to obvious violations in other areas.) A total of 1,319 (56.3 percent) were coded with brake violations (including non-adjustment related) severe enough to place the truck out-of-service. Considering only brake adjustment related problems, 1,655 (70.6 percent) had at least one brake with a violation and 1,068 (45.6 percent) of the inspected trucks were placed out-of-service.

2.3 Methodology of Part 2

2.3.1 Combined Mechanical and Statistical Analyses for Evaluating the Out-of Service Criteria

The purpose of the combined analyses was to assess the ability of the 20-percent rule in separating vehicles according to their stopping capabilities. Up to this point, the study has focused on predictions of the stopping capability predictions using the demerit and the brakeability methods. Using the brake efficiency calculation procedure discussed by R. Heusser in "Heavy Truck Deceleration Rates as a Function of Brake Adjustment"[4], data from the NTSB brake inspections was analyzed to determine if the braking efficiency of vehicles that were inspected supported the out-of-service determinations of the 20-percent rule.

During the review of roadside inspection report databases, it was determined that the NTSB data is the only source that includes pushrod stroke measurements on all brakes inspected—those that were in violation as well as that were not in violation. None of the State databases contained information on brakes that were not in violation of the readjustment limits. The NTSB data also include data on the brake chamber size. This is essential for relating the stroke measurement to the out-of-service criteria. The level of detail covered in the NTSB database is sufficient to support calculations of braking capability using the brakeability method. The NTSB inspection data was processed using the brakeability method and the braking efficiency method to provide a sound and practical comparison between the two approaches. Using the brakeability method, the 20-percent rule was evaluated to determine if it adequately screens out trucks with insufficient braking capability.

The braking capability was calculated for all NTSB inspection reports on vehicles equipped with S-cam brakes. The vehicles were then divided into two groups based on whether or not they were placed out-of-service under the 20-percent rule. Distributions of the braking capability for out-of-service vehicles and those vehicles that were not placed out-of-service show that there is a significant overlap between the two groups. While none of the trucks with inadequate stopping capability (defined as 80 percent or less of the braking capability when all of the brakes are fully adjusted) passed the 20-percent rule, a significant portion of the out-of-service trucks had braking capabilities in excess of 80 percent of that available for the fully-adjusted case.

2.3.2 Statistical Modeling and Analysis of Brake Adjustment Data

Most of the analysis of brake inspection data is based on the NTSB inspection reports. The inspection data from Oregon and Wisconsin were used in the analysis to supplement the NTSB data. The general purpose of the analysis was to determine the factors in vehicle configuration and operations that are related to brake adjustment problems. The Oregon data includes information on all trucks inspected but does not include brakes that were defect-free. The Wisconsin file only includes information on trucks with one or more brake violations. The Wisconsin data does not cover any brakes that were defect-free. Although the Oregon and Wisconsin data contain valuable information, the usefulness of the data for the statistical analysis is limited.

Several techniques were used in the analysis. The first was a series of simple tabulations. The purpose of the tabulations was to take advantage of the wealth of data elements in the NTSB database to explore the factors relating to vehicle configuration, equipment, and type of operations that are associated with brakes being either out-of-adjustment or defective [5]. The findings from the tabulations were refined into statistical models. The advantages of using statistical models to understand the usage factors are that (1) the models produce measures of the association of different factors to out-of-service and out-of-adjustment, showing the size of the effect of the factors, and (2) a multivariate model allows several factors to be considered at the same time, showing the effect of each factor in the presence of other factors and allowing their relative contribution to be assessed.

Two statistical models were developed. One modeled the probability of a brake being out-of-adjustment and the other modeled the probability of a vehicle having sufficient brake adjustment violations to be classified as out-of-service. The models measure the contribution different characteristics of the vehicle and its operation make to the likelihood of brake violations. These models are the best approach to relate characteristics of vehicles or truck operations to brake adjustment status.

The logit model is the appropriate technique for modeling probabilities with categorical predictor variables. In a logit model, the dependent or response variable ranges from zero to one and can be essentially considered the probability of an event. For purposes of illustration, consider the case where the response variable is the probability that a brake is out-of-adjustment. In terms of the model, this means the number of out-of-adjustment brakes divided by the total number of brakes inspected. The independent or predictor variables are incorporated into the model as categorical variables with discrete nominal values. In these models, the predictor variables are in the form of dummy variables - coded zero where the factor is absent and one where it is present. For example, the variable for slack adjusters was coded either zero for manual slack adjusters or one for automatic slack adjusters.

In the logit model, odds of an event are calculated by dividing the probability of an outcome, p, by the probability that the outcome does not occur, (1-p). The general form of the logit model is as follows:

$$\ln\left(\frac{p}{1-p}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots. + \beta_n X_n \qquad (2)$$

where p is the probability of an outcome, a is a constant, and b_n is the coefficient associated with the predictor variable X_n. The coefficients of the predictor variables show the change in the odds ratio in the presence of the predictor variable relative to some baseline case. The odds ratio is the ratio of the odds of outcome 1 [i.e., p(1)/(1-p(1))] to the odds of outcome 0 [i.e., p(0)/(1-p(0))]. This can be interpreted as a change in risk, relative to the baseline case. For example, the coefficient for slack adjusters is the natural log of the odds of a brake being out-of-adjustment with automatic slacks divided by the odds of a brake being out-of-adjustment if the brake chamber had manual slack adjusters. (The baseline case includes manual slack adjusters.) The logit equation can also be used to calculate the probability of an outcome of different factors. By rearranging equation (2) above, it can be shown that:

$$p = \frac{e^{\alpha+\beta_1 X_1+\beta_2 X_2+\ldots\ldots.+\beta_n X_n}}{1+e^{\alpha+\beta_1 X_1+\beta_2 X_2+\ldots\ldots.+\beta_n X_n}} \qquad (3)$$

Since odds ratios are somewhat difficult to interpret directly, the probabilities of out-of-adjustment brakes or out-of-service situations are presented along with the parameter coefficients produced by statistical modeling in the results section of this report.

2.3.3 Development of a Procedure for Determining Brake Adjustment Intervals

2.3.3.1 Service Factors

Service factors are the aspects of vehicle usage that influence the rate of brake wear and thereby influence the period of service between brake adjustments. The rate of brake wear was studied by examining the number of miles a vehicle travels between relinings. The approach involved (1) determining the amount of lining wear that would result in brakes reaching the readjustment limits, (2) determining the life of the brake lining, (3) estimating the number of brake adjustments over the life of the brake lining, and (4) determining the amount of vehicle service between readjustments.

The mechanical ratio of the change in stroke to the change in lining thickness depends on the effective length of the slack adjuster, the effective radius of the S-cam, and a shoe geometry factor. The displacement at the center of the lining is approximately 1/2 of the displacement at the cam end of the shoe for fixed pivot brakes. Hence a shoe geometry factor of 2 was used in estimating the mechanical ratio. This relationship can be represented by the following equation:

$$\text{Mechanical ratio} = \frac{\text{Shoe geometry factor} * \text{Effective length of slack adjuster}}{\text{Effective cam radius}}$$

For a 6-inch slack adjuster with an effective cam radius of 1/2-inch and a shoe geometry factor of 2, the mechanical ratio would be 24. Perhaps because the shoe geometry factor is uncertain, different sources indicate that the mechanical ratio for this combination of slack adjuster length and S-cam could be either 18 or 21. Using a conservative approach in the development of the adjustment interval procedure, a mechanical ratio of 24 was used. This means that 0.02 inches of lining wear would result in a 0.48 inch increase in stroke. For a typical Type 30 brake chamber, there is approximately 0.5 inches of stroke between the fully adjusted brake and the readjustment limit. Therefore the amount of lining wear per adjustment would be 0.5/24 = 0.0208 inches. If the original lining thickness is 0.75 inches and the thickness at relining is 0.25 inches, the number of adjustments would be 0.5/0.0208 = 24. As long as the total lining wear (0.5 inches) is equal to the stroke change per adjustment, the number of adjustments will be equal to the mechanical ratio.

Given that it is not practical to expect brakes to be adjusted at precisely the right time, there would need to be more brake adjustments if brakes were not to be out-of-adjustment at any time. Perhaps 50 adjustments during the life of the lining might be performed in order to keep the brake in adjustment.

Examples of Estimates of Vehicle Miles Between Relinings

Estimates from a brake manufacturer: 250,00 - 300,000 miles for mild service 180,000 miles for typical service 50,000 - 60,000 miles for heavy service 10,000 - 20,000 miles for refuse hauler
Estimates from a trucking association: 70,000 - 600,000 miles (average 200,000 miles) for tractors 30,000 - 350,000 miles for trailers 50,000 miles for buses/motor coaches
Estimates from a large fleet: 300,000 miles for tractors used mainly for doubles in line-haul service on high quality roads (average speed approximately 51 mph) 130,000 miles for trailers 130,000 miles for converter dollies No averages for tractors used to deliver goods within urban areas.

The differences in the estimates given above are quite large and indicate the need for a general brake adjustment interval procedure that is applicable to many different types of carrier operations. The fleet information has been used as follows to illustrate estimated results for brake adjustment intervals:

tractors ➧ 300,000/24 = 12,500 miles per adjustment
(which may be approximately once a month)

trailers ➧ 130,000/24 = 5,400 miles per adjustment
(which may be approximately once a month)

dollies ➧ 130,000/24 = 5,400 miles per adjustment
(since dollies travel twice as many miles per year as trailers, the brakes may require adjustment every two weeks.

Perhaps because of the expense that would be associated with such frequent brake adjustment, many large fleets have been using automatic slack adjusters.

Given the preliminary results above, many carriers were contacted in an effort to locate studies on brake linings. Although no studies were located, one fleet did maintain a special database of repairs on their trucks. The company's maintenance manager was able to provide a list of brake repairs for the fleet. The list of repairs covered trucks (purchased brand new after January 1, 1989) operating in four different regions of the United States.

The data needed to be reduced to determine the first relining for each truck. First, the entries in the data field used for describing the reason for the repairs were interpreted. (The entries made by various mechanics ranged from part number to detailed descriptions.) Many of the irrelevant repairs were eliminated by inspecting this data field. Other fields were then used (price, repair location, and date) for further elimination until most of the trucks had a repair that could be regarded as the first relining. The few trucks that did not have an obvious first relining were removed from consideration.

The managers from the four different regions were contacted to find out further information. The primary concerns were load, terrain, and frequency of stops. Use of retarders was discussed by one of the managers and included in the profile. The mileage for the vehicles was then grouped and averaged according to these parameters. On follow-up calls, the managers confirmed the averages for the miles traveled between relinings.

The results for different vehicles operating at different locations and carrying different types of loads varied considerably. This information is presented in Table 6 and forms the basis for the results and findings pertaining to guidelines on brake adjustment intervals.

Table 6. Operating condition variations used in determining service factors

	Region	Load	Service	Daily Miles	Retarders	Statistics on Miles to Relining: Average	Standard Dev.	High	Low	Median
1	St. Cloud Minnesota	Moderate (appliances)	Interstate	691	yes	361932	26689	393130	337029	358785
2	Clearfield Utah	Light/Moderate (chips/potatoes)	Interstate (Mountainous)	359	yes	298916	62210	400984	185643	295164
3	Clearfield Utah	Moderate (diapers/others)	Interstate (Few Mountains)	505	yes	291505	80359	431783	146937	292217
4	Albuquerque New Mexico	Light/Moderate (chips/potatoes)	Interstate 40% Mountainous	387	Yes	284536	55905	343944	192798	300421
5	Porter Indiana	Heavy (steel)	Interstate	231	No	116999	35905	222322	58014	104353
6	St. Cloud Minnesota	Heavy (animal food)	Pickup & Delivery	240	Yes	115634	24549	152025	89678	118299
7	Blue Island Illinois	Heavy (paper)	Interstate	259	no	114357	28203	163571	78945	110872
8	Blue Island Illinois	Heavy (paper)	Pickup & Delivery (city)	192	no	69558	5934	75501	63634	69539

2.3.3.2 Determination of Service Factor Values

The service factor values are based on the operating conditions for the vehicle. For tractors the study uses 12,000 miles between brake adjustments as the baseline operating condition. The baseline operating condition for trailers is 5,200 miles between brake readjustments. The baseline operating conditions correspond to set of baseline service factors. When a vehicle is operated under conditions that differ from the baseline, the service factor is adjusted to account for the new operating conditions.

The service factor value depends on four variables: A, retarder usage; B, distance the vehicle travels daily; C, terrain in which the vehicle operates; and D, vehicle loading. The relationship between these variables and the service factor is represented by the following equation:

$$SF = \frac{1}{A \cdot B \cdot C \cdot D} \qquad (4)$$

The baseline operating conditions for which the service factor (SF) has a value of 1.0 (all of the variables have a value of 1) are as follows: the tractor is not equipped with a retarder; in a typical day the unit covers more than 400 miles (very few pickup and delivery jobs);

the vehicle operates primarily on level roads; and on an average, loading conditions are moderate (50 to 75 percent of the gross combination weight rating).

In the process of determining service factors that represent operating conditions that differ from the baseline conditions the following assumptions were made:

(1) When retarders are used (engine, electric or hydraulic), the life of the brake linings is extended by 30 percent.

(2) An exhaust retarder will extend the life of the lining by only 10 percent since its retarding power is 1/3 of other retarders.

(3) A vehicle that is used primarily for pickup and delivery covers less than 250 miles in a typical driving day. Vehicles operating under baseline conditions (more than 400 miles daily and with very few pickup and delivery jobs) travel 70 percent more miles between relinings than vehicles used in pickup and delivery operations.

(4) Mountainous driving will wear brake linings 30 percent faster than driving on level roads.

(5) Rolling-hills driving will wear brake linings 10 percent faster than driving on level roads.

(6) There are three loading conditions for vehicles: (a) lightly loaded (up to 50 percent of the GCWR, or up to 26 percent of the payload capacity); (b) moderately loaded (50 to 75 percent of the GCWR, or 26 to 63 percent of the payload capacity); and (c) fully loaded (over 75% of the GCWR, or over 63 percent of the payload capacity). Compared to the baseline condition, moderately loaded, a lightly loaded operation will result in approximately 15 percent more miles between relinings, while a fully loaded operation will have 20 percent fewer miles between relinings. Table 7 summarizes the factors used in determining the service factor.

Table 7. Values for variables used in calculating the service factor

Service Factor Variables	Vehicle Operating Conditions	Values
A	No retarder	1.0
	Exhaust retarder	0.9
	Engine, electric, or hydraulic retarder	0.7
B	Less than 250 miles of use per day	1.7
	Between 250 and 400 miles of use per day	1.3
	More than 400 miles of use per day	1.0
C	Mountainous driving	1.3
	Rolling hills driving	1.1
	Level driving	1.0
D	Fully loaded (more than 75% of GCW)	1.2
	Moderately loaded (50-75% of GCW)	1.0
	Lightly loaded (less than 50% of GCW)	0.85

2.3.3.3 Development of Procedure to Determine Brake Adjustment Intervals

The procedure to determine brake adjustment intervals is intended to be used to minimize the chances that a heavy truck will be operated with misadjusted brakes. The process of establishing brake adjustment frequency entails the assessment of the ratio of the distance traveled by the truck and the subsequent stroke increase and the adjustment cycle. (See Figure 7.) With a proper understanding of the stroke-distance relationship, an accurate prediction of when brakes will reach their readjustment limit is possible.

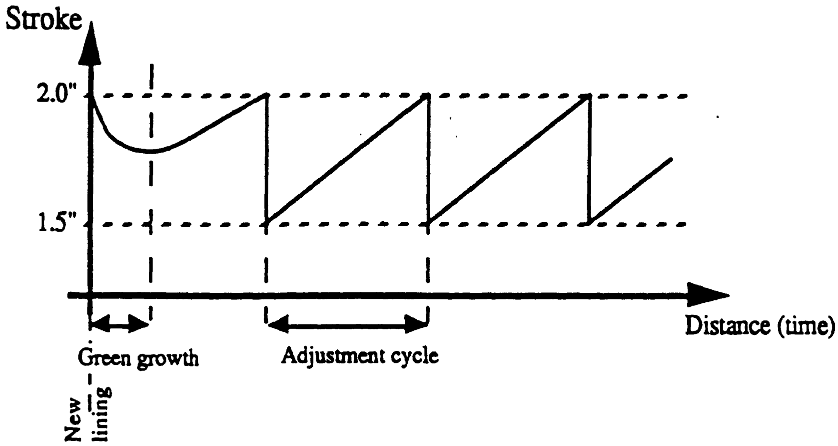


Figure 7. Stroke vs. distance per adjustment cycle

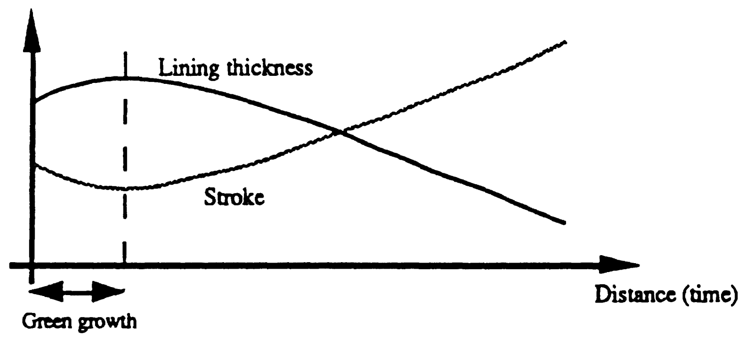


Figure 8. Influence of green growth (swell stage)

The procedure for determining brake adjustment intervals presented in this report is relatively short and does not require unreasonable accuracy in measuring the stroke. It is a prediction-correction process. Each prediction is corrected by what is found in the next brake inspection. The procedure assumes the following:

1. From the fully-adjusted position, a stroke increase of 0.5 inch means that readjustment is necessary.

2. Stroke measurements can be made to an accuracy of 1/8 inch.

3. One complete turn of the adjusting nut on a slack adjuster covers 12 notches or clicks of the nut. Therefore the adjustment can only be made to the nearest 1/12th of a turn. Each notch or 1/12th turn changes the stroke by approximately 1/8 of an inch.

4. The "green growth" or swell stage of the brake linings is completed. (See Figure 8.)

5. The operating conditions for each of the vehicles for which the adjustment frequency is being established are consistent.

6. The brakes on trailers and dollies wear at a rate approximately 3 times that of tractors.

7. If brake adjustment is performed exactly when needed, there would be approximately 25 brake adjustments performed over the life of the lining.

8. Baseline conditions for brake lining wear rate are:
   Tractors - 0.02 inch/12,000 miles
   Trailers/dollies - 0.06 inch/12,000 miles

Using the above assumptions, the procedure can be represented conceptually.

Starting Point: The brakes are fully adjusted and in the case of new linings, the green growth period has been completed.

Initial Prediction: Based on the type of service that is anticipated for the vehicle, try to predict how many miles the unit will travel, or the number of days the unit will be in service before the amount of brake wear is equivalent to 1/12th of a turn (one notch or click) of the adjusting nut on the slack adjuster. (This means that 1/12th of a turn of the adjusting nut on the slack adjuster will return the brake to its fully-adjusted state.) The prediction is made by using the service factor.

Classification of Maintenance Schedules: At this point, a decision on the predictability of the fleet operation must be made. The levels of predictability relate to the frequency with which the brakes will be readjusted to prevent the stroke from exceeding the readjustment limits.

Schedule 1 - This schedule is for a very conservative operation with respect to the frequency of brake adjustment. The schedule is intended for carriers with the highest level of variety in operating conditions and the lowest level of predictability in the distance/time versus stroke relationship. The prediction is based on the distance/time the unit will be in service before the amount of brake wear is equivalent to 1/12th of a turn (one notch or click) of the adjusting nut on the slack adjuster.

Schedule 2 - This schedule is for a moderate operation with respect to the frequency of brake adjustment. This schedule is for carriers with a moderate amount of variety in operating conditions and a moderate level of predictability. The prediction is based on the distance/time the unit will be in service before the amount of brake wear is equivalent to 1/6th of a turn (two notches or clicks) of the adjusting nut on the slack adjuster.

Schedule 3 - This schedule provides the greatest distance/time between brake adjustments. It is intended for carriers with minimum variety in operating conditions and the highest level of predictability. The prediction is based on the distance/time the unit will be in service before the amount of brake wear is equivalent to 1/4th of a turn (three notches or clicks) of the adjusting nut on the slack adjuster.

Verification of Prediction:

Schedule 1:

At this point the process is practically completed. The prediction for the time/distance between the fully-adjusted condition and the point at which 1/12th of a turn of the adjusting nut will be needed to return the brake to the fully-adjusted condition is verified.

Schedule 2:

Monitor the time/distance traveled between the fully-adjusted condition and the point at which 1/6th of a turn (two notches or clicks) of the adjusting nut will be needed to return the brake to the fully-adjusted condition. During this period in which the prediction is fine tuned, the stroke is measured but the brakes are not adjusted. After reaching the point at which two notches or clicks are required, the brakes are readjusted and the interval is verified.

Schedule 3:

Monitor the time/distance between the fully-adjusted condition and the point at which 1/4th of a turn (three notches or clicks) of the adjusting nut will be needed to return the brake to the fully-adjusted condition. During this period in which the prediction is fine tuned, the stroke is measured but the brakes are not adjusted. After reaching the point at which three notches or clicks are required, the brakes are readjusted and the interval is verified.

As a safety margin, it is not recommended that this method be used beyond a "three notch" or schedule 3 operation. Also, if errors are found in the prediction, the process must be started from the beginning. The errors can be easily corrected by starting from the beginning but failure to do so will result in a likelihood of having the brakes out-of-adjustment. This procedure is considered successful when the predictions are verified. The predictions are verified when the vehicle returns after each interval and number of notches or clicks needed to provide fully adjusted brakes consistently agrees with the prediction.

3.0 Results and Findings

3.1 Technical Adequacy of the 20-Percent Rule for Brake Adjustment

The results and findings presented in this section address the following question: Does the use of the brake adjustment criteria under the 20-percent rule accurately distinguish between trucks with insufficient braking capabilities and those with sufficient braking capabilities? Ideally, the out-of-service criteria should readily separate vehicles by their braking capabilities. Vehicles placed out-of-service would be expected to have lower braking capabilities than those that are allowed to continue in service. However, the use of the brakeability method for evaluating brake adjustment indicates that the out-of-service population overlaps with the population of vehicles that is not placed out-of-service. A significant percentage of vehicles placed out-of-service for only brake adjustment violations have braking capability exceeding 80 percent of their braking capability with fully adjusted brakes. Trucks with more than 80 percent of their brakes working properly have been considered safe per the 20-percent rule and traditional recommendations concerning the readjustment limit.

The NTSB inspected a total of 2,343 trucks. Of these, 196 had no front axle brakes or some brakes that were either disc or wedge. Since the focus of this study is on S-cam brakes, those 196 vehicles were eliminated. One truck had an unusual brake chamber size for which the UMTRI brakeability value could not be calculated, so it too was eliminated. These deletions leave 2,146 trucks, which were used in the statistical analysis. Of these 2,146 trucks, 936 had sufficient brake violations, considering just brake adjustment, to be put out-of-service.

It is very important to remember that this study focuses on out-of-service violations due to brake adjustment problems. The study of the criteria involved a review of the use of the 20-percent rule as it is applied to brake adjustment. The rule dealing with defective brakes on steering axles is not applied in this section. The sole criterion of out-of-service here is whether 20 percent or more of the brakes were defective (counting two brakes at or less that 1/4 inch beyond the readjustment limit as one defective brake). In practice, neglecting the steering axle rule had little effect. Only 36 trucks warranted being put out-of-service solely because of one defective steering axle brake.

Roadside inspection data from the NTSB was reviewed to assess the number of vehicles placed out-of-service under the 20-percent rule, and the number of vehicles that were not placed out-of-service. The data was then distributed according to the measures of UMTRI-calculated brakeability and the NTSB's braking efficiency. The bar chart in Figure 9 illustrates the findings from this distribution. Table 8 shows the frequency distribution.

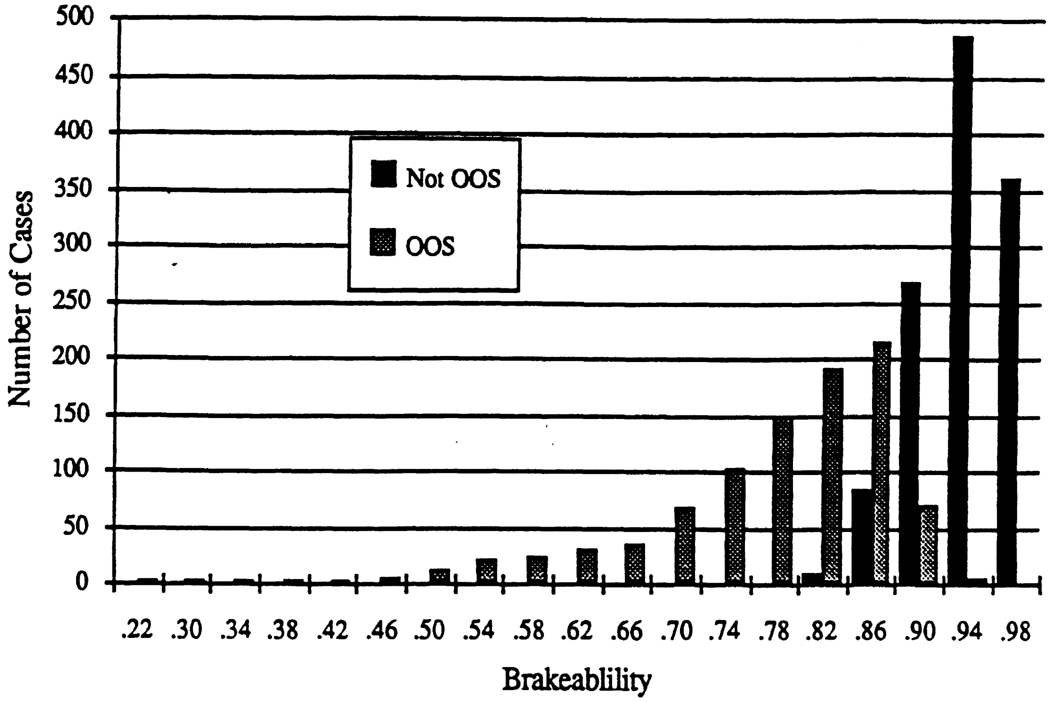


Figure 9. UMTRI brakeability values for NTSB inspection data

Table 8. Frequency distribution for UMTRI brakeability

Brake-ability	Not OOS N	OOS N
0.22	0	1
0.3	0	3
0.34	0	1
0.38	0	3
0.42	0	3
0.46	0	4
0.5	0	11
0.54	0	22
0.58	0	23
0.62	0	31
0.66	0	36
0.7	0	67
0.74	0	102
0.78	0	149
0.82	10	191
0.86	83	214
0.9	269	70
0.94	487	5
0.98	361	0
total	1,210	936

Overall, the 20-percent rule divides the truck population into reasonably distinct groups. Vehicles that passed the 20-percent rule had a mean brakeability of 0.94, with a range of 0.82 to 1.00 and standard deviation of 0.036. The average brakeability for vehicles placed out-of-service was 0.78 with a range of 0.24 to 0.93 and a standard deviation of 0.105. A test of the difference of means was significant at better than 0.0001 indicating that there is more than a 99.99% chance that the means are truly different. None of the vehicles that passed the adjustment criteria had a brakeability below 0.8 (80 percent of the braking potential if all of the brakes were fully adjusted). Therefore, all trucks with an insufficient braking capability (due to improper brake adjustment alone) failed the 20-percent rule.

While none of the trucks with a brakeability below 0.8 passed the 20-percent rule, many trucks with a greater brakeability failed the brake criteria. Table 9 shows the breakdown of the NTSB inspection data. Of 936 trucks placed out-of-service for brake adjustment, 480 (51.3 percent) had adequate braking, as indicated by brakeability values greater than 0.8. (The value of 0.8 was chosen as the cut-off point because the goal of the 20-percent rule is to require that at least 80-percent of the vehicle's brakes be properly adjusted which, absent of other factors, would suggest 80-percent of fully adjusted braking capability.) Keep in mind that for the purposes of this study, the 20-percent rule for placing vehicles out-of-service is based solely on the brake adjustment criteria. Violations such as grease on the linings or drums, cracked drums, or problems with air pressure are not considered. Thus the 480 out-of-service trucks with adequate braking can be considered "false positives" cases where the 20-percent rule incorrectly indicated a problem. There were no "false negatives," cases where the 20-percent rule incorrectly indicated adequate braking capability.

Table 9. UMTRI brakeability values for vehicles under the 20-percent rule

	Brakeability score		
Status	<.8	>=.8	Total
Not OOS	0	1,210	1,210
	(0.0)	(100.0)	(100.0)
OOS	456	480	936
	(48.7)	(51.3)	(100.0)
Total	456	1,690	2,146
	(21.2)	(78.5)	(100.0)

At this point in the discussion, the NTSB's measure of braking efficiency is also worth considering. The NTSB braking efficiency measures are calculated in a manner similar to brakeability, but the values are normalized to an estimate of available friction. The scatter plot in Figure 10 shows that the measures are similar but not identical. The NTSB braking efficiency values were calculated assuming brake temperatures of 400°F and 80,000 pounds gross vehicle weight. These are the same temperature and loading assumptions used for the brakeability calculations. Braking efficiency shows a greater range of values, between 0.02 and 1.00. The braking efficiency values are highly correlated but not collinear.

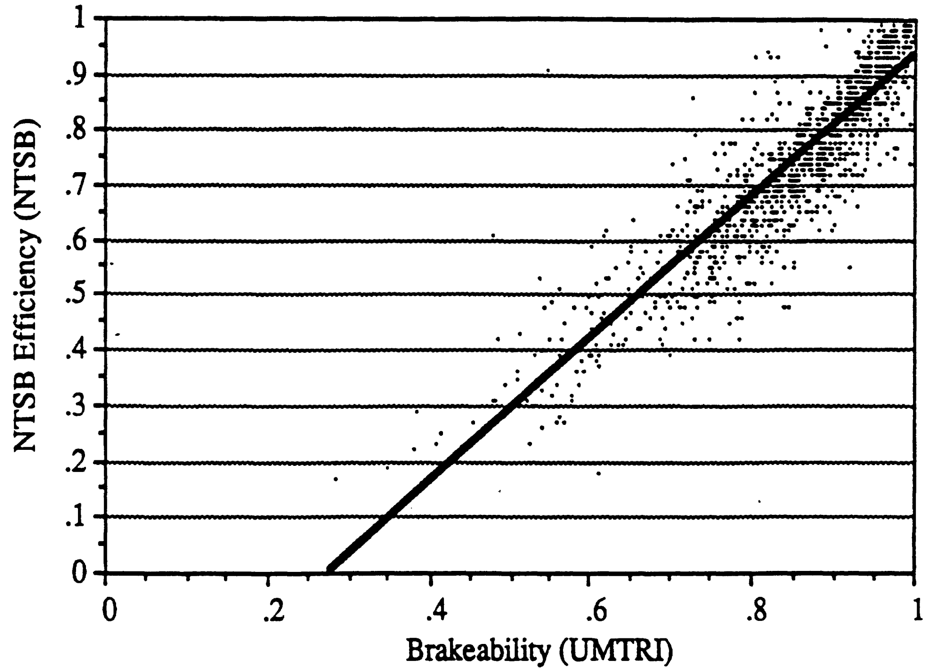


Figure 10. NTSB-calculated braking efficiency by UMTRI brakeability including regression line

Figure 11 displays the NTSB-calculated braking efficiency at 400F brake temperature and 80,000 pounds gross vehicle weight for vehicles examined during the NTSB's study. The peak (greatest number of cases with the same braking efficiency value) of the out-of-service trucks is well below 0.8, while the peak braking efficiency value for those vehicles that passed the 20-percent rule is well above 0.8. The mean braking efficiency for the out-of-service vehicles is 0.63. The mean braking efficiency for vehicles which passed the 20-percent rule was 0.86. Table 10 shows the frequency distributions. (1,383 trucks had both NTSB-calculated braking efficiencies and only S-cam brakes.)

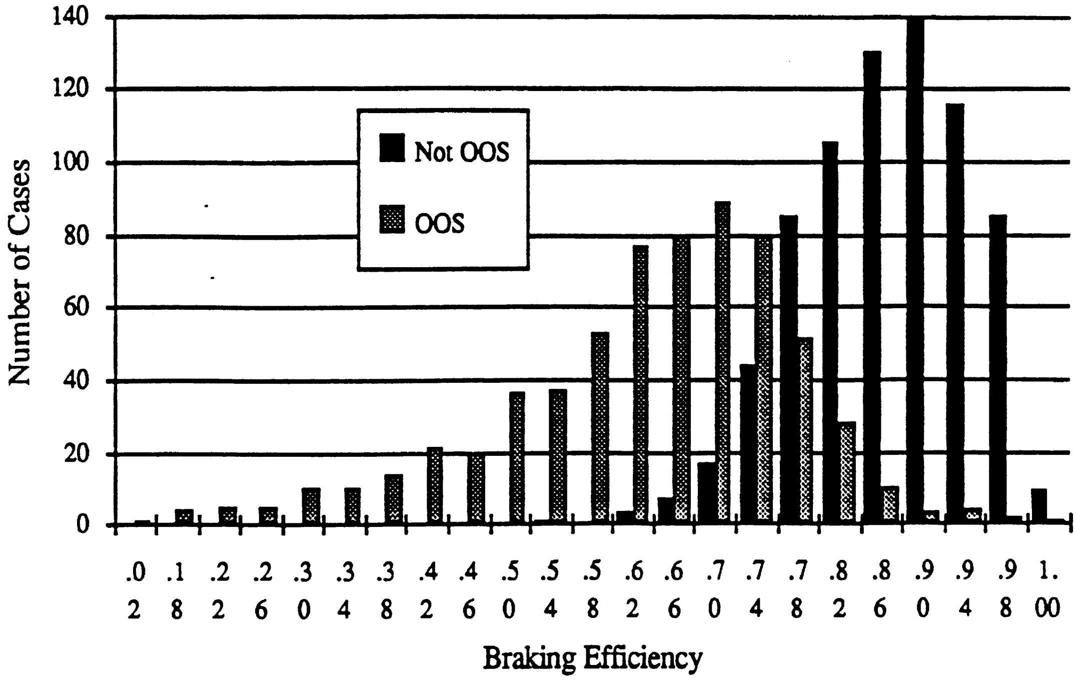


Figure 11. NTSB braking efficiency at 80,000 lb and 400°F OOS using 20-percent rule only

Table 10. NTSB braking efficiency distribution at 80,000 pounds and 400 °F

Braking efficiency	Not OOS N	OOS N
0.02	0	1
0.18	0	4
0.22	0	5
0.26	0	5
0.30	0	10
0.34	0	10
0.38	0	14
0.42	0	21
0.46	0	20
0.50	0	36
0.54	1	37
0.58	0	53
0.62	3	77
0.66	7	80
0.70	17	89
0.74	44	80
0.78	85	51
0.82	105	28
0.86	130	10
0.90	140	3
0.94	116	4
0.98	85	2
1.00	9	1
total	742	641

Figure 12 displays the NTSB-calculated braking efficiency at 600F brake temperature and 80,000 pounds gross vehicle weight. The figure shows that the out-of-service population and the vehicles passing the inspection criteria are fairly distinct though the curves are somewhat flattened and shifted to the left, as would be expected given the higher brake temperature. The mean braking efficiency for vehicles passing the 20-percent rule is 0.76, while the mean for vehicles placed out-of-service is 0.48. Table 11 shows the frequency distribution.

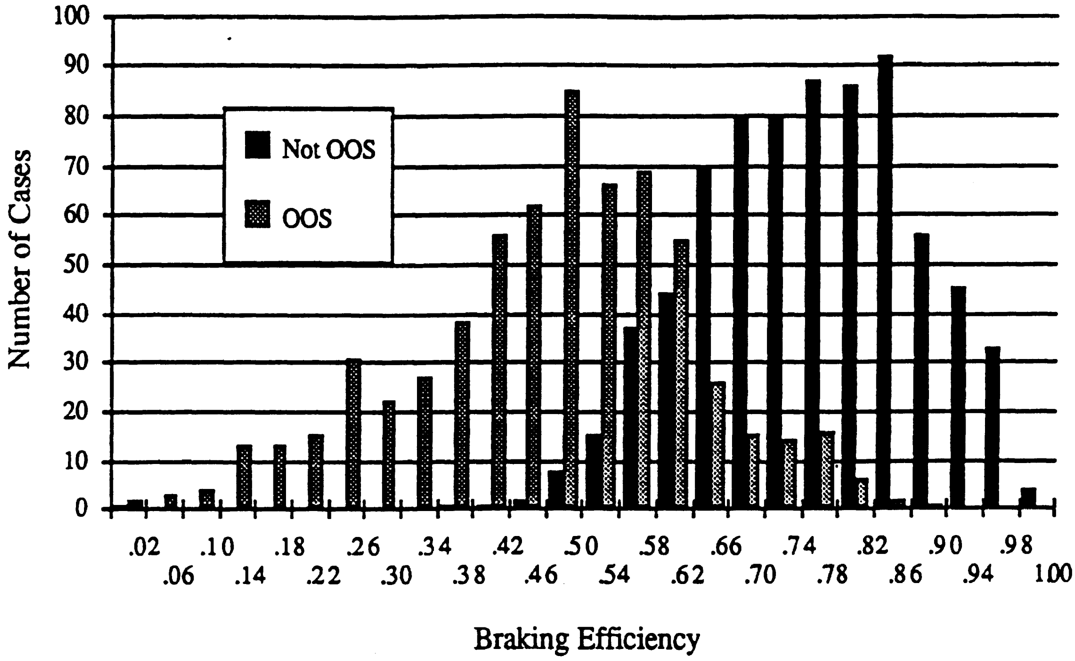


Figure 12. NTSB braking efficiency at 80,000 lb and 600°F OOS using 20-percent rule only

Table 11. NTSB braking efficiency distribution at 80,000 pounds and 600 °F

Braking efficiency	Not OOS N	OOS N
0.02	1	2
0.06	0	3
0.10	0	4
0.14	0	13
0.18	0	13
0.22	0	15
0.26	0	31
0.30	0	22
0.34	0	27
0.38	1	38
0.42	1	56
0.46	2	62
0.50	8	85
0.54	15	66
0.58	37	69
0.62	44	55
0.66	70	26
0.70	80	15
0.74	80	14
0.78	87	16
0.82	86	6
0.86	92	2
0.90	56	1
0.94	45	0
0.98	33	0
1.00	4	0
total	742	641

Figures 11 and 12 illustrate that the out-of-service population overlaps the population of vehicles passing the 20-percent rule. The overlap illustrated for the NTSB braking efficiency is greater than the overlap for the UMTRI brakeability (shown in Figure 9). Note that all of the braking measures show some degree of overlapping populations. The amount of overlap for each figure can be estimated by converting the bar charts into curves and calculating the area that falls under both curves. The brakeability score separates the two populations best with only 15.7 percent overlap. For the 400F braking efficiency values the overlap is 24.7 percent. The overlap is 27.3 percent for the 600F braking efficiency values. The braking efficiency measure, since it includes considerations that are not directly related to brake adjustment, is not as closely related to the 20-percent rule as brakeability. Also, while the 20-percent rule identifies populations that are, on average, different with respect to braking capabilities, the criteria results in some vehicles being placed out-of-service with greater braking capability than that of some of the vehicles that pass.

Considering the 2,146 vehicles with S-cam brakes that were inspected by the NTSB, 936 (43.6 percent) failed the 20-percent rule. Four hundred and eighty of those vehicles had at least 80 percent of the stopping power that would have been available if brakes were fully adjusted. Moreover, a large proportion of the false positives failed the inspection solely on the basis of brake adjustment. Only 170 of the false positives had other out-of-service violations, including other brake violations. Approximately one-third (310) of the vehicles classified as out-of-service due to brake adjustment had adequate braking and no other violations detected. It is important to remember that the NTSB inspections focused on brakes and not other vehicle problems.

The structure of the 20-percent rule provides opportunities for false positives since each brake is given the same weight as all other brakes and the range of stroke measurements are classified into three categories. Two examples illustrate how trucks with good brakeability values can fail the 20-percent rule.

A typical pattern is a truck with each steering axle brake at 1/4 inch beyond the readjustment limit and all other brakes properly adjusted. The two defective brakes would represent 20 percent of the brakes on a five axle combination vehicle and therefore the vehicle would fail the 20-percent rule. However, the steering axle brakes bear the smallest share of the braking load and are typically activated by Type 16 or Type 20 brake chambers. Therefore, the improper adjustment of steering axle brakes has only a small practical effect. It should be emphasized that these results in no way suggest that steering axle brakes do not have an impact on the braking ability of heavy vehicles, only that two steering axle brakes which are slightly out-of-adjustment are not as detrimental to braking ability as other out-of-adjustment brakes.

Another frequent pattern is a vehicle with four brakes just at the readjustment limit, and all other brakes fully adjusted. The four brakes at the readjustment limit count as two defective brakes under the 20-percent rule, yet in many instances the brakeability value for the vehicle is greater than 0.8.

As described previously, brakeability represents the percentage change in stopping capability of a vehicle due to its brake adjustment status. It basically answers the question: If the inspected truck with some of its brakes out-of-adjustment were fully laden, what stopping capability would it have relative to the same truck with its brakes fully adjusted? Or equivalently, how much braking force could its brakes generate given its current adjustment status, relative to the braking force produced with its brakes fully adjusted?

Brakeability assesses the braking ability of the subject truck based only on its brake adjustment status, normalized to fully adjusted conditions. Other parameters that are not related to brake adjustment are not considered. Braking efficiency as computed by the NTSB and as explained in "Heavy Truck Deceleration Rates as a Function of Brake Adjustment" [7], incorporates considerations that are not necessarily brake-adjustment related. It is based on the premise of wheel locking ability; the closer the truck is to locking all of its wheels, the higher the efficiency.

In concept, both brakeability and braking efficiency start off in a similar manner. Based on the geometries involved (such as slack adjuster length, drum diameter, etc.), the current adjustment status at each brake is considered to evaluate chamber-bottoming effects and the resultant losses of braking force. From this point the two methods proceed in different directions. The efficiency computes drag (the lesser between braking force and a sliding tire), and normalizes it to the assumed road friction of 0.56. By contrast, brakeability normalizes the available braking force to that which is obtained with fully adjusted brakes. No limited adhesion considerations are made.

As for a comparison between the brakeability and demerit methods, they are conceptually similar. Both are aimed at estimating the amount of loss of braking capability due to out-of-adjustment brakes. One of the primary differences between the two methods is the extent to which the brake system hardware and geometrics are accounted for. To provide a sound, practical comparison between the two methods, the NTSB inspection data was processed using both methods.

By virtue of the more detailed and comprehensive computations involved with the brakeability method, it was considered more accurate than the demerit method. The brakeability method was therefore used as a baseline for evaluating the accuracy of the results obtained by the demerit method.

The demerit method uses brake adjustment factors to account for the degradation of braking ability over certain ranges of stroke. As described in section 2.2.4, three different sets of brake adjustment factors were used while attempting to refine the accuracy of the demerit method (Tables 1, 3, and 4). The NTSB data was therefore processed using each of these sets, and each time the results were plotted together with those obtained using the brakeability method. By evaluating the resultant plots both qualitatively and quantitatively, an assessment of the accuracy of the demerit method was made.

The brake adjustment factors as listed in Table 3 were found to be the best combination for accuracy and practicality. While those factors in Table 1 resulted in demerit values where were unsatisfactory from the accuracy standpoint, using the factors in Table 4 provided only a marginal improvement over the results obtained by the factors from Table 3. However, the finer division of stroke intervals in Table 4 (eight divisions in Table 4 versus 6 divisions in Table 3), might jeopardize the practicality of the demerit method as a simple way to evaluate brake adjustment. The finer divisions could make the computations more complicated such that the simplicity advantages of the demerit method are lost. A more detailed discussion comparing the various ramifications of the different methods to evaluate brake adjustment is provided later in this section.

The comparison of the demerit and brakeability methods is illustrated in Figure 13. Using the brake adjustment factors from Table 3, the demerit results from the NTSB inspection data are shown with the results obtained by using the brakeability method. Applying the concept of placing vehicles out-of-service under the 20-percent rule, particular attention is focused on the demerit and brakeability values around 0.8. Figure 14 provides a magnified view of the graph in the area between the 0.7 and 0.9 values.

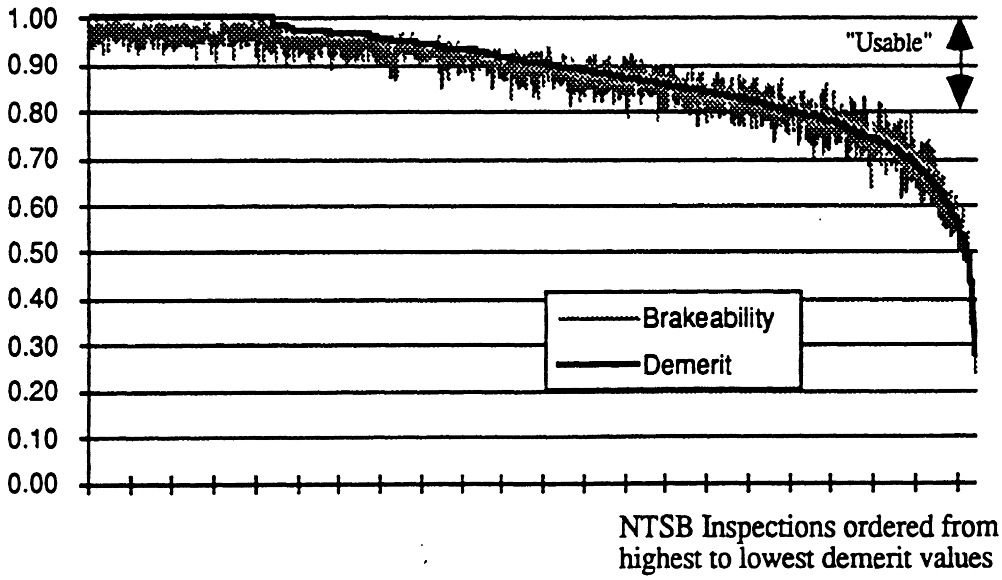


Figure 13. Demerit and brakeability results for the NTSB data

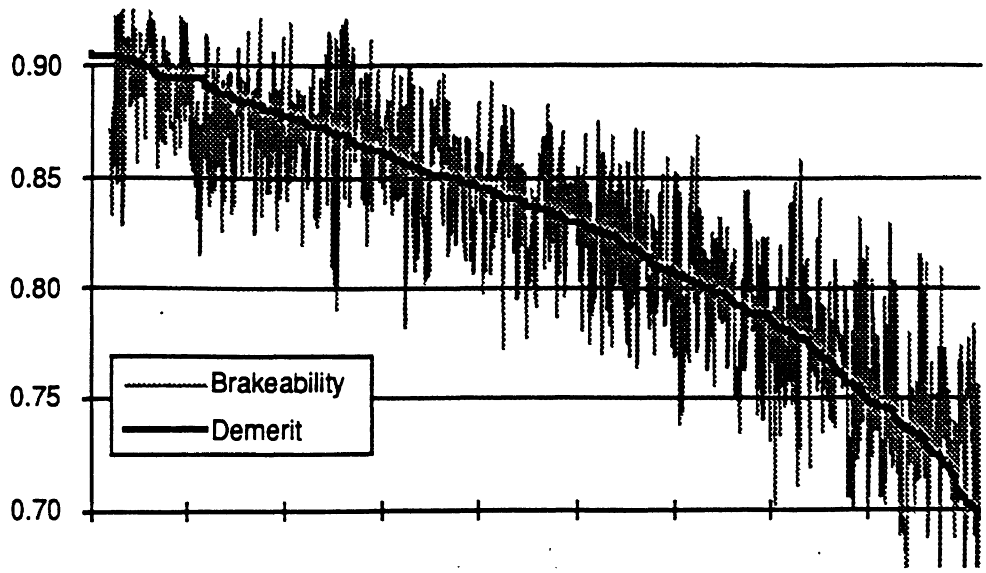


Figure 14. Demerit and brakeability results for the NTSB data — 0.7-0.9 values

Several observations can be made from Figures 13 and 14. First, Figure 13 resembles a plot of the characteristic output force versus stroke for a brake chamber. Using that mechanically-sound analogy, those trucks that would be placed out-of-service (below the 0.8 value for the demerit and brakeability methods) are well into the area where the output force for the chambers drops off rapidly. Trucks above the 0.8 value line are positioned in the area where the output force for the chamber is acceptable and will not be placed out-of-service. Second, the degree to which the demerit method values agree with those of the brakeability method around 0.8 is relatively high.

In order to further investigate the conformity level between the demerit and brakeability methods, the values obtained for the NTSB data were plotted against each other. The plot is shown in Figure 15 with the equation of the linear fit line. The R^2 value of 0.944 indicates a high level of correlation between the demerit and brakeability results. As with Figure 13, the area around the 0.8 value is of particular interest. Figure 16 provides a magnified view. The plot in Figure 16 is divided into quadrants:

Quadrant 1 - 1,671 vehicles out of the total of 2,146 vehicles (77.9 percent) represent trucks that would have passed under both the demerit and brakeability methods;

Quadrant 2 - 61 out of the 2,146 vehicles (2.8 percent) represent trucks that would have passed using the demerit method and placed out-of-service using the brakeability method;

Quadrant 3 - 371 out of the 2,146 vehicles (17.3 percent) represent trucks that would have been determined out-of-service by both the demerit and brakeability methods;

Quadrant 4 - 43 out of the 2,146 vehicles (2.0 percent) represent trucks that would have been placed out-of-service using the demerit method and passed using the brakeability method.

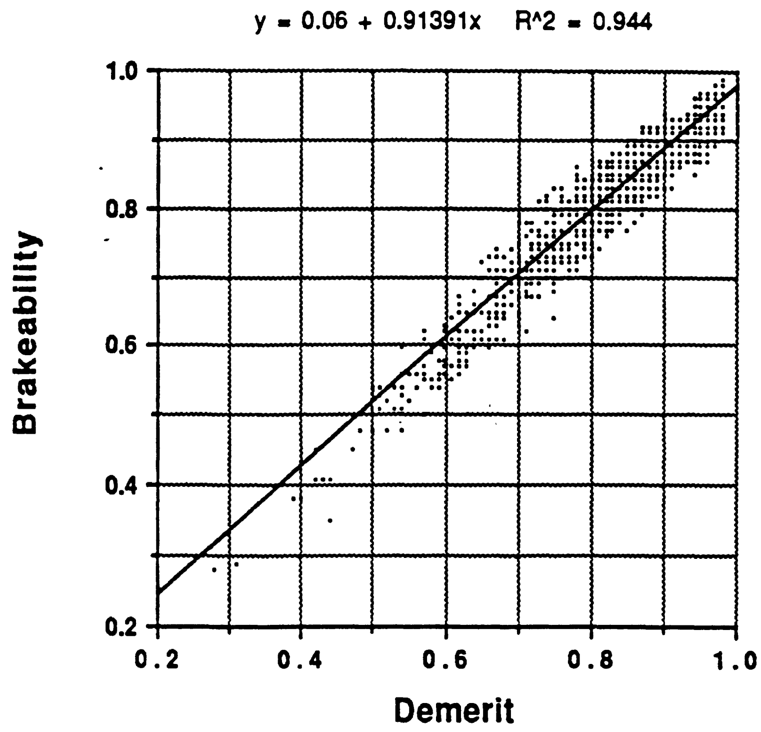


Figure 15. Demerit vs. brakeability results of the NTSB data including regression line

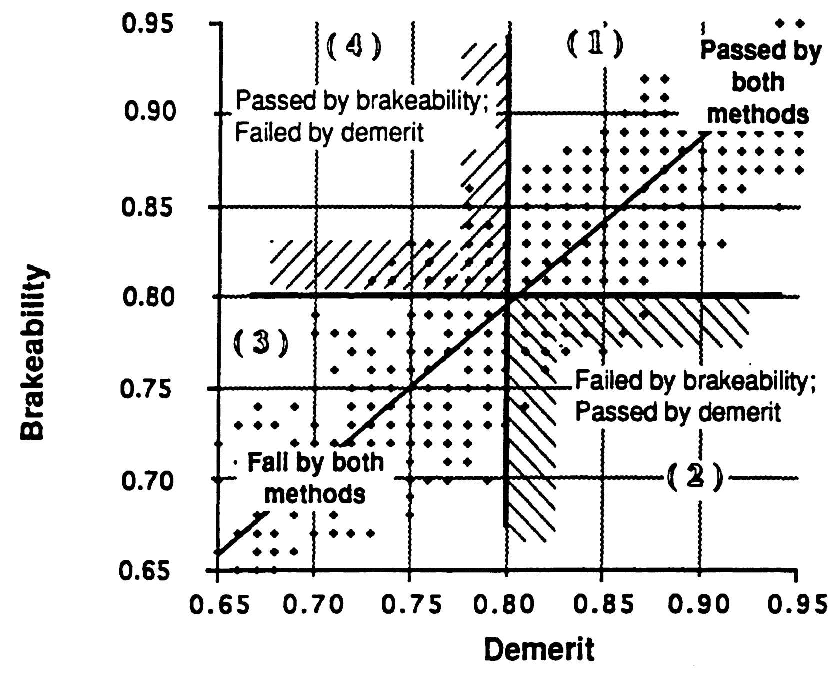


Figure 16. Demerit vs. brakeability results of the NTSB data including regression line — 0.65-0.95 values

Assuming that the brakeability method is the more accurate way to evaluate a vehicle's stopping capability based on its brake adjustment, applying the demerit method to the NTSB data would result in 3.52 percent false negatives (vehicles with inadequate braking capability passing the inspection --100*(61)/(61+1671)=3.52%) and 10.39 percent false positives (vehicles with adequate braking capability being placed out-of-service -- 100*(43)/(43+371)=10.39%).

Currently, the brake adjustment of heavy trucks is being evaluated under the 20-percent rule. At this point, three alternative methods were introduced as substitutes: (1) NTSB's braking efficiency, (2) UMTRI's demerit, and (3) UMTRI's brakeability. Table 12 provides a comparative summary for all four methods. The last four rows or qualities in the table are rated on a scale of 1 to 4 with 1 being the best and 4 being the worst.

Table 12. Brake adjustment evaluation methods - comparative summary

	20-Percent Rule	**NTSB's Efficiency (400°F, 80,000 lb)**	**UMTRI's Demerit**	**UMTRI's Brakeability**
Measurement requirements	Chamber size Stroke	Chamber size Stroke Slack arm Inspection pressure	Chamber size Stroke	Chamber size Stroke Slack arm Inspection pressure
Computation requirements	Readjustment point	Road friction Sets of equations	Readjustment point Brake adjustment factors	Chamber data Sets of equations
Computing tool	Tables	Computer	Tables, calculator	Computer
Uniform	4	3	2	1
Technically sound	4	3	2	1
Practical	1	4	2	3
Appropriate	4	3	2	1

3.2 Carrier and Vehicle Information from NTSB Data

Given the quality of the NTSB data file, the data were used for the bulk of the analysis of the effect of vehicle use on brake adjustment. The results are presented in discussions preceding Tables 13 through 32.

3.2.1 Carrier Types and Sizes in the NTSB Data

Approximately 71 percent of the trucks in the sample were operated by for-hire carriers. Private carriers accounted for 29.1 percent of the vehicles (681 out of 2,343) of the total number of inspections performed by the NTSB and one vehicle was operated by a U.S. mail carrier. (Of the 2,343 vehicles inspected, 2,146 were equipped entirely with S-cam brakes.) As might be expected, there were some differences between the trucks inspected at interstate sites and those inspected off the interstates. The trucks inspected at the off-interstate sites were more likely to be private carriers, 34.3 percent at off-interstate and 25.4 percent at interstate sites.

Table 13. Carrier type by inspection site

Inspection Site	Carrier Type			
	For-hire	Private	U.S. Mail	Total
Interstate	1,020	347	1	1,368
(%)	(74.6)	(25.4)	(0.0)	(100.0)
Off Interstate	641	334	0	975
(%)	(65.7)	(34.3)	(0.0)	(100.0)
Total	1,661	681	1	2,343
(%)	(70.9)	(29.1)	(0.0)	(100.0)

The sample also included a good distribution across the range of carrier sizes. Carriers ranged from operators of one vehicle to the largest carriers in the country. There were 31 trucks in the sample operated by carriers with more than 5,000 trucks in their fleet. Carriers with 2 to 49 trucks were the largest group but over 8 percent of the sample were single-truck operations and 11.2 percent of the carriers had 1,000 or more vehicles. The interstate sample tended to have more large carriers, while off-interstate sites had a higher proportion of small and single-truck operations. This could be expected since the largest carriers concentrate on long-haul freight carriage which tends to take place on interstate roads. Trucks operated off the interstates are more often used by local businesses for local operations.

Table 14. Carrier size by inspection site

Inspection Site	Carrier size (number of vehicles)							
	1	2-49	50-99	100-499	500-999	>999	Unk.	Total
Interstate	98	611	157	252	67	174	9	1,368
(%)	(7.2)	(44.7)	(11.5)	(18.4)	(4.9)	(12.7)	(0.7)	(100.0)
Off Interstate	99	505	101	131	45	88	6	975
(%)	(10.2)	(51.8)	(10.4)	(13.4)	(4.6)	(9.0)	(0.6)	(100.0)
Total	197	1,116	258	383	112	262	15	2,343
(%)	(8.4)	(47.6)	(11.0)	(16.3)	(4.8)	(11.2)	(0.6)	(100.0)

3.2.2 Trailer Body Types and Tractor Model Years in the NTSB Data

Van type trailers were the dominant trailer body style among the combination vehicles inspected with almost 58 percent of the cases. Flatbeds and lowboys are the next largest group with 19.2 percent. The "bulk/container" group includes hopper type trailers, grain trailers, and similar trailers. The "other/unknown" group includes auto carriers, logging and pole trailers. Only two cargo body types were coded "unknown," both in the interstate sample. The proportion of vans is significantly higher in the interstate sample than in the off-interstate sample, while there were more bulk and other trailers inspected as part of the off-interstate group. Thirty-seven doubles combinations were sampled, 36 of them at interstate sites.

Table 15. Trailer cargo body type by inspection site

Inspection Site	Van	Flat	Tank	Dump	Bulk/ Container	Other/ Unknown	Total
Interstate	862	267	88	46	79	26	1,368
(%)	(63.0)	(19.5)	(6.4)	(3.4)	(5.8)	(1.9)	(100.0)
Off Interstate	481	183	69	41	155	46	975
(%)	(49.3)	(18.8)	(7.1)	(4.2)	(15.9)	(4.7)	(100.0)
Total	1,343	450	157	87	234	72	2,343
(%)	(57.3)	(19.2)	(6.7)	(3.7)	(10.0)	(3.1)	(100.0)

The sampled trucks also appear to have had a reasonable distribution by the model year of the tractor. Model years ranged from 1955 to 1992, with 21.1 percent older than 1983, 47.4 percent from 1983 to 1988 and 31.2 percent 1989 through 1992. Once again, the population sampled at the off-interstate sites was somewhat different from the interstate sites. The trucks at the off-interstate sites tended to be older. Twenty-seven percent of the off-interstate site combination vehicles were tractor model years before 1983 compared to 16.9 percent of the interstate site sample. The proportion of newer model trucks at the off-interstate sites was correspondingly diminished.

Table 16. Tractor model year by inspection site

Inspection Site	Model Year <1983	1983-88	1989-91	Unknown	Total
Interstate	231	672	456	9	1,368
(%)	(16.9)	(49.1)	(33.3)	(0.7)	(100.0)
Off Interstate	263	438	274	0	975
(%)	(27.0)	(44.9)	(28.1)	(0.0)	(100.0)
Total	494	1,110	730	9	2,343
(%)	(21.1)	(47.4)	(31.2)	(0.4)	(100.0)

To summarize, both the sampling procedure and the data collected are consistent with the conclusion that the sample is representative of the national truck populations, at least for the purpose of analyzing brake adjustment. The data broadly cover the range of trucks in the U.S. with respect to carrier type and size, trailer body type, and tractor model year. Populations sampled on interstate and non-interstate roads highlight the diversity of the trucking industry. The interstate population tended to have a higher proportion of for-hire, large carriers, with newer model power units and more van trailers. The off-interstate group had a higher proportion of private carriers (while the majority of off-interstate group consisted of for-hire carriers) with more single-truck and small carriers, older vehicles and non-van type trailers.

3.3 Factors Associated with Out-of-Adjustment Brakes

The NTSB teams inspected 2,343 trucks. Each combination truck had five axles so there are potentially brake-adjustment data on 23,430 axle ends. In the sample, 150 trucks had no front axle brakes, eliminating 300 brakes. In addition, there were 214 wedge brakes and four disc brakes. The non-S-cam cases have been excluded from the brake adjustment analysis, leaving 22,912 brakes to be considered. The information presented in this section is, with a few exceptions, based on 22,912 brake measurements.

The North American Uniform Vehicle Out-of-Service Criteria Policy Statement was used to classify the adjustment status of each brake and whether the vehicle was out-of-service due to adjustment violations. The NTSB brake data includes the appropriate variables for this determination, including, for each brake on the truck-trailer combination, the slack type, slack length, brake chamber size, and stroke length. A computerized algorithm was developed to produce a variable for "adjustment status" for each brake, coding each brake as properly adjusted, less than 1/4 inch beyond the readjustment limit, or defective. A second variable records whether the vehicle qualified to be put out-of-service due to brake adjustment violations. These two variables, out-of-adjustment at the brake level, and out-of-service at the vehicle level, are used throughout this analysis.

The following tables are organized around broad influences on brake adjustment. Several factors which may be associated with brake adjustment problems were identified. First, there is the mechanical design of the brake and certain brake system components. The NTSB data includes variables for slack adjuster type and the use of retarders. Next there is the general category of trucking operations and the business and regulatory environment. This category has to do with the extent to which competitive pressures of business operations may affect maintenance practices. Another broad category has to do with how the equipment is used and the effect of age and usage on brake adjustment. Included in this category are the model year (both the power unit and trailers), and trailer body type. The last set of tables covers power unit make and cab style (conventional or cab-over-engine).

Overall, of the variables available for analysis, automatic slack adjusters seemed to have the greatest effect on keeping brakes in adjustment. Trailer brakes had a higher rate of adjustment violations than power unit brakes . The use of retarders was associated with a lower proportion of out-of-adjustment brakes and limiting valves appeared to be associated with a lower proportion of steering axle brakes being out-of-adjustment. Differences by cab style were minimal.

3.3.1 Axle Number and Location

The proportion of adjusted and out-of-adjustment brakes by axle number and location is shown in Table 17. The table includes all vehicles in the NTSB data file with the exception of wedge and disc brakes and axles with no brakes. The column headings are as follows: "OK" indicates a properly adjusted brake; "1/2-def" indicates a brake that is at, or less than 1/4-inch beyond the readjustment limit; "def" indicates a brake that is 1/4-inch or more beyond the readjustment limit. The frequencies are provided with the percentages in parentheses for each axle number and location.

The first three axles are typically on the power unit and axles 4 and 5 are trailer axles. The table shows that trailer axles have a higher rate of adjustment problems than tractor axles. Approximately 80 percent of the power unit axles are properly adjusted, but only 70-72 percent of trailer axles passed the inspection. While trailer axle brakes are typically accessible for adjustment, tractor axle brakes appear to get more maintenance attention. Another possible explanation is that some operators may use trailer axles more heavily to save wear on tractor brakes.

Table 17. Out-of-adjustment status by axle number and location (wedge, disc, and absence of brakes excluded)

Axle and Side	OK	1/2-DEF	DEF	Unknown	Total
1 left	1,733	190	231	0	2,154
(%)	(80.5)	(8.8)	(10.7)	(0.0)	(100.0)
1 right	1,696	230	228	0	2,154
(%)	(78.7)	(10.7)	(10.6)	(0.0)	(100.0)
2 left	1,906	221	195	1	2,323
(%)	(82.4)	(9.5)	(8.4)	(0.0)	(100.0)
2 right	1,865	225	232	1	2,323
(%)	(80.3)	(9.7)	(10.0)	(0.0)	(100.0)
3 left	1,830	257	235	1	2,323
(%)	(78.8)	(11.1)	(10.1)	(0.0)	(100.0)
3 right	1,801	253	267	2	2,323
(%)	(77.5)	(10.9)	(11.5)	(0.0)	(100.0)
4 left	1,687	316	326	0	2,329
(%)	(72.4)	(13.6)	(14.0)	(0.0)	(100.0)
4 right	1,667	331	331	0	2,329
(%)	(71.6)	(14.2)	(14.2)	(0.0)	(100.0)
5 left	1,662	341	324	0	2,327
(%)	(71.4)	(14.7)	(13.9)	(0.0)	(100.0)
5 right	1,620	340	366	1	2,327
(%)	(69.6)	(14.6)	(15.7)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

Data from the 1989 inspections in Oregon show the same general pattern. The bulk of the brake violations recorded were for trailer brakes. Power units (the truck-tractor or straight truck) accounted for 35.3 percent of brake violations while trailers of all types accounted for the remainder. The data are not available on an axle-by-axle basis although the pattern is similar to the NTSB data.

Table 18. Distribution of brake adjustment violations by unit type (excludes non-combination vehicles)

Unit type	N	Percent
Straight	757	5.0
Tractor	4,552	30.3
Semi	6,581	43.8
Pole	1,472	9.8
Full	1,263	8.4
Dolly	228	1.5
Other	145	1.0
Unknown	15	0.1
Total	15,013	100.0

3.3.2 Slack Adjuster Type

Table 19 shows the association between slack adjuster type and out-of-adjustment status. Brakes with automatic slack adjusters (ASAs) have a much higher proportion of proper adjustment than brakes with manual slack adjusters. The proportion of

ASA-equipped brakes which are at or less than 1/4-inch beyond the readjustment limit (considered as 1/2 defective brake under the 20-percent rule) is only slightly lower than that for brakes equipped with manual slack adjusters. However, the proportion of ASA-equipped brakes which are 1/4-inch or more beyond the readjustment limit (considered as a defective brake under the 20-percent rule) is less than a third of that for brakes equipped with manual slack adjusters. The major advantage of the ASAs appears to be in preventing brakes from getting so far out-of-adjustment as to be considered a defective brake.

Table 19. Out-of-adjustment status by slack adjuster type (wedge, disc, and absence of brakes excluded)

Slack Type	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Auto	5,200	585	262	1	6,048
(%)	(86.0)	(9.7)	(4.3)	(0.0)	(100.0)
Manual	12,267	2,119	2,473	5	16,864
(%)	(72.8)	(12.6)	(14.7)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

3.3.3 Use of Retarders

The NTSB data included information on whether or not the vehicles were equipped with retarders. A retarder includes any sort of drive line, transmission or engine retarder. The use of retarders primarily serves to extend the life of brake linings but the NTSB data indicates that retarders are also associated with lower rates of brakes-out-adjustment. Over 80 percent of the brakes on vehicles with retarders were properly adjusted compared with 73.4 percent for trucks without retarders. The difference in the proportion of brakes 1/4-inch or more beyond the readjustment limit is relatively large with 9.3 percent for retarders and 13.9 percent for brakes on vehicles without retarders.

Table 20. Out-of-adjustment status by retarder usage (wedge, disc, and absence of brakes excluded)

Engine Retarder	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Yes	7,532	984	870	4	9,390
(%)	(80.2)	(10.5)	(9.3)	(0.0)	(100.0)
No	8,563	1,481	1,616	2	11,662
(%)	(73.4)	(12.7)	(13.9)	(0.0)	(100.0)
Unknown	1,372	239	249	0	1,860
(%)	(73.8)	(12.8)	(13.4)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

3.3.4 Use of Limiting Valves

Limiting valves apparently have very little effect on overall brake adjustment. Limiting valves moderate the braking pressure applied to steering axle (front axle) brakes to prevent wheel lock-up. By limiting the pressure applied, there would be reason to expect that steering axle brakes should go out-of-adjustment less often than otherwise. About 83 percent of the front axle brakes on tractors equipped with limiting valves were properly adjusted, compared with 77 percent on vehicles without limiting valves.

Table 21. Out-of-adjustment status by limiting valve usage
(steering axle brakes only; wedge, disc, and absence of brakes excluded)

Limit Valve	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Yes	1,363	120	161	0	1,644
(%)	(82.9)	(7.3)	(9.8)	(0.0)	(100.0)
No	1,613	242	239	0	2,094
(%)	(77.0)	(11.6)	(11.4)	(0.0)	(100.0)
Unknown	453	58	59	0	570
(%)	(79.5)	(10.2)	(10.4)	(0.0)	(100.0)
Total	3,429	420	459	0	4,308
(%)	(79.6)	(9.7)	(10.7)	(0.0)	(100.0)

3.3.5 Carrier Size and Types

Differences by carrier type are slight. Carrier type is coded as either private or for-hire. (One truck was coded as U.S. Mail.) For-hire carriers have only a slightly higher proportion of properly adjusted brakes than the private carriers, 76.7 percent versus 75.0 percent respectively. The differences in proportion of 1/2-defective brakes and defective brakes is also slight. It appears that carrier type is not related to the probability of brakes being properly adjusted.

Table 22. Out-of-adjustment status by carrier type
(wedge, disc, and absence of brakes excluded)

Carrier Type	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
For-hire	12,447	1,894	1,872	5	16,218
(%)	(76.7)	(11.7)	(11.5)	(0.0)	(100.0)
Private	5,011	809	863	1	6,684
(%)	(75.0)	(12.1)	(12.9)	(0.0)	(100.0)
U.S. Mail	9	1	0	0	10
(%)	(90.0)	(10.0)	(0.0)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

When carriers are separated by size (measured by the number of trucks operated), it appears that the larger carriers do a better job of keeping brakes in adjustment. Single-truck operations and carriers with 2 to 100 trucks have less than 75 percent of their brakes properly adjusted. For carriers with more than 100 trucks, nearly 80 percent of the brakes were found to be in adjustment. Much of the difference appears to be in the proportion of brakes that are 1/4-inch or more beyond the readjustment limit. Between 13 and 14 percent of the brakes of single-truck or small operations are classified as defective compared to 9 percent for larger carriers.

Table 23. Out-of-adjustment status by carrier size
(wedge, disc, and absence of brakes excluded)

Carrier Size	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
1	1,401	230	263	0	1,894
(%)	(74.0)	(12.1)	(13.9)	(0.0)	(100.0)
2 - 100	10,275	1,656	1,812	5	13,748
(%)	(74.7)	(12.1)	(13.2)	(0.0)	(100.0)
101 - 9000	5,689	795	641	1	7,126
(%)	(79.8)	(11.2)	(9.0)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

The final carrier-related aspect considered in this section is the question of responsibility for keeping the brakes properly adjusted. Drivers were asked if they were responsible for keeping brakes in adjustment. About 59 percent of the drivers indicated that they were. The differences found were not significant. The proportion of properly adjusted brakes is 0.4 percent higher when the driver is responsible as compared to the proportion of properly adjusted brakes when someone else is responsible.

Table 24. Out-of-adjustment status by driver responsibility
(wedge, disc, and absence of brakes excluded)

Driver Responsible?	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Yes	10,253	1,543	1,634	4	13,434
(%)	(76.3)	(11.5)	(12.2)	(0.0)	(100.0)
No	6,747	1,085	1,056	2	8,890
(%)	(75.9)	(12.2)	(11.9)	(0.0)	(100.0)
Unknown	467	76	45	0	588
(%)	(79.4)	(12.9)	(7.7)	(0.0)	(100.0)
Total	17,467	2,704	2,735	6	22,912
(%)	(76.2)	(11.8)	(11.9)	(0.0)	(100.0)

3.3.6 Power Unit Cab Type

Brakes on trucks with conventional cabs have a slightly higher probability of being properly adjusted than brakes on cab-over-engines, 80.9 percent versus 77.4 percent respectively. It has been suggested that the steering axle brakes of conventionals are more easily accessed than on cabovers, so they might be serviced more often. This difference might account for the slightly higher rate of in-adjustment brakes for conventionals, but the NTSB data do not support this hypothesis. Looking at steering axle brakes, 80.9 percent of steering axle brakes on conventionals were in adjustment, compared to 77.3 percent for cabovers. Note, however, that the proportions for steering axle brakes is approximately the same as the proportions for all brakes for the two cab types. Within each cab type, the proportion of steering axle brakes in adjustment is almost the same as the proportion of drive axle brakes in adjustment. Overall, the differences between the two cab types are slight.

Table 25. Out-of-adjustment status by power unit cab type
(Wedge, disc, and absence of brakes excluded)

Cab Style	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Conv.	7,046	828	836	0	8,710
(%)	(80.9)	(9.5)	(9.6)	(0.0)	(100.0)
COE	3,785	548	552	5	4,890
(%)	(77.4)	(11.2)	(11.3)	(0.1)	(100.0)
Total	10,831	1,376	1,388	5	13,600
(%)	(79.6)	(10.1)	(10.2)	(0.0)	(100.0)

3.3.7 Make and Model Year of Power Unit

Table 26 shows the adjustment status of brakes by the make of the power unit. Only tractor brakes are included in the table. There appear to be some differences by make in the adjustment status of the brakes. Freightliner, Kenworth, and White/GMC all do better than average, while Ford and GMC trucks do somewhat worse. This may be related to the manufacturer of the brake system, but it could not be tested because the manufacturer could only be determined in about 25 percent of the cases. Another possibility is the type of slack adjusters used. Makes with a higher proportion of automatic slack adjusters had a higher proportion of brakes in adjustment with the exception of Kenworths. Only about 20 percent of the brakes on Kenworth vehicles had automatic slack adjusters (compared to 46 percent for Freightliners) yet Kenworths had the third highest proportion of properly adjusted brakes.

Table 26. Out-of-adjustment status by make of power unit
(wedge, disc, and absence of brakes excluded)
(Power unit brakes only)

Make	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Ford	463	76	91	0	630
(%)	(73.5)	(12.1)	(14.4)	(0.0)	(100.0)
F'liner	2,727	287	234	0	3,248
(%)	(84.0)	(8.8)	(7.2)	(0.0)	(100.0)
GMC	336	48	74	0	458
(%)	(73.4)	(10.5)	(16.2)	(0.0)	(100.0)
Navistar	2,254	394	331	1	2,980
(%)	(75.6)	(13.2)	(11.1)	(0.0)	(100.0)
Kenworth	1,747	176	189	0	2,112
(%)	(82.7)	(8.3)	(8.9)	(0.0)	(100.0)
Mack	1,054	142	186	0	1,382
(%)	(76.3)	(10.3)	(13.5)	(0.0)	(100.0)
Peterbilt	1,310	149	185	0	1,644
(%)	(79.7)	(9.1)	(11.3)	(0.0)	(100.0)
W'st'n Star	124	10	12	4	150
(%)	(82.7)	(6.7)	(8.0)	(2.7)	(100.0)
White	191	22	31	0	244
(%)	(78.3)	(9.0)	(12.7)	(0.0)	(100.0)
White/GMC	354	35	25	0	414
(%)	(85.5)	(8.4)	(6.0)	(0.0)	(100.0)
Other	271	37	30	0	338
(%)	(80.2)	(10.9)	(8.9)	(0.0)	(100.0)
Total	10,831	1,376	1,388	5	13,600
(%)	(79.6)	(10.1)	(10.2)	(0.0)	(100.0)0

Table 27 shows the relationship of power unit model year and brake adjustment status. Older tractors have a higher proportion of brakes in the 1/2-defective brake category than newer tractors. There appears to be a step change, particularly with respect to the percentage of defective brakes around the 1986 model year. From the 1986 to 1987 model years, the proportion of brakes 1/4-inch or more past the readjustment limit decreases from 11.8 percent to 8.3 percent. Typically as trucks age, they are moved from high mileage, high intensity use to less demanding service. The older vehicles are also less likely to be equipped with automatic slack adjusters. However, as the statistical models presented later in this report indicate, the age effect still exists even when slack adjuster type is taken into account.

Table 27. Out-of-adjustment status by power unit model year (wedge, disc, and absence of brakes excluded) (power unit brakes only)

Model Year	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
pre-1983	1,867	305	466	4	2,642
(%)	(70.7)	(11.5)	(17.6)	(0.2)	(100.0)
1983	354	49	65	0	468
(%)	(75.6)	(10.5)	(13.9)	(0.0)	(100.0)
1984	806	113	149	0	1,068
(%)	(75.5)	(10.6)	(14.0)	(0.0)	(100.0)
1985	906	138	168	0	1,212
(%)	(74.8)	(11.4)	(13.9)	(0.0)	(100.0)
1986	849	125	130	0	1,104
(%)	(76.9)	(11.3)	(11.8)	(0.0)	(100.0)
1987	995	116	101	0	1,212
(%)	(82.1)	(9.6)	(8.3)	(0.0)	(100.0)
1988	1,253	198	91	0	1,542
(%)	(81.3)	(12.8)	(5.9)	(0.0)	(100.0)
1989	1,622	174	105	1	1,902
(%)	(85.3)	(9.1)	(5.5)	(0.1)	(100.0)
1990	1,357	126	91	0	1,574
(%)	(86.2)	(8.0)	(5.8)	(0.0)	(100.0)
1991	464	25	21	0	510
(%)	(91.0)	(4.9)	(4.1)	(0.0)	(100.0)
1992	346	7	1	0	354
(%)	(97.7)	(2.0)	(0.3)	(0.0)	(100.0)
1993	12	0	0	0	12
(%)	(100.0)	(0.0)	(0.0)	(0.0)	(100.0)
Total	10,831	1,388	1,376	5	13,600
(%)	(79.6)	(10.2)	(10.1)	(0.1)	(100.0)

3.3.8 Trailer Body Type and Model Year

Trailer body type can give some insight into the type of industry and therefore use of the vehicle. Vans are typically used for moving freight over long distances. Vans travel most often on interstate highways. Dump trailers, in contrast, are used primarily for moving heavy bulk loads short distances and are used more often on non-interstate roads. Looking at the NTSB data, vans and flatbeds have the highest proportion of properly adjusted brakes. Bulk and dump trailers have significantly more brakes out-of-adjustment. Over one-fifth of the brakes on dump combinations were found to be 1/4-inch or more beyond the readjustment limit. Dump trailers are often heavily loaded and operated on side roads or off-road conditions such as construction sites. In such circumstances, their brakes are likely to go out-of-adjustment more quickly, yet they are not serviced as often as necessary. The "other" trailer group includes auto carriers, logging and pole trailers. The brakes on logging trailers had the worst record of any trailer type with almost 33 percent of the brakes in the defective range and an additional 10 percent in the 1/2-defective brake range. Such trailers are probably subject to the most severe service, carrying very heavy loads over logging roads with apparently insufficient maintenance.

Table 28. Out-of-adjustment status by trailer body type
(Wedge, disc, and absence of brakes excluded)

Trailer Cargo Body	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Bulk	644	144	148	0	936
(%)	(68.8)	(15.4)	(15.8)	(0.0)	(100.0)
Dump	214	58	76	0	348
(%)	(61.5)	(16.7)	(21.8)	(0.0)	(100.0)
Flatbed	1,260	247	289	0	1,796
(%)	(70.2)	(13.8)	(16.1)	(0.0)	(100.0)
Tank	432	89	99	0	620
(%)	(69.7)	(14.4)	(16.0)	(0.0)	(100.0)
Van	3,893	766	664	1	5,324
(%)	(73.1)	(14.4)	(12.5)	(0.0)	(100.0)
Other	187	22	71	0	280
(%)	(66.8)	(7.9)	(25.4)	(0.0)	(100.0)
Unknown	6	2	0	0	8
(%)	(75.0)	(25.0)	(0.0)	(0.0)	(100.0)
Total	6,636	1328	1347	1	9,312
(%)	(71.3)	(14.3)	(14.5)	(0.0)	(100.0)

The Oregon inspection data provides some additional insight here. Companies are classified by activities and operating authorities. The company type codes give some idea of the kind of service for which the vehicles are used. (In the table below "intra" refers to intrastate operations, "inter" to interstate operations, and "exempt" to carriers exempt from Interstate Commerce Commission regulations.) The table shows the distribution of trucks with brake violations by company type, and the distribution of all vehicles inspected. The normalized rate column shows the ratio of trucks with brake violations to all trucks. A value greater than 1.0 indicates that the company type is over-represented among the vehicles with brake violations. Trucks with intrastate authority are, in general, slightly more likely to have brake adjustment problems. Similarly, for-hire firms are more likely to have brake adjustment problems than private. Interestingly, the business type with the greatest over-representation are for-hire carriers of logs, sand, or ore.

Table 29. 1989 Oregon inspection data:
Brake adjustment violations vs. all vehicles inspected
by company type, combination vehicles

Company Type	Brake Adj. Viol. N	%	All Vehicles Inspected N	%	Normalized Rate
Intra Gen. Freight	1,718	28.1	5,152	25.5	1.10
Intra Logs, Sand, Ore	1,526	24.9	4,433	21.9	1.14
Intra Other For-hire	12	0.2	88	0.4	0.45
Intra Private	1,046	17.1	4,130	20.4	0.84
Inter For-hire	1,356	22.2	4,789	23.7	0.94
Inter Exempt	166	2.7	557	2.7	0.99
Inter Private	284	4.6	995	4.9	0.94
		0.0			
Unknown	11	0.2	88	0.4	0.41
Total	6,119	100.0	20,232	100.0	1.00

As with tractor model year, trailer model year is related to the probability of out-of-adjustment brakes. This is illustrated in the NTSB data summarized in Table 30. The relationship seems to be linear, with older trailers fairly consistently having more brake adjustment violations than newer trailers. Note also that over a third of the cases fall into the oldest group.

Table 30. Out-of-adjustment status by trailer model year
(wedge, disc, and absence of brakes excluded)
(trailer brakes only)

Trailer Model Year	Adjustment Status OK	1/2-DEF	DEF	Unknown	Total
Pre-'83	2,173	508	580	1	3,262
(%)	(66.6)	(15.6)	(17.8)	(0.0)	(100.0)
1983	326	64	66	0	456
(%)	(71.5)	(14.0)	(14.5)	(0.0)	(100.0)
1984	454	104	102	0	660
(%)	(68.8)	(15.8)	(15.4)	(0.0)	(100.0)
1985	490	108	110	0	708
(%)	(69.2)	(15.3)	(15.5)	(0.0)	(100.0)
1986	514	80	86	0	680
(%)	(75.6)	(11.8)	(12.6)	(0.0)	(100.0)
1987	623	107	130	0	860
(%)	(72.4)	(12.4)	(15.1)	(0.0)	(100.0)
1988	693	139	98	0	930
(%)	(74.5)	(14.9)	(10.5)	(0.0)	(100.0)
1989	683	128	97	0	908
(%)	(75.2)	(14.1)	(10.7)	(0.0)	(100.0)
1990	404	68	60	0	532
(%)	(75.9)	(12.8)	(11.3)	(0.0)	(100.0)
1991	208	20	12	0	240
(%)	(86.7)	(8.3)	(5.0)	(0.0)	(100.0)
1992	64	2	6	0	72
(%)	(88.9)	(2.8)	(8.3)	(0.0)	(100.0)
1994	4	0	0	0	4
(%)	(100.0)	(0.0)	(0.0)	(0.0)	(100.0)
Total	6,636	1,328	1,347	1	9,312
(%)	(71.3)	(14.3)	(14.5)	(0.0)	(100.0)

3.3.9 Summary of Factors Associated with Out-of-Adjustment Brakes

To summarize the results presented in this section, automatic slack adjusters seem to have the largest impact on brake adjustment though their effect seems primarily to reduce the number of brakes that are 1/4-inch or more beyond the readjustment limit. Retarders also have a positive effect while limiting valves seem to help only on the adjustment of steering or front axle brakes. Overall, tractor brakes are kept in better adjustment than trailer brakes but differences between the brake adjustment status by cab type are slight, with conventional cabs doing only slightly better than cab-over-engine models. Carriers operating over 100 trucks do a better job of keeping brakes in adjustment than smaller carriers. Delegating responsibility for adjusting brakes to the driver seems to have no impact on the probability that the brakes are properly adjusted. Newer tractors and trailers have a lower rate of brake adjustment problems, and combinations that see severe service, as shown by trailer body type, have markedly higher rates of brakes out-of-adjustment. The next section will assess the magnitude of these factors and the extent to which the factors are interrelated.

3.4 Statistical Models

In the brake models developed for this study, the important variables were slack adjuster type, tractor model year, the use of a retarder, and whether the vehicle was issued a CVSA decal within the last six months. Automatic slack adjusters had the greatest effect on the probability of a brake being out-of-adjustment. Brakes with automatic slack adjusters had 0.62 times the odds of being out-of-adjustment compared to manual slack adjusters. Retarders had a similar though smaller effect as did the presence of a CVSA inspection sticker issued within the last six months. There is also an interaction effect between slack adjuster type and model year such that automatic slack adjusters on newer truck models do much better than the sum of each effect alone. As to predicting whether the vehicle overall would be placed out-of-service due to brake adjustment problems, newer trucks with automatic slack adjusters and retarders, operated by large companies with interstate operations are the least likely to be placed out-of-service. The number of automatic slack adjusters, retarders, model year, carrier size, and trip type all have an effect on out-of-service probability. Only automatic slack adjusters have a direct mechanical relationship to keeping brakes in adjustment. The other variables seem to reflect an operation that pays closer attention to its equipment and operates in a less demanding environment.

3.4.1 Model for Brakes Out-of-adjustment

The first model deals with individual brakes. The response variable is the probability that a brake is out-of-adjustment (OOA). In this model, out-of-adjustment includes both the brake adjustment level that is classified as 1/2-defective brake and the brake adjustment level that is classified as one defective brake. The predictor variables in the model are the type of slack adjusters, whether the vehicle is equipped with a retarder, the presence of a CVSA decal issued within the last six months, and the model year of the power unit. The slack adjuster variable codes 0 for manual slack adjusters and 1 for automatic slack adjusters. The retarder variable is coded 0 for trucks without retarders and 1 for trucks with retarders. Truck model year was divided into older trucks (model year 1986 or older) coded 0 and newer trucks coded 1. The cut-off points for the CVSA decal and model year were based on the point at which there was a large and consistent change in the proportion of out-of-adjustment brakes. For this model the baseline vehicle has manual slack adjusters, no retarder, either no CVSA decal or a decal older than six months, and is a 1986 or older model year. The baseline case was chosen so that each characteristic would contribute to a higher probability of out-of-adjustment brakes. In other words, the baseline case is the worst case. Consequently, all the coefficients in the model, except for one interaction, are negative, indicating that the factors reduce the probability that a brake is out-of-adjustment if added to the baseline case.

Table 31 shows the coefficients and standard errors for each of the predictor variables in the model. Overall, the model fit the data reasonably well with a scaled deviation of 12.44 on 9 degrees of freedom. Treating the deviance as a chi-square statistic, this means that the probabilities predicted by the model do not differ significantly from the probabilities observed in the data. The standard errors measure the reliability of each coefficient. A coefficient approximately twice the size of its standard error is statistically significant at the 5-percent level, meaning that there is a 95 percent chance that the true value of the coefficient is not zero. In this model, all terms are significant at the 5-percent level.

Table 31. Coefficients and standard errors for logit model of out-of-adjustment brakes for the NTSB data

Coeff.	St.Err.	Predictor
-0.7007	0.0273	baseline
-0.4798	0.0800	slack(1)
-0.1684	0.0378	year(1)
-0.3449	0.0491	cvsa(1)
-0.4002	0.0378	retarder(1)
-0.5080	0.0933	slack(1).year(1)
0.1950	0.0902	slack(1).retarder(1)

Table 32 shows the probabilities observed in the data and predicted by the model year for each of the 16 cells in the data matrix. The 16 cells are determined by all of the combinations of the predictor variables. Also shown are the residuals for each cell. The residuals are the difference between the observed and predicted probabilities and are a measure of how well the model fits. The residuals can be examined for patterns which indicate that variables not included in the model are important. Generally, the model predicts the data well, though some cells have large residuals, particularly the cell with retarders, a recent CVSA decal, automatic slack adjusters and an older model year. This cell only had 63 cases, the fewest in the data matrix.

Table 32. Observed and predicted probabilities of brakes out-of-adjustment NTSB data

Slack type	Retarder	Model year	Days since CVSA	Observed probability of OOA	Predicted probability of OOA	Residual
man	no	pre '87	>180	0.34	0.33	0.004
			<181	0.23	0.26	-0.028
		post '86	>180	0.29	0.30	-0.001
			<181	0.21	0.23	-0.018
	yes	pre '87	>180	0.25	0.25	0.000
			<181	0.18	0.19	-0.015
		post '86	>180	0.21	0.22	-0.006
			<181	0.19	0.17	0.027
auto	no	pre '87	>180	0.22	0.23	-0.010
			<181	0.17	0.18	-0.007
		post '86	>180	0.14	0.14	0.002
			<181	0.11	0.10	0.011
	yes	pre '87	>180	0.21	0.20	0.014
			<181	0.21	0.15	0.056
		post '86	>180	0.11	0.11	-0.005
			<181	0.08	0.08	-0.003

The model coefficients show that slack adjuster type, retarder usage, and carrier size are all important in the probability of out-of-adjustment brakes. Brakes with automatic slack adjusters have a significantly lower probability of losing their adjustment. The odds of out-of-adjustment brakes when automatic slack adjusters are used is $e^{-0.4798}=0.62$ times that of manual slack adjusters. Table 32 shows that the predicted probability of out-of-adjustment brakes for the baseline case is 0.33. For the baseline case with automatic slack adjusters, the probability is only 0.23. Slack adjuster type interacts with model year, so that newer trucks with automatic slack adjusters have even fewer brakes out-of-adjustment than can be accounted for by the effects of model year and slack adjuster type separately. Looking at Table 32, the two cells with the lowest probability of brakes out-of-adjustment have a recent CVSA, automatic slack adjusters, and newer model years. The probabilities are about the same with and without retarders.

Retarders also significantly reduce the odds of a brakes becoming out-of-adjustment. The size of the coefficient associated with the main effect is somewhat less than automatic slack adjusters (-0.4002 to -0.4798) but still large. Table 32 also shows that the model predicts that the proportion of brakes out-of-adjustment decreases from 0.33 to 0.25 when retarders are added to the baseline vehicle. It is not clear why retarders are associated with lower probabilities of brake adjustment problems. Retarders should not have any direct, mechanical effect on brake adjustment although they extend brake life. The explanation could be that companies that are sufficiently concerned to equip their vehicles with retarders also do a better job of adjusting brakes.

The main effect of the model year is to decrease the odds of out-of-adjustment brakes by $e^{-0.1684}$ or 0.85. Newer models have a lower odds of brakes out-of-adjustment. There is also an interaction between slack adjuster type and model year, with the substantial coefficient of -0.5080. Newer models with automatic slack adjusters have fewer brakes out-of-adjustment than would be expected from the separate effects of slack adjuster type and model year. In short, the positive effect of the model year is greatly enhanced when the brakes have automatic slack adjusters. Note that the cells with automatic slack adjusters and new model years have the lowest probability of out-of-adjustment brakes.

The possession of a CVSA decal dated within the last six months also is associated with a lower probability of out-of-adjustment brakes. Although the CVSA decals are only valid for three months (for the purposes of screening vehicles at roadside inspections), there was not much difference between the group with three months or less and the group with three to six-month old decals. Therefore the two groups were combined. Apparently passing a CVSA inspection within the previous six months increases the probability that the brakes are in adjustment. Of course, unless attended to, brakes are expected to go out-of-adjustment in much less than six months. Presumably, the explanation is that companies whose operations are such that they have to submit to an inspection and pass it are somewhat more likely to keep their brakes in adjustment.

To summarize the results of this model, automatic slack adjusters, retarders, and CVSA decals are all associated with lower probabilities of brakes out-of-adjustment. These factors have the largest effect on the probability of brakes being out-of-adjustment. Automatic slack adjusters account for the greatest decrease in the probability of out-of-adjustment brakes. Newer truck models also are associated with lower probabilities of out-of-adjustment brakes. Though the main effect of model year is less than the other factors, new model years in association with automatic slack adjusters substantially decrease the probability of out-of-adjustment brakes beyond what would occur from the separate effects of model year and slack adjuster type. Finally, the operators of trucks that have passed a CVSA inspection appear to do a better job than others when it comes to keeping brakes properly adjusted.

3.4.2 Model for Out-of-service Due to Brake Adjustment

The second model considers the probability of a vehicle having enough brakes out-of-adjustment to warrant being placed out-of-service. To determine this, an algorithm was developed to apply just the brake adjustment portion of the North American Uniform Driver-Vehicle Inspection Criteria. This was used to classify vehicles in the NTSB data as out-of-service. The determination of out-of-service is limited to brake adjustment violations only and may differ from whether the vehicle was actually placed out-of-service. The predictor variables were model year, retarder usage, carrier size, the number of automatic slack adjusters, and whether the company operating the vehicle operated across state lines. The definitions of the first two predictors are the same as in the first model. Carrier size was divided between carriers with one hundred or fewer trucks (coded 0) and those with more than one hundred trucks (coded 1). With respect to the automatic slack adjuster variable, combinations with fewer than four automatic slack adjusters were coded 0 while those with four or more were coded 1. Typically, either all brakes on a unit (tractor or trailer) in a combination had automatic slack adjusters or they were all manual. Consequently, the automatic slack adjuster dichotomy splits the trucks between those with no automatic slack adjusters and those where at least the trailer had all brakes equipped with automatic slack adjusters. For the carrier type variable, trucks with either a ICC Motor Carrier number or a US DOT number were coded 1 as an interstate carrier and trucks without either number were considered to be intrastate and coded 0.

Table 33. Logit coefficients and standard errors for vehicle out-of-service due to brake violations (NTSB brake adjustment data)

Coeff.	St.Err.	Predictor
1.1469	0.1604	baseline
-0.4148	0.1056	autoslacks(1)
-0.5750	0.0980	retarder(1)
-0.6407	0.1643	carrier type(1)
-0.4666	0.1004	model year(1)
-0.2963	0.1084	carrier size(1)

The fit of this model to the data was very good. Scaled deviation was reduced to 24.04 with 24 degrees of freedom -- the model accounts for a substantial amount of the variance with only five parameters and no interactions. Note also that all the terms are highly significant. Observed and predicted out-of-service probabilities for the data are shown in Table 34, along with the residuals for the model. There were three cells that had no data at all and seven with fewer than 10 cases. Those cells are associated with the largest residuals.

Table 34. Observed and predicted probabilities of truck out-of-service due to brake adjustment violations (NTSB brake adjustment data)

carrier type	model year	engine retarder	automatic slacks	carrier size	observed probability of OOS	predicted probability of OOS	residual
intra	pre '87	no	<4	<101	0.77	0.76	0.010
				>100	0.64	0.68	-0.032
			>=4	<101	0.58	0.64	-0.056
				>100	1.00	0.54	0.461
		yes	<4	<101	0.63	0.66	-0.039
				>100	0.55	0.57	-0.021
			>=4	<101	0.37	0.53	-0.158
				>100	0.75	0.42	0.327
	post '86	no	<4	<101	1.00	0.70	0.299
				>100	0.75	0.61	0.143
		yes		<101	1.00	0.59	0.405
				>100	0.60	0.49	0.108
			>=4	<101	0.00	0.45	-0.452
inter	pre '87	no	<4		0.61	0.62	-0.011
				>100	0.52	0.52	0.002
			>=4	<101	0.46	0.48	-0.018
				>100	0.38	0.38	-0.006
		yes	<4	<101	0.49	0.51	-0.018
				>100	0.41	0.41	0.006
			>=4	<101	0.40	0.37	0.032
				>100	0.31	0.28	0.032
	post '86	no	<4	<101	0.59	0.55	0.039
				>100	0.48	0.45	0.030
			>=4	<101	0.37	0.41	-0.041
				>100	0.37	0.31	0.056
		yes	<4	<101	0.51	0.44	0.073
				>100	0.30	0.34	-0.037
			>=4	<101	0.30	0.30	0.000
				>100	0.18	0.22	-0.045

In this model, carrier type (inter- or intrastate) has the greatest effect on out-of-service. The odds of the vehicle operated by an interstate company being placed out-of-service for brake adjustment is half ($e^{-0.6407}$=0.53) those of vehicles from intrastate companies. The predicted probability of the vehicle being placed out-of-service for the baseline case is 0.76 (odds = 0.76/1-0.76 = 3.2), but for the baseline case an interstate carrier, the probability of being placed out-of-service is 0.62 (odds = 0.62/1-0.62 = 1.63).

As in the previous model, retarders and newer model years are also associated with a lower risk of vehicles out-of-service due to brake adjustment. For both factors, trucks with retarders had approximately 0.6 times the odds of being placed out-of-service compared with trucks that did not have retarders or were older models, respectively. It is surprising that the effect of these variables is larger than the effect of having at least four automatic slack adjusters, since the slack adjuster type variable was so powerful in the brake level model. Part of the explanation is that a substantial number of cases coded as having automatic slack adjusters had them only on the trailer, and as earlier tables indicated, trailer brakes had a higher incidence of out-of-adjustment brakes than tractor brakes. Vehicles with automatic slack adjusters all around passed at a 78-percent rate. Carriers with more than 100 vehicles are also associated with lower probabilities of out-of-service though the effect is a relatively weak 0.74 times the odds of small carriers.

Other than the variable for the number of automatic slack adjusters, the variables in the out-of-service model are related to the type of trucking operation more than some direct, mechanical relation to keeping brakes in adjustment. Trucks that operate in interstate commerce are associated with the greatest impact on the probability of out-of-service vehicles. Large carriers appear to do a better job of keeping brakes in adjustment, although the effect is not large. Carriers with more than one hundred trucks have 0.74 times the odds of out-of-service compared to the baseline case. The vehicle group that performed the best was a new truck with at least four automatic slack adjusters, a retarder, operated by a large carrier that operated interstate. These characteristics are all arguably related to an operation that has better equipment and pays closer attention to maintenance. Moreover, trucks operated by interstate companies are more likely to travel on interstate-quality roads, with less severe demands on the braking system.

3.5 Guidelines on Brake Adjustment Intervals

3.5.1 Variations of Results Within a Fleet

The basic information (gathered from a fleet operating in several different regions of the company, and having several different conditions of service for its vehicles) that was used in calculating the statistics on miles between brake relinings (presented previously in Table 6) is plotted in Figure 17 for each of the eight cases. An examination of the eight cases listed in Table 6 indicates that the results can be divided into four low mileage cases and four high mileage cases. Histograms and estimated normal distributions fitted to the histograms are presented in Figure 18. The low mileage cases (numbers 5 to 8) are characterized by more demanding service involving heavy loads, pick-up and delivery operations, and averaging less than 260 miles per day. (Incidentally, the make of tractor differed between the high and low mileage cases -- one make of tractor was used in the demanding service (cases 5 to 8) and another make of tractor was used in the high mileage service (cases 1 to 4). Looking at this data by make of tractor, one make of tractor looked extraordinarily better than the other as far as the mileage before the first brake relining.) An examination of the data shows a wide variation in results even for situations where the operating circumstances are very similar.

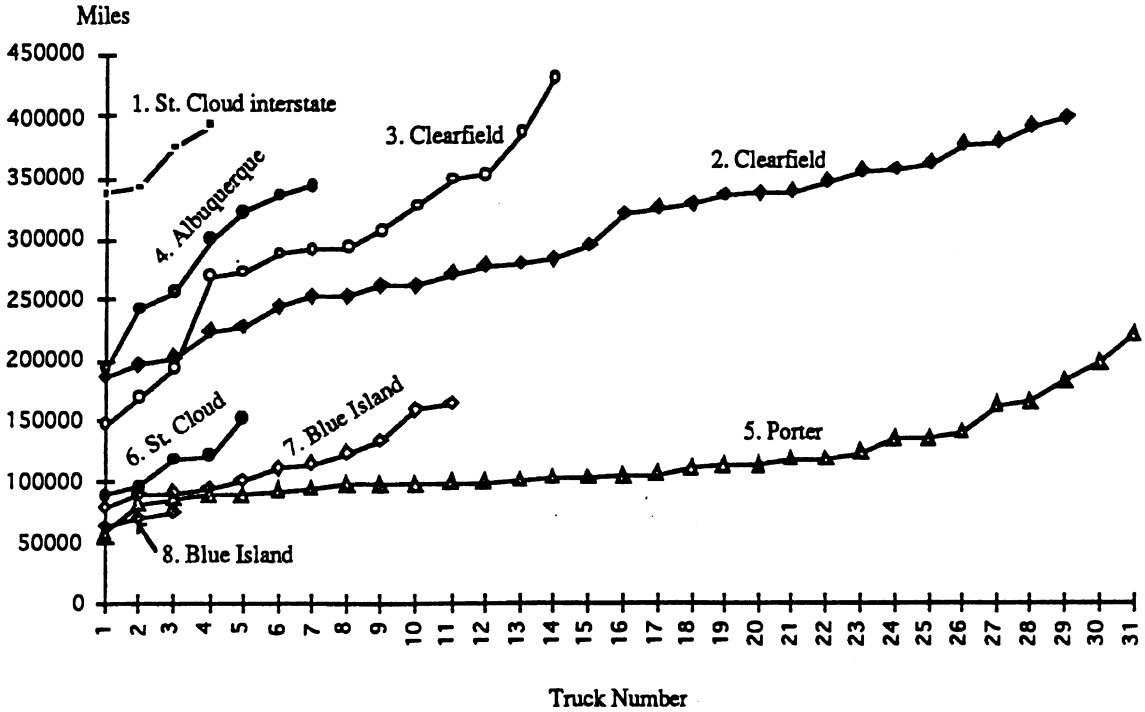


Figure 17. Mileage at first relining

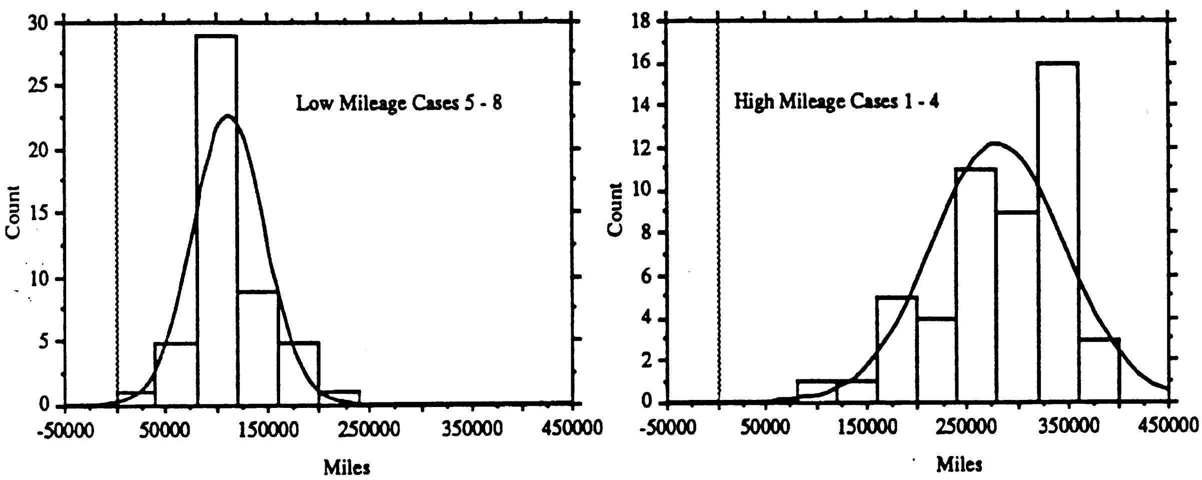


Figure 18. Histograms of mileage

The finding derived from these results is that it is impractical to expect to be able to use a few pieces of information on types of service to generalize on the frequency with which brakes need to be adjusted on a particular vehicle. For example, assuming twenty-four adjustments over the life of the lining, the average vehicle in case 3 at Clearfield, Utah, would require a brake adjustment every 12,146 miles, while vehicles at one standard deviation either way would require adjustments at 12,146 ± 3,348 miles. The high and low mileage vehicles would require adjustments every 17,991 and 6,122 miles respectively. Based upon these results, there is a need for developing procedures involving stroke measurements in order to predict and schedule when the brakes on a particular vehicle in a particular type of service need to be adjusted.

Such procedures would account for the green growth and swell that occurs with current types of non-asbestos linings when they are new. For some linings this could mean an increase in lining thickness that is equivalent to 1/2 inch of stroke (the equivalent of the stroke change between a fully adjusted brake and a brake at the readjustment limit). This means that a procedure for determining the frequency of readjustment would start after the green growth and swell period had ended and the brake was wearing at a fairly uniform rate. Even so, periods of very hot brake operation would result in very accelerated wear rates such that the need for adjustment might be much shorter than average. Perhaps there is a need for almost continual checking of the stroke. For example, the worst case low mileage to relining in Table 6 would require that the brakes be adjusted every 2,651 miles for service periods including operation of the brakes at elevated temperatures. In conclusion, procedures such as those discussed in section 2.3.3 are needed to arrive at a reasonable procedure for setting the frequency of brake adjustment for a particular vehicle. For vehicles with bad out-of-adjustment records, the operators need to consider the use of automatic slack adjusters and brake adjustment indicators.

Given that vehicle operators will continue to use manually adjusted S-cam brakes, the study included a focus on information that could be used to provide a method for evaluating the service factors for various types of vehicle service and consequently a prediction or estimate of the frequency with which the brakes on a particular vehicle need to be adjusted.

3.5.2 Definition of a Procedure for Predicting Brake Adjustment Frequency

The following procedure uses a service factor derived in section 2.3.3 (see Table 7). The procedure employs numerical coefficients that were determined by the predictor-corrector method described in section 2.3.3. The procedure assumes that the person performing the procedure knows how to adjust brakes and how to measure stroke per the appropriate procedures. Industry standards on brake adjustment (such as that contained in *Manual and Automatic Slack Adjuster Removal, Installation and Maintenance, Recommended Practice RP-609A*, The Maintenance Council, American Trucking Associations) should be used to insure that the brakes are being adjusted properly. The details of the procedure for establishing brake adjustment frequency is presented in Table 35.

Table 35. Procedure for establishing brake adjustment frequency

Getting Started

Summary You commence at point '0' with your brakes fully adjusted, your goal is to have the unit back in the shop after 'X' miles (days) with the brakes one notch or "click" (1/12 of a turn) off the fully adjusted position. X is a guess (prediction) that the following procedure attempts to evaluate.

Steps

1. Perform checks and record information per the following list:

   a. CHECK that the brake components are in an OK condition (RP-609).

   b. RECORD lining thickness (at least 0.35").

   c. RECORD miles since last relining.

   d. RECORD make of linings.

   e. RECORD drum temperature. If possible, let cool below 100°F before proceeding.

   f. CHECK that pneumatic system is fully charged (at least 100 psi).

2. Adjust the brakes according to the standard recommended procedure (RP-609).

   Measure and record the strokes of all the brakes.

3. Perform checks and record information per the following list:

   a. CHECK and RECORD the largest stroke on the unit under full treadle pedal application (at least 90 psi).

   b. RECORD treadle application pressure obtained.

4. Evaluate service factor (SF). (See Table 31.)

   Record the value of SF.

5. Have the unit back at the shop based on the appropriate case below (evaluate 'X'):

Case 1: The unit is a **tractor**:

Return after $\mathbf{X = \frac{1}{4} \cdot 12{,}000 \cdot SF}$ miles;

Case 2: The unit is a **trailer** or a **dolly** whose mileage can be tracked:

Return after $\mathbf{X = \frac{1}{4} \cdot 5{,}200 \cdot SF}$ miles;

Case 3: The unit is a **trailer** or a **dolly** whose mileage cannot be tracked:

Return after $\mathbf{X = \frac{1}{4} \cdot 5{,}200 \cdot SF \cdot TF}$ days;
(TF which is the Time conversion factor, is: TF = 365 / total miles per year)

6. As you progress along the following stages, what is referred to as '$\mathbf{X_{old}}$' in one stage, is '**X**' or '$\mathbf{X_{new}}$' that the preceding stage terminated with.

Stage I (When the unit returns)

Summary You inspect the adjustment status. If the results are satisfactory, the process can continue. Otherwise you go back to start at point '**0**' (while modifying the guess for '**X**').

Steps

1. You should only measure strokes here. Unless otherwise specified, do not perform brake adjustment.

2. Perform checks and record information per the following list:

   a. CHECK that the brake components are in an OK condition.

   b. RECORD drum temperature. If possible, let cool below 100°F before proceeding.

   c. CHECK that pneumatic system is fully charged (at least 100 psi).

3. CHECK and RECORD the largest stroke increase on the unit under full treadle pedal application (at least 90 psi).

4. Compute and RECORD the "click position" of that brake:

$$\textbf{Click position} = \left\{\textbf{Largest Stroke increase}/0.125\right\} \text{(round to nearest integer)}$$

5. Based on the click position findings, proceed as follows:

(a) Brakes too tight (dragging, need to be released):

Explanation: Brakes are swelling.

Action: Make sure the "green growth" process is completed, and have the unit back for adjustment after the "green growth" process is completed. Adjust then, and RESTART at point '0' (keep using the same 'X').

(b) Brakes at click point 0 (no adjustment needed):

Explanation: Bad guess for 'X' (too small).

Action: Make sure it is not due to swelling (in which case proceed as in (a)). Otherwise RESTART at point '0', but have the unit back after '2·X' ($X_{new} = 2 \cdot X$).

(c) Brakes at click point 1:

Explanation: Good guess for 'X' (or good correction for 'X_{new}'). You're on the right track.

Action: If you wish to be a "one-click" type of operation, adjust the brakes at this point, and commence with the VERIFICATION stage (use 'X', or 'X_{new}' if it was modified, for interval in that stage). Otherwise have the unit back when it has accumulated 2·X (or $2 \cdot X_{new}$) since point '0', and commence with stage II.

(d) Brakes at click point 2:

Explanation: Bad guess for 'X' (too large).

Action: Adjust the brakes, RESTART at point '0', but have the unit back after 'X/2' ($X_{new} = X/2$).

(e) Brakes at click point 3:

Explanation: Bad guess for 'X' (too large).

Action: Adjust the brakes, RESTART at point '0', but have the unit back after 'X/3' ($X_{new} = X/3$).

(f) Brakes at click point 4 or more:

Explanation: Bad assessment of service conditions that leads to a bad guess for 'X' (much too large).

Action: Revise SF, adjust the brakes, and RESTART at point '0'. Make sure the new interval is not higher than 'X/4' ($X_{new} <= X/4$). You also might want to re-inspect the brake components for wear.

Stage II (When the unit returns)

Summary Your goal is being a two- or three-clicks type of operation. You are now $2 \cdot X_{old}$ since point '0', and at the end of the last stage your brakes were 1 click off adjustment. Inspect the adjustment status, and if the results are satisfactory — proceed to the next stage. Otherwise, RESTART the procedure.

Steps

1. Repeat steps 1 through 4 as in stage I.

2. Based on the click position findings, proceed as follows:

   (a) Brakes at click point 1:

Action: Adjust the brakes, RESTART at point '0', but have the unit back after $X_{new} = X_{old}/0.53$.

   (b) Brakes at click point 2:

Action: If you wish to be a "two-click" type of operation, adjust the brakes at this point, and commence with the VERIFICATION stage (use $2 \cdot X_{old}$ for interval in that stage). Otherwise have the unit back when it has accumulated $3 \cdot X_{old}$ since point '0', and commence with stage III.

   (c) Brakes at click point 3 or 4:

Action: Adjust the brakes, RESTART at point '0', but have the unit back after $X_{new} = X_{old}/1.38$.

Stage III (When the unit returns)

Summary Your goal is being a three-clicks type of operation. You are now $3 \cdot X_{old}$ since point '0', and at the end of the last stage your brakes were 2 clicks off adjustment. Inspect the adjustment status, and if the results are satisfactory — proceed to the VERIFICATION stage. Otherwise, RESTART the procedure.

Steps

1. Repeat / note steps 1 through 4 in stage I.

2. Based on the click position findings, proceed as follows:

   (a) Brakes at click point 2:

   Action: Adjust the brakes, RESTART at point '0', but have the unit back after $X_{new} = X_{old}/0.8$.

   (b) Brakes at click point 3:

   Action: Adjust the brakes at this point, and commence with the VERIFICATION stage (use $3 \cdot X_{old}$ for interval in that stage).

   (c) Brakes at click point 4:

   Action: Adjust the brakes, RESTART at point '0', but have the unit back after $X_{new} = X_{old}/1.21$.

Verification stage (Starts before the unit leaves the shop)

Summary The appropriate stage (for one-, two-, or three-clicks type of operation) was successfully attained, and some *interval* (of miles of service or time) was established. That interval now needs to be verified before the brake adjustment frequency can be set. The unit has its brakes fully adjusted at this point.

Steps

1. Have the unit returned at the end of the set *interval*.

2. When the unit returns, repeat / note steps 1 through 4 in stage I.

3. To successfully conclude the process of determining brake adjustment frequency, the inspection results should conform with the type of operation aimed at. That is, at this point, for a "one-click" type of operation the brakes should be 1 click off adjustment, for a "two-clicks" type of operation the brakes should be 2 clicks off

adjustment, and for a "three-clicks" type of operation the brakes should be 3 clicks off adjustment.

4. The brake adjustment frequency for the subject unit is the value of ***interval***.

5. If the condition portrayed in item 3 above is not satisfied — adjust the brakes, and RESTART at point '**0**'. Use the latest 'X_{new}' established.

The overall procedure is summarized in Figure 19.

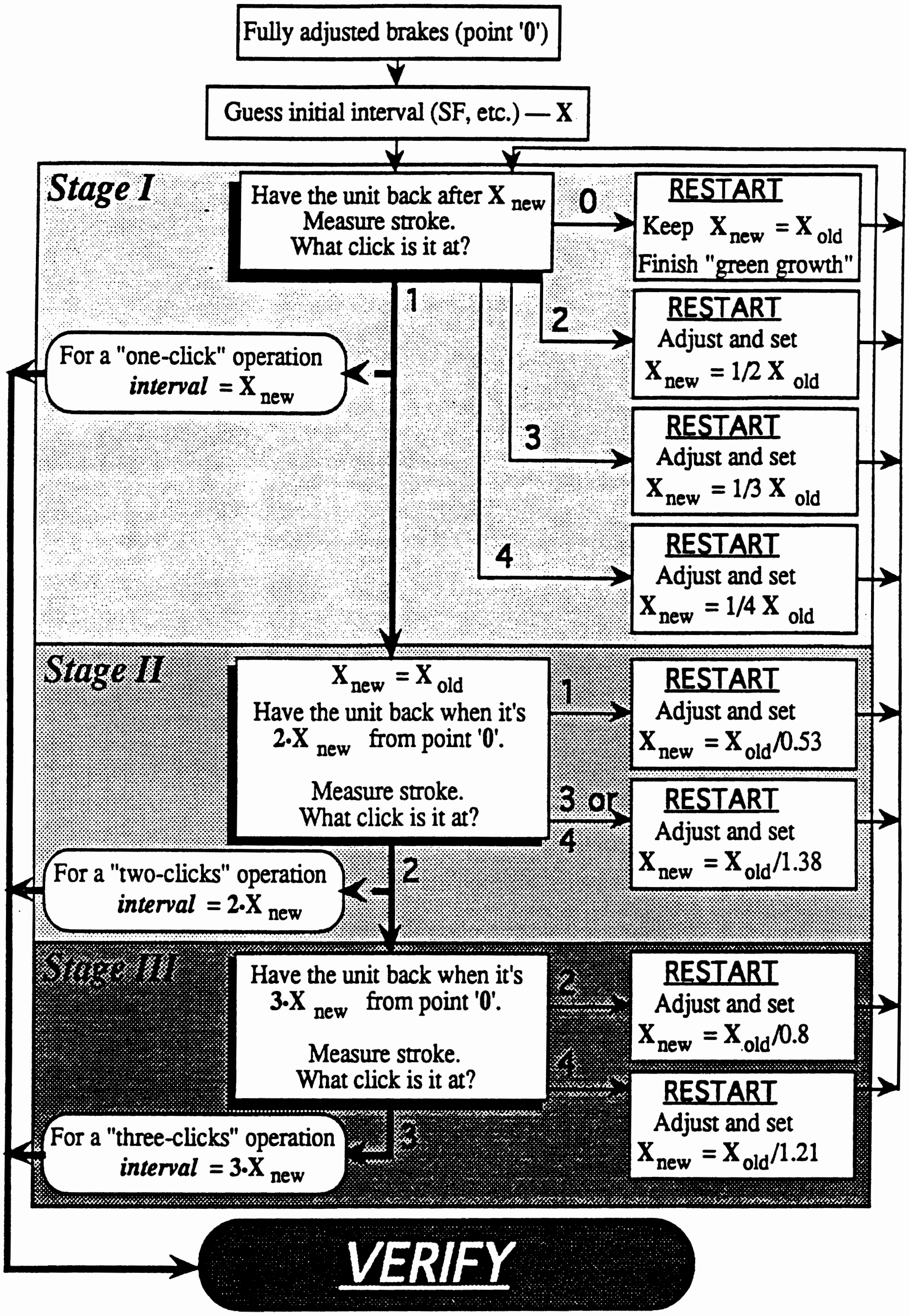


Figure 19. Flow diagram of the procedure for establishing the frequency of brake adjustment

4.0 Conclusions and Recommendations

4.1 Adequacy of the 20-Percent Rule

The findings and results of this study indicate that the 20-percent rule as currently applied results in placing a number of vehicles with adequate braking capability out-of-service. Some of these vehicles have braking capability that is more than 80 percent of that available if the vehicle would have had all of its brakes fully adjusted. This means that some of the vehicles placed out-of-service have more braking capability than some of the vehicles that are allowed to continue operating. The costs associated with removing vehicles from their transportation mission are large. The FHWA and the CVSA should consider revising the out-of-service criteria in order to reduce the incidence of placing vehicles with adequate braking capability out-of-service.

The basis for considering a change in the out-of-service criteria is associated primarily with the idea that the de facto goal has been to use 80 percent of the fully adjusted braking capability as the criteria. Currently, the 20-percent rule is less precise than one might consider necessary to do a uniform and appropriate job in attaining that goal. As described in section 3, a detailed analysis of over 2,100 inspections of five-axle trucks indicated that employing the 20-percent rule results in many trucks being placed out-of-service even though they have more than 80 percent of their fully adjusted braking capability. If the goal of reducing the number of false positives for brake adjustment is accepted, we recommended that the following ideas be considered in revising the criteria.

Two alternative approaches to determine brake adjustment criteria are the brakeability and demerit methods. Both provide inspection practices that are more uniform, technically sound, and appropriate than the 20-percent rule. In order to evaluate brakeability the inspectors need to use a computer to be efficient and accurate while tables and a calculator will suffice when using the demerit method (although a computer would be more efficient for the demerit method).

If long term planning concerning brake adjustment data collection and analysis and a high level of accuracy are critical considerations, the brakeability method is recommended. Once computers are in use for the brakeability method, other tasks (either current or future improvements) carried out at the inspection site might be incorporated into the brake inspection program. If needed, modifications to the data fields (for example, information on new types of brake chambers) or algorithm can easily be implemented. Also, the type of work discussed in this report could be extended to larger samples if the stroke measurements from MCSAP inspections were recorded.

If, on the other hand, immediate improvement of the results is the primary goal for which a small sacrifice in accuracy is acceptable, the demerit method may be the best option. The tables used for the demerit method can be prepared in a short time, and with the assumption that calculators are readily available for the inspectors, the demerit method could be implemented quickly. An alternative approach: implement the demerit method immediately while developing the long-term program for utilizing the brakeability method in the future.

In practical terms, if computers are employed, the inspector would need to enter the stroke measurements, the chamber sizes, and the slack adjuster length. The computer would perform the calculations to determine the out-of-adjustment and out-of-service violations. Although it may not seem unreasonable to ask inspectors to gather this information, it would require more time than inspectors currently spend. However, the time and effort would not be equivalent to that of the NTSB inspection teams since the information the MCSAP inspectors would need is only a fraction of that gathered by the NTSB.

In summary, the current 20-percent rule for brake adjustment provides a good initial indication of the amount of loss in stopping capability for heavy trucks. However, there are more technically sound means of evaluating stopping capability which can be applied more uniformly across the spectrum of possible brake adjustment situations. The benefits of changing the criteria would be (1) stricter criteria with regard to those vehicles that are placed out-of-service, (vehicles with a completely backed-off brake that now pass the criteria would no longer pass if the braking capability of the vehicle is less than 80 percent of that for the fully adjusted case), and (2) fewer false positives.

4.2 Guidelines on Brake Inspection and Maintenance

With the great deal of public interest concerning the number of heavy trucks placed out-of-service for brake adjustment, a number of groups have developed recommended procedures for adjusting brakes. The procedures cover situations in which the wheels can be raised off the ground and situations in which it is not practical to raise the wheels. However, some of the procedures do not include measuring the power stroke with 90 psi in the brake lines. Given the number of brakes that are found to be out-of-adjustment during inspections, the findings of this study support a recommendation that brake adjustment procedures include a final step in which the power stroke is measured per the CVSA inspection procedure and that the power stroke for fully-adjusted brakes be recorded for various combinations of brake chambers and slack adjuster lengths.

In addition to knowing how to adjust brakes and measure the stroke, attention must be focused on determining how often brakes need to be adjusted. This study provides a straightforward method for estimating the frequency with which the brakes on heavy trucks need to be adjusted. The procedure is based upon a predictor/corrector approach to establish an appropriate period of service between brake adjustments. The procedure starts with an initial prediction of the period of service and then allows the vehicle to operate over the predicted period. Once the period is completed, the vehicle is inspected and the amount of stroke change is compared with the predicted amount of stroke change. If the prediction proves to be satisfactory, the process is repeated to verify that an appropriate period between adjustments has been found. If the change in stroke is too large the period is corrected to a shorter value and the experiment is repeated. Likewise, if the stroke change is too small, the period is corrected to a larger value and the experiment is repeated. Experimental steps are repeated until the process converges onto an appropriate period between brake adjustments.

The procedure can be used to determine the period between brake adjustments in those situations in which routine maintenance procedures are failing to keep brakes in adjustment. In such situations, the results of the procedure for a specific vehicle should be used for the individual vehicle and should not be used to predict the frequency of brake adjustment for the fleet. The study shows that a significant variation in the number of miles between relinings (and hence the time/distance between brake adjustments) can exist even between the same make and model year of vehicles at the same fleet terminal. If the brake adjustment problems are widespread in the fleet then a review of the carriers overall brake maintenance procedures (specifically brake adjustment responsibilities) may be in order.

4.3 Recommendations for Future Studies

1. The procedure for determining the period between brake adjustments should be given a field trial using a cross0-section of representative fleets. The results of the field trial would be used to assess the effectiveness of the procedure and the reactions of truck operators with regard to the practicality of the procedure and their willingness to measure stroke.

2. A pamphlet or booklet covering the procedure for determining brake adjustment frequency should be prepared for use by motor carriers. A preliminary pamphlet should be distributed to a sample of fleets as a field trial of the usefulness of the pamphlet. The field trial would include fleets with good and poor records with respect to brake adjustment. Feedback from the trial would be used to revise the pamphlet and then a mass distribution of the information would follow.

3. The brakeability and demerit methods should be studied in a limited field trial. The field trial would involve inspection crews doing the inspection by each of three techniques: the 20-percent rule; the demerit method; and the brakeability method. Since the information needed for applying the 20-percent rule is contained in the information needed for the other methods, this field trial essentially amounts to collecting data on stroke measurements, brake chamber sizes, and the slack adjuster arm lengths for the vehicles inspected. The main purpose of this field exercise is to assess the practicality of gathering the brake information in the field under the conditions ordinarily experienced by MCSAP inspectors.

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APPENDIX A

INTERVIEW PLAN

This document presents a plan for interviewing Motor Carrier Safety Assistance Program (MCSAP) inspectors with regard to brake inspection, brake adjustment, and the out-of-service criteria for brake adjustment. This plan has been prepared by the University of Michigan Transportation Research Institute (UMTRI) for a project entitled, "Evaluation of Criteria for Truck Air Brake Adjustment" (Contract No. DTFH61-00106). This project is being performed in support of a major goal of the Office of Motor Carriers of the Federal Highway Administration (FHWA)—specifically, to ensure safe operation of motor vehicles engaged in interstate commerce.

The broad goals of the study are to (a) reevaluate the brake OOS criteria, and (b) generate information that will tell motor carriers how often they need to adjust brakes. Specifically, the objectives of the study are as follows:

(1) Evaluate the technical adequacy of the existing "Out-of-Service (OOS) Criteria" for the brakes. The focus of this evaluation will be on the brake adjustment criteria;

(2) Make recommendations on revisions to either the OOS or the Federal Motor Carrier Safety Regulations (FMCSR) to make them uniform, technically sound, practical, and appropriate;

(3) Develop guidelines on brake inspection and maintenance, especially on brake adjustment for drivers, mechanics, and motor carriers;

(4) Determine what effect vehicle use has on brake adjustment; and

(5) Determine how often brakes require adjustment for various types of vehicles and various types of operations.

To aid in accomplishing these objectives, the intention of the interviews is to draw on the knowledge, perspectives, and experience of the MCSAP inspection personnel. Although the requirements for brake adjustment to compensate for brake wear may seem straightforward, the actual practice of roadside safety inspection requires practical skill and judgment in assessing the state of brake adjustment. The insights of the inspectors are expected to aid in obtaining information that is relevant and applicable to the practice of roadside safety inspection. In particular, the inspectors' responses are expected to aid us in making recommendations that are practical from economic, safety, and environmental perspectives.

In summary, the purpose of this plan is to provide an orderly structure so the interviews can be conducted efficiently, and to ensure that appropriate topics will be treated in a logical order. The following section contains a listing of the sequence in which basic questions will be addressed in the interviews.

INTERVIEW OUTLINE (sequence of questions)

The intention here is to start with questions and discussions pertaining to the inspection process itself. In this way the interviewer and the inspectors are expected to establish a level of mutual understanding that will aid the interview process when the questions become less straightforward and more abstract or more speculative. Clearly, the inspectors should understand that they are not expected to know everything, but that their knowledge is valuable.

Question #1: ***How is brake adjustment inspected?***

•Subquestions:

—What are your procedures for inspecting brake adjustment?

—What equipment do you use?

—How do your procedures relate to the MCSAP/CVSA and FMCSR requirements?

—Would you like to see changes in the MCSAP instructions?—in the FMCSR?

—How accurately can stroke be measured?

—Do trucks arrive with hot brakes and, if so, how are they treated?

Question #2: ***What do you record about brake adjustment in relation to the vehicle being inspected? Cover factors such as the number of brakes OOA, the degree of OOA, and the distribution of stroke from brake to brake around the vehicle.***

•Subquestions:

—What data gets recorded?

—What is the data used for?

—Is it automated (computerized)?

—What can be learned by looking at the data?

—For vehicles put OOS and perhaps for vehicles receiving CVSA stickers, what information is gathered about the vehicle? Its configuration? Loading and cargo type? Type of service? Registration, etc? Is it coded (computerized)?

Question #3: **What do you know about vehicles with brakes OOA?**

•*Leading question*: If you were to try to select a vehicle with brakes OOA, how would you select one?

•In this context, cover the types of vehicles and the segments of the industry that may have disproportionate numbers of vehicles placed OOS.

Question #4: ***What do you think might be done to improve highway safety through better brake adjustment and brake inspection procedure?***

•Discuss:

(1) The relationship between brake adjustment levels, lining properties, pneumatic timing and stopping distance. Have you ever performed stopping distance tests?

(2) The use and effectiveness of devices which automatically adjust brakes - How can brakes be adjusted reliably?

(3) The use and effectiveness of devices which warn drivers of imminent brake failures and defects, including OOA.

(4) Should there be vehicles that are not given CVSA stickers because a small amount of brake wear would put them OOS?

*Question #5: **What are your views on the OOS criteria for brakes?***

•Cover:

(1) Problems with the current OOS criteria for brakes.

(2) Aspects of brake OOS criteria that require further research.

(3) Recommended changes in brake OOS criteria.

*Question #6: **How often do brakes need to be adjusted?***

•*Leading question*: If you were to estimate how frequently brake adjustments or brake inspections had been performed on the OOS vehicles, what would that estimate be based upon?

•In this context, discuss the frequency of brake adjustment required for different vehicle configurations and operating conditions.

*Question #7: **Have we missed something of importance and relevance?***

•That is, are there other problems, issues, or suggestions regarding the inspection of brakes?

DISCUSSION OF THE INTERVIEW OUTLINE

The outline has been structured to cover the entire scope of the issues and questions that w have formulated and that appear in the statement of work for this project. In this sense, it is not reasonable to expect that each inspector has a definitive answer for every subject area. Nevertheless, any views and opinions that the inspectors wish to express are desired in each question area. If the inspectors know of sources of information on pertinent issues and questions, those sources are to be identified and recorded for future use.

The outline will serve as the interview form. By this we mean that the interview form will simply be a "spread-out" version of the interview outline.

Question #1 and #2 pertain to the processes that the inspectors perform in their immediate tasks associated with inspecting brakes. For the most part, the questions in these areas can be answered with facts. However, in one case, judgments are required for evaluating brake inspection procedures and instructions.

Question 4 might be considered as asking for the solution to the overall goals of the MCSAP program as they apply to brake adjustment. One might be skeptical about asking this type of question, but if anyone has the desire to think "big," we want to hear their ideas. In any event, no one is expected to do more than try to formulate ideas that may prove to be helpful. In particular, pieces of information pertaining to automatic slack adjusters, stroke indicators, and brake adjustment procedures would be important contributions to the results of the interview.

The first discussion point in Question #4 is aimed at considering all of the brake system factors that might degrade stopping performance. The question about stopping distance tests provides the opportunity to discuss the influences of brake timing on 20 mph stops (In some cases, the vehicle may be nearly stopped before the trailer brakes become fully-actuated.) That question also provides the opportunity to observe that brake lining materials can react differently in 60 mph tests than they do in 20 mph tests. The effectiveness of the brakes may be considerably greater in stops from 20 mph than they are in stops from 60 mph. The ability to discuss the first point in Question #4 will depend upon the extent that an individual inspector has become an expert on the performance of brake systems.

Item (4) in Question #4 is a philosophical question concerning the meaning of the results of the brake inspection process. Given that the OOS criteria are very definitely specified, there is a fine line between passing and failing. One way to "broaden" that line (with respect to encroaching on the passing side) is to have an intermediate category which includes vehicles that barely passed, but will soon be in need of brake adjustment. in any event, the question will provide the opportunity to begin to think critically and constructively about the reasons for measuring brake adjustment.

Questions #5 and #6 pertain directly to the broad, overall goals of this study. (Here we are directly asking for and accepting help with respect to the goals for which we are responsible.)

We anticipate that brake inspectors are eminently qualified to address the practical and pragmatic aspects of the brake OOS criteria with regard to any of the items to be covered in Question #5.

Question #6 is another aspect of the material covered in Question #3. However, the emphasis in this case is focused on helping fleets to do a better job of adjusting brakes and passing inspections.

The interview outline ends with question #7 which provides an opportunity to discuss relevant subjects that we did not cover explicitly in Questions #1 through #6 of the interview.

LOGISTICS OF CARRYING OUT THE INTERVIEW PLAN

This plan will have been approved by the FHWA before it is implemented. The contracting officer's technical representative (COTR) at FHWA will recommend no more than nine inspectors and contact the appropriate FHWA officials regarding the interviews.

Once the interview plan is approved, copies will be provided to the FHWA Office of Motor Carriers Regional Directors and the state MCSAP officials. Copies will be furnished to the individual inspectors ten days prior to the interview. This will allow the inspectors to familiarize themselves with the nature of the questions and the subjects to be discussed during the interview. If the inspectors were so inclined, they could gather pertinent materials and references on the subjects to be discussed.

The first two interviews will include observing brake inspections in the field with the Federal Highway Administration personnel. It is anticipated that three persons from UMTRI will attend the first interview, two or three persons from UMTRI will attend the second interview, and perhaps no more than one person will go to the other interviews. If the schedule permits, Mr. Ray Masters of UMTRI will attend all of the interviews and be the person responsible for collecting the information recorded on the interview forms.

CONCLUDING REMARKS

We close with observations on what the project is trying to accomplish. The information recorded on the interview forms will provide the basis for a report summarizing the findings from the interviews.

From a more general perspective, it seems essential to us that both the drivers and the inspectors understand that the driver generally will not be aware that brakes are OOA during the course of normal stops. Frequent measurement of the brake adjustment is necessary in order to make sure that sufficient stroke is there in the event that full brake torque is needed. Thus, the inspections are intended to check brake adjustment in as straightforward and efficient a manner as possible. A better picture of the influence of the type of service and the configuration of the vehicle on brake wear, and hence, the need for brake adjustment should lead to improved and more practical OOS criteria. More to the point, this information should assist truck operators in keeping brakes in adjustment.

APPENDIX B

FINDINGS FROM INTERVIEWS OF MCSAP INSPECTORS

INTRODUCTION

This report pertains to Task B of a study entitled, "Evaluation of Criteria for Truck Air Brake Adjustment." The broad goals of the study are to (1) reevaluate the brake out-of-service (OOS) criteria used in the Motor Carrier Safety Assistance Program (MCSAP) as it applies to air-braked heavy vehicles and (2) generate information that will tell motor carriers how often they need to adjust brakes (see References [1,2]). The work in Task B has included interviewing inspectors from eight states per an interview plan developed to provide practical information and informed opinions regarding topics related to the following seven questions.

- How is brake adjustment inspected?

- What do you record about brake adjustment in relation to the vehicle being inspected?

- What do you know about vehicles with brakes OOA?

- What do you think might be done to improve highway safety through better brake adjustment and brake inspection procedures?

- What are your views on the OOS criteria for brakes?

- How often do brakes need to be adjusted?

- Have we missed something of importance and relevance?

After providing information on the interview process in the next section, summaries of the inspectors' answers to the above questions are presented in the following section. The purposes of these summaries are to (a) capture the important points made by the inspectors, and (b) organize these points into universal findings where possible. The report concludes with subsections that present our interpretations of the meanings of the results and findings with respect to brake adjustment OOS criteria and brake maintenance.

INFORMATION ON THE INTERVIEW PROCESS

The initial efforts in Task B resulted in the development of an interview plan which was submitted to the Office of Motor Carriers (OMC) of the Federal Highway Administration for comments and suggestions. (A copy of the approved Interview Plan is included here in Appendix A.) Then the OMC provided liaison with inspectors in eight states through the appropriate regional directors. The locations, persons, and dates of the interviews were as follows:

<u>MCSAP Inspector Interview Respondents (1990)</u>
Michigan—Lieutenant Norman Gear—May 29
Wisconsin—Inspector Darrell Bender—May 30
New York—Inspector Raymond Gagnon—June 19

Maine—Inspector John Fraser—June 20
Oregon—Inspector Mike Sullivan—June 26
Utah—Sergeant Ken Mecham—June 27
California—Captain Larry Rollin—June 27
Georgia—Lieutenant Don Lively—July 2

The interviews were conducted at the inspector's facility, primarily by Ray Masters of UMTRI with Ken Campbell and Paul Fancher participating in three and two interviews, respectively. During the first two visits, the inspectors explained and demonstrated how they performed inspections using vehicles that were stopped for inspection.

SUMMARIES OF THE RESULTS FROM THE INTERVIEWS

Question #1: How is brake adjustment inspected?

The inspectors unanimously reported that their procedures followed North American Standard Inspection criteria. However, in actual application, their procedures varied in the following ways:

- One inspector had fastened a ruler to the device holding the soapstone to create a single tool for greater convenience.
- One inspector did not mark the pushrod. Instead, he held his measuring tool beside the pushrod during movement and mentally computed the difference.
- One inspector used a ruler attached to a telescoping handle to measure travel in situations with low undercarriage clearance. In these instances, the pushrod was not marked, and the travel was figured mentally.
- One inspector began his procedure at the rearmost axle.
- Five inspectors did not follow the counterclockwise pattern, preferring to mark and measure at one axle at a time, first one side and then the other.

Despite the variations in technique, the inspectors all felt that they measured pushrod travel accurately. The thought of all is characterized by one who said that stroke can be measured "as accurately as the tool used for measurement allows." A variety of measuring devices were used, including six inch metal rulers, six foot retractable tapes, and six inch sections cut from aluminum yardsticks. The tools were marked in gradations of 1/32", 1/16", or 1/8". The accuracy of measurement claimed depended on the gradation of the tool employed by each inspector.

Several factors affecting accurate measurement were cited:

- Inclement weather;
- Boots surrounding pushrods;
- Brackets on cannisters;
- Low undercarriages;
- Thickness of drums; and
- Drum temperature.

Trucks arriving with hot brakes were treated as special cases. Usually, that condition was found to be the result of component defects rather than the result of grade or frequent application. It was generally felt inappropriate to apply OOS criteria for adjustment to a hot brake. States have been careful not to locate either permanent or roadside inspection sites in an area where a vehicle has just completed a steep descent requiring exceptional brake use.

Overall, the inspectors felt that their training in and application of MCSAP and CVSA requirements were consistent with the broad aims of the program. Further, no changes were recommended for practices and standards of brake adjustment inspection alone.

Question #2: What do you record about brake adjustment in relation to the vehicle being inspected?

In each state visited, brake adjustment information generally is recorded only for brakes in violation. The primary reason for recording the information is to support the violation. States vary in terms of the recorded information that locates the brake. Each state locates the brake with regard to the unit in the combination, but many do not located either the axle or the axle-end.

The forms used by some of the states visited (Michigan, Georgia, and Oregon) provide space to record pushrod travel by unit, axle, and axle-end. (See Appendix B for copies of the forms used in the eight states that were visited.) Although the measurements are made by most of the inspectors on every brake, this information is generally not recorded unless the brake adjustment is in violation. In most states, even less information is computerized. Only Wisconsin has codes for the actual pushrod travel: one to indicate travel over 1.75", and one for travel exceeding 2.0". It appears that pushrod travel is frequently included in a comments section of the Oregon computerized data. However, this information is not readily extracted for analysis.

Although the Wisconsin data form does not have as much detail on brake adjustment as some, their data system is remarkable in comparison to the other states visited. Data is entered on-line during the inspection process. Driver license, vehicle registration, and carrier information are available on-line, so this information is immediately displayed on the screen once the appropriate plate number, driver license number, or carrier name are entered. This is the only computerized data system observed that actually saves the inspectors time over the course of the inspection. In many cases, the inspector simply has to verify addresses, unit number, VIN, etc. Thus, while the Wisconsin violation form does not have as much detail as some, the computerized information on brake violations provides more detail than any of the states visited, locating the brake violations by unit, axle, and axle-end.

Question #3: What do you know about vehicles with brakes out-of-adjustment?

This question produced a considerable volume of response in most states. For the most part, many of the inspectors' observations were consistent from state to state, with only occasional regional differences reflecting unique operations or vehicles. A brief summary of the most pertinent and common responses is attempted here.

With regard to the root cause of out-of-adjustment brakes, the state inspectors interviewed were virtually unanimous in stating that if the driver and company do not make the necessary effort to keep the brakes in adjustment, good adjustment will not be maintained no matter how many times the vehicle may be inspected. Many inspectors felt that weekly, or even daily, inspections by two people - one to apply the brakes and one to check adjustment - were necessary to maintain brake adjustment. Besides this obvious source of OOA brakes, a number of other patterns in the occurrence of OOA brakes identified by the inspectors interviewed included:

(1) Trailer brakes are more likely to be OOA, possibly because they receive less regular maintenance than power units and many have no record of miles traveled.

(2) Steering axles are not particularly prone to be OOA, although they still occasionally find some disconnected.

(3) Trucks used in rough off-road terrain such as dump and refuse are prone to undercarriage damage that sometimes affects brake operation.

(4) Leased equipment seems to be more likely to be OOA since drivers will usually use the brakes on leased equipment, if they work, over equipment they own.

(5) The rear axle on log trucks is sometimes backed-off to eliminate wheel hop when empty.

(6) An axle that is hard to get at is more likely to have brakes OOA. This includes low ride trailers, chip haulers with the brake chamber above the axle, and front axles blocked by the faring on the new aerodynamic tractors.

(7) The older automatic slack adjusters often do not work if they do not receive regular maintenance. The newer automatic slack adjusters generally provide more uniform adjustment from axle to axle. The inspectors' experience with automatic slack adjusters was mixed. some felt automatic adjusters would eliminate most OOA problems, and others were more skeptical, saying that they gave the driver a false sense of security that fostered a lack of attention to brake adjustment.

(8) Right side brakes may possibly be more prone to OOA, perhaps due to the crown in the road loading the right side a little more, or us of left-hand threads on the right side of the vehicle.

(9) Generally, older trucks have more violations of all kinds than newer equipment.

Question #4: What do you think might be done to improve highway safety through better brake adjustment?

For the most part, inspectors had not performed stopping distance tests. One inspector had worked previously as Safety Director of a trucking company and had been involved in such tests. Three other inspectors had experience with decelerometer testing.

The inspectors had general familiarity with the relationship between brake adjustment levels, lining properties, and pneumatic timing as they effect stopping distance, but few had technical backgrounds or training to provide them with insight into what degree or in what ways stopping distance might be affected.

More to the point, the focus expressed by the inspectors was to apply established criteria and to enforce law. One inspector said that to improve highway safety by better brake adjustment, "Apparently, it's going to take stiffer and more frequent penalties."

Another inspector said that "Brake inspection procedures are adequately addressed." The consensus was that the burden of achieving better brake adjustment belongs to companies and drives. Companies must evaluate their operations in order to know when to inspect and adjust. Also, they must institute regular programs of education and training to ensure that those responsible for brake adjustment in fact know what they are doing and how to do it.

One inspector summarized this question area by stating that the best way to achieve better brake adjustment is :

•for drivers and mechanics to more fully understand the entire brake system;

•for scheduled checks to be strictly performed; and

•for aggressive, consistent MCSAP inspection to be continued.

Automatic slack adjusters were thought to be helpful, but no panacea in keeping brakes within criteria. Responses are typified by the statements:

•"Much fewer violations are detected on vehicles equipped with auto slack adjusters."

•"Automatic adjusting brake devices are available to industry for a price which functions well with proper maintenance."

•"On most occasions, automatic slack adjusters work."

•"From what I've seen so far, automatic slack adjusters are not reliable enough."

•"Auto adjusters still require maintenance, and may make things worse if no one gets under (the) vehicle to check other items."

Several inspectors reported that drivers, who operate trucks equipped with automatic adjusters and yet determined to have brake adjustment defects, tend to dispute the findings claiming that "It's impossible for the brakes to be out-of-adjustment—they're automatic!"

Stroke indicators, such as lock rings or color coded markings on the pushrod, were listed as aids which had potential for operators to assess adjustment levels, but more often than not these devices seemed to have been ignored by the users who had them.

Low pressure warning lights were thought to be of little value. Pressure drops are a part of normal operations, so the lights tend to be ignored or disabled. Instances of catastrophic failure result in activation of the spring brakes.

The predominant opinion of the inspectors was that CVSA stickers should be issued even though a small amount of wear would put a vehicle OOS. Representative responses included:

•"If the OOS criteria gets too cluttered with 'this-for-that" no one will be able to understand it or apply it."

•"We should sticker all vehicles meeting a minimum requirement. We should not attempt to project future wear conditions."

Question #5: What are your views on the OOS criteria for brakes?

One inspector responded to this question with the comment "too slack." If this was a pun, we missed it at the time. Nevertheless, the trend was to suggest tightening the criteria. No inspector said that the criteria should be relaxed or backed off in some manner.

The following summary of the results contains comments on a variety of specific topics. Most of these topics were mentioned by only one person, but a couple items were mentioned more than once.

•The "25 mile restricted service" option was mentioned by inspectors from two different states. Their view was that it should not be allowed. On the other hand, another inspector who used portable sales and did inspections on the sides of secondary roads, needed provisions to get OOS vehicles to safe parking areas ("safe havens"). A suggested answer was to escort OOS vehicles off of the roadside to detention and repair areas.

•"The "20-percent rule" was questioned. Inspectors felt that exceptions were needed for situations in which one brake was rendered inoperable or completely backed-off. One inspector felt that items like missing return springs, cracked linings, defective drums, etc. on one brake should be sufficient for OOS even if the total vehicle did not violate the 20-percent rule. Another inspector questioned whether a fully-laden truck needed all brakes operating properly for the vehicle to stop satisfactorily from high speed. A third inspector was aggravated by experiences in which vehicles were proceeding on with one defective brake because the owners knew the vehicle would pass the 20-percent rule.

To counter these problems and concerns, it was suggested that any defective brake should put the vehicle OOS.

•The following items were suggested once:

—The performance of the breakaway system needs to be checked.

—One brake defect should put overweight vehicles OOS.

—Contaminated brakes should put vehicles OOS.

—Re-instate the "half inch" difference in stroke on the front axle as an OOS criteria.

—Develop methods for measuring brake drums and OOS criteria for deficient drums. (Allow drums to be machined to no more than 0.12", for example).

—Develop rules for brake valves, especially, "fits-all-brakes" valves.

—Require tractor protection valves on straight trucks equipped to pull trailers.

—Develop methods for measuring the state of lining wear and pertinent OOS criteria.

—Establish rules for mix and match parts, cut rate parts, etc.

—Develop rules for drive-away vehicles.

—Develop rules concerning brake lines, relay booster valves, and the like.

Lest we give the wrong impression, we should report that there were positive feelings with respect to the current OOS criteria and a willingness to support them. Comments such as "no objections," "no changes recommended," and "any changes in MCSAP would cause confusion," were offered. In general, the existing criteria appeared to be well accepted - several inspectors simply had ideas involving additional factors that need inspection.

Question #6: How often do brakes need to be adjusted?

As will become apparent, the answers to this question provide insights into matters relevant to the plans being developed for monitoring brake adjustment in a last phase of this research study.

First, the inspectors generally agreed that in a certain sense it was impossible to say how often brakes need adjustment. There are "too many variables to know." The adjustment level is related to the type of service, use of the trailer brake, maintenance scheduling (or the lack of it) for trailers, the use of retarders, the braking tendencies of individual drivers, and company practices.

Second, however, many inspectors also took another tack which can be characterized by the statement "When brakes are detected out-of-adjustment, they need to be readjusted." As obvious as this statement seems, it provides the foundation for several positive ideas revolving around each trucking company developing its own brake adjustment schedule. For example, on person suggested that companies check brakes at a two-day interval fro two weeks to establish how often they need to adjust brakes. Another person suggested checking brakes daily and after severe mountain descents. Others felt that weekly inspections would be sufficient to maintain brake adjustments at levels that would pass inspections.

On the one hand, the inspectors seemed to be somewhat offended that they were asked this question. They felt that it should be referred to brake engineers who conduct wear tests on lining friction materials. On the other hand, they felt strongly that keeping proper brake adjustment was a matter of understanding, willingness to learn proper inspection and adjustment procedures, and diligence on the part of companies, mechanics, and drivers. When the inspectors were in the latter frame of mind, they emphasized the importance of trucking company policy. they tended to feel that configuration and operating conditions per se were of lesser importance to maintaining proper brake adjustment than having a company policy that reflected the company's intention of knowing how their type of service affected brake adjustment for their vehicles.

Question #7: Have we missed something of importance and relevance?

Inspectors from three states simply replied "no" or "nothing" as a direct response to this question. Other inspectors added new thoughts or expanded upon items suggested before under Question #5. These ideas included:

- A suggestion that the maximum crack pressure for front axle limiting valves be at 10 to 15 psi, not 30 psi.

- Concern over the lack of access for appraisal of shoe wear, drum condition, etc.

- Addition of information on brake adjustment and brake chamber readjustment limitss in Part 393 of the FMCSR. (This would make pertinent information more readily available to companies, mechanics, and drivers.)

- Decelerometer testing like that used in one state to check buses.

- Concerns with having balanced stroke throughout the vehicle.

- Concerns with pneumatic timing.

- Develop a tool or template for checking the angle of the slack adjuster arm.

Finally, there are a few additional relevant items that came up in the course of the interviews. Even though the following items may not have been offered as direct answers to Question #7, we have chosen to include them here because they seem to be pertinent subjects.

- The parent organizations of the MCSAP inspectors differ from state to state. This causes differences in how vehicles are selected for inspection although each organization has both "random" and probable cause" selection processes. In Michigan, for example, the inspectors are police officers. The state law defines their prerogatives. They stop vehicles for which they have an observable reason to suspect a violation, or they proceed using a rigorous random selection method. The rigorous random selection is done using a page of random numbers generated for that day. For example, the numbers might range from one to eight, with "one" meaning to take the next vehicle and "two" meaning to take the vehicle after next, etc. This would give a random sample as long as the inspection reports for vehicles stopped for probable cause are not confused with those for vehicles stopped randomly. (Some vehicles would fit both the random and probable cause requirements and that would be satisfactory.)

- On one occasion, there might have been confusion over the meaning of "setting the brakes." The parking brakes operate at a level approximately equivalent to 60 psi. This does not require as much stroke as an 80 to 90 psi application. The inspector needs to check that the operator is applying 80 to 90 psi to get an indication of the amount of braking effort that would be available in an emergency stop.

- Technical questions should be addressed to brake companies so that important information is not missed.

CONCLUDING INTERPRETATIONS CONCERNING (A) OOS CRITERIA FOR BRAKE ADJUSTMENT AND (B) BRAKE MAINTENANCE

The objectives of the study (including Task B) are as follows:

(1) Evaluate the technical adequacy of the existing "Out-of-Service (OOS) Criteria" for brakes. The focus of this evaluation will be on the brake adjustment criteria.

(2) Make recommendations on revisions to either the OOS or the Federal Motor Carrier Safety Regulations (FMCSR) to make them uniform, technically sound, practical, and appropriate.

(3) Develop guidelines on brake inspection and maintenance, especially on brake adjustment for drivers, mechanics, and motor carriers.

(4) Determine what effect vehicle use has on brake adjustment.

(5) Determine how often brakes require adjustment for various types of vehicles and various types of operations.

The interviews with inspectors have contributed useful insights with regard to these objectives and to the conduct of future tasks in this study.

More specifically, the interviews with inspectors have provided a better understanding and practical perspectives on brake adjustment procedures and equipment. They have shown that the inspectors have a general understanding of the relationships between brake adjustment levels, lining condition, drum condition, and pneumatic timing (and the influences of brake valves) on stopping performance. However, this is not a quantitative understanding, rather the inspectors have a qualitative feel for the elements of a satisfactory braking system. Their training, study, and experience appear to have provided them with the knowledge needed to measure and judge the quality of air brake systems.

The following concluding statements address OOS criteria and brake maintenance.

OOS Criteria for Brake Adjustment

With respect to OOS criteria, the interviews conducted in Task B were aimed at identifying (a) problems with current OOS criteria, (b) aspects of brake OOS criteria that require further research, and 9c) recommended changes in brake OOS criteria. These topics have been discussed under Question #5. In general, the results of the interviews show that although the inspectors did have numerous suggestions on a variety of aspects of the OOS criteria, they were for the most part satisfied with the OOS criteria as it applied to brake adjustment.

Three inspectors favored tightening the criteria for situations in which obvious maintenance deficiencies were apparent even though 20 percent of the brakes were not out-of-adjustment. There was one suggestion that the 20-percent rule may not be adequate for stopping fully-laden heavy trucks from high speeds. Research on this subject was not recommended. Also, one inspector felt that consideration should be given to reinstating the old rule requiring that the stroke on the front brakes be with 1/2".

Nevertheless, the inspectors' comments indicated that, as a group, they were conservative with regard to changing the OOS criteria in that changes might cause confusion.

Brake Maintenance

A number of the topics targeted for Task B fall under the heading of "Brake Maintenance" related subjects. Specifically, the brake maintenance related topics were as follows:

- Brake inspection procedures and equipment.
- Factors, such as the number and distribution of axles, the number of brakes out-of-adjustment, and the degree of OOA, which place vehicles OOS.
- Types of vehicles and segments of the industry that may have a disproportionate number of vehicles placed OOS for brake adjustment.
- Frequency for adjusting brakes for different vehicle configuration and operating conditions.
- The use and effectiveness of devices which warn drivers of imminent brake failures and defects, including OOA.
- The use and effectiveness of devices which automatically adjust brakes.

Our general interpretations of the results for these topics are based on responses from most of the Questions used in the interviews. (See specific questions for statements on detailed matters.) The following ideas have been derived from talking to brake inspectors:

(1) Quantitative information is available on which brakes tend to be out-of-adjustment. The information saved in computerized form in Wisconsin appears to be useful for studying OOA differences from brake to brake on the vehicles inserted.

(2) The inspectors observe that heavy vehicles in seasonal enterprises such as logging and construction tend to have brakes OOA. Also, refuse haulers have been singled out. These results have not been quantified but perhaps some of them can be verified quantitatively using the data recorded in Oregon.

(3) The inspectors' approaches to questions concerning frequencies of brake adjustment indicate the importance that they place on company policy rather than on the type of service or the type of vehicle the company employs. A very important observation is that each company needs to establish its own brake adjustment schedule for its operation. (We have noted this same approach being recommended by brake suppliers to their customers.)

Perhaps the most important finding from the interviews will be that the key to aiding truckers in maintaining proper brake adjustment is to establish procedures that each trucking company can use itself (or the trucking company can be forced to use if they have a poor inspection record) to determine the appropriate brake inspection and brake maintenance schedules for their operations.

REFERENCES

[1] . . . , "North American Uniform Driver-Vehicle Inspection Manual," Motor Carrier Safety Assistance Program, Federal Highway Administration, (draft) May 1989.

APPENDIX C

INSPECTION FORMS FROM

MICHIGAN

WISCONSIN

MAINE

NEW YORK

OREGON

UTAH

CALIFORNIA

GEORGIA

NATIONAL TRANSPORTATION SAFETY BOARD

MICHIGAN STATE POLICE
Motor Carrier Division

☐ 1 NAS
• ☐ 2 VEH WALK AROUND
• ☐ 3 DRIVER ONLY
☐ 4 SPECIAL
☐ 5 ______
☐ 6 ______

DRIVER/EQUIPMENT COMPLIANCE

MI No. 302113

DATE	TIME AM PM	CARRIER NO OFFICE USE	DOT NO. PRIVATE CARRIER	CTY NO.	DIST. NO.	LOC. N1	LOC. N2	LOC. X1	LOC. X2	LOC. X3	SITE	CLASS	INTE...
•	•			•	•								

CARRIER NAME	MC/MPSC	ADDRESS
•		•

CITY	STATE	ZIP	SHIPPER	BILL OF ...
•				

OWNER	ADDRESS	CITY	STATE/ZIP

DRIVER (FIRST, MIDDLE, LAST)	D.O.B.	LIC. NO.	LIC. STA...
•	•	•	•

• DRIVERS LOG RECAP DATE	ON DUTY HRS	• CITATIONS COMPLAINTS	• CITATION CODE
1		1	
2		2	
3		3	
4		4	
5			
6			
7		• PBT	• DRUG KIT
8			
TOTALS			

UNIT TYPE	YR/MAKE	UNIT NO.	TRACTOR PLATE	STATE	CVSA ISSUED SELF INSP
	•		•	•	

UNIT TYPE	YR/MAKE	UNIT NO.	TRAILER PLATE	STATE	CVSA ISSUED SELF INSP
	•		•	•	

UNIT TYPE	YR/MAKE	UNIT NO.	TRAILER PLATE	STATE	CVSA ISSUED SELF INSP
	•		•	•	

UNIT TYPES: TR = STRAIGHT TRUCK; TT = TRUCK TRACTOR; ST = SEMI TRAILER; BU = B...; PT = POLE TRAILER; FT = FULL TRAILER; DC = DOLLY CONVERTER; OT = O...

COMMODITY/HAZARDOUS MATERIAL

HAZ. MAT. CODE	REPORTABLE QUANTITY	HAZARDOUS WASTE	PLACARD REQUIRED

PUSH ROD TRAVEL

AXLE	LEFT	RIGHT	AXLE	LEFT	RIGHT	AXLE	LEFT	RIGHT	AXLE	LE...
1			4			7			10	
2			5			8			11	
3			6			9			TOTAL	VIO...

VIOLATION CHECKLIST

VIO. | O/S

DRIVER CHECK

- • 1 ____ SEAT BELTS
- • 2 ____ NO LOG
- • 3 ____ LOG NOT CURRENT
- 4 ____ FALSE LOG
- 5 ____ 10 HR. RULE
- 6 ____ 15 HR. RULE
- 7 ____ 60/7 RULE
- 8 ____ 70/8 RULE
- • 9 ____ MEDICAL CERT.
- 10 ____ OTHER MEDICAL
- 11 ____ UNDER AGE
- 12 ____ DRIVER QUAL.
- 13 ____ LICENSE OPR/CHAUFF.
- • 14 ____ OTHER DRIVER REG.

POWER UNIT

- 15 ____ HEATER/DEFROSTER
- 16 ____ HORN/SPEEDOMETER
- 17 ____ CAB FLOOR
- 18 ____ WIRING
- • 19 ____ FIRE EXTINGUISHER
- • 20 ____ WARNING DEVICES/ FLAGS/FLARES
- 21 ____ BRAKE APPLIED/ PRESSURE LOSS
- • 22 ____ LOW AIR WARNING

VIO. | O/S

- 23 ____ PARKING BRAKE
- 24 ____ GLASS
- • 25 ____ WINDSHIELD WIPERS/ WASHERS
- • 26 ____ HEADLIGHTS
- 27 ____ FRONT TURN SIGNALS
- 28 ____ CLEAR/ID LIGHTS/TAIL
- 29 ____ STEERING TIRES
- 30 ____ FRONT WHEELS/ LUGS/RIMS
- 31 ____ STEERING COMPNTS
- 32 ____ FRONT BRAKES
- 33 ____ REARVIEW MIRRORS
- • 34 ____ FUEL SYSTEM
- 35 ____ BATTERY INSTALL
- • 36 ____ EXHAUST SYSTEM
- • 37 ____ AIR HOSES/LEAKS
- • 38 ____ TIRES
- • 39 ____ WHEELS/LUGS/RIMS
- • 40 ____ BRAKES
- • 41 ____ SUSPENSIONS
- 42 ____ FRAMES
- • 43 ____ COUPLING DEVICES
- • 44 ____ REAR TURN SIGNALS
- • 45 ____ STOP LAMPS
- 46 ____ MUD FLAPS
- 47 ____ REAR END PROT.
- • 48 ____ CARGO SECUREMENT

VIO. | O/S

- 49 ____ TARPING REQUIRED
- • 50 ____ OTHER VIOLATIONS

1ST TOWED UNIT

- • 51 ____ COUPLING DEVICES
- 52 ____ HEADERBOARDS
- 53 ____ MRKR/CLEAR LIGHTS/TAIL
- • 54 ____ TIRES
- • 55 ____ WHEELS/LUGS/RIMS
- • 56 ____ BRAKES
- 57 ____ AIR HOSES/LEAKS
- 58 ____ FRAMES
- • 59 ____ SUSPENSIONS
- 60 ____ WIRING
- • 61 ____ TURN SIGNALS
- • 62 ____ STOP SIGNALS
- 63 ____ MUD FLAPS
- 64 ____ REAR END PROT.
- • 65 ____ CARGO SECUREMENT
- 66 ____ TARPING REQUIRED
- • 67 ____ OTHER VIOLATIONS

2ND TOWED UNIT

- • 68 ____ COUPLING DEVICES
- 69 ____ MRKR/CLEAR LIGHTS/TAIL
- • 70 ____ TIRES
- • 71 ____ WHEELS/LUGS/RIMS
- • 72 ____ BRAKES

VIO. | O/S

- 73 ____ AIR HO...
- 74 ____ FRAME...
- • 75 ____ SUSPEN...
- 76 ____ WIRING
- • 77 ____ TURN SIGNAL...
- • 78 ____ STOP SI...
- 79 ____ MUD FL...
- 80 ____ REAR E... PR...
- • 81 ____ CARGO SECU...
- 82 ____ TARPING REQ...
- • 83 ____ OTHER ...

OTHE... VIOLA... O...

- 84 ____ VEHICLE IDE...
- 85 ____ FUEL PERMIT
- 86 ____ MPSC P...
- • 87 ____ BILLS/M... REQ. D...
- 88 ____ VEHICLE REG...
- 89 ____ UNAUTH. DR...
- 90 ____ DNR HA...
- • 91 ____ OTHER ...

COMMENTS:

OFFICER SIGNATURE	BADGE NO.	TIME ENDED	DRIVER SIGNATURE
• ☐ MCO ☐ TPR.	•	• AM PM	•

MOTOR CARRIER SAFETY INSPECTION REPORT

Z 42492

SP4342 188

Inspection Type ☐ I ☐ II ☐ III	Federal Census #	WI Account # WI-	Date of Inspection	Day of Week	Time Stopped AM ☐ PM ☐	Time Completed AM ☐ PM ☐
On Highway		Location			County	City, Village, Town
Owner Name			DBA			
Street Address			City		State	Zip
Lessee			DBA			
Street Address			City		State	Zip
Vehicle Type ☐ Trac ☐ Trk ☐ Bus		Make Year	Fleet Number	Vehicle Identification No.		Checke ☐
License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length / Width	Height
Vehicle Type ☐ Semi-Trl ☐ Full Trl ☐ Trac ☐ Trk ☐ Auto		Make Year	Fleet Number	Vehicle Identification No.		Checke ☐
License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length / Width	Height
Vehicle Type ☐ Semi-Trl ☐ Full Trl ☐ Trac ☐ Trk ☐ Auto		Make Year	Fleet Number	Vehicle Identification No.		Checke ☐
License Type	License Number	State	Expires (Mo-Yr)	License Weight	Veh Length / Width	Height
Haul Type ☐ Private ☐ For Hire		Authorities LC	IC	MC	☐ Interstate	☐ Intrastate
Commodity Description			Bill/Shipping Paper No		Placards Required ☐ Yes ☐ No	HAZARDOUS MATERIAL Code / Rq / Ha
Consignor			Origin			
Consignee			Destination			
Driver Name (Last, First, Middle)			Driver License No		State	DL Type ☐ Chauf ☐ Re
Date of Birth	Sex / Eyes / Hair	Wt / Ht	Signature X			

Violation Sect No	O/S	Cit	(Out-of-Service, Cit = Citation Issued)

Citation No

☐ This vehicle may not be operated until defects marked "O/S" are repaired pursuant to Trans. 325/49 Sec. 396.9.

☐ This driver may not drive until compliance with Trans. 325/49 Sec. 395.1

X ______________________
(Person Issuing Report) (WSP No

Motor Carrier - Return This Report Within 15 Days TO:

Wisconsin Dept. of Transportation
Division of State Patrol
Motor Carrier Inspection

I certify that the defects and violations identified on this report have been repaired and corrected.

☐ Driver
☐ Repairman
☐ Carrier Official

X ______________________
(Signature) (Date)

MOTOR CARRIER COMPLIANCE REPORT

MAINE STATE POLICE
Traffic Division
State House Station 20
Augusta, Maine 04333

1. MSP USE ONLY	2. NAME OF MOTOR CARRIER		
3. STREET ADDRESS			4. ICC DOCKET NO.
5. CITY	6. State	7. ZIP CODE	

8. INSPECTION LOCATION A _____ B _____ C _____ *(Nearest City or Town)* *(State)* *(Code)*	9. TYPE OF FACILITY A CARRIER'S TERMINAL B ROADSIDE C OTHER	10. INSPECTION TYPE A FULL B EEE C SPECIAL STUDY	11. INSPECTION DATE ___/___/___ *(MO)* *(DA)* *(YR)*

12. SPECIAL STUDY NO. ___ ___ ___	13. MC DOCKET NO.	14. DATE OF MEDICAL CERTIFICATE	15. *(RESERVED)*	16. TIME STARTED ___ : ___ AM PM

17. DRIVER IDENTIFICATION — BIRTH DATE — LICENSE ISS. BY:

A _____ B _____ C ___ D ___/___/___ E _____
(LAST NAME) *(FIRST NAME)* *(MI)* *(MO)* *(DA)* *(YR)* *(STATE)*

18. DRIVER IS:
A EMPLOYED
B TERM LSED
C TRIP LSED

19. COMMODITY TRANSPORTED	20. ORIGIN A _____ B _____ *(CITY)* *(STATE)*	21. DESTINATION A _____ B _____ *(CITY)* *(STATE)*	22. FOR HIRE? A YES B NO

Out-of-Service Notice

_____ Pursuant to Maine statutes, I hereby declare the following vehicle(s) "out-of-service." No person shall remove the herein numbered sticker(s)

_____ _____

or operate such vehicle(s) until necessary repairs have been made and the vehicle(s) restored to safe operating condition.

_____ Pursuant to Maine statutes, I hereby notify and declare the driver named on this report "out-of-service." No motor carrier shall permit or require the driver to drive or operate any motor vehicle until: _____

HAZARDOUS MATERIALS TRANSPORTED

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liq.
M—Radioactive Mat.
N—Organic Peroxide
O—Irritating Mat.
P—Orm A, B, or C
Q—Orm E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

Y - YES N - NO

	CODE	RQ?	HW?
27			
28			
29			

PLACARDS REQUIRED

30	

Brake Adjustment

Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6

23. SHIPPING PAPER NO.	24. WHOSE DOCUMENT?
25. IF CARGO TANK, ENTER MC SPEC OR "NON" ___ ___ ___	26. IF H M BEING TRANSPORTED UNDER EXEMPTION, ENTER "E" NUMBER. ___ ___ ___ ___

VEHICLE IDENTIFICATION

	UNIT NUMBER	UNIT TYPE	OWN-LSED	MAKE	CO NUMBER	LICENSE NO & STATE
31	1					
32	2					
33	3					
34	4					
35	5					
36	6					

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer
FT = Full Trailer DC = Dolly Converter BU = Bus OT = Other
OWN-LSED: A = Owned B = Term Leased C = Trip Leased

NO.	VIOLATION IDENTIFICATION	UNIT no.	OUT OF SVC	VIOLATIONS DISCOVERED
37	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			
	| | • | | | |			

REPORT PREPARED BY:	54. CODE	55. TIME COMPLETED ___ : ___ AM PM	COPY RECEIVED BY:

(Notice to Motor Carrier—Detach and Mail to Address Shown Below)

MAINE STATE POLICE—TRAFFIC DIVISION
MOTOR CARRIER SECTION
STATION 20
AUGUSTA, MAINE 04333

CITATION

You are hereby notified that you have operated a vehicle to-wit: _____
Co. Unit No. _____, driven by _____ on date of _____, at or near _____, Maine, in violation of the Maine Statutes, and/or the rules of the Bureau of State Police. Continued violation of this nature will subject you to penalties provided by Title 29, Chap. 25, Sec. 2707. You are directed to return this portion of the compliance check within 15 days. This is to certify that the corrections and/or repairs have been made on the above vehicle on date of _____ 19___.

Signed _____ Title _____
Motor Carrier _____

Original (White) to Carrier
Duplicate (Canary) to M.S.P.
Triplicate (Pink) to Inspector

Form 17.80

NYS Department of Transportation
TRAFFIC & SAFETY DIVISION
MOTOR CARRIER SAFETY ASSISTANCE PROGRAM
1220 WASHINGTON AVENUE
ALBANY, NY 12232

DRIVER-VEHICLE EXAMINATION REPORT

GENERAL INFORMATION

1. DOT USE ONLY (REPORT #)	2. INSPECTION DATE	3. TIME STARTED
NY A 91499	__/__/__ (M D Y)	__ : __

4. INSP. LOCATION	5. STATE CENSUS NO.	6. DOT CENSUS NO.	7. ICC DOCKET NO.

9. NAME OF MOTOR CARRIER			
10. STREET ADDRESS			
11. CITY		12. STATE	13. ZIP CODE

8. INTERSTATE SHIPMENT? YES ☐ NO ☐

14. NAME OF SHIPPER	15. SHIPPING PAPER NO.

16. DRIVER IDENTIFICATION (LAST, FIRST, MI)	17. DRIVER LICENSE NO.	18. DRIVER LICENSE STATE

19. DRIVER DATE OF BIRTH __/__/__ (M D Y)	20. SPECIAL STUDY NO.	21. UNIFORM TRAFFIC TICKET ISSUED? (Circle 1) Y N
22. CARGO TANK	23. COMMODITY TRANSPORTED	24. DMV INSPECTION CERT. EXP. DATE (M Y)

BRAKE ADJUSTMENT

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7
RIGHT							
FRONT							
LEFT							
TYPE							

25. # ADJUSTMENTS O/S

26. DMV INSPECTION CERT. NUMBER

27. VEHICLE ODOMETER

28. C.V.S.A. DECAL NO. — UNIT NO.
NY
NY

HAZARDOUS MATERIALS TRANSPORTED

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liquid
M—Radioactive Material
N—Organic Peroxide
O—Irritating Material
P—Ora A, B, or C
Q—Ora E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

	CODE	RQ?	HW?
29.			
30.			
31.			

PLACARDS REQUIRED? 32.

Y = YES N = NO

VEHICLE IDENTIFICATION

	UNIT NO.	UNIT TYPE	MAKE	CO. NUMBER	LICENSE TAG NUMBER	STATE
33.	1					
34.	2					
35.	3					
36.	4					
37.	5					
38.	6					

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer
FT = Full Trailer DC = Dolly Converter BU = BUS OT = Other

VIOLATIONS

NO.	VIOLATION IDENTIFICATION	UNIT NO.	OUT OF SVC	VIOLATIONS DISCOVERED
SEE CONTINUATION SHEET YES NO				

VEHICLE/DRIVER OUT OF SERVICE NOTICE

☐ Pursuant to the authority contained in Subdivision 2 of Section 140 of the Transportation Law and the regulations of the Commissioner of Transportation promulgated pursuant there to, I hereby declare vehicles with defects followed by an "X" in the "Out of Service" column in the violations discovered section of this report OUT OF SERVICE. No person shall operate such vehicles until the out of service defects have been repaired and the vehicles have been restored to safe operating condition.

☐ Pursuant to authority contained in Subdivision 2 of Section 211 & 212 of the Transportation Law and the regulations of the Commissioner of Transportation promulgated pursuant there to, I hereby notify and declare the driver named on this report OUT OF SERVICE. No motor carrier shall permit or require this driver to drive or operate any motor vehicle until: ____________

REPORT PREPARED BY	A. ID OR BADGE #	B. TIME COMPLETED	COPY RECEIVED BY
		__ : __	

NOTE TO DRIVER: This report must be furnished to the motor carrier whose name appears at the top of this report. NOTE TO MOTOR CARRIER: If entries are made in the violation section above, please sign the certification below, and within fifteen days return this report to the address which appears in the upper left corner of this report.

The undersigned certifies that all violations noted on this report have been corrected and action has been taken to assure compliance with the Transportation Law and regulations.

SIGNATURE OF CARRIER OFFICIAL	TITLE	DATE SIGNED

TE 241b (11/87)

PUBLIC UTILITY COMMISSION OF OREGON
420 LABOR AND INDUSTRIES BUILDING
SALEM, OREGON 97310-0335

NO. S 143958

DRIVER EQUIPMENT COMPLIANCE CHECK

U.S. DOT NO	INSP TYPE	PRE-SELECT ☐ RANDOM ☐	AUDIT ☐ OTHER/SPECIAL	PRE-OP ☐ PRE-NOTE ☐

NAME OF CARRIER	AF NO	CLASS	INSPECTION DATE / /
STREET ADDRESS	START TIME ☐ AM ☐ PM		INTERSTATE? ☐ YES ☐ NO
CITY / ST / ZIP	PLACE OF INSPECTION		SCALE NO

DRIVER A	LICENSE NO.	ST	DATE OF BIRTH	PHYSICAL DATE	OS
DRIVER B	LICENSE NO.	ST	DATE OF BIRTH	PHYSICAL DATE	OS

SHIPPER	ORIGIN	SHIPPING DOCUMENT NO
RECEIVER	DESTINATION	

COMMODITY	HAZARDOUS MATERIAL? ☐ YES ☐ NO	RQ? ☐ YES ☐ NO	HW? ☐ YES ☐ NO	PLACARD DISPLAYED	UN/NA NO

PUC PLATE/PASS	VIN NO.	CARGO TANK SPEC. NO	NO AXLES REQ. BRAKES	MILEAGE	☐ SPEEDO ☐ HUB

UNIT TYPE: TR - STRAIGHT TRUCK TT - TRUCK TRACTOR ST - SEMI TRAILER PT - POLE TRAILER FT - FULL TRAILER DC - DOLLY CONVERTER BU - BUS OT - OTH

VEHICLE ORDER	UNIT TYPE	MAKE	BASE PLATE	ST	COMPANY NO	OUT OF SERVICE
1						
2						
3						
4						
5						
6						

BRAKE ADJUSTMENT MEASUREMENTS

	STEERING										
RIGHT											
	TYPE	AXLE 1	TYPE	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7	AXLE 8	AXLE
LEFT											

DECAL TT/TR | DECAL TRL 1 | DECAL TRL 2 | DECAL TR

MCS PART NO.	OAR 860	VEH. ORDER	OS	VIOLATIONS, DEFECTS, FINDINGS AND REMARKS

OUT OF SERVICE NOTICE: IN ACCORDANCE WITH OREGON REVISED STATUTES, CHAPTER 767, AND OREGON ADMINISTRATIVE RULES, CHAPTER 860, I HEREBY DECL AND MARK THE FOLLOWING VEHICLE(S) "OUT OF SERVICE." NO PERSON SHALL REMOVE THE HEREIN NUMBERED STICKER(S) OR OPERATE SUCH VEHICLE(S) UNTIL NECESSARY REPAIRS HAVE BEEN COMPLETED AND THE VEHICLE(S) RESTORED TO SAFE OPERATING CONDITION.

VEHICLE/DRIVER ORDER	"OUT OF SERVICE" REQUIRED REPAIRS UNDER MCSR PART 396.7 / OAR 860-65-028	OUT OF SERVICE STICKER NO.(S)

SIGNATURE/INSPECTOR CODES	FINISH TIME ☐ AM ☐ PM	COPY RECEIVED BY

DRIVER: GIVE THIS FORM TO THE MOTOR CARRIER LISTED AT THE TOP OF THE FORM

MOTOR CARRIER: SEE OTHER SIDE

PUC FORM 242 (27) (01-80) MCS-63

IF VIOLATIONS ARE NOTED ON THE REVERSE SIDE, THE FOLLOWING REQUIREMENTS MUST BE MET:

1. ALL VIOLATIONS AND DEFECTS ARE TO BE CORRECTED OR REPAIRED.
2. THE PERSON COMPLETING "OUT OF SERVICE" REPAIRS MUST SIGN THE FORM AS REPAIRMAN.
3. A COMPANY OFFICIAL MUST SIGN THE FORM CERTIFYING COMPLIANCE WITH FEDERAL AND STATE MOTOR CARRIER SAFETY AND HAZARDOUS MATERIALS REGULATIONS.
4. THE FORM IS TO BE MAILED TO THE PUBLIC UTILITY COMMISSION, 420 LABOR & INDUSTRIES BUILDING, SALEM, OREGON 97310-0335 WITHIN **15 DAYS** FROM THE DATE OF INSPECTION.

FAILURE TO COMPLY WITH THE ABOVE REQUIREMENTS MAY RESULT IN A MONETARY PENALTY OF $100 PER DAY FOR EACH DAY OF NONCOMPLIANCE.

I CERTIFY THAT THE VIOLATIONS LISTED IN THE "OUT OF SERVICE REQUIRED REPAIRS" SECTION HAVE BEEN SATISFACTORILY COMPLETED AS OF THE DATE INDICATED.

SIGNATURE OF REPAIRMAN	NAME OF SHOP (GARAGE)	DATE

THE UNDERSIGNED CERTIFIES THAT ALL VIOLATIONS NOTED ON THIS REPORT HAVE BEEN CORRECTED AND ACTION HAS BEEN TAKEN TO ASSURE COMPLIANCE WITH THE FEDERAL AND STATE MOTOR CARRIER SAFETY AND HAZARDOUS MATERIAL REGULATIONS INSOFAR AS THEY ARE APPLICABLE TO MOTOR CARRIERS AND DRIVERS. I UNDERSTAND THAT FAILURE TO COMPLY WILL SUBJECT ME TO ADDITIONAL VIOLATIONS UNDER THE REGULATIONS NOTED.

SIGNATURE OF CARRIER OFFICIAL	TITLE	DATE

MAIL TO:

PUBLIC UTILITY COMMISSION OF OREGON
420 LABOR AND INDUSTRIES BUILDING
SALEM, OREGON 97310-0335

CVSA NUMBER
UT A03801

UTAH HIGHWAY PATROL
MOTOR CARRIER SECTION

DRIVER/EQUIPMENT COMPLIANCE CHECK

NAME OF MOTOR CARRIER — OWNED — LEASED

PRINCIPAL OFFICE STREET ADDRESS

CITY — STATE — ZIP CODE

DRIVER INFORMATION
D L No ____ LICENSE STATE ____

LAST NAME ____ FIRST NAME ____ M I ____ D O B __/__/__ M D Y

USDOT NUMBER

I C C NUMBER

ACCIDENT? Y N

INSPECTION LEVEL 1 2 3 4

DATE OF THE INSPECTION __/__/__ M D Y

WHAT TIME DID THE INSPECTION START? MILITARY TIME

LOCATION OF INSPECTION P O E., COUNTY & ROAD

COMMODITY CARRIED

CODE FOR TYPE OF TRANSPORT
A - INTERSTATE CARRIER B - INTRASTATE CARRIER

DESCRIPTION OF EACH UNIT

TT TR POWER UNIT NO ____
MAKE ____ YEAR ____
LICENSE # ____ STATE ____
MC __ __ __ STICKER # ____

ST FT 1ST TOWED UNIT NO ____
MAKE ____ YEAR ____
LICENSE # ____ STATE ____
MC __ __ __ STICKER # ____

ST FT 2ND TOWED UNIT NO ____
MAKE ____ YEAR ____
LICENSE # ____ STATE ____
MC __ __ __ STICKER # ____

ST FT 3RD TOWED UNIT NO ____
MAKE ____ YEAR ____
LICENSE # ____ STATE ____
MC __ __ __ STICKER # ____

ENTER CODE(S) FOR ALL HAZARDOUS MATERIALS

A - EX A	H - COR	O - IRRIT
B - EX B	I - OXI	P - ORM
C - EX C	J - POI A	Q - HAZ WST
D - FL	K - POI B	R - ETIO AGT
E - FS	L - COMB	S BLAST AGT
F - FLG	M - RAM	T - CRYOGENICS
G - NFG	N - ORGP	Z - OTHER

PRODUCT ____

QUANTITY OF HAZARDOUS MATERIAL
A - LESS THAN 1000 LB
B 1001 LB - 10 TON
C OVER 10 TON

ARE PLACARDS REQUIRED? : AFFIXED?
Y N Y N

RULE OR STATUTE #	*OUT OF SERV	CIT	UNIT NUMBER	VIOLATIONS DISCOVERED

* DRIVER OUT OF SERVICE NOTICE: THIS DRIVER SHALL NOT DRIVE ANY COMMERCIAL MOTOR VEHICLE UNTIL ____

CARRIER NOTIFICATION
BY OFFICER DRIVER

• OUT OF SERVICE NOTICE: THIS VEHICLE IS OUT OF SERVICE IF INDICATED ABOVE, AND SHALL NOT OPERATE UNTIL ALL OUT OF SERVICE VIOLATIONS ARE REPAIRED OR CORRECTED.

REPORT RECEIVED BY
NAME ____

CERTIFICATION OF "OUT OF SERVICE" DEFECTS REPAIRED I CERTIFY THAT THE REPAIRS LISTED ON THE "OUT OF SERVICE" STICKERS AFFIXED TO THIS VEHICLE HAVE BEEN REPAIRED PRIOR TO FURTHER OPERATION OF THE VEHICLE

DATE REPAIRED ____ TIME REPAIRED ____ AM PM SIGNATURE ____

REPORT PREPARED BY
NAME ____ NUMBER ____

WHAT TIME DID THE INSPECTION END?
MILITARY TIME ____

NOTE TO MOTOR CARRIER ALL DEFECTS NOTED ON THIS AND ANY CONTINUATION SHEETS MUST BE CORRECTED A RESPONSIBLE COMPANY OFFICIAL CERTIFIES THAT ALL DEFECTS HAVE BEEN CORRECTED

NAME ____ TITLE ____ DATE ____

THIS REPORT MUST BE RETURNED WITHIN 15 DAYS TO DEPT. OF TRANSPORTATION SAFETY, 4501 SOUTH 2700 WEST, SALT LAKE CITY, UTAH 84119

HPF 56 (P-155) Rev. 12/89

White - Office Copy *Canary - Officer Copy Pink - Driver Copy Goldenrod - Driver Copy

DEPARTMENT OF CALIFORNIA HIGHWAY PATROL

SAFETYNET DRIVER/VEHICLE INSPECTION REPORT

CHP 407F (Rev 9-88) OPI 063

039351

DATE	TIME START			LOC. CODE	BEAT	INSPECTED BY	I.D. NO.

DRIVER INFORMATION

FIRST NAME	M.I.	LAST NAME	LICENSE NUMBER	STATE

COMPLIES		YES	NO	OS	COMPLIES		YES	NO	OS	COMPLIES		YES	NO	OS	COMPLIES		YES	NO
Driver license	A				Medical certificate	B				Driver's log	C				Driver's hours	D		

CARRIER INFORMATION

CHP NUMBER	PUC NUMBER	ICC NUMBER
CA		MC

CARRIER NAME	U.S. DOT NUMBER

STREET ADDRESS (INCLUDE CITY, STATE AND ZIP CODE)

VEHICLE INFORMATION

VEH. NO.	TYPE	VEHICLE MAKE	LICENSE NUMBER	STATE
1				
2				
3				
4				

BRAKE ADJUSTMENT

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE
RIGHT							
FRONT							
LEFT							

VEHICLE INSPECTION

VEHICLE 1 COMPLIES		YES	NO	OS	VEHICLE 2	YES	NO	OS	VEHICLE 3	YES	NO	OS	VEHICLE 4	YES	NO	OS	
Registration	E				E				E				E				E
Lights—stop/turn	F				F				F				F				F
Steering components	G				G				G				G				G
Air loss: unapplied	H				H				H				H				H
Air loss: applied	I				I				I				I				I
Low air warn. device	J				J				J				J				J
Brake hoses	K				K				K				K				K
Brake adjustment	L				L				L				L				L
Brake drums/shoes	M				M				M				M				M
Connection devices	N				N				N				N				N
Exhaust	O				O				O				O				O
Fuel system	P				P				P				P				P
Frame	Q				Q				Q				Q				Q
Suspension	R				R				R				R				R
Wheels	S				S				S				S				S
Tires	T				T				T				T				T
Warning devices	U				U				U				U				U
Maintenance	V				V				V				V				V

COMMENTS

HAZARDOUS MATERIALS INSPECTIO

COMPLIES		YES	NO	OS
Ship paper/manifest	HA			
HM license	HB			
HW registration	HC			
Placards	HD			
Packaging	HE			
Marking	HF			
Labels	HG			
Loading/securement	HH			
Cargo/Portable tanks	HI			
Safety equipment	HJ			

CODE	RQ?	HW?

PLACARDS REQUIRED

☐ Yes ☐ No

CODES

A—Explosives A	L—Combustible liquid
B—Explosives B	M—Radioactive materi
C—Explosives C	N—Organic peroxide
D—Flammable liquid	O—Irritating material
E—Flammable solid	P—Orm A, B, or C
F—Flammable gas	Q—Orm E
G—Nonflammable gas	R—Etiologic agent
H—Corrosives	S—Blasting agent
I—Oxidizers	T—Cryogenics
J—Poison A	Z—Other
K—Poison B	

CITATION NUMBER	OFFICER I.D. NUMBE
CVSA STICKERS ISSUED	OWNER'S RESPONSIBILITY ☐ Yes ☐ N
TIME END	LEVEL

I acknowledge that I have reviewed and received a copy of this report.

DRIVER'S SIGNATURE

MOTOR CARRIER
SAFETY ASSISTANCE PROGRAM
STATE OF GEORGIA

1. Report No. 68707

GEORGIA PUBLIC SERVICE COMMISSION
DRIVER-VEHICLE EXAMINATION REPORT

2. INSPECTION DATE ___/___/___ (MO) (DA) (YR)
3. TIME STARTED ___ : ___
4. INSPECTION LOCATION ___ (County) ___ (Nearest City or Town)
5. STATE NO
6. DOT NO
7. ICC DOCKET NO
8. INTERSTATE? Y N
9. NAME OF MOTOR CARRIER
10. STREET ADDRESS
11. CITY
12. STATE
13. ZIP CODE
14. NAME OF SHIPPER
15. SHIPPING PAPER NO.
16. DRIVER IDENTIFICATION
A ___ (LAST NAME) B ___ (FIRST NAME) C ___ (MI)
17. DRIVER LICENSE NO.
18. LIC. STATE
19. BIRTH DATE ___/___/___ (MO) (DA) (YR)
20. ORIGIN OF SHIPMENT ___ (City) ___ (State)
21. CONSIGNEE
22. COMMODITY TRANSPORTED
23. DESTINATION OF SHIPMENT ___ (City) ___ (State)
24. FOR HIRE? A YES B NO
25. DRIVER IS: A Employed B Term LSD C Trip LSD
26. WHOSE DOCUMENT?
27. IF CARGO TANK, ENTER MC SPEC OR "NON"
28. H.M. EXEMPTION NUMBER

HAZARDOUS MATERIALS

A—Explosives A
B—Explosives B
C—Explosives C
D—Flammable Liquid
E—Flammable Solid
F—Flammable Gas
G—Nonflammable Gas
H—Corrosives
I—Oxidizers
J—Poison A
K—Poison B
L—Combustible Liq
M—Radioactive Mat
N—Organic Peroxide
O—Irritating Mat
P—Orm A,B or C
Q—Orm E
R—Etiologic Agt.
S—Blasting Agt.
T—Cryogenics
Z—Other

	CODE	RQ?	HW?
29.			
30.			
31.			

Placards Required? 32. ___ Y-Yes N-No

VEHICLE IDENTIFICATION

	UNIT NUMBER	UNIT TYPE	MAKE	CO NUMBER	LICENSE TAG NO. & STATE
33.	1				
34.	2				
35.	3				
36.	4				

Unit Type: TR = Straight Truck TT = Truck Tractor ST = Semi Trailer PT = Pole Trailer FT = Full Trailer DC = Dolly Converter BU = Bus OT = Other

	AXLE 1	AXLE 2	AXLE 3	AXLE 4	AXLE 5	AXLE 6	AXLE 7	BRAKE ADJUSTMENT
RIGHT / FRONT								
LEFT								

VIOLATIONS

NO.	VIOLATION IDENTIFICATION	UNIT NO.	OUT OF SVC	VIOLATIONS DISCOVERED
38.				

SEE CONTINUATION SHEET YES NO

CITATION NO.(S)

VEHICLE/DRIVER OUT OF SERVICE NOTICE

Pursuant to authority contained in Title 49, Code of Federal Regulations, Section 396.9, I hereby declare vehicles with defects followed by an "X" in the "Out of Service" column in the violations discovered section of the report *Out of Service*. No person shall remove the out of service stickers applied to these vehicles, or operate such vehicles until the out of service defects have been repaired and the vehicles have been restored to safe operating condition.

Pursuant to authority contained in Title 49, Code of Federal Regulations, Section 395.13, I hereby notify and declare the driver named on this report Out of Service. No motor carrier shall permit or require this driver to drive or operate any motor vehicle until.

OUT OF SERVICE STICKER NO(S)

GPSC ENFORCEMENT OFFICER
A. INSPECTOR CODE
B. TIME COMPLETED ___ : ___
COPY RECEIVED BY:

NOTE TO DRIVER: This report must be furnished to the motor carrier whose name appears at the top of this report. **NOTE TO MOTOR CARRIER:** Please sign the below certification and return this report to the address which appears on the other side of this report within fifteen days.

The undersigned certifies that all violations noted on this report have been corrected and action has been taken to assure compliance with the Georgia Public Service Commission Motor Carrier Safety and Hazardous Material Regulations insofar as they are applicable to motor carriers and drivers.

SIGNATURE OF CARRIER OFFICIAL
TITLE
DATE SIGNED

FORM GPSC 33 (Rev. 3-88)

White Copy: GPSC
Green Copy: Carrier
Canary Copy: Driver
Pink Copy: Tractor
Gold Copy: Enforcement Officer

NTSB 5-AXLE TRUCK BRAKE INSPECTION

Location:	Route:	Date:	Inspection No.:

Carrier:	Phone:

Inter: Intra:	Type: For Hire Private	Size:
ICC/MC:	USDOT:	CVSA Date: G Y O W 1 2 N
Origin:	Destination:	Distance:
Driver resp Brakes: Yes No	Jake Brake: Yes No	Hazardous Material: Yes No
FHWA Insp.Date:		Radar Detector: Yes No

Tractor Year:	Tractor Make:	Cab Type: COE Conv.
State Registration:	License No.:	Leased by: Carrier/Driver
Steering: Power Manual	Limit Valve: Yes No	Owned by: Carrier/Driver
VIN:		

TRACTOR BRAKE COMPONENTS **RR Axle 1:** **RR Axle 2:** **RR Axle 3:**

MAN/AUTO	Slack Length	Manuf. (if auto)	Chamber Size	Pushrod Stroke	Inoperative
1L					
1R					
2L					
2R					
3L					
3R					

Excessive Air Leak:	Moderate Air Leak:	Minor Air Leak:	Tractor Brakes At/Past:

NOTES:

Tra Year:	Tra Make:	Tra Type:	State Registration:
License:	VIN:		FHWA Date:
Owned: Carrier/Driver	Leased: Carrier/Driver		

TRAILER BRAKE COMPONENTS **RR Axle 4:** **RR Axle 5:**

MAN/AUTO	Slack Length	Manuf. (if auto)	Chamber Size	Pushrod Stroke	Inoperative
4L					
4R					
5L					
5R					

Excessive Air Leak:	Moderate Air Leak:	Minor Air Leak:	Trailer Brakes At/Past:

TTL Brakes At/Past:	**TTL Brk OOS Viol:**	**Other OOS Viol:**	**Truck Out of Service:**

Actual Drag:	Actual Efficiency:	80K Drag:	80K Efficiency:
400F Drag:	400F Efficiency:	80K 400F Drag:	80K 400F Eff:
600F Drag:	600F Efficiency:	80K 600F Drag:	80K 600F Eff:
900F Drag:	900F Efficiency:	80K 900F Drag:	80K 900F Eff:

TTL Weight:	**Steer Axle:**	**Drive Axles:**	**Trailer Axles:**

APPENDIX D

LITERATURE REVIEW

This review pertains primarily to the adjustment of air actuated S-cam brakes used on heavy trucks and large buses. The review supports work aimed at maintaining heavy vehicle brakes in proper adjustment.

The material presented is expected to be effective in attaining the goals of this investigation, but it is not claimed to be a comprehensive listing of all of the work that has been reported on brake adjustment. Rather, it covers applicable material that is readily available to the authors. In particular, the material is intended to apply to the topics to be addressed in interviews with MCSAP inspectors and in other tasks later in the research study.

This appendix contains:

(1) a summary of the findings of the literature review, and

(2) an annotated bibliography on specified documents.

Further findings and data on the influences of brake adjustment on brake performance are presented in separate appendices (Appendices C and D).

SUMMARY OF THE FINDINGS OF THE LITERATURE REVIEW

Out-of-Service Criteria (OOS)

The following quotations, describing the current OOS criteria as it pertains to brake adjustment, are taken directly from reference [1]:

APPENDIX A

PART II

NORTH AMERICAN UNIFORM VEHICLE OUT-OF-SERVICE CRITERIA

POLICY STATEMENT

The purpose of this part is to identify critical vehicle inspection items and provide criteria for placing a vehicle(s) in an out-of-service or restricted service category subsequent to a safety inspection.

OUT-OF-SERVICE CONDITON: When any motor vehicle(s) by reason of its mechanical condition or loading, is determined to be so imminently hazardous as to likely cause an accident or breakdown, or when such condition(s) would likely contribute to loss of control of the vehicle(s) by the driver, said vehicle(s) shall be placed out-of-service. No motor carrier shall require nor shall any person operate any motor vehicle declared and marked "out-of-service" until all required repairs have been satisfactorily completed.

INSPECTION ITEM	OUT-OF-SERVICE CONDITION
1. Brake System	
a. Defective Brakes.	The number of defective brakes is equal to or greater than 20% of brakes on the vehicle or combination. A defective brake includes any brake that meets on e of the following criteria: (NOTE: Steering axle brakes under lb. - may also be included in 20% criterion.)

•
•
•
•

(5) Readjustment limits. With engine off and reservoir pressure of 80 to 90 psi with brakes fully applied.

(a) One brake at 1/4" or more beyond the readjustment limit. (Example: Type 30 clamp type brake chamber pushrod measured at 2-1/4" would be one defective brake.) (396.3A1)

(b) Two brakes at the readjustment limit or less than 1/4" beyond the readjustment limit also equal one defective brake. Example: Clamp type 30 pushrods measure:

1 - Two at 2-1/8"
2 - One at 2-1/8" and one at 2"; or
3 - Two at 2"

Each example would equal one defective brake.

(See the following chart.) (396.3A1)

Brake Adjustment. Shall not meet those specifications contained hereunder relating to "Maximum Stroke at which brakes must be readjusted". (Dimensions in inches.)

CLAMP TYPE BRAKE CHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
6		4-1/2	1-1/4
9		5-1/4	1-3/8
12		5-11/16	1-3/8
16		6-3/8	1-3/4
20		6-25/32	1-3/4
24		7-7/32	1-3/4 (See note)
30		8-3/32	2
36		9	2-1/4

NOTE: 2 inches for long stroke design.

BOLT TYPE BRAKE CHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
A	12	6-15/16	1-3/8
B	24	9-3/16	1-3/4
C	16	8-1/16	1-3/4
D	6	5-1/4	1-1/4
E	9	6-3/16	1-3/8
F	36	11	2-1/4
G	30	9-7/8	2

ROTOCHAMBER DATA

TYPE	EFFECTIVE AREA (SQ. IN.)	OUTSIDE DIAMETER	MAXIMUM STROKE AT WHICH BRAKES MUST BE READJUSTED
9		4-9/32	1-1/2
12		4-13/16	1-1/2
16		5-13/32	2
20		5-15/16	2
24		6-13/32	2
30		7-1/16	2-1/4
36		7-5/8	2-3/4
50		8-7/8	3

WEDGE BRAKE DATA

Movement of the scribe mark on the lining shall not exceed 1/16 inch.

rual , 19

Earlier requirements concerning differences in adjustment across the front axle have been removed [1] and the test results and analyses described in reference [2] provide evidence showing that the effects of this type of problem do not cause special difficulties for truck drivers in controlling their vehicles unless one of the brakes is well beyond the readjustment limit.

A remaining issue appears to be whether the OOS criteria on adjustment is restrictive enough given the findings concerning the influences of brake temperature on stroke [2]. Brakes that are at their recommended limit on stroke may be on the borderline of running out of stroke if the temperature of the drum is raised by approximately 400 degrees F above its cool temperature. The following figure from reference [3] shows how stroke is consumed. If the stroke at 90 psi happened to be at 2 inches, an additional temperature rise from 200 degrees F to 600 degrees F could use up the 0.5 inches of reserve stroke available before the pushrod bottoms out.

Another point to consider is the 20-percent factor. This could be construed implicitly to imply that reductions of 20 percent or more in braking performance are not to be accepted. Perhaps this criteria can be used in making judgments in this study concerning various factors that influence the braking capability of a heavy truck.

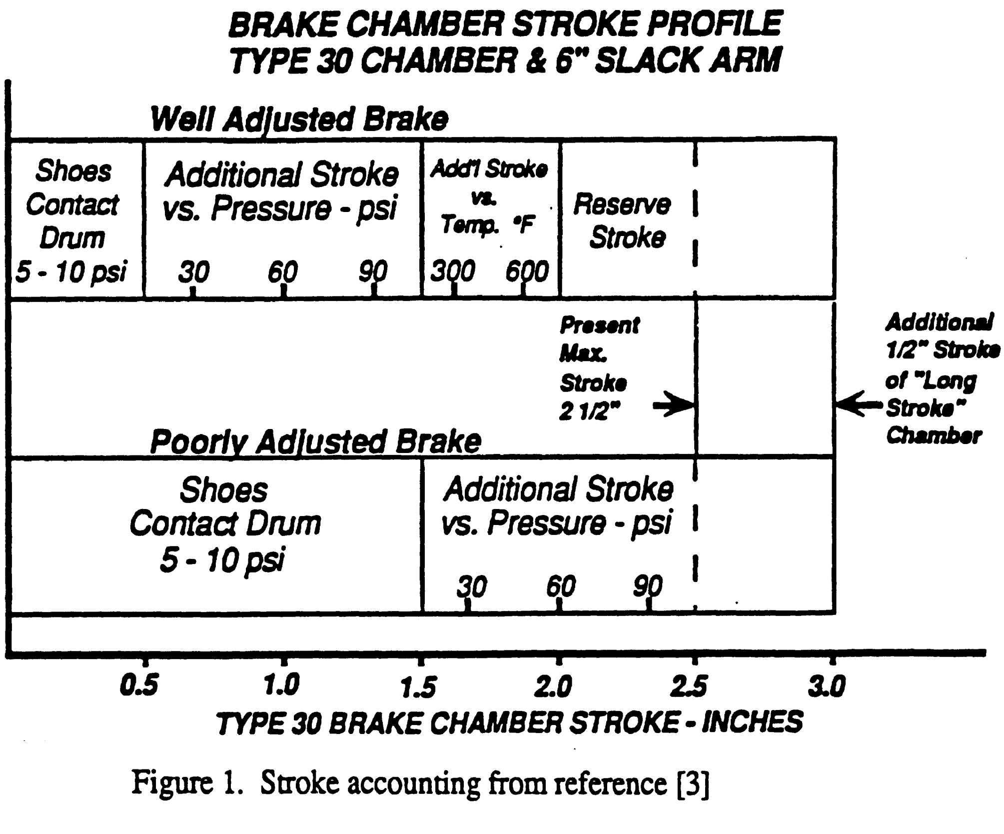


Figure 1. Stroke accounting from reference [3]

Brake Inspection

Procedures for adjusting brakes differ from one organization to another. The following Figure lists some possibilities [3]. There are more. For example, for vehicles used in our test work we set the stroke at 100 psi to be approximately 1.25 inches for a type 30 chamber. This might introduce a small amount of short term wear in taking off any high spots or out of roundness, but it is safe with respect to running out of stroke and the wear penalty is very small.

The adjustment methods 1 and 2 listed in Figure 2 are convenient for one person adjusting the brakes alone. Perhaps, the first method (involving measuring the clearance at the center of the shoe) is the easiest for a single person to perform.

Inspection methods involving two people may differ from adjustment methods used when only one person is available. Information on inspection procedures will be gathered as this project progresses. (Information on the MCSAP inspection procedures follows Figure 2.)

S - CAM BRAKES

ADJUSTMENT METHODS

1. *Adjust to .010" Lining to Drum clearence at center of shoe*
2. *Jack up wheel; tighten until Brake drags and back off Slack Adjuster two clicks (1/6 turn)*
3. *Adjust to 1/2" free stroke*

FREQUENCY OF ADJUSTMENT

- *A Cam Brake will require at least 20 Adjustments/ Lining Set*
- *You must detemine proper frequency for your operation*
- *Adjust or check Adjustment before a run in the mountains*
- *Consider Automatic Adjusters*

Figure 2. Brake adjustment methods [3]

The procedures stated in the MCSAP inspection manual [1] are as follows:

May 1989

11. BRAKE ADJUSTMENT - Required on Level I inspections only.

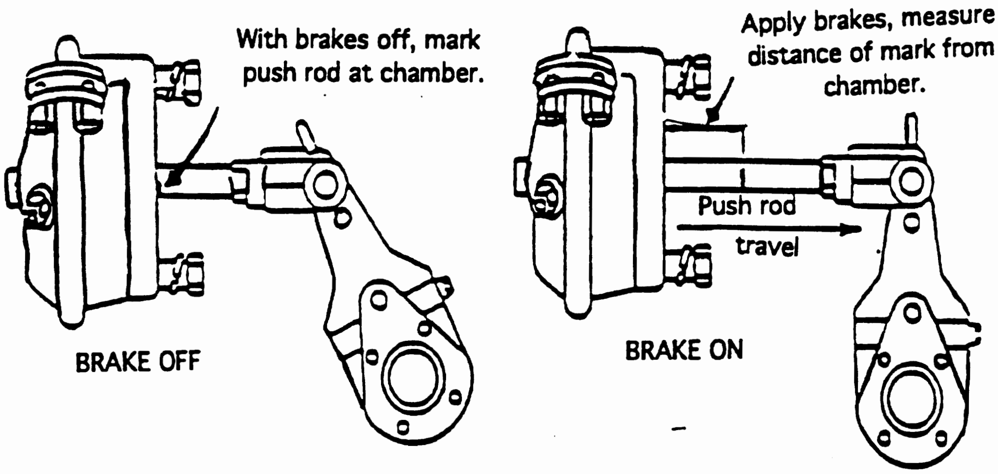
a. General Instructions

(1) This procedure requires the measurement of pushrod travel on all brakes of a vehicle or combination unit with air brakes.

Inspection procedure (pushrod travel)

CAUTION: Chock wheels before commencing this inspection as vehicle emergency brake(s) must be off.

(Welder's flat soap stone works will for the following procedure.)



(2) The majority of air-brake equipped vehicles will have clamp type, size 30 brake chambers, except on the steering axle. Steering axle brake chambers on over-the-road power units usually have chambers smaller than size 30.

(3) Brake chamber pushrod stroke readjustment limits must be measured at 80-90 psi. application pressure. To achieve the proper pressure in the system prior to measurement, increase the reservoir pressure with the engine running, or decrease the reservoir pressure with engine off, while applying and exhausting the brakes until 90 psi. is achieved in the reservoir. A reservoir pressure of 90 psi. will produce 80-90 psi. application pressure with the engine off.

b. Measuring Pushrod Travel

(1) Cam Brakes. With the brakes applied by a full pressure application, measure from the face of the brake chamber to the mark made on the brake chamber pushrod when the brakes were released. (A full pressure application means between 80 psi. and 90 psi.)

Brake chamber pushrod travel that meets or exceeds the limits shown in the column headed "Maximum Stroke at

Which Brakes Must be Readjusted" shown in the Appendix A part II table is a condition of improper maintenance.

(2) Disc Brakes. After the brakes have been applied by a full pressure application, measure the pushrod travel from the released position as described for cam brakes in paragraph 11b (1).

Disc brake chamber pushrod travel that meets or exceeds the maximum stroke at which brakes must be readjusted in Appendix A part II is a condition of improper maintenance.

c. Wedge Brake Adjustment

(1) Wedge Brakes. With the inspection hole cover removed from the brake dust shield, check the adjustment at each wheel using the gauge illustrated on the next page.

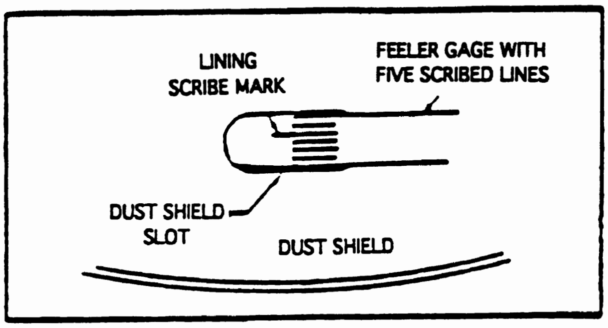
(a) Insert the flat end of the gauge into the inspection hole in the dust shield ore, if there is no dust shield, midway between the ends of the shoe. Place one edge of the gauge against dust shield inspection hole or the brake drum lip with the square end against the brake lining or shoe.

(b) With the brakes released, make a scribe mark on the brake lining or shoe opposite of the scribe lines on the gauge as illustrated on the next page.

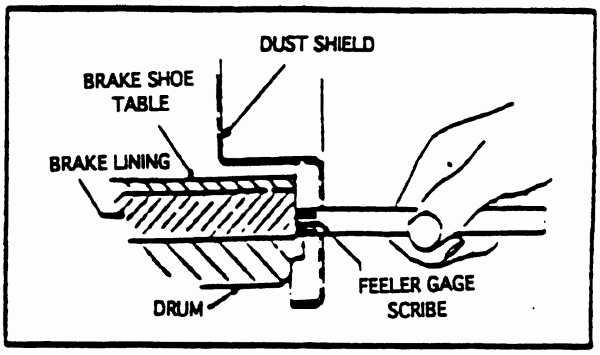
(c) Movement of the scribe mark on the lining of more than 1/16 inch with respect to the marks on the gauge when the brakes are applied, as illustrated on the next page, is a condition of improper maintenance.

(d) Failure of the brake shoes to move is a condition of improper maintenance.

Measurement Gauge and Lining Scribe Mark



Measurement of Wedge Brake Adjustment



Note: The gauge may be made of feeler gauge stock 0.025-inch x 3/8 inch x 8 inch. Scribe five 1/2-inch lines spaced 1/16 inch apart.

Influences of Brake Adjustment on Brake Performance

An air brake system consists of an air compressor and air tanks for storing compressed air, a treadle valve for applying air to the brake system, air lines , relay and other valves, air chambers (for applying pushrod forces to the actuation mechanism), S-cams or other actuation mechanisms for applying the linings of the shoes to the drums, shoes, and drums [4]. As the lining wears the clearance between the unapplied shoes and the drum increases. When air is applied the stroke increases. The amount of pushrod stroke needed to apply the brake increases as the lining wears. If the brake is not properly adjusted, the stroke at the air chamber may become so large that the pushrod approaches the end of the air chamber thereby limiting the force available for applying the brake linings to the drum. The reason for adjusting the brake is to prevent the pushrod from "bottoming out" on the bottom of the air chamber.

Figure 3 shows the characteristics of the pushrod force as a function of its stroke [2]. Above 2", this type 30 chamber has a dramatic reduction in pushrod force. For brakes adjusted so that the stroke at 100 psi is less than 2 inches, the amount of stroke does not influence the actuation force from the pushrod onto the slack adjuster arm. However, if the stroke increases beyond 2 inches because the lining has worn away or the drum expands due to temperature increases, there is a loss of force to actuate the brake; and there is a sudden loss in actuation or pushrod force when the stroke reaches approximately 2.5 inches as shown in Figure 3.

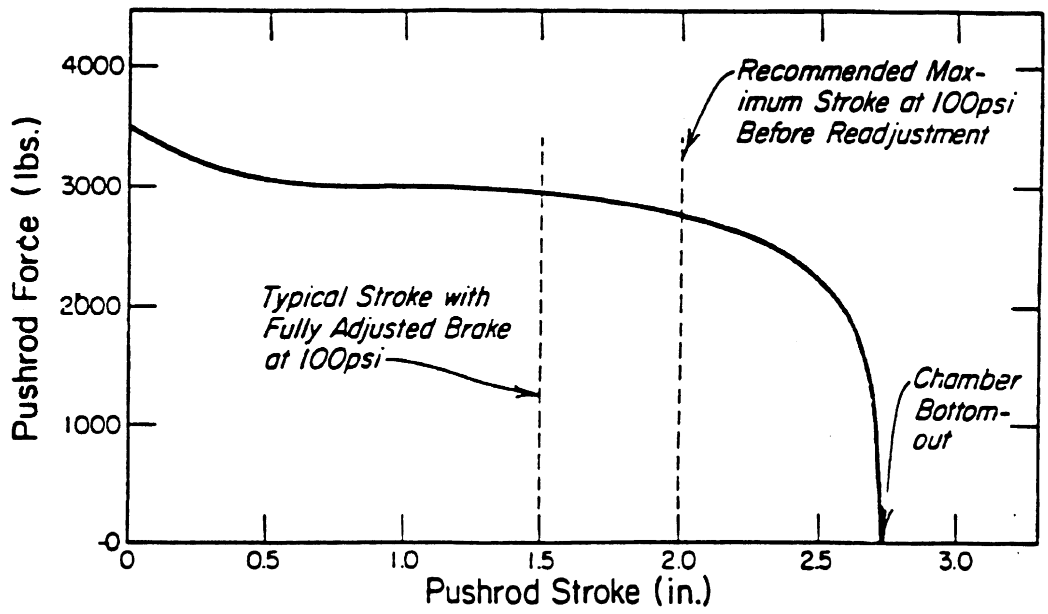


Figure 3. Pushrod force versus pushrod stroke at 100 psi [2]

The influence of running out of stroke is illustrated by the data presented in Figure 4 [2]. For stroke less than 2" and temperatures less than 400°F there is less than

10 percent decrease in brake torque. However at 600°F there is a very dramatic loss in brake torque, reaching over 50 percent starting from a cold static stroke of 2.25" at 100 psi and getting substantially worst at higher levels of cold stroke. The dramatic loss in brake torque illustrated in Figure 4 clearly indicates the need for maintaining proper adjustment so that reasonable brake torque capability will be maintained even if the brake becomes hot on a long, steep mountain grade or in stop and go driving. Furthermore, even if the brake is at 200 degrees F and the cold stroke is above 2.25", there is more than a 20 percent loss in torque at 100 psi of air pressure.

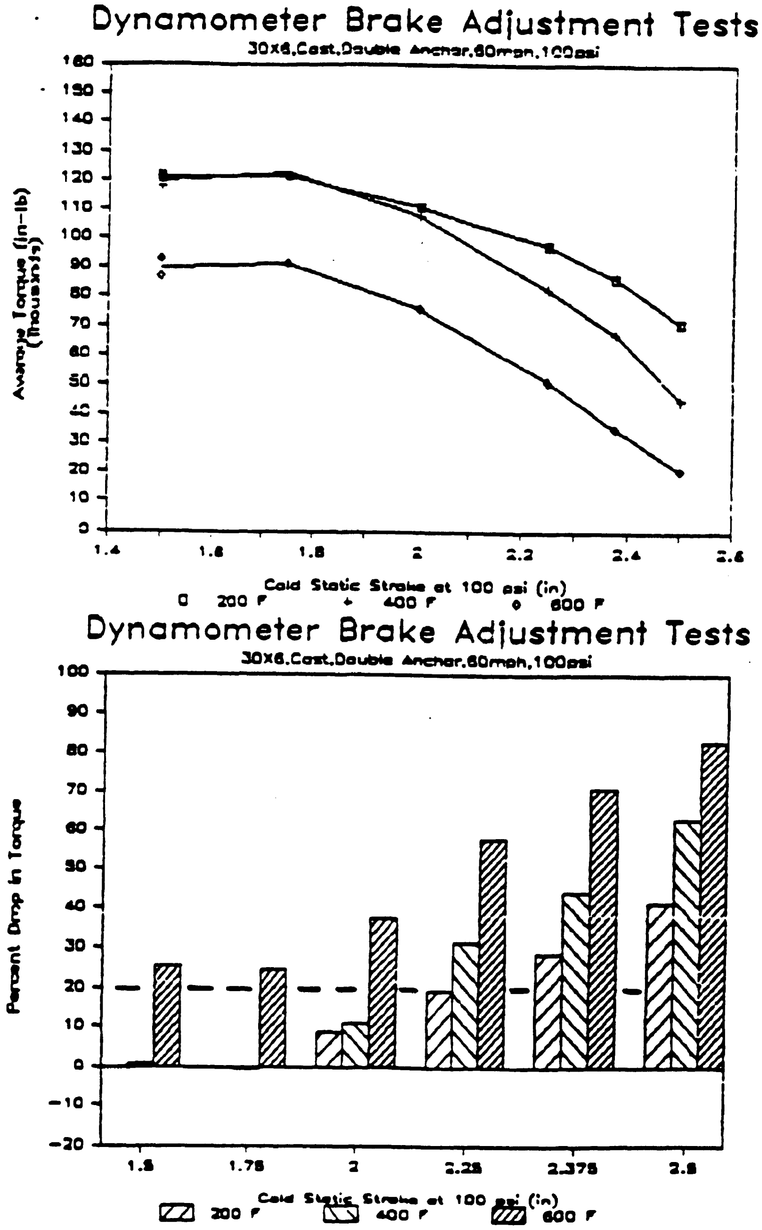


Figure 4. The influence of stroke on brake torque [2]

A subtle point concerning the loss of brake torque at high cold stroke is that the driver may not be aware of this danger because it may not be apparent during normal stopping. As shown previously in Figure 1, an inch of stroke is consumed in going from pushout pressure to 100 psi. Figure 5, taken from [3], indicates that most brake applications (about 80 percent) are at less than 20 psi. and according to Figure 1 these applications require less than 0.2" of stroke—meaning that the stroke would be approximately 0.8" less than it would be at 100 psi. This stroke margin means that the driver is not able to feel the danger of running out of stroke in normal driving situations. Brake adjustment needs to be checked to prevent the hazards of not knowing that the maximum torque available for an emergency is very limited if the brake is out-of-adjustment and especially if the brake is hot.

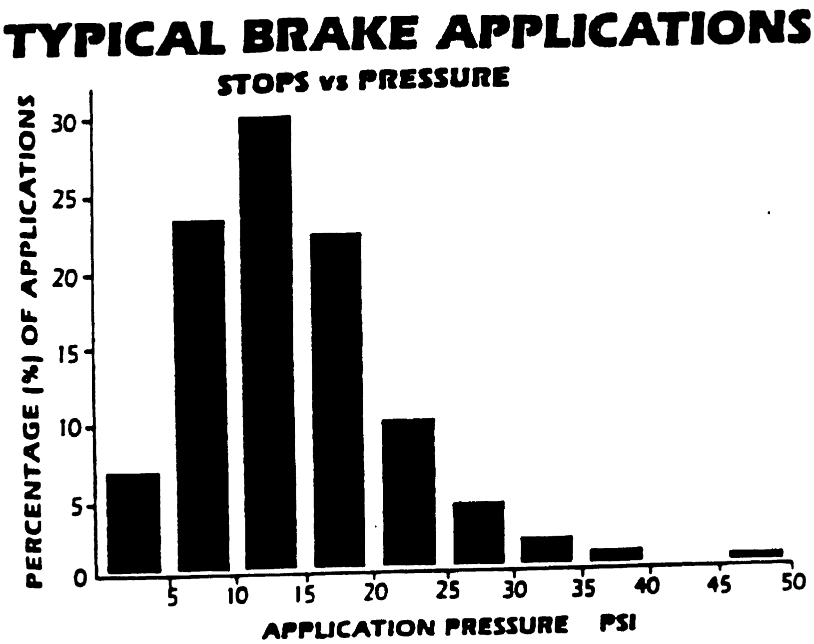


Figure 5. The percentage of brake applications in various pressure ranges [3]

The Nature of the Processes Involved in Brakes Becoming Out-of-Adjustment

Aside from some type of misadjustment, brakes become out-of-adjustment because they wear. An S-cam brake will require at least 20 (see Figure 2) and more like 30 adjustments during the life of a lining set [3]. The time between adjustments depends upon the severity of the service that the brake is subjected to.

Brake wear is known to be highly dependent upon the temperature levels that the brake reaches in its service application. Figure 6 from [5] provides an example showing the influences of lining temperature upon the amount of wear of a type 30 S-cam brake. As indicated in Figure 6, the amount of wear is not only dependent upon the temperature but on the previous work history of the brake. The dashed lines in Figure 6 show that after operation at a high temperature, the remaining surface of the lining wears much more rapidly at 200°F than it would ordinarily. This phenomenon has been attributed to the development of a char layer on the lining during high temperature operation. This layer wears rapidly until "uncharred" lining material is reached again. These results indicate that the need for brake adjustment is very dependent upon the type of service involved. Strenuous service involving high temperatures implies the need for frequent brake adjustments

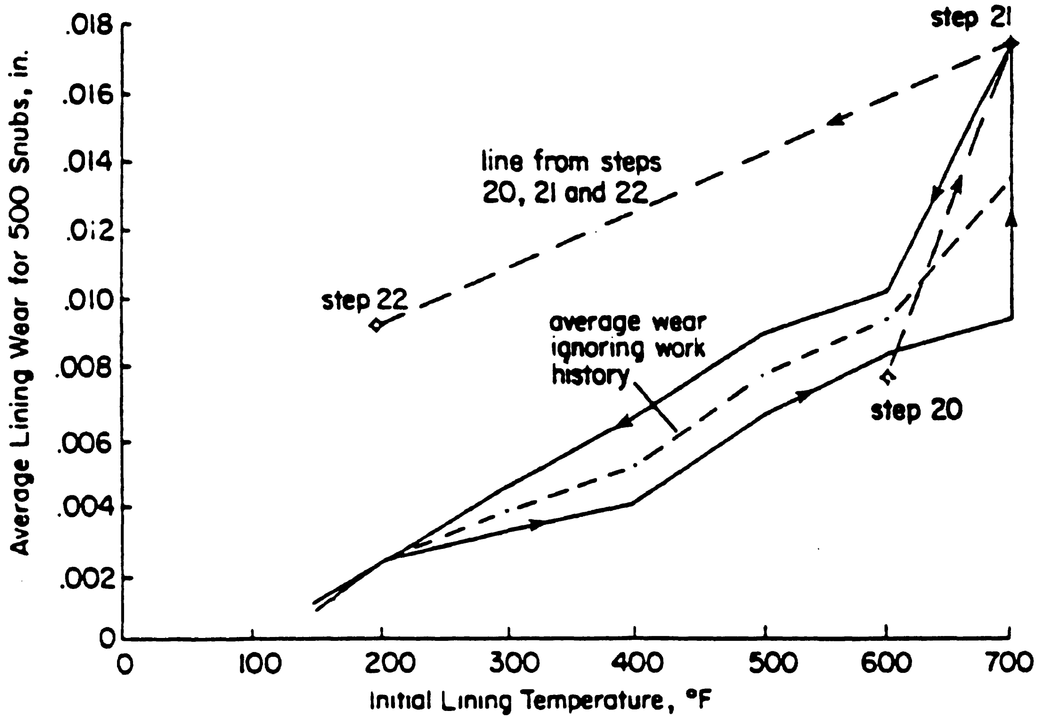


Figure 6. The influence of temperature on wear [5]

From a braking system standpoint, the brake that wears fastest may be doing more than its share of the work. The brake that is not wearing may be the problem brake since it is not doing its share of the work.

During this project we expect to develop a better understanding of the relationships between service demands, wear, brake proportioning, and the need for brake adjustment. Recent publications indicate that there is now the possibility for predicting wear and operational life of a brake lining using computer simulation (for example [6]). Perhaps, information on the time between brake relinings can be used to estimate the time between adjustments given approximately 30 adjustments over the life of the lining.

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[2] Flick, M. A., The Effect of Brake adjustment on Braking Performance, National Highway Traffic Safety Administration, DOT HS 807 287, APRIL 1988.

[3] Friend, P., et al, Air Brake Technical Seminar 1984, Bendix Heavy Vehicle Systems Group.

[4] Segel, L., et al, Mechanics of Heavy Duty Trucks and Truck Combinations, Engineering Summer Conferences, University of Michigan, 1989.

[5] Fancher, P., and Winkler, C., Retarders for Heavy Vehicles: Phase III -- Experimentation and Analysis; Performance, Brake Savings, and Vehicle Stability, DOT-HS-9-02239, University of Michigan Transportation Research Institute, January 1984.

[6] Van Heck, J., Prediction of Wear and Operational Life of Drum-brake Linings, SAE 885141, September 1988.

AN ANNOTATED BIBLIOGRAPHY ON SPECIFIED DOCUMENTS

"Heavy Truck Safety Study" (DOT-HS-807-109, March 1987) identifies vehicle factors related to the cause of truck accidents and programs and needs of enforcement agencies responsible for compliance of heavy trucks with traffic laws. Further, the report summarizes current knowledge about each issue, describes possible action toward improvement, and presents research agendas for longer-term issues. Brake adjustment as related to heavy trucks involved in accidents is identified as a factor not statistically demonstrated because "Equipment that is degraded, but still intact, such as brakes that are out-of-adjustment, is usually not reported." Again, because brake adjustment problems are not often reported, the report excludes brake adjustment from its definition of brake failure or deficiency. The report discusses findings at roadside inspections which indicate from about 60-70 percent of trucks put OOS were done so due to brake related problems. How many of those problems were due to brake adjustment is not identified. However, the report concludes that "the portion of all truck accidents that potentially have brake system issues as a contributing factor could be as much as one third."

"The Effect of Brake Adjustment on Braking Performance" (DOT-HS-807-287, April 1988) describes tests used to evaluate the relationship between brake adjustment on heavy vehicles equipped with air brake systems and stopping performance of those vehicles. The report describes the three sites used for the actual vehicle stopping tests and computer simulations of brake performance. In general, the report finds current OOS criteria appropriate for brakes at cooler temperatures. However, the performance of brakes at higher temperatures (400°F or greater) are found to degrade 40-50 percent.

"Brake Performance Levels of Trucks" (FHWA, September 1984) compared brake performance test results conducted in 1983-84. Two-axle trucks performed better in 1974 than in the later tests. Three-axle, truck-brake performance improved over the period. Truck-trailer combinations also improved. Tractor-semi combinations are reported to have deteriorated. Brakes OOA are reported to be 30 percent for the whole group. a general correlation between brake adjustment and stopping distance is offered: each brake OOA resulted in .5 to 1.5 feet of stopping distance over the range weights of the test vehicles as a speed of 20 mph. The report establishes a rating system of relative importance of brake problems. In order of importance, the number of brakes OOA ranks fourth. The average percentage of adjustment required to maintain the vehicle in-service is ranked fifth. The other factors affecting stopping time are reported, in order of importance, as total weight, the age of the vehicle, and whether the vehicle was operated for hire.

"A Demonstration of the Safety Benefits of Front Brakes on Heavy Trucks" (DOT-HS-807-061, December, 1986) describes tests performed on heavy trucks to evaluate the effectiveness of the use of front brakes. Test vehicles included bobtail tractors, tractors with empty semitrailers, and a tractor with a loaded semitrailer resulting in a gross combination weight of 80,000 pounds. All vehicles are reported to have superior braking performance with full front brakes. Partial Front brakes performed less well. By inference, front brakes which are OOA would also be expected to perform poorly than properly adjusted front brakes.

The "North American Uniform Driver-Vehicle Inspection Manual" of the Motor Carriers Assistance Program clearly describes procedures for inspecting heavy truck brake system adjustment. The vehicle inspection routine is performed counter-clockwise around and under the vehicle. During the first pass, around and under the vehicle, the inspector examines the brakes, along with other components, for defects, and marks the pushrod of each brake. After the first pass, the inspector measures pushrod travel for each brake. The manual is complete with diagrams for marking and measuring pushrod travel for each brake. The manual is complete with diagrams for marking and measuring pushrods for cam brakes, and also includes procedures for assessing the adjustment of disc brakes and wedge brakes with feeler gauges.

Accident Analysis and Prevention, Vol. 9, pp. 167-176, "A Comparative Evaluation of Two Roadside Brake Testing Procedures" reports the process used in Michigan to assess the effectiveness of two motor vehicle brake system effectiveness procedures, the "Moving Stopping Test" and the "Wheel Pull Inspection." Field surveys were set up in conjunction with Michigan State Police and the Michigan Office of Highway Safety Planning. The Moving Stopping Test was found to be more stringent and less costly than the Wheel Pull Inspection and was thought to more accurately identify vehicles with brake performance problems.

"Heavy Duty Vehicle Brake Research at NHTSA," a collection of charts, graphs, and topics generated by in-house and contract research, illustrates brake-related areas such as front braking, braking under load, braking under severe weather conditions, brake lock-up, brake compatibility within configurations, and brake adjustment sensitivity. Brake temperature is shown to be a considerable factor in geographic illustration. Load sensing and anti-lock mechanisms are suggested as areas to be explored further.

"The Performance of Trucks Braking on Ice" (UMTRI-87-23, August 1987) describes tests performed under severe winter conditions to assess the effectiveness of front brakes on trucks as well as the use and placement of tire chains. The report shows that when brakes are provided the opportunity to function to maximum advantage, both stopping distance and steering control will improve.

"Grade Severity Rating System" (FHWA-IP-88-015, May 1988) is concerned with a system to reduce the probability of large truck runaways on severe downgrades. Mathematical models using truck weight and downgrade characteristic are employed to predict brake system temperatures. Temperature estimates determine safe downgrade speeds. The manual provides methods of identifying severe grades by length and angle of slope, models brake temperature for grade and weight combinations, and suggests maximum safe speeds based on those factors in order to maintain acceptable brake temperature.

"Air Brake Technical Seminar" (Bendix Heavy Vehicle Systems Group 1984) was conducted to provide air brake system users with a knowledge base from which to make informed decisions about heavy truck brakes, reports that cam brakes demand a minimum of twenty adjustments per lining set; that the type of operation in which a vehicle is involved has direct bearing on the need for adjustment; and that the adjustment must be checked before a mountain run. Installation of automatic adjusters is suggested.

APPENDIX E

BRAKING PERFORMANCE–RELATIONSHIPS BETWEEN BRAKING EFFICIENCY, VEHICLE STABILITY, AND BRAKE ADJUSTMENT

In operational terms, a heavy truck brake is a device that converts air pressure into a torque retarding wheel rotation. The performance of this device is quantified by brake "effectiveness," where effectiveness is a measure of the gain of the brake expressed in units of torque output per unit of line pressure input. [1]

However, each brake in a vehicle is embedded in an overall braking system consisting of an air compressor, air reservoirs, valves, lines, brake chambers, actuation mechanisms, shoes, linings, drums, and tires. Furthermore, braking performance depends upon tire/road friction and the load transfer from rear to front due to the deceleration of the vehicle.

Braking performance on roads with differing frictional properties may be expressed in terms of "braking efficiency" which is the ratio of (a) the vehicle deceleration attainable without locking wheels to (b) the friction level existing at the road surface.

The reason for the phrase "without locking wheels" has to do with directional stability and control of the vehicle. If the wheels on the front axle lock up, the vehicle will not respond properly to steering. If the rear wheels on a straight truck lock up, the vehicle is directionally unstable and it will tend to spin around. If the drive wheels on a tractor in a tractor-semitrailer combination lock up, the tractor tends to jackknife. If the trailer wheels lock, the trailer tends to swing out of line. If all wheels lock, the vehicle is completely out of control and one hopes that the vehicle stops before anything bad happens. The general idea is that if any wheels lock, undesirable consequences may ensue. Desirable braking performance involves not locking wheels as well as the capability to decelerate rapidly if necessary.

The following material emphasized the influence of brake adjustment upon braking performance. Brakes on heavy trucks often have manual slack adjusters. If these brakes are not adjusted properly, the brake chambers will run out of "stroke"–that is, they will bottom out on the end of the brake chamber, thereby limiting the effort for applying the brake, and hence, limiting the available braking torque. In extreme cases, the adjustment may be so poor that no brake torque is available.

Aside from errors in adjusting the brakes, the reason that brakes become out-of-adjustment is that linings wear. The wear rate depends upon the type of service of the vehicle as well as lining and drum properties. The brake that wears the fastest is the one that is doing the most work per unit of lining surface available. Wear rate also depends upon lining temperature. The later stages of this study will include investigations into the relationships among vehicle service characteristics, brake wear, and the need for brake adjustment.

The next section provides an overview of how the components of the braking system influence braking performance.

OVERVIEW OF THE PERTINENT PROPERTIES OF BRAKING SYSTEMS

A straightforward method for organizing the discussion of the braking system is to follow the sequence of events that take place in going from movement of the brake valve to the generation of braking force. The sequence for most brakes is as follows (see Figure 1): (1) air pressure at the treadle valve increases when the valve is moved, (2) these pressures act as control signals that are transmitted through brake lines, (3) these control signals arrive at relay valves which apply air from supply reservoirs to the brake chambers, (4) the brake chambers apply force to a pushrod that moves through a stroke, (5) the movement of the pushrod rotates a cam mechanism that rotates the linings of the brake shoes into contract with the drum, (6) frictional forces between the lining and the brake drum generate a braking torque that slows the wheel, (7) the braking torque creates a longitudinal force at the tire/road interface thereby decelerating the vehicle. Each of these steps involves particular pieces of hardware ("components" of the braking system). The performance of the braking system depends upon the pertinent mechanical properties of these components. [1]

PERTINENT PROPERTIES OF AIR LINES

The time between (a) when the driver asks for braking by moving the treadle valve, and (b) when the control signal has reached the relay valve represents a loss in time that increases the stopping distance of the vehicle. This time delay contributes to the delay before the chamber pressure rises from zero as illustrated in Figure 2. [2] The amount of delay depends upon the diameters and lengths of lines involved with the brake in question. Experimental data available in Reference [2] can be used to evaluate this parameter.

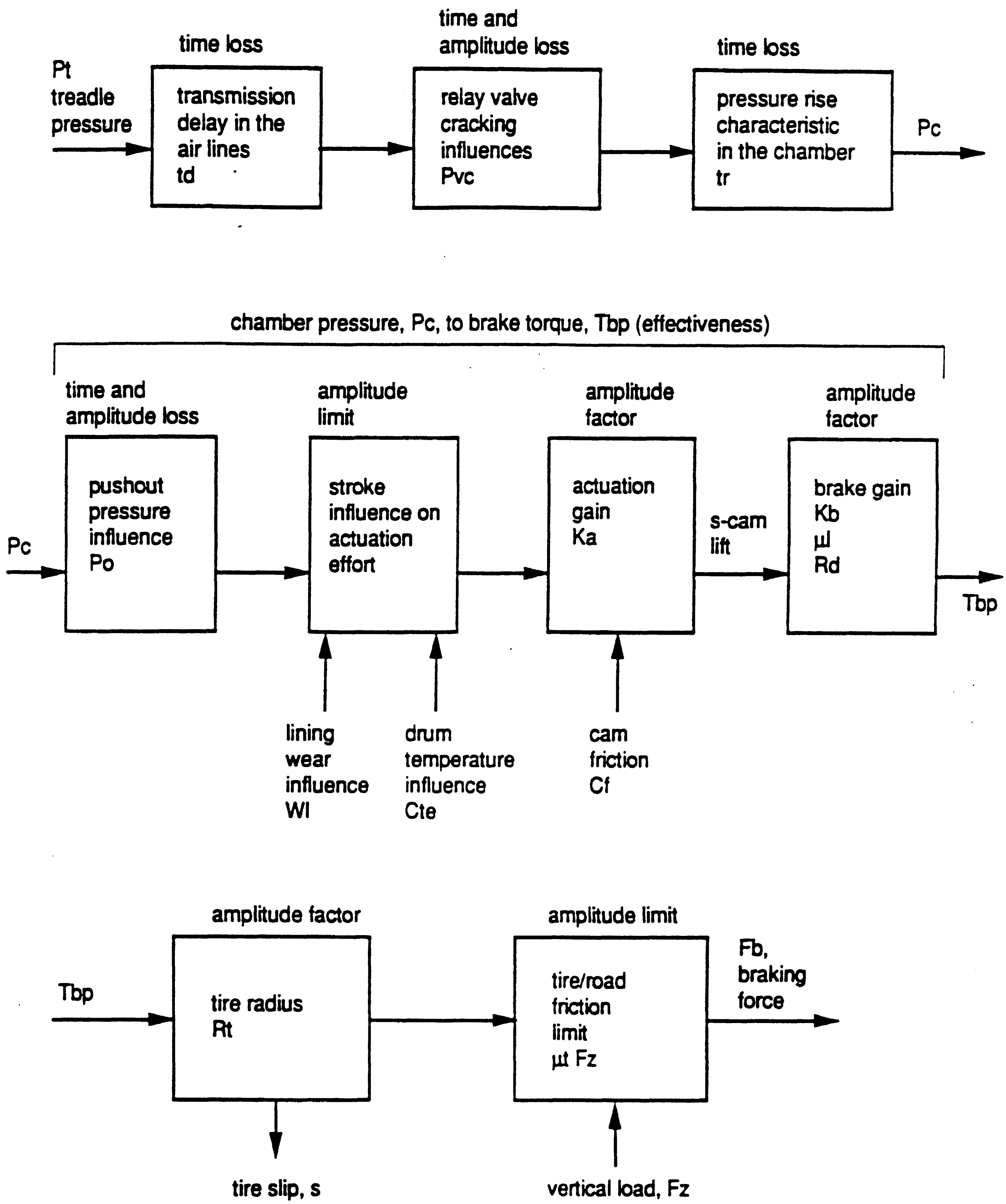


Figure 1. From treadle pressure to braking force

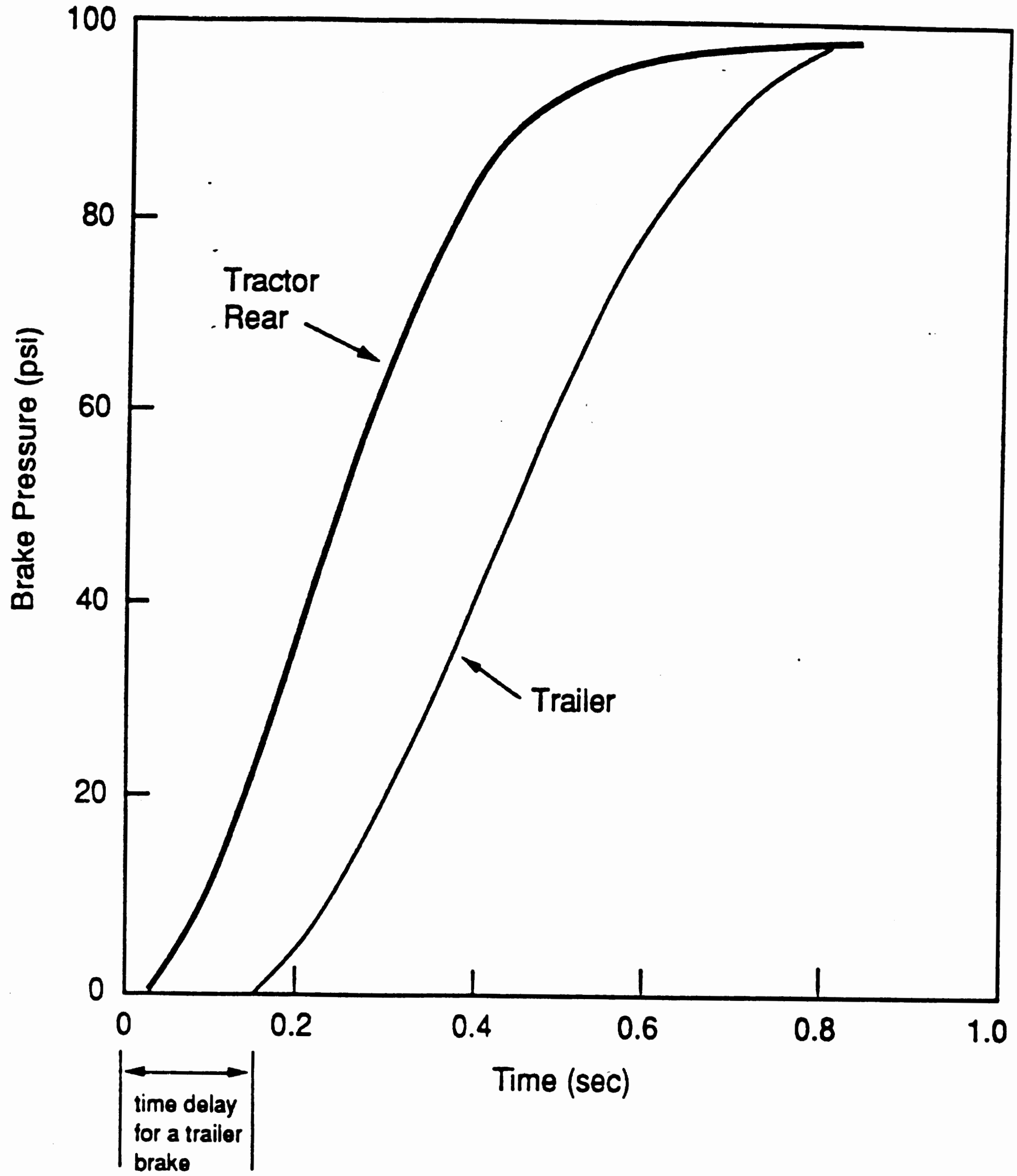


Figure 2. Brake pressures versus time measured in a tractor trailer combination [2]

VALVE CRACKING INFLUENCES

Relay valves are characterized by the difference in pressure needed to cause the valve to open–that it, the "cracking pressure." The cracking pressure needed to operate the valve represents a loss in braking pressure. Also, differences in cracking pressures between relay valves can cause brakes to come on at different times with possibly large effects for low pressure applications. (These differences may be particularly noticeable between the valves used on tractors and those used on trailers.)

PRESSURE RISE IN THE BRAKE CHAMBER

The "apply time" used in FMVSS 121 is the time for the chamber pressure to reach 60 psi in a rapid 100 psi application on the treadle valve. This time includes the transmission delay time associated with the air lines and the rise time involved with filling the air chamber to a 60 psi level. The rise time characteristics can be determined from measurements of pressure time histories made on vehicle combinations. (See reference [2] for examples.)

Incidentally, brake adjustment may have an influence on the delay included n the apply time (see Figure 3).

PUSHOUT PRESSURE

The brake chamber and the shoes have return springs used in deactivating the brakes. During brake applications, the forces created by these springs must be overcome before the linings touch the drums. The amount of pressure needed to cause braking action to begin is the "pushout pressure." Often a net pushout pressure is determined by including together the influences of not only the return springs, but also the influences of valve cracking and any other pressure losses in the system.

STROKE INFLUENCE ON ACTUATION EFFORT

Once the pressure in the brake chamber rises above the pushout level, the stroke of the pushrod increases–first, in taking up the "slack" between the linings and the drum, and then, with pressure as the linings are compressed against the drum. The motion of the pushrod is tied to the rotational motion of a cam (in an s-cam brake) through an arrangement consisting of a slack arm, fixed cam bearings, etc. The air pressure in the brake chamber supplies the reaction torque required for the cam action used in pressing the lining against the drum.

If the brake is sufficiently out-of-adjustment, the pushrod and its associated diaphragm will bottom out on the bottom of the air chamber. (See Figure 4 to envision how this happens. [3]) Increasing the pressure in the brake chamber (beyond that which

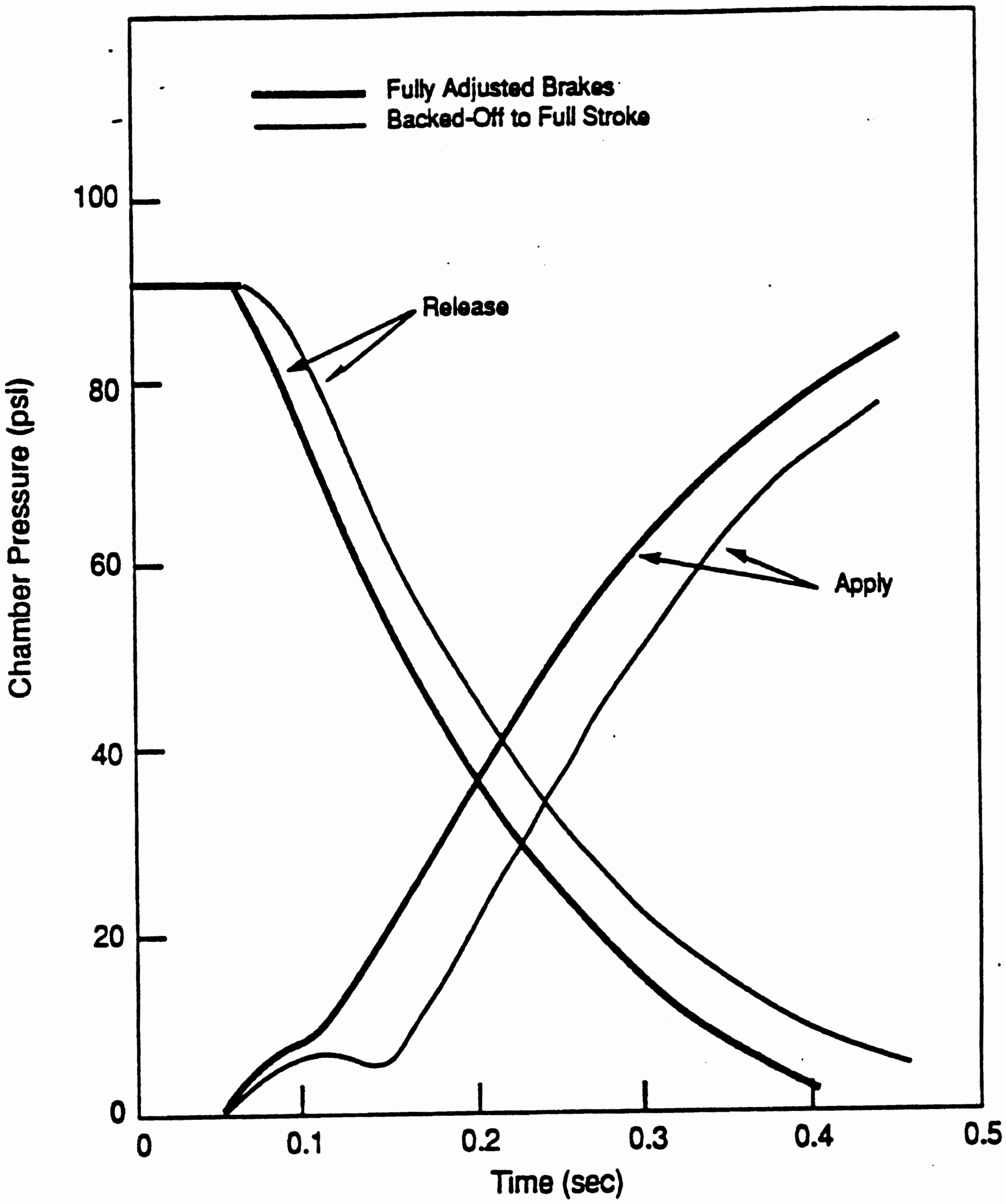
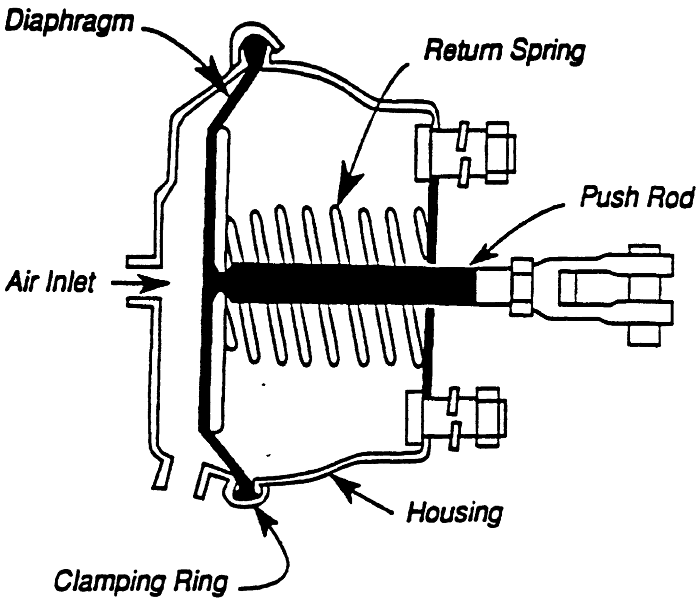


Figure 3. Brake chamber pressure versus time for apply and release of a brake at two different adjustment levels [2]



Clamp Ring Type Diaphragm Chamber

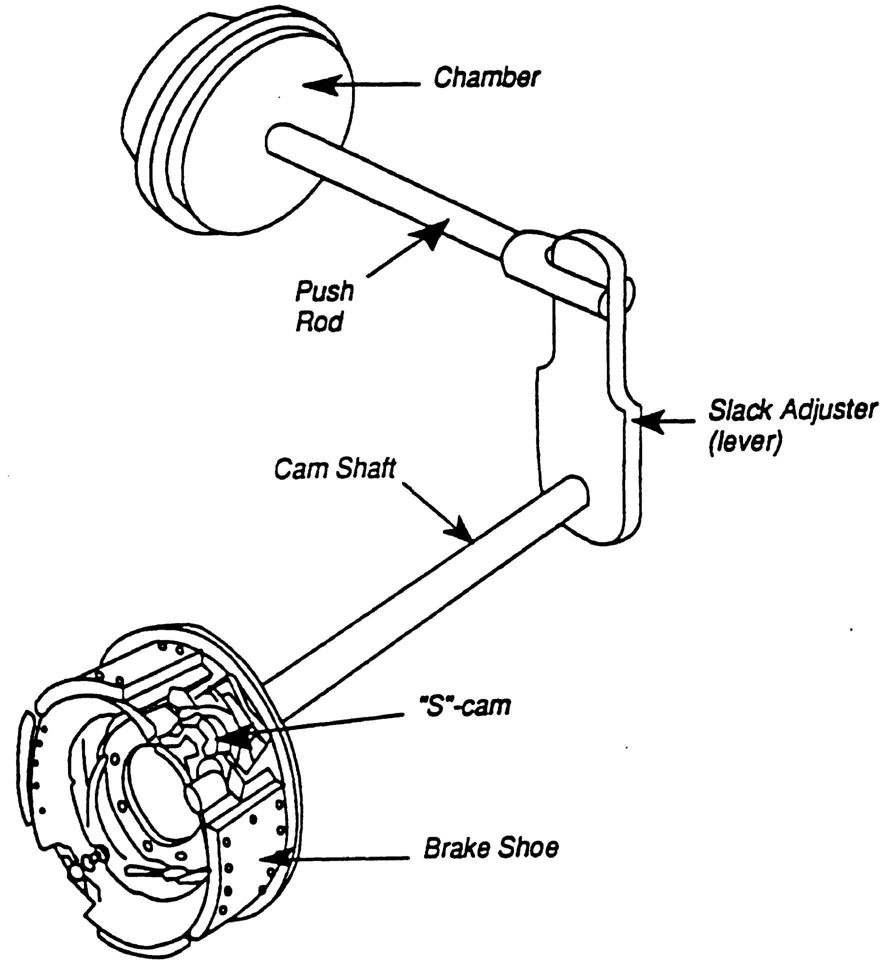


Figure 4. Brake chamber and cam linkage [2]

causes the pushrod to bottom out) will not increase the actuation effort applied to the s-cam mechanism by the pushrod if the pushrod has bottomed out.

In effect, if the brake is out-of-adjustment, the stroke limit of the brake chamber acts as a mechanism that limits the brake torque available. The curves graphed in Figure 5 provide a quantitative example illustrating the nature of the process resulting in the limiting of the actuation force on the pushrod of a Type 30 brake chamber.

The line designated as the "operating line" in Figure 5 has been superimposed upon curves representing the relationship of actuation force to stroke and pressure as might be measured for a brake chamber. (Reference [3] gives the 100 psi curve for a typical brake chamber.) The influences of slack due to (a) clearance for the unactuated brake, (b) lining wear, and (c) stroke shown along the horizontal axis in Figure 5. The operating line starts at the amount of stroke needed to take up the slack and increases with stroke and pressure. It indicates the resulting actuation force as the lining are compressed against the drum.

The slope of the operating line depends upon (a) the compliance of the shoe and lining combination, (b) the mechanical advantage of the cam mechanism, (c) the self-actuation of the leading shoe, and (d) the pressure/actuation force characteristics of the chamber.

The point where the operating line intersects the upper- or right-most line of constant pressure in the figure indicates the maximum actuation force that can be obtained from the brake chamber. The equivalent pressure for a well-adjusted brake would be approximately that indicated by the y-intercept and its corresponding pressure level as indicated in Figure 5. In this example, the maximum force is achieved at an equivalent pressure of 60 psi. At equivalent pressures above this level, the braking force would not increase above that corresponding to the limiting force of 1700 pounds as indicated in Figure 5.

In summary, the primary effect of the phenomena associated with running out of stroke is that the brake torque will be limited to that torque corresponding to the equivalent pressure level at which the pushrod bottoms out. If the brake were never to be adjusted, the linings would eventually wear to the point where all of the stroke would be consumed in slack and there would not be any braking torque produced even at 100 psi.

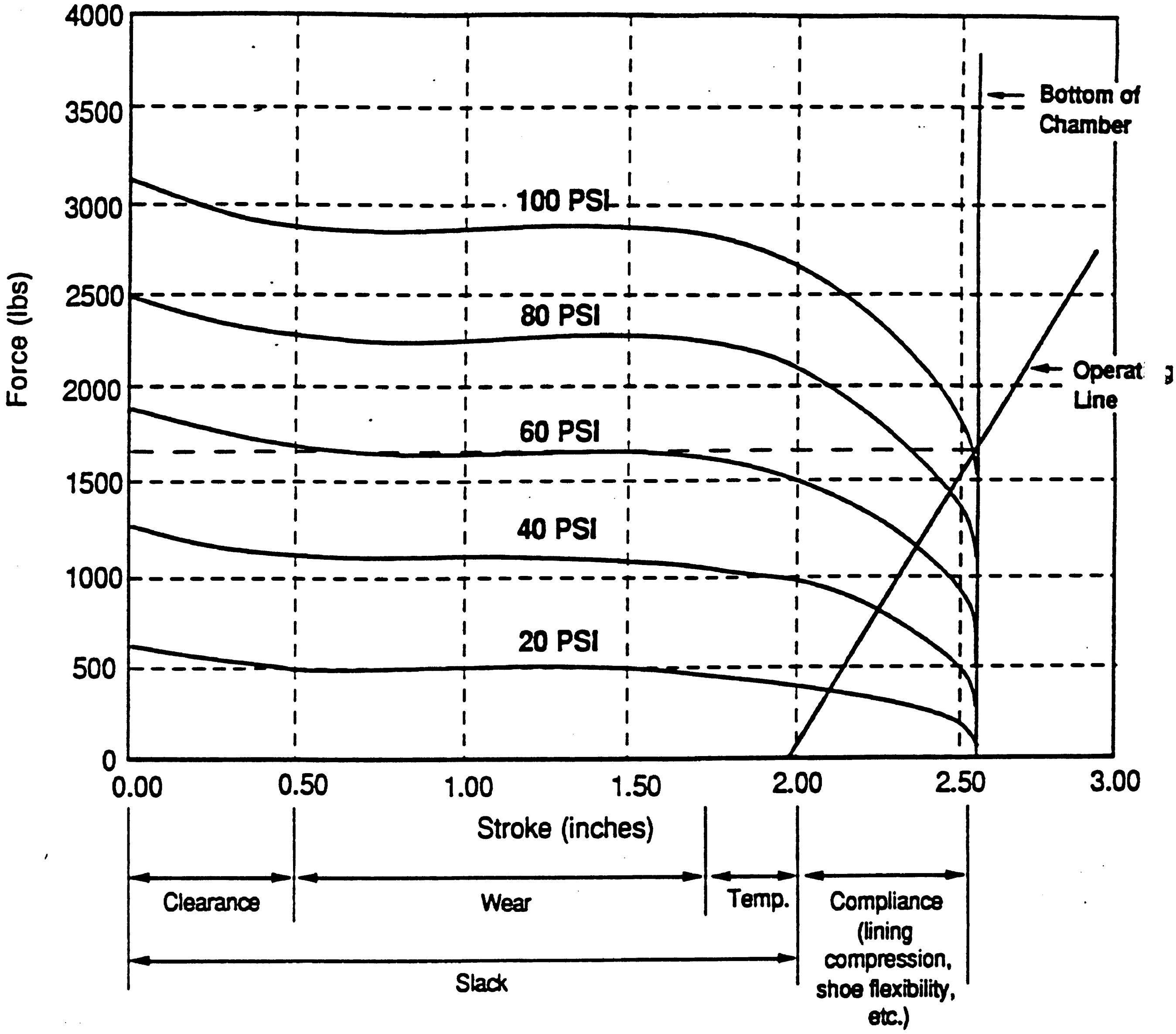


Figure 5. Limit on actuation force from the brake chamber

ACTUATION GAIN OF THE S-CAM MECHANISM

The mechanical advantage of the cam mechanism is determined by the length of the sack arm and the effective cam radius. For example (given that the angle of the slack arm is properly oriented), a mechanism with a 6" slack arm and a 1/2" cam radius would have a mechanical advantage of twelve–resulting in a situation in which the stroke of the air chamber is approximately twelve times the movement associated with pressing the lining against the drum; of course, the actuation effort is increased by twelve times also.

In an s-cam brake, the cam movement is the input that presses the linings against the drum. The actuation forces on the shoes are not equal but the movements are. This leaves a torque to be reacted through the cam bearings. The influence of friction in the cam bearings results in a loss in the gain of the brake such that even though the nominal gain might be twelve, the actual gain would be less–perhaps approximately ten for typical amounts of friction. [4]

INFLUENCES OF THE GEOMETRY AND FRICTION OF THE BRAKE ASSEMBLY

The pressure distribution between the linings and the drum depend upon (a) the shape the lining has worn to, (b) the dimensions describing the geometric features of the bake assembly (the position of the linings on the shoes, the location s of the pivots of the shoes, the angles to the actuation forces on the shoe tips, etc.), (c) the amount of drum expansion due to temperature, and (d) other factors including the compliances of the shoes and linings. These influences have been studied analytically using finite element analyses. [5,6]. Although the finite element analyses are useful for designing brakes, they are more complicated than needed for characterizing brake gain in this discussion.

The gain of a brake assembly (actuated by an s-cam and having fixed pivots for the shoes) can be represented by parameters characterizing (a) the geometric gain factor accounting for the arrangement of both the leading and trailing shoes, (b) the friction coefficient between the lining and the drum, and (c) the drum radius. [1]

The gain of a particular brake in service on a vehicle is difficult to predict accurately. The state of lining wear and the compliance of the lining can change the gain significantly. In addition, friction coefficients of lining/drum combinations are known to have large standard deviations about their mean values and also friction levels maybe dependent upon the work history of the brake. Results from dynamometer tests are desirable for estimating the capability of a particularly type of brake. Even so, a brake in service may have torque capabilities that are significantly different than those obtained in the dynamometer tests/

TIRE GEOMETRY

The discussion of the properties of components has reached the point where the relationship between brake torque and treadle pressure has been covered. However, there are tire- and vehicle-factors that influence the braking force acting on the vehicle.

A very simple, but important consideration is the radius of the tire. The braking force acting upon the vehicle is the brake torque divided by the tire radius. Hence, smaller diameter tires will provide larger braking forces at a given pressure level (all else being equal).

TIRE/ROAD FRICTION LIMIT

The maximum braking force between the tire and the road depends upon the frictional capability existing at the tire/road interface. This capability depends not only on the friction coefficient (or some more complex means for describing friction between the tire and road), but also upon the vertical load carried by the tire. The tire loads on the vehicle depend, in turn, on the dynamics of the vehicle–especially the deceleration achieved during braking. This means that there is a set of simultaneous relationships (involving the dynamics of the vehicle) determining the vertical loads on the tires.

The dynamic vertical load multiplied by the friction coefficient sets the level of braking force capability available for decelerating the vehicle. If the bake torque exceeds the maximum level of torque that can be reacted by the tire, the wheel rapidly locks up and the brake torque reduces to that required to lock the wheel. In other words, the friction limit existing at the tire/road interface limits the braking force attainable. Increasing the brake pressure beyond that which will lock the wheel will not increase the force available for decelerating the vehicle.

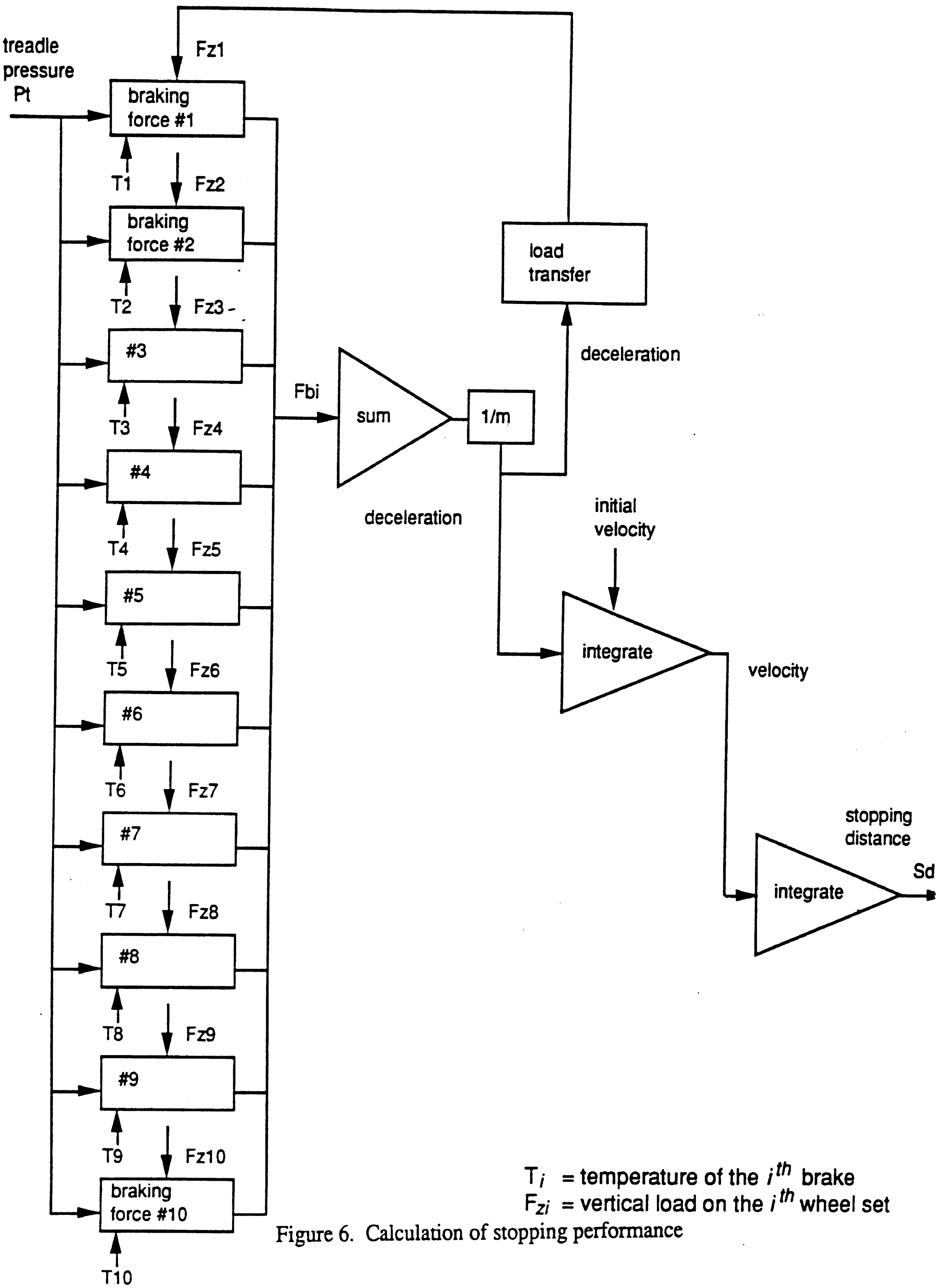
SUMMARY OF THE PERTINENT MECHANICAL PROPERTIES RELATED TO STOPPING

In order to analyze the stopping performance of a vehicle, information is needed on the influences of the following mechanical properties of the components of the overall braking system:

- Transmission delays in the air lines;
- Valve cracking pressures;
- Pressure rise characteristics in the air chambers;
- Pushout pressures;
- Actuation force versus stroke and pressure for the air chambers;
- Mechanical advantage (gain) of the s-cam mechanism and associated slack arm;
- Friction in the cam bearings;
- Brake factor (gain) of the brake assembly;
- Lining friction coefficient;
- Slack due to lining wear;
- Slack due to drum temperature (thermal expansion coefficient for drum materials);
- Drum diameter (radius);
- Tire radius;
- Tire/road friction; and

- Load transfer characteristics for determining the influences of deceleration on tire loads.

For a five-axle tractor-semitrailer with ten brakes, the above properties need to be known for each brake. Figure 6, which follows, indicates how these ten brakes each contribute to the stopping performance of the vehicle. (Only stopping characteristics are represented in Figure 6 and directional and lateral stability are not included here.)



T_i = temperature of the i^{th} brake
F_{zi} = vertical load on the i^{th} wheel set

Figure 6. Calculation of stopping performance

The response to treadle pressure consists of (a) deceleration, (b) velocity, and (c) stopping distance. In addition to the brake system characteristics listed above, these outputs depend upon the weight of the vehicle in its initial velocity. As indicated in the figure, deceleration is integrated over time to obtain velocity and is integrated over time to obtain stopping distance.

SIMPLIFIED ANALYSES OF STOPPING PERFORMANCE

Assuming constant deceleration, the basic formula relating stopping distance and deceleration is as follows:

$$Sd = (Vo)^2/2D$$

where Sd is stopping distance, Vo is the initial velocity, and D is deceleration.

(The weight or mass of the vehicle does not appear in this formula because its influence is used in determining the deceleration which is taken to be known here.)

(For snubs, the snubbing distance, d, given by the similar formula

$d = ((Vo)^2 = (Vf)^2)/2D$ where VF is the final velocity at the end of the snub.)

In actual stops, the deceleration is not obtained immediately. As described earlier, there is a delay time before any brake comes on and the braking force increases with time as the pressures rise in the brake chambers. To first approximation, the deceleration time history may be characterized as a delay time followed by a linear rise and then a constant level of deceleration (see Figure 7). This type of representation has been used in [2] to study braking timing matters. Here we have employed the simplified representation of deceleration to look at the differences between stops from initial velocities of 60 and 20 mph. The results (see Table 1 and Figure 8) indicate that approximately half of the stopping distance in a 20 mph stop is associated with the deceleration available during the time that the pressures are rising in the brake chambers. On the other hand, during stops from 60 mph, the stopping distance depends primarily upon the full deceleration level, even though 40 to 60 feet of stopping distance may be associated with the time to reach full braking deceleration.

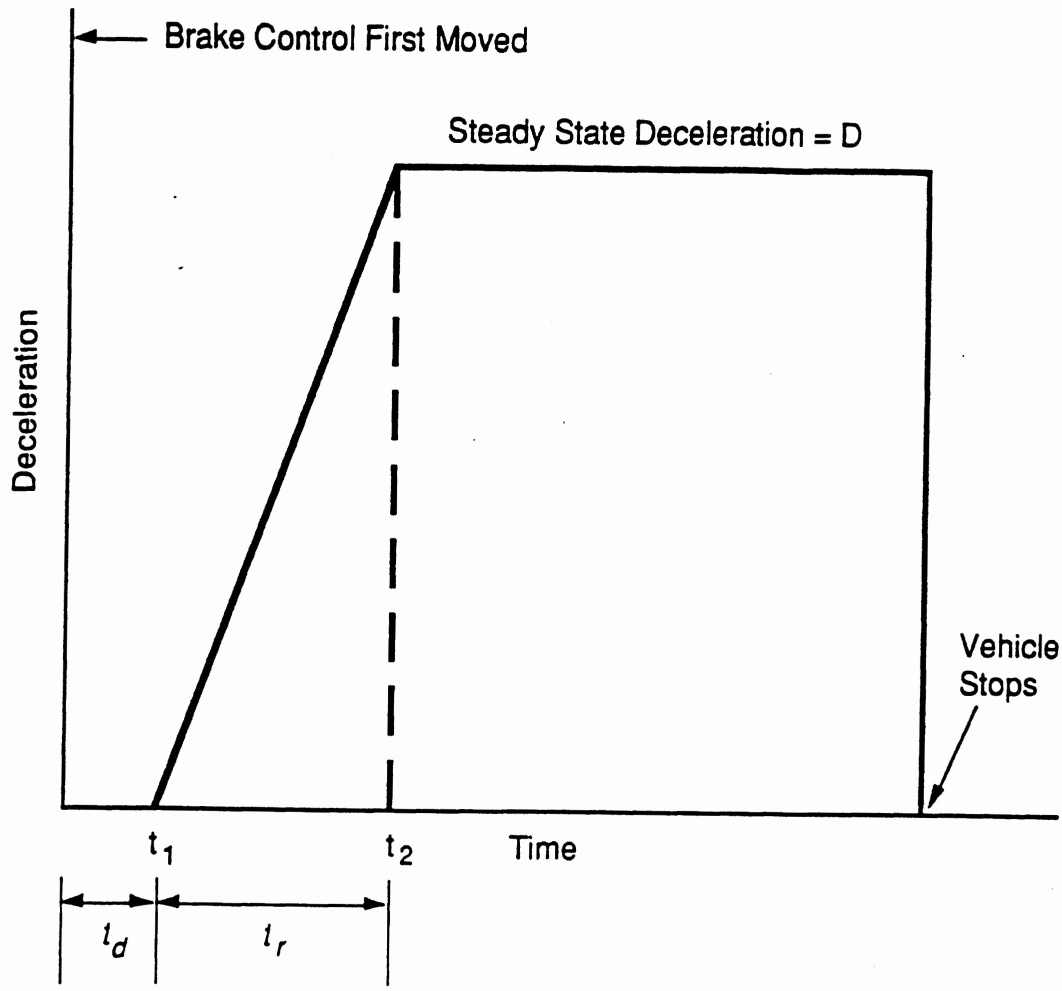


Figure 7. Simplified deceleration versus time for a stop

The point of the above material is that the 20 mph stop used in OMC work does not challenge the full deceleration properties of the vehicle as much as a 60 mph stop would. If the times for pressures to rise were longer than those used for tractor semitrailers in Table 1 (as they could be for doubles or triples combination without booster relay valves for example), the vehicle might stop before the rearmost brakes were completely actuated. The 20 mph test might not show the influences of poor adjustment of the rearmost brakes (or the directional stability problems that might ensue during a 60 mph stop).

Table 1. Influences of delay, rise, and constant deceleration on stopping distance

Case Names	Vo	INPUTS td	tr	D=Fp/m	Dd	Dr	Vtr	OUTPUTS tb	Db	Sd	ts
20 mph,Base case	29.33	0.075	0.7	16	2.1998	19.2243	23.73	1.48313	17.5973	39.0214	2.25813
20 mph,Long td	29.33	0.1	0.7	16	2.933	19.2243	23.73	1.48313	17.5973	39.7546	2.28313
20 mph,Short td	29.33	0.05	0.7	16	1.4665	19.2243	23.73	1.48313	17.5973	38.2881	2.23313
20 mph,Long tr	29.33	0.075	0.9	16	2.1998	24.237	22.13	1.38313	15.3043	41.741	2.35813
20 mph,Short tr	29.33	0.075	0.5	16	2.1998	13.9983	25.33	1.58313	20.0503	36.2484	2.15813
20 mph,Lower D	29.33	0.075	0.7	12	2.1998	19.551	25.13	2.09417	26.3132	48.064	2.86917
20 mph,Higher D	29.33	0.075	0.7	20	2.1998	18.8977	22.33	1.1165	12.4657	33.5631	1.8915
60 mph,Base case	88	0.075	0.7	16	6.6	60.2933	82.4	5.15	212.18	279.073	5.925
60 mph,Long td	88	0.1	0.7	16	8.8	60.2933	82.4	5.15	212.18	281.273	5.95
60 mph,Short td	88	0.05	0.7	16	4.4	60.2933	82.4	5.15	212.18	276.873	5.9
60 mph,Long tr	88	0.075	0.9	16	6.6	77.04	80.8	5.05	204.02	287.66	6.025
60 mph,Short tr	88	0.075	0.5	16	6.6	43.3333	84	5.25	220.5	270.433	5.825
60 mph,Lower D	88	0.075	0.7	12	6.6	60.62	83.8	6.98333	292.602	359.822	7.75833
60 mph,Higher D	88	0.075	0.7	20	6.6	59.9667	81	4.05	164.025	230.592	4.825

<u>Sequence of calculations:</u>

$$D_d = V_0 \cdot t_d$$

$$D_r = V_0 \cdot t_r - \frac{D \cdot t_r^2}{6}$$

$$V_{tr} = V_0 - \frac{D \cdot t_r}{2}$$

$$t_b = \frac{V_{tr}}{D}$$

$$D_b = V_{tr} \cdot t_b \cdot 0.5$$

$$S_d = D_d + D_r + D_b$$

$$t_s = t_d + t_r + t_b$$

<u>Units:</u>

V_0	[ft/sec]
t_d	[sec]
t_r	[sec]
D	[ft/sec^2]
D_d	[ft]
D_r	[ft]
V_{tr}	[ft/sec]
t_b	[sec]
D_b	[ft]
S_d	[ft]
t_s	[sec]

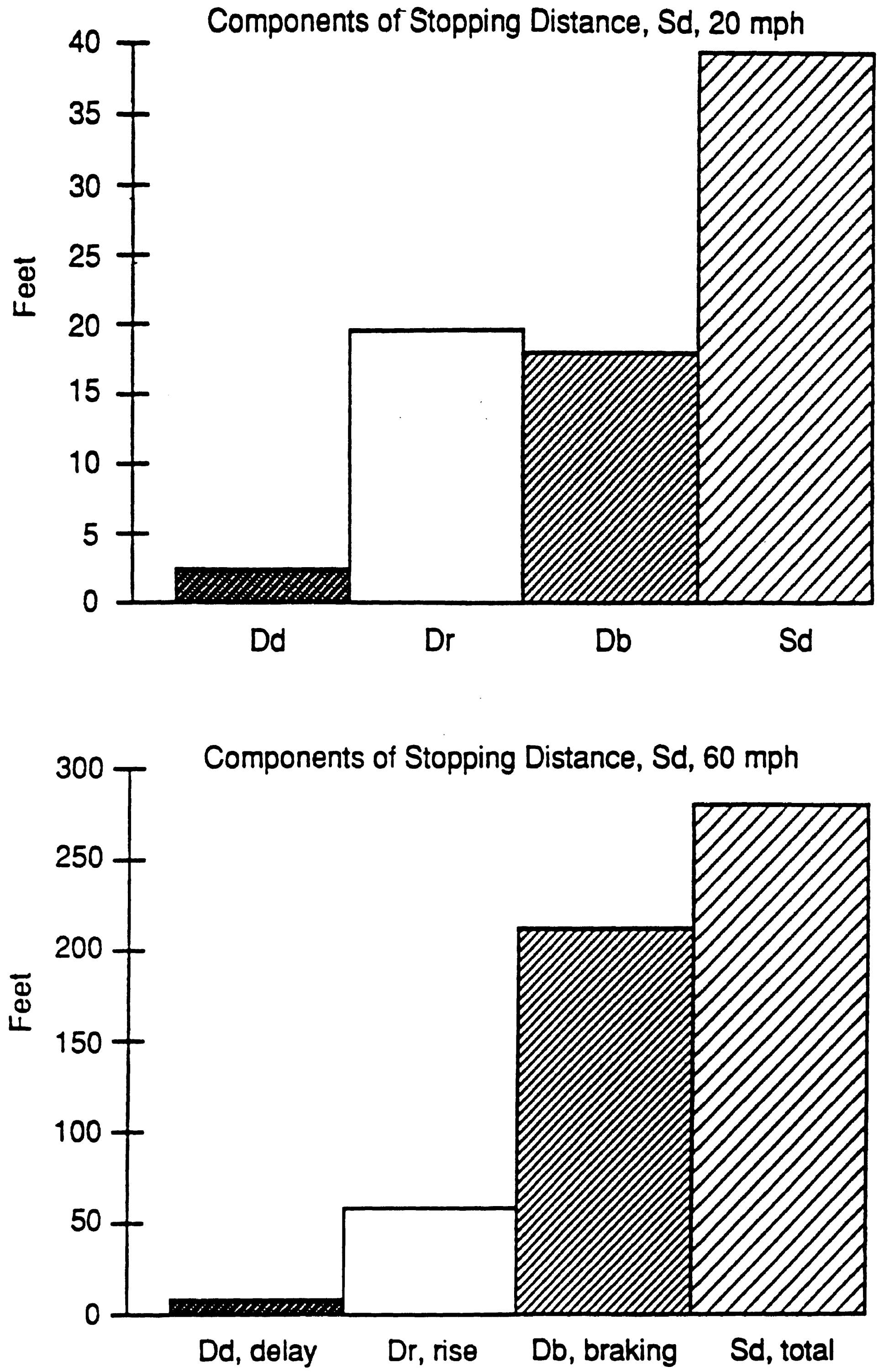


Figure 8. Components of stopping distance at 20 mph and 60 mph

BRAKING EFFICIENCY CALCULATIONS

The notion of braking efficiency usually applies to the steady deceleration level attained after the brakes have been fully applied. (If stopping distance is to be considered, the distances traveled during (a) the transmission delays and (b) the rise times of the brake chamber pressures need to be included in determining the total stopping distance.) The efficiency can be defined as the ratio of (a) the deceleration to (b) the friction utilization required to prevent the wheels on the "worst" axle from locking. ("Worst" meaning the axle with the largest ratio of braking force to vertical load, that is, the axle about to lock up utilizing the minimum friction possible.)

However, if a vehicle does not have enough braking capability to lock any wheels, the efficiency is the ratio of (a) the deceleration attainable at maximum pressure (100 psi) to (b) the friction coefficient available at the tire/road interface. This situation often applies to fully-laden heavy trucks with a maximum deceleration capability of approximately 0.4 g on a good road with a friction coefficient that might be approximately 0.8. (In this type of situation, the vehicle would become more efficient as the road got slipperier, but that is not important other than to recognize that a level of tire road friction needs to be chosen for use in calculating efficiency in this case.) The important notion here is that OOA brakes would lower the maximum acceleration attainable thereby lowering the efficiency below that of a truck with well-adjusted brakes.

There exist simplified vehicle models that have been developed for predicting the influences of braking system properties on braking efficiency. [7] These models (which are available at UMTRI) could be employed to represent the effects of various levels of brake adjustment by including the limiting effects of bottoming the pushrod as discussed earlier. It would be a straightforward exercise to study the sensitivity of deceleration to various levels of brake adjustment using the straight line braking model.

BRAKE TEMPERATURE CALCULATIONS

With regard to the influence of brake adjustment, drum temperature plays a significant role. For a 16.5" drum diameter and a thermal expansion coefficient of approximately 8.5 parts per million, a temperature rise of 300°F could correspond to an increase in slack of approximately 0.25" measured at the pushrod. Depending upon the level of adjustment, this could result in a hot brake running out of stroke (see Figure 5). Further data illustrating the effect of temperature on stroke are illustrated in Reference [3 and 8].

The types of service resulting in high drum temperature are either ones involving long steep mountain descents, or ones involving stop and go driving such as urban pickup and delivery. The potential energy to be dissipated during a mountain descent can be several times the kinetic energy involved in a stop from 60 mph. [1] The mountain descent situation requires careful attention to brake adjustment in order to lessen the risk of a runaway vehicle.

A grade severity rating system has been under development by the FHWA. [9]. The results from the research studies involved in developing this system have been used to examine the influences of grade length and slope on brake temperatures. [1] Recently, the UMTRI set of simplified (part task) models has been expanded to include a brake temperature model. Although this model is based upon the same concepts originally used for the grade severity calculations, it computes the bulk temperature of each brake rather than an average temperature for all of the brakes lumped together. Hence, it is possible to consider (a) the temperature of the hottest brake and (b) the influences of OOA brakes upon the temperatures of the other brakes on the vehicle.

In order to use the UMTRI model one needs to know the following:

- Thermal capacity of each brake (specific heat and weight);
- Cooling coefficient for each brake (this is a function of velocity);
- Proportion of braking effort acting at each brake;
- "Natural retardation" (rolling resistance and aerodynamic drag for the vehicle);
- Engine drag;
- Retarder power if one is used;
- Weight of the vehicle;
- Elevation profile for the route; and
- Velocity profile for the route.

Given that the model uses both a velocity profile as well as an elevation profile, the model can be employed to study stop-and-go conditions either on the level or during mountain descents. Although brake adjustment might not be important at pressure levels below the limiting pressure corresponding to bottoming the stroke (which is likely to be the case in a mountain descent at a safe speed), stopping performance in a high pressure emergency stop would be affected by the combined influences of temperature and OOA level.

(In order to use the brake temperature and the straightline braking models interactively, it might be necessary to segment the calculations to take into account how stroke changes with temperature and adjust brake effectiveness accordingly as the temperature rises.)

CONCLUDING REMARKS

It appears that the ideas presented and the models mentioned here could be used to address the following items (which are like those listed for analysis in Task E):

- Identifying key factors related to brake OOA;
- Relating various combinations of OOA brakes to braking efficiency by configuration, load, number of axles, which axles are OOA, amount of OOA, brake temperature, or other factors. (Studies of braking efficiency would pertain to both stopping distance and vehicle stability.);
- Identifying adjustment thresholds beyond which stopping distance levels or braking efficiencies will exceed critical thresholds;
- Providing a quantitative basis for confirming or changing OOS brake adjustment criteria.

The analytical work listed above would provide a technically sound foundation for working with field data. Findings with respect to deterministic matters that depend upon the mechanical properties of vehicle components are readily determined by analysis.

Matters requiring statistical treatment such as how means and variances of braking performance measures depend upon the levels of brake adjustment are obviously dependent upon identifying appropriate computerized data bases. Currently, we have not found suitable data bases but we are still looking. Perhaps we can use statistical data on braking system properties along with braking system models plus the theory of propagation of precision indices to calculate predictions of the variance of stopping performance (for different combinations of OOS brake adjustment) using the variances associated with the pertinent mechanical properties of (a) the key components of the braking system and (b) vehicle weights.

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[2] R. Radlinski and S. Williams, "NHTSA Heavy Duty Vehicle Brake Research Program Report No 5 -- Pneumatic Timing," DOT HS 06 897, NTIS, Springfield, VA, December 1985.

[3] M. Flick, "The Effect of Brake adjustment on Braking Performance," DOT HS 807 287, NTIS, Springfield, VA, April 1988.

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[6] J. Van Heck, "Prediction of Wear and Operational Life of Drum Brake Linings," Paper No. 885141, SAE, September 1988.

[7] --, "Simplified Models of Truck Braking and Handling," UMTRI, Engineering Research Division, February 1988.

[8] R. Radlinski, et al. "The Importance of Maintaining Air Brake adjustment," Paper No. 821263, SAE, 1982.

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APPENDIX F

AN ASSESSMENT OF DATA PERTAINING TO THE INFLUENCES OF OUT-OF-ADJUSTMENT LEVEL, VEHICLE CONFIGURATION, LOADING, AND BRAKE TEMPERATURE ON BRAKING PERFORMANCE

This document provides information on the influences of OOA, vehicle configuration, loading, and brake temperature on braking performance. It centers on reviewing the data in three references pertaining to the following subjects:

(1) Vehicle inspections, weight checks, and 20 mph stopping distance tests. [1]

(2) Speed control on long, steep downgrades as influenced by vehicle weight [2]

(3) Heavy vehicle braking for combinations of load, speed, and brake temperatures [3]

The first reference [1] contains data gathered in 1983 in three states–Maryland, California, and Michigan. These data were gathered during vehicle inspection exercises that included measuring brake adjustments, weighting the vehicles, and performing 20 mph stopping distance tests. The data were compared to data measured in 1974. The data were categorized into information on:

(1) Total weight

(2) ICC-certified or not, age of truck or tractor

(3) Vehicle configuration, for hire or not

(4) The number of brakes OOA

(5) Average percentage adjustment needed to bring all brakes into proper alignment; the numbers in parentheses indicate the order of importance of the factors effecting stops from 20 mph for most vehicle configurations.

With regard to the number of brakes OOA, an additional 0.5 to 1.5 feet per OOA brake was required to stop from 20 mph. (To put this additional distance in perspective, the FMCSR required stopping distance from 20 mph is 40 feet for combination vehicles.)

Having examined the results given in [1], the following initial assessments appear to be pertinent to our current study of brake adjustment:

(1) Straight trucks with less than three axles tend to have hydraulic brakes, and hence, the data for 2-axle trucks should be eliminated from consideration in the study of pneumatically actuated s-cam brakes. (We have done this in the tables selected from [1] and presented in Appendix D.A.)

(2) Although the comparison with results from 1974 is interesting and important, the comparison is not useful for this study. (Comparisons with

1974 results have been eliminated from the tables presented in Appendix D.A.)

(3) Vehicle weight has a large influence on braking performance in stopping distance tests. The data needs to be sorted by weight since weight is a first order determinant of stopping distance for brake-torque-limited heavy trucks.

(4) The data concerning the number of brakes OOA and the average percentage adjustment appears to be influenced by vehicle weight. Perhaps the original data could be analyzed to separate the contribution of vehicle weight from the results for brake adjustment.

(5) Analyses performed in the current study indicate that the stopping distance attained in a 20 mph stop is highly dependent upon pressure delays and rise-times in the braking system. Since brake timing was not measured for the vehicles involved in the tests, the influences of brake timing was not measured for the vehicles involved in the tests. Although measurements of brake timing were probably impractical then, the results nevertheless have an important source of variability which could be investigated now (if brake timing were to be measured.)

(6) The data indicate that drivers do much better on subsequent braking trials than they do on the first trial. this points out that there is a source of variability due to driver characteristics and experience in performing stopping distance testing. (This situation is supported by our past experience in which we have found that test drivers can stop in shorter distances than over-the-road-drivers in braking performance tests.)

Pertinent results from [1] are tabulated in Appendix D.A. and Appendix D.B. contains a list of questions based on Items (a) through (f).

Findings that corroborate and extend the results presented in Reference [1] were obtained by reviewing studies performed by NTSB [4] and New York State [5]. The results of the NTSB investigation of thirty-two accident cases involving heavy trucks with brake problems fit in well with the results of the OMC study conducted in 1984. With respect to brake adjustment, the NTSB study found that older trucks were worse than newer trucks. Large fleets have newer trucks and better levels of brake adjustment than smaller fleets. NTSB recommends that NHTSA require automatic slack adjusters and that fleets provide (a) driver training on adjustment, plus (b) indicator for OOA brakes.

The New York State study involved working with six truck fleets. The study included 1,003 inspections on fifty-five tractors and forty-five trailers. Pertinent findings are as follows:

•Trailer axles should be adjusted at an interval less than 5,000 miles–especially the rear axle which experiences the greatest amount of wear.

•The front tractor axle has few problems. The front drive axle has some problems, but the brakes on the rear drive axle need to be adjusted every 3,000 miles for eight of ten brakes to remain in adjustment.

•Automatic slack adjusters work very well if they are properly maintained (not so well otherwise).

•Drivers and mechanics often adjust brakes without reporting it and without training in some cases. All mechanics and all drivers should be trained in proper brake adjustment procedures including reporting when brakes are adjusted.

•Brake wear is rapid during the break-in of new brake linings. (This implies that wear history is non-linear such that linear extrapolations from initial periods of wear will not be representative of long-term wear–such extrapolations would over-predict brake wear.)

•If the trailer hand control valve is used frequently, trailer brakes will wear rapidly and these brakes will need to be monitored closely.

•Some vehicles have repetitive adjustment problems. Vehicles that have weekly adjustment problems should be identified and their brake systems should be given a thorough inspection.

•The participating companies did not experience totally similar problems. Each company needs to analyze its experience and develop separate adjustment criteria for both tractors and trailers. (The factors of influence were believed to include road traffic and type plus driver habits including the use of the trailer trolly valve and retarders.)

•It was difficult (practically impossible in some cases) to document trailer miles traveled. Perhaps a time-based adjustment interval should be developed for trailers. (Again, each company would need to develop its own periodic maintenance schedule for trailer brakes.)

Reference [2] is a user's manual with some technical detail on computing an average brake temperature. It contains no measured data.

The grade severity range system [2] uses gross vehicle weight plus the physical characteristics of the downgrade to predict an average brake temperature at the end of the descent. Predictions for various speeds of descent (control) speeds) are used to determine a relationship between gross-vehicle weight and control speed such that the average brake temperature (including a rapid stop at the bottom of the descent) will be less than 500°F. These predictions form the basis for "weight specific speed" (WSS) signs that inform drivers of the appropriate target (control) speed to use as a function of vehicle weight.

This manual gives instructions on how to inspect a site and install WSS signs. These directions, although they are important, are not particularly relevant to the current study. However, the prediction of brake temperature is relevant to the analysis of the influences of brake adjustment levels.

Reference [2] gives the equations used to predict average brake temperature. These results could be compared with predictions of individual brake temperatures [6] in the analyses to be performed in Task E. (We expect reasonable correspondence between the individual and average temperature predictions because they are based on similar theory using "bulk" temperature calculations.)

Information from Reference [7] may be used in Task E to aid in evaluating predictions of brake temperatures. For example, [7] gives the following "rules of thumb:"

•Drum expansion is 0.01" per 100°F temperature increase.

•Pushrod force decreases by 250 pounds per 100°F for brake adjustment at 1.75" and 80 psi brake line pressure.

•Pushrod travel increases 0.07" per 100°F. (This appears to be low according to other work that we did. Perhaps 0.1" per 100°F would be better.)

An extensive amount of experimental work has been performed to investigate the effect of brake adjustment on braking performance (see Reference [13]). The study [3] included (a) stopping distance tests on a single unit truck and two tractor trailer combinations, (b) brake dynamometer tests on six types of s-cam brakes, and (c) computer simulations to extend the results to situations not tested.

The vehicle configurations used in stopping performance tests were 6.4 straight truck a 3-S2 tractor semitrailer combination, and a 2-S1-2 doubles combination. The vehicles were instrumented to measure deceleration, speed, stopping distance, control line pressure, brake lining temperature, and wheel lockup. Also, pushrod force and stroke were measured at the brake chambers. Stopping-distance tests were made at selected levels of brake adjustment. These tests were run on a good dry surface using initial speeds of 20 and 60 mph. These data provide deterministic, quantitative information that will be useful in evaluating the influences of brake adjustment.

Tests were also conducted on a curved path on a slippery, wet surface. Although these tests are important with respect to directional control during braking and the influences of side to side misadjustment of the brakes on the front axle, it does not appear that these results will be used in the current study because OOS criteria no longer contains special provisions pertaining to the adjustment of the steering axle brakes.

The vehicle test results involve many combinations of levels of brake adjustment at various brakes—thirty-one cases for the truck, twenty for the 3-S2, and thirty-two for the double, plus tests at high brake temperatures and for lightly-loaded vehicles. Pertinent tables from [3] are presented in Appendix D.C. These data are assessed to be a definitive source of information on the influences of various levels of brake adjustment on stopping distance.

In addition to vehicle test results, [3] contains an extraordinary set of dynamometer data indicating the effect of brake adjustment on brake torque. These data are fundamental to analyzing the influence of brake adjustment on stopping distance. They were used in [3] to develop a mathematical model for predicting stopping distance performance (and we expect to use it in our work later in this project). The following excerpts from [3] describe the brakes and procedures covered in the dynamometer tests. An example set of results follows the excerpts. These results illustrate the influence of cold stroke and temperature on brake torque for a typical 30x6 s-cam brake.

"The dynamometer tests were used to determine the effect of brake adjustment on the brake torque output under various operating conditions. In addition, the data collected were used in developing a computerized mathematical model of the brake. Both of these require a wide range of operating conditions such as brake pressure, shaft speed and initial temperature.

Various brake configurations were tested to determine the sensitivity of these configurations to brake adjustment. Prior to testing each of these configurations, a new set of ABEX 614 EF asbestos linings was installed. The configurations tested were:

1. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum

2. 16.5" Double Anchor Pin Brake, Type 214 Chamber, 6" Slack Adjuster and a Cast Drum

3. 15 x 4" Double anchor Pin Brake, Type 20 Chamber, 5.5" Slack Adjuster and a Cast Drum

4. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Fabricated Drum

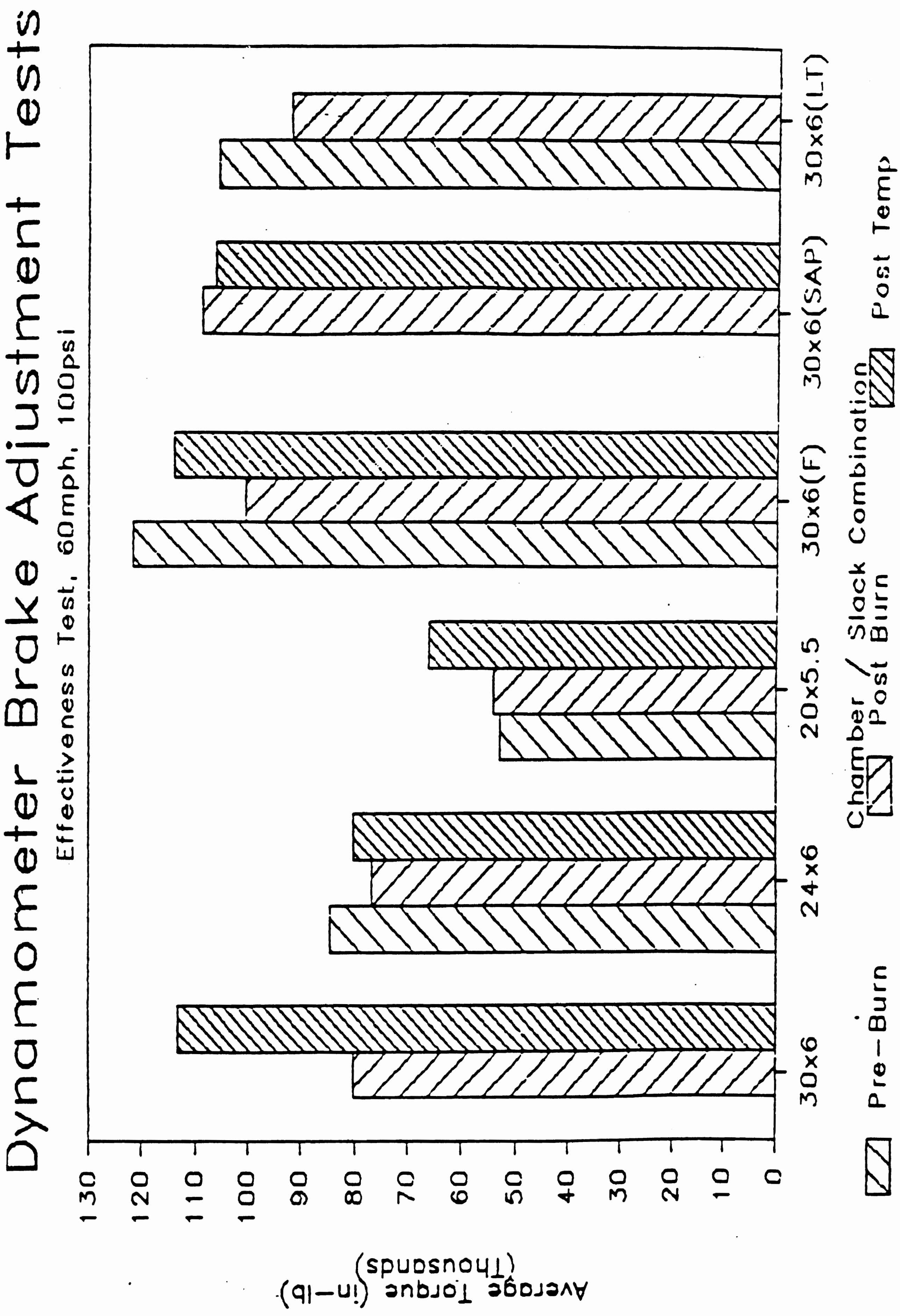
5. 16.5 x 7" Single Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum

6. 16.5 x 7" Double Anchor Pin Brake, Type 30 Chamber, 6" Slack Adjuster and a Cast Drum with Modified Conditioning Phase.

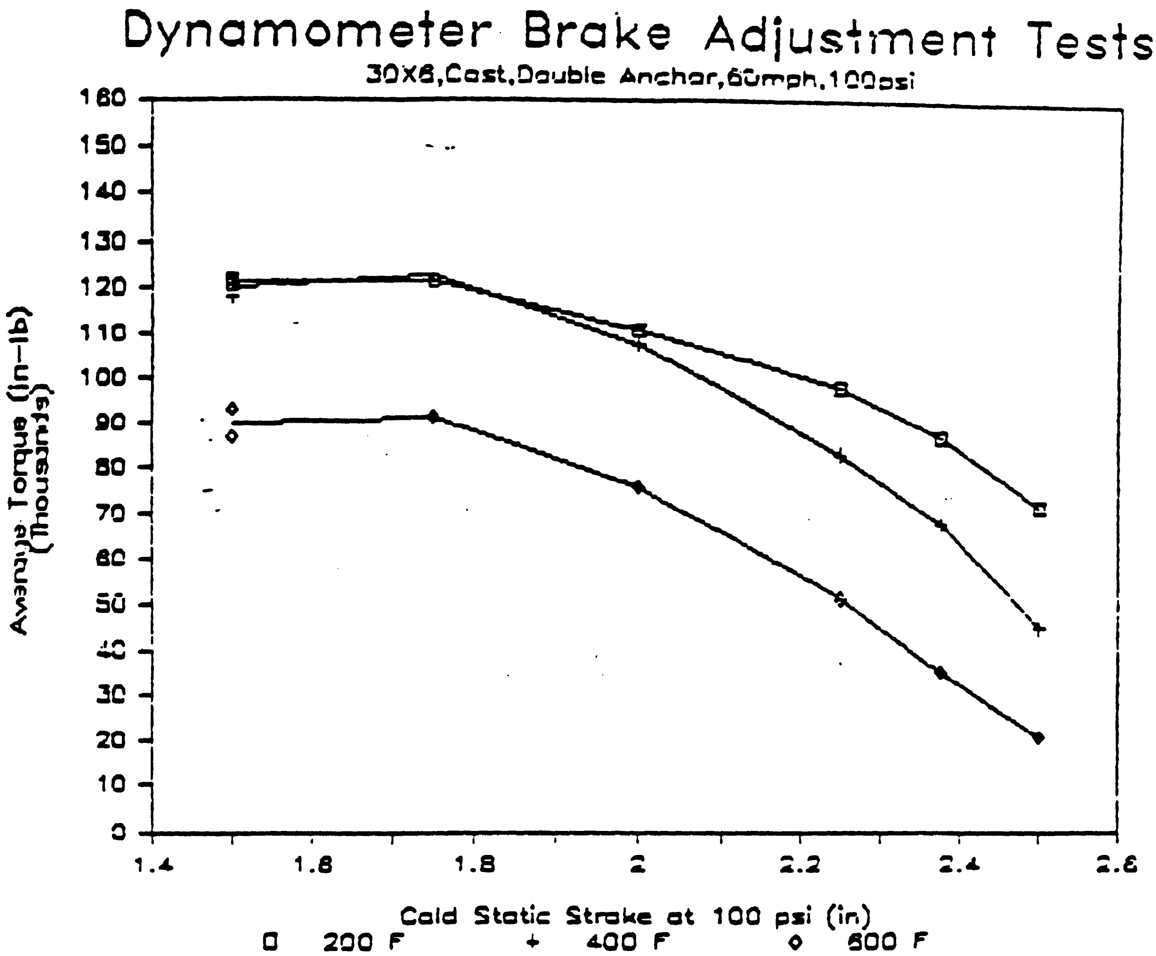
The test procedure used for dynamometer testing is given in Table 13. The brake conditioning phase of the test was run at the beginning of each brake configuration to stabilize the new brake linings."

Table 13. Dynamometer test schedule from [3]

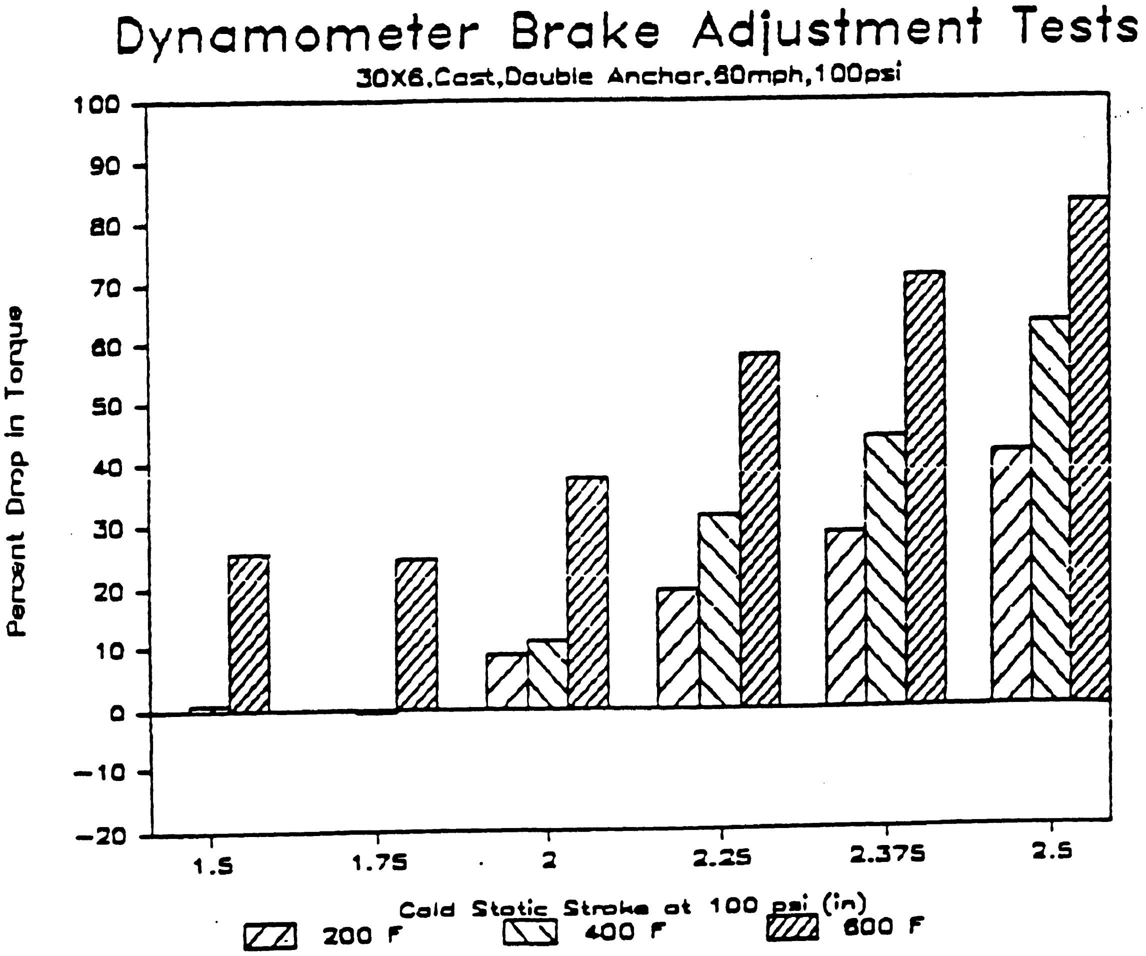
Number of Stops	Speed (mph)	Pressure (psi)	Decel (ft/s/s)	Initial Temperature (°F)
Brake Conditioning Phase				
Pre-burnish Effectiveness				
5	60-0	100		150
Burnish				
1000	40-0		10	500
Post Burnish Effectiveness				
5	60-0	100		150
High Temperature Conditioning				
10	60-0	100		700
Post Temperature Conditioning Effectiveness				
5	60-0	100		150
Brake adjustment Tests (Repeat Sequence Three Times for Each Adjustment Level)				
Static Measurement		100		150
1	20-0	100		200
1	40-0	100		200
1	60-0	20		200
1	60-0	60		200
1	60-0	100		200
Static Measurement		100		600
1	20-0	100		600
1	40-0	100		600
1	60-0	20		600
1	60-0	60		600
1	60-0	100		600


Dynamometer Brake Adjustment Tests
Effectiveness Test, 60mph, 100psi
Average Torque (in-lb) (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
30x6
24x6
20x5.5
30x6(F)
30x6(SAP)
30x6(LT)
Chamber / Slack Combination
Pre-Burn
Post Burn
Post Temp

Source: [3]



Dynamometer Brake Adjustment Tests
30X6,Cast,Double Anchor,60mph,100psi
Average Torque (in-lb) (Thousands)
Cold Static Stroke at 100 psi (in)
200 F
400 F
600 F



Dynamometer Brake Adjustment Tests
30X6,Cast,Double Anchor,60mph,100psi
Percent Drop in Torque
Cold Static Stroke at 100 psi (in)
200 F
400 F
600 F

Source: [3]

The model developed in [3] includes (a) the influences of the apply times of the brakes, (b) the relationship between pressure, stroke, and torque for each brake (including factors representing drum expansion during the stop and self-actuation), and (c) simple integration algorithms for integrating deceleration to obtain velocity and integrating again to obtain stopping distance. The model was used to produce the following results:

Percent increase in stopping distance at minimum CVSA out-of-service levels

	200° (%)	400° (%)	600° (%)
Six Wheel Case			
50 % ≥ RA	4	24	53
20 % Defective	4	19	35
Front Imbalance	0	7	11
Front $\frac{1}{4}$" Beyond Limit	3	12	20
Ten Wheel Case			
50 % ≥ RA	4	32	49
20 % Defective	4	14	23
Front Imbalance	0	6	10
Front $\frac{1}{4}$" Beyond Limit	1	9	15

NOTE: Minimum CVSA Out-of-Service Levels - At out-of-service criteria with all other brakes fully adjusted.

50 ≥ RA - Earlier CVSA Out-of-Service Level which has since been removed.

Conditions Resulting in 20 Percent Increase in Stopping Distance Not Covered by CVSA Criteria

Number of Wheels at Given Adjustment Level

Initial Brake Temperature	Fully Adj - Readj Point	Readj Point - Readj Point+0.25in	Readj Point+0.25in - Backed Off	Backed Off
Six Wheel Case				
200°F	5	0	0	1
400°F	5	1	0	0
	5	0	1	0
	4	2	0	0
	6	0	0	0
Ten Wheel Case				
200°F	9	0	0	1
400°F	8	2	0	0
	8	1	1	0
	9	1	0	0
	7	3	0	0
	9	0	1	0
	10	0	0	0

The appendices D.A. and D.C. which follow the references, contain tables of data thereby providing a compact presentation of selected results from References [1] and [3].

REFERENCES

[1] E.O. Hargadine and T.M. Klein, "Braking Performance Level of Trucks: 1983," Contract No. DTFH61-83-C-00082, September 1984, available from NTIS.

[2] B.L. Bowman, "Grade Severity Rating System (GSRS) - Users Manual," Contract No. DTFH61-86-C-00116, May 1988, available from NTIS.

[3] M.A. Flick, "The Effect of Brake adjustment on Braking Performance," Report No. DOT HS 807 287, April 1988, available from NTIS.

[4] National Transportation Safety Board, "Braking Deficiencies on Heavy Trucks in 32 Selected Accidents," Accession No. PB88-917008, available from NTIS.

[5] New York State Traffic and Safety Division Commercial Vehicle Safety Program, "Study of Brake adjustments Tractors and Trailers," supplied by M.J. Ryan, Chief, Hazardous Materials and Commercial Motor Vehicle Safety.

[6] University of Michigan Transportation Research Institute (UMTRI) Engineering Research Division, "Simplified Models of Truck Braking and Handling," February 1988, available from UMTRI.

[7] R. Limpert and D.F. Andrews, "Analysis of Truck Braking Accidents," SAE Paper No. 870504.

APPENDIX G

SELECTED DATA FROM REFERENCE [1]

DISTRIBUTION OF VEHICLES BY FOR-HIRE STATUS

VEHICLE CONFIGURATION	FOR HIRE	NOT FOR HIRE	UNKNOWN	TOTAL
Single Unit Truck				
3-axle	40% (21)	54% (28)	6% (3)	100% (52)
Tractor-Semi Combination				
2-S1	24% (21)	76% (68)	0% (0)	100% (89)
2-S2	50% (16)	50% (16)	0% (0)	100% (32)
3-S2+	74% (99)	24% (32)	2% (2)	100% (133)
Truck-Trailer Combination	27% (12)	69% (31)	4% (2)	100% (45)
Double Bottom Trailer	28% (11)	65% (26)	7% (3)	100% (40)
TOTAL	180	201	10	391

AVERAGE TRUCK/TRACTOR AND TRAILER AGE (YEARS)

VEHICLE CONFIGURATION	TRUCK/TRACTOR (Years)	TRAILER (Years)
Single Unit Truck		
3-axle	6.6	NA
Tractor-Semi Combination		
2-S1	5.3	9.2
2-S2	5.8	9.8
3-S2+	7.5	7.2
Truck-Trailer Combination	7.7	9.3
Double Bottom Trailer	6.4	7.9

AVERAGE NUMBER AND PERCENTAGE OF BRAKES OUT OF ADJUSTMENT PER VEHICLE

VEHICLE CONFIGURATION	AVERAGE NUMBER	PERCENTAGE	SAMPLE SIZE
Single Unit Truck			
3-axle	1.92	31%	49
Tractor-Semi Combination			
2-S1	1.91	32%	87
2-S2	2.09	26%	32
3-S2+	3.02	30% ***	133
Truck-Trailer Combination	2.50	26%	38
Double Bottom Trailer	5.53	36%	38
TOTAL		30%	377

PERCENTAGE OF VEHICLES TESTED MEETING FMCSR REQUIREMENTS DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE CONFIGURATIONS		1984 PASSED (%)
Single Unit Truck		
3-axle		38
Tractor-Semi Combination		
2-S1		53
2-S2		59
3-S2+		45
Truck-Trailer Combination		51
Double Bottom Trailer		40

Using the pushrod measurements, the average percentage adjustment required to maintain the vehicle in-service was calculated for each brake for each vehicle. For example, for a clamp type brake chamber with a 30 square inch effective area (type 30), the maximum stroke at which brakes should be adjusted (the out-of-service level) is 2 inches. If the actual measurement obtained during the test was two and one half inches, then the percentage adjustment required to maintain the vehicle in-service was calculated as [(2.5 - 2.0)/2.0] or 25 percent. The average percentage adjustment required was obtained by averaging the individual percentage adjustments required.

AVERAGE PERCENTAGE ADJUSTMENT REQUIRED

VEHICLE CONFIGURATIONS	
Single Unit Truck	
3-axle	18%
Tractor-Semi Combination	
2-S1	15%
2-S2	16%
3-S2+	14%
Truck-Trailer Combination	20%
Double Bottom Trailer	19%

AVERAGE STOPPING DISTANCE (feet)
DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE CONFIGURATIONS	FMCSR Req. (20 mph)	1984 (ft)
Single Unit Truck		
3-axle	35	39.1
Tractor-Semi Combination		
2-S1	40	41.7
2-S2	40	37.9
3-S2+	40	41.9
Truck-Trailer Combination	40	42.8
Double Bottom Trailer	40	47.8

AVERAGE STOPPING DISTANCE (feet)
DETERMINED BY SHORTEST STOPPING DISTANCE

VEHICLE CONFIGURATION	FMCSR Req. (20 mph)	1984 (ft)
Single Unit Truck		
3-axle	35	36.4
Tractor-Semi Combination		
2-S1	40	38.1
2-S2	40	35.7
3-S2+	40	38.9
Truck-Trailer Combination	40	39.9
Double Bottom Trailer	40	45.6

PERCENTAGE OF VEHICLES TESTED MEETING FMCSR REQUIREMENT USING THE SHORTEST STOPPING DISTANCE

VEHICLE CONFIGURATIONS		1984 OVERALL (%)
Single-Unit Truck		
3-axle		56
Tractor-Semi Combination		
2-S1		69
2-S2		81
3-S2+		59
Truck-Trailer Combination		69
Double Bottom Trailer		43

AVERAGE STOPPING DISTANCE BY TEST

	Sample Size	Average Stopping Distance (ft)
TEST #1	518	40.0
TEST #2	392	37.8
TEST #3	200	37.0

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS DETERMINED BY THE FIRST STOPPING DISTANCE

VEHICLE TYPES	MD	CA	MI	TOTAL
Single Unit Truck				
3-axle	41%(32)	22% (9)	45%(11)	38%(52)
Tractor-Semi Combination				
2-S1	67% (3)	34%(35)	65%(51)	53%(89)
2-S2	67%(12)	33% (9)	73%(11)	59%(32)
3-S2+	47%(94)	35%(26)	54%(13)	45%(133)
Truck-Trailer Combination	-	26%(23)	86%(22)	51%(45)
Double Bottom Trailer	-	36%(11)	41%(29)	40%(40)
TOTAL	141	113	137	391

FIRST STOPPING DISTANCE AND TOTAL WEIGHT BY STATE

VEHICLE CONFIGURATION	MD (0.95)	CA (0.76)	MI (0.85)
Single Unit Truck			
3-axle	38.8	40.6	38.7
	29,530	29,056	33,675
Tractor-Semi Combination			
2-S1	39.7	46.6	38.4
	20,333	31,682	29,635
2-S2	36.3	42.1	36.2
	37,331	39,304	33,036
3-S2+	41.3	43.4	43.2
	48,998	52,818	60,125
Truck-Trailer Combination	-	48.8	36.0
	-	73,340	32,229
Double Bottom Trailer	-	49.5	47.5
	-	51,882	83,725

AVERAGE STOPPING DISTANCE AND TOTAL WEIGHT

VEHICLE TYPES	FIRST STOPPING DISTANCE (feet) PASSED	FAILED	TOTAL WEIGHT (lbs.) PASSED	FAILED	PERCENTAGE DIFFERENCE IN WEIGHT PASS VS. FAIL
Single Unit Trucks					
3-axle	29.9	44.8	30224	30388	1
Tractor-semi Combination					
2-S1	34.0	50.2	28186	32382	15
2-S2	32.9	45.2	34212	40013	17
3-S2+	33.8	48.6	43768	56472	29
Tractor-trailer Combination	34.3	51.7	37757	71299	89
Double Bottom Trailer	35.6	55.9	55007	87079	58

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY FOR-HIRE STATUS

VEHICLE CONFIGURATION	FOR HIRE	NOT FOR HIRE
Single Unit Truck		
3-axle	24% (21)*	46% (28)
Tractor-Semi Combination		
2-S1	48% (21)	54% (68)
2-S2	56% (16)	63% (16)
3-S2+	40% (99)*	59% (32)
Truck-Trailer Combination	33% (12)	56% (32)
Double Bottom Trailer	36% (11)	44% (25)
TOTAL	180	201

COMPARISON OF THE AVERAGE NUMBER OF BRAKES OUT OF ADJUSTMENT

VEHICLE CONFIGURATION	MD	CA	MI
Single Unit Truck			
3-axle	1.47 (32)	2.00 (10)	3.55 (11)
Tractor-Semi Combination			
2-S1	1.75 (4)	1.43 (37)	2.32 (50)
2-S2	1.85 (13)	2.40 (10)	2.27 (11)
3-S2+	3.13 (98)	1.84 (31)	4.15 (13)
Truck-Trailer Combination		2.25 (12)	6.81 (27)
Double Bottom Trailer		2.13 (23)	2.88 (16)

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY THE NUMBER OF BRAKES OUT OF ADJUSTMENT

NUMBER OF BRAKES OUT OF ADJUST	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0	35%(17)	55%(22)	45%(11)	58%(26)	42%(12)	57%(7)
1	20%(5)	58%(12)	67%(3)	25%(16)	67%(3)	0%(2)
2	54%(13)	54%(28)	100%(3)	50%(24)	71%(7)	33%(3)
3	100%(1)	67%(6)	43%(7)	56%(16)	20%(5)	67%(3)
4	38%(8)	67%(15)	100%(5)	54%(13)	40%(5)	57%(7)
5	33%(3)	25%(4)	100%(1)	27%(15)		100%(1)
6	50%(2)		0%(2)	67%(12)	50%(2)	0%(2)
7				20%(5)	100%(1)	33%(3)
8				0%(3)	67%(3)	0%(1)
9				0%(1)	100%(1)	
10				0%(1)		0%(1)
11						0%(2)
12					0%(1)	
13				0%(1)		
14					0%(1)	0%(4)
15					23%(13)	100%(1)
16					0%(7)	0%(1)

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY 5,000 LB. WEIGHT INTERVALS

WEIGHT (000 lbs)	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0- 5						
5- 10						
10- 15	0%(1)				100%(1)	
15- 20	40%(5)	67%(3)	100%(1)		100%(1)	
20- 25	36%(14)	81%(21)	100%(2)	50%(2)	80%(5)	
25- 30	45%(11)	32%(22)	88%(8)	64%(25)	100%(1)	25%(4)
30- 35	43%(7)	61%(18)	20%(5)	73%(22)	100%(3)	
35- 40	50%(2)	60%(15)	40%(5)	28%(7)	100%(10)	100%(3)
40- 45	25%(8)	14%(7)	100%(5)	50%(6)	0%(1)	44%(9)
45- 50	100%(1)	0%(3)	0%(3)	83%(6)	100%(1)	50%(4)
50- 55	50%(2)		50%(2)	25%(4)		100%(2)
55- 60			0%(1)	22%(9)		67%(3)
60- 65	0%(1)			14%(7)	0%(1)	
65- 70				15%(13)		
70- 75				44%(18)	0%(1)	0%(1)
75- 80				18%(11)	23%(13)	
80- 85				0%(1)	0%(7)	50%(2)
-//-						
110-115				100%(1)		0%(1)
115-120						0%(1)
120-125				0%(1)		0%(1)
125-130						0%(2)
130-135						0%(1)
135-140						0%(1)
140-145						
145-150						0%(1)
150-155						25%(4)
TOTAL	38%(52)	53%(89)	58%(32)	45%(133)	51%(45)	40%(40)

INDICATORS OF BRAKE ADJUSTMENT

VEHICLE TYPES	NUMBER OF BRAKES OUT OF ADJUST.		AVERAGE PERCENT ADJUST REQ'D	
	PASSED	FAILED	PASSED	FAILED
Single Unit Trucks			—	—
			—	—
3-axle	2.1	1.8	13.0	20.8
Tractor-semi Combination				
2-S1	1.7	2.1	17.0	12.2
2-S2	2.2	1.9	16.2	15.6
3-S2+	2.6	3.3	17.9	10.5
Tractor-trailer Combination	2.7	2.3	16.6	23.4
Double Bottom Trailer	3.6	6.5	22.8	15.8

PERCENTAGE OF VEHICLES MEETING FMCSR REQUIREMENTS BY AGE OF TRUCK/TRACTOR

TRUCK/ TRACTOR AGE (years)	Single-unit truck	Tractor-semi comb.				
	3-axle	2-S1	2-S2	3-S2+	Truck-Trailer	Double Bottom
0	100%(3)	100%(4)	50%(2)	0%(3)		75%(4)
1	33%(6)	33%(3)	100%(3)	75%(8)		100%(2)
2	100%(1)	54%(13)	100%(4)	50%(10)	0%(1)	50%(2)
3	20%(5)	60%(5)	0%(1)	75%(4)	100%(1)	0%(1)
4	40%(5)	75%(12)	75%(4)	57%(14)	50%(2)	40%(5)
5	60%(5)	43%(21)	80%(5)	47%(15)	78%(9)	0%(4)
6	43%(7)	40%(5)	40%(5)	40%(5)	78%(9)	75%(4)
7	100%(1)	40%(5)		67%(6)	0%(2)	0%(3)
8		67%(3)	0%(1)	30%(10)	75%(4)	0%(1)
9	33%(3)	67%(3)	0%(1)	13%(8)	0%(3)	
10	25%(4)	50%(4)	33%(3)	42%(12)	20%(5)	40%(5)
11	0%(3)	17%(6)		45%(11)	50%(4)	0%(3)
12	40%(5)	50%(2)	0%(1)	50%(4)	50%(2)	33%(3)
13				33%(3)	0%(1)	
14		100%(1)	100%(1)	100%(2)		50%(2)
15	0%(1)	100%(1)		0%(5)	0%(1)	
16				0%(2)	0%(1)	
17	0%(1)			0%(1)		
18	0%(2)			67%(3)		
-//-						
25				0%(1)		
28			0%(1)			
TOTAL	38%(52)	53%(88)	56%(32)	44%(127)	51%(45)	38%(39)

AVERAGE TRUCK/TRACTOR AND TRAILER AGE (YEARS)

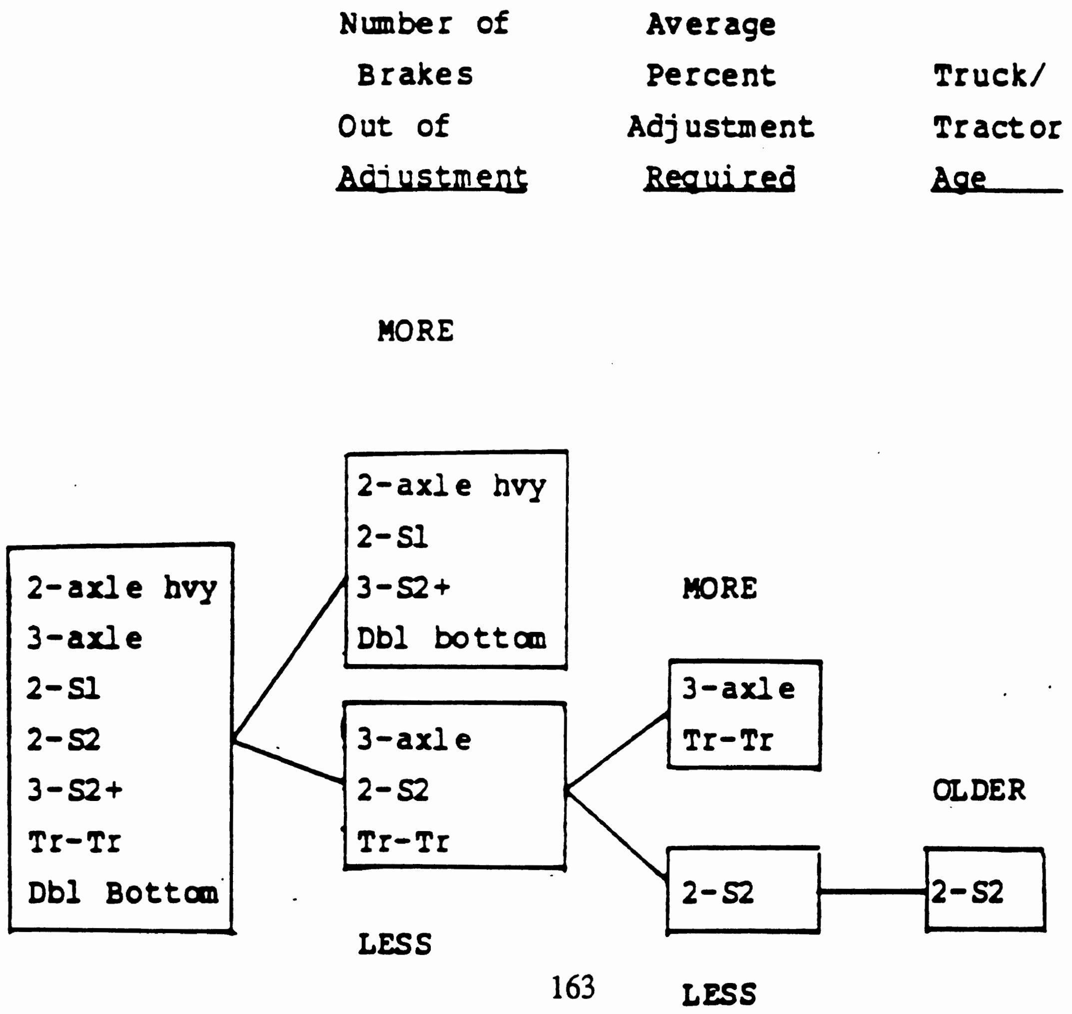
VEHICLE TYPES	TRUCK AGE		TRAILER AGE	
	PASSED	FAILED	PASSED	FAILED
Single Unit Truck				
3-axle	4.9	7.7	NA	NA
Tractor-Semi Combination				
2-S1	5.0	5.7	8.7	9.7
2-S2	4.2	8.1	10.2	9.3
3-S2+	6.6	8.3	7.1	7.2
Truck-Trailer Combination	6.6	8.9	6.1	12.7
Double Bottom Trailer	5.1	7.2	5.3	9.7

Factors affecting braking performance for most vehicle configurations in order of importance are:

- o total weight,
- o age of the truck/tractor,
- o whether the vehicle was operated for hire,
- o the number of brakes out of adjustment, and
- o the average percentage adjustment required to maintain the vehicle in-service.

No single factor, such as total weight or number of brakes out of adjustment, adequately explained the vehicles' compliance status. Nor did any single regression model combining these factors adequately explain the results for the various configurations. However, the regression coefficients obtained for the relationship of the number of brakes out of adjustment and stopping distance indicated that an additional 0.5 to 1.5 feet per out-of-adjustment brake was required to stop.

WHY DID THEY FAIL?



APPENDIX H

QUESTIONS CONCERNING MATERIAL IN REFERENCE [1]

- Are heavier vehicles likely to have brakes in adjustment?

- Why not leave out 2-axle vehicles because they are largely hydraulically braked?

- Are older trailers maintained better?

- Why not use pounds of load per axle in comparison?—or some weighting of brake power per pound of load carried?

- Seems like percentage adjustment required out to work better than the number of brakes OOA (all else being equal). Perhaps something (such as weight or pressure delays) correlates with the number of brakes OOA or the percentage adjustment required?

- Are the maintenance practices of "not-for-hire" carriers better than those of "for-hire" carriers?

- What do you do about physically impossible results which imply that something else was uncontrolled?—in particular, the number of brakes OOA versus percentage adjustment required. Perhaps information on brake timing is needed to explain these results. Also vehicle weight must be accounted for.

APPENDIX I

SELECTED DATA FROM REFERENCE [3]

TABLE 2
6 X 4 Truck Straight Line Stopping Distance
Test Results

Condition	Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted w/ALV	A	35	82	307	80
Fully Adjusted	1	37	82	288	84
#1 FA, #2 @ 2", #3-#6 FA	* 2	37	85	290	85
No Fronts, #3-#6 FA	* 3	43	83	341	90
#1-#2 @ 2.125", #3-#6 FA	* 4	37	100	310	85
#1-#2 FA, #3-#4 @ 2.5", #5-#6 FA	* 5	51	100	481	100
Fully Adjusted	6	34	100	282	85
#1-#5 FA, #6 @ 2.25"	7	34	100	296	85
#1-#3 FA, #4-#6 @ 2"	* 8	36	100	311	80
#1-#2 @ 1.75", #3 @ 2", #4-#6 FA	* 9	35	100	293	80
#1-#2 @ 1.625", #3-#6 @ 1.875"	10	37	100	293	90
#1-#2@1.625", #3-#4@2.25", #5-#6@1.875"	* 11	38	100	297	100
Fully Adjusted	12	35	100	300	80
Fully Adjusted	13	35	100	290	85
#1-#2 @ 1.75", #3-#6 @ 2"	* 14	38	100	309	90
#1-#2 @ 1.5", #3-#6 @ 1.875"	15	36	100	305	85
No Fronts, #3-#6 @ 1.875"	* 16	41	100	354	85
#1 @ 2", #2 @ 1.5", #3-#6 @ 1.875"	* 17	38	100	306	85
#1-#2@1.5", #3@2.25", #4-#6@1.875"	18	37	100	297	90
#1-#2 @ 1.5", #3-#6 @ 1.875"	19	37	100	299	85
Fully Adjusted	20	34	100	306	80
#1-#2 @ 1.75", #3 @ 2", #4-#6 @ 1.875"	* 21	36	100	347	100
Fully Adjusted	22	35	85	315	75
#1-#2 @ 1.625", #3-#6 @ 1.875"	23	36	100	308	85
#1-#2 FA, #3-#4 @ 2.5", #5-#6 FA	* 24	48	100	460	100
#1-#2@1.625", #3-#4@2.25", #5-#6@1.875"	* 25	38	100	318	80
#1-#2 @ 1.75", #3-#6 @ 2"	* 26	38	100	291	100
Fully Adjusted	27	35	95	283	85
#1-#2 @ 1.75", #3-#6 @ 2"	* 28	37	100	303	85
#1-#2 @ 1.75", #3 @ 2", #4-#6 @ 1.875"	* 29	38	100	324	75
#1-#2 FA, #3-#4 @ 2.375", #5-#6 FA	* 30	39	100	353	80
Fully Adjusted	31	35	100	285	85

#1 - Left Front   #3 - Left Intermediate   #5 - Left Rear
#2 - Right Front   #4 - Right Intermediate   #6 - Right Rear
FA - Fully Adjusted
* - Conditions meeting CVSA out-of-service criteria

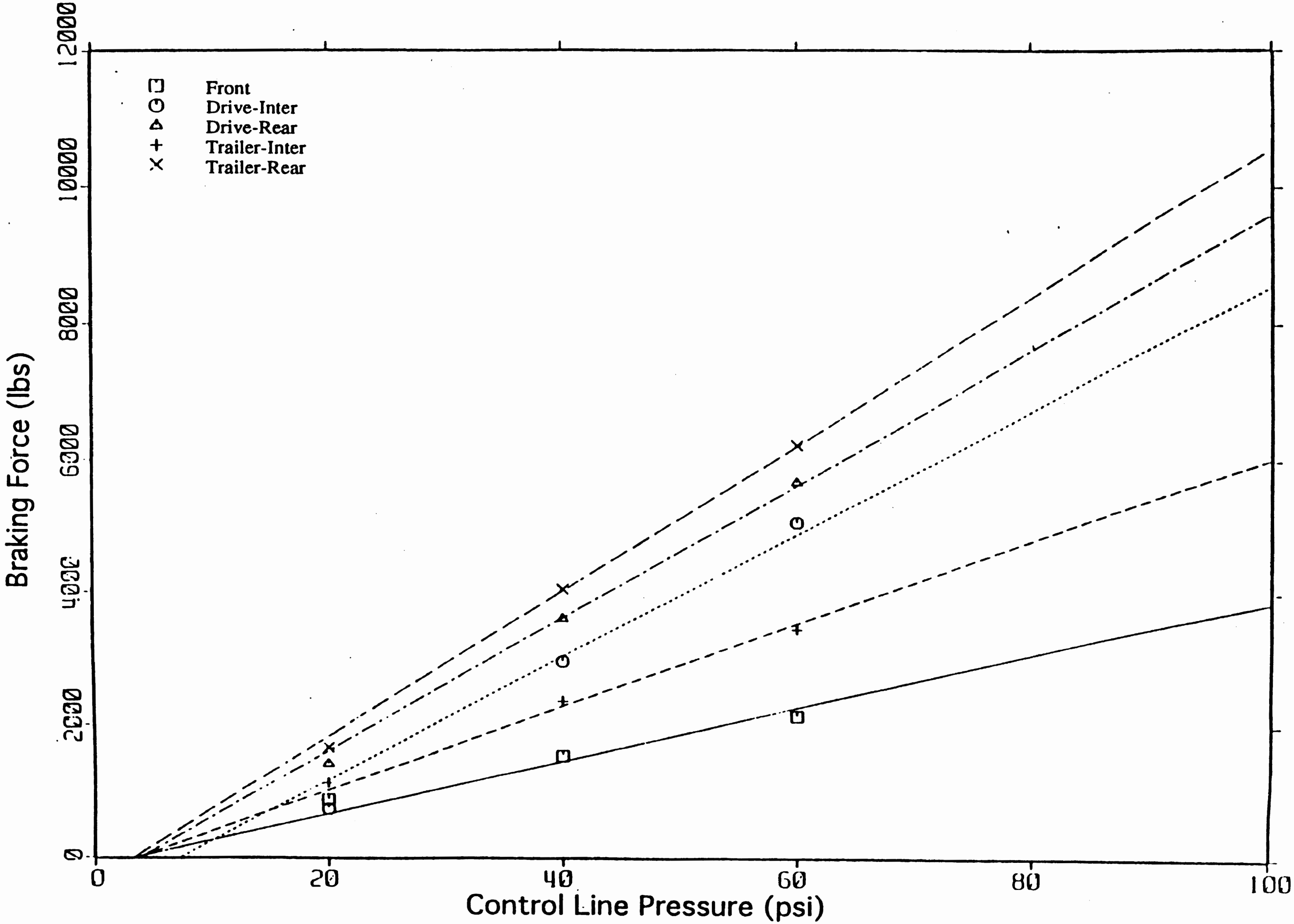
NOTE: All tests were conducted with the ALV bypassed except as noted.

TABLE 4
Tractor Semitrailer Straight Line Stopping Distance
Test Results

Condition		Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted		1	36	100	310	80
#1 FA, #2 @ 2", #3-#10 FA	*	2	36	100	309	80
#1-#2 @ 2.125", #3-#10 FA	*	3	37	100	282	90
No Fronts, #3-#10 FA	*	4	37	100	318	80
Fully Adjusted		5	35	100	295	80
#1-#2 FA, #3-#4 @ 2.5", #5-#10 FA	*	6	43	100	366	85
#1-#6 FA, #7-#8 Off, #9-#10 FA	*	7	39	100	335	85
#1-#4 FA, #5-#6 @ 2.25", #7-#10 FA	*	8	37	100	312	80
Fully Adjusted		9	36	100	309	80
#1-#5 RA, #6-#10 FA	*	10	38	100	321	80
#1-#5 FA, #6-#10 RA	*	11	37	100	299	85
#1-#4 FA, #5-#6 @ 2.375", #7-#10 FA	*	12	39	100	314	85
Fully Adjusted		13	36	100	287	90
#1-#6 FA, #7-#8 @ 2.375", #9-#10 FA	*	14	38	100	303	90
#1-#6 FA, #7-#8 @ 2.25", #9-#10 FA	*	15	37	100	291	100
Fully Adjusted		16			291	90
Fully Adjusted		17	34	100	290	85
#1-#2 FA, #3-#6 @ 2.125", #7-#10 FA		18	36	100	313	85
#1 FA, #2 @ 1.75", #3-#10 FA	*	19	36	100	286	85
Fully Adjusted		20	34	100	282	85

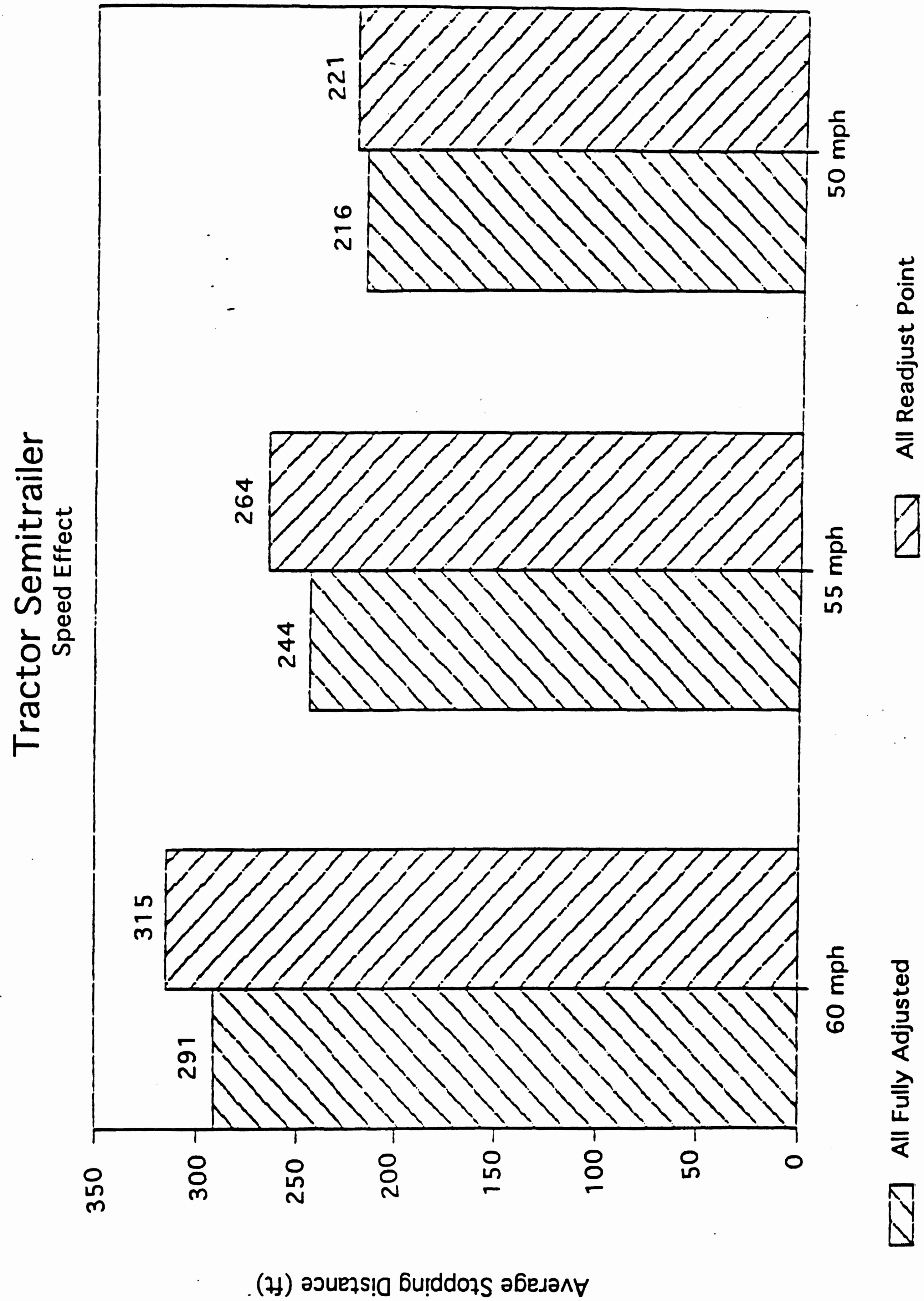
#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All test were conducted with the ALV bypassed.



Tractor Semitrailer Brake Distribution

Figure 10



Tractor Semitrailer
Speed Effect
Average Stopping Distance (ft)
350
300
250
200
150
100
50
0
291
315
244
264
216
221
60 mph
55 mph
50 mph
All Fully Adjusted
All Readjust Point

TABLE 6
Tractor Semitrailer Lightly Loaded Stopping Distance Test Results

Condition		Key	Stopping Distance (ft)	Line Pressure (psi)
20 mph Straight Line Dry Pavement Tests				
Fully Adjusted		1	34	45
Fully Adjusted w/ ALV		2	34	45
#1-#2 Off, #3-#10 FA	*	3	37	45
#1-#2 @ 1.875", #3-#10 FA		4	34	45
#1-#2 @ 1.875", #3-#10 FA w/ ALV		5	32	50
Fully Adjusted		6	33	45
60 mph Straight Line Dry Pavement Tests				
Fully Adjusted		1	301	34
Fully Adjusted w/ ALV		2	310	34
#1-#2 Off, #3-#10 FA	*	3	356	32
#1-#2 @ 1.875", #3-#10 FA		4	329	32
#1-#2 @ 1.875", #3-#10 FA w/ ALV		5	338	32
Fully Adjusted		6	317	32
35 mph Wet Jennite Curve				
Fully Adjusted		1	249	15
Fully Adjusted w/ ALV		2	266	15
#1-#2 Off, #3-#10 FA	*	3	277	15

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All test were conducted with the ALV bypassed except as noted.

TABLE 7
Tractor Semitrailer High Temperature Test Results

	Key	Initial*** Fully Adj Baseline (ft)	(psi)	Cool Brake Stops (ft)	(psi)	1st** Hot Stops (ft)	2nd** Hot Stops (ft)	Final*** Fully Adj Baseline (ft)	(psi)
Fully Adjusted	A	317	60			295	336	294	65
No Fronts, #3-#10 FA	* B	288	65	300	65	326	401	299	60
#1-#2FA,#3-#4@2.125", #5-#6FA,#7-#8@2.125", #9-#10FA	* C	299	60	334	55	322	372	283	65
#1-#2 FA,#3-#6 RA, #7-#9 FA,,#10 RA	* D	283	65	331	55	282	317	283	65
#1-#2 @ 1.5", #3-#10 @ 1.75"	E	283	65	284	65	310	336	309	60
#1-#10 RA	* F	309	60	324	60	334	413	291	65

#1 - Left Front #3 - Left Intermediate #5 - Left Rear
#2 - Right Front #4 - Right Intermediate #6 - Right Rear
#7 - Trailer Left Front #9 - Trailer Left Rear
#8 - Trailer Right Front #10 - Trailer Right Rear
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

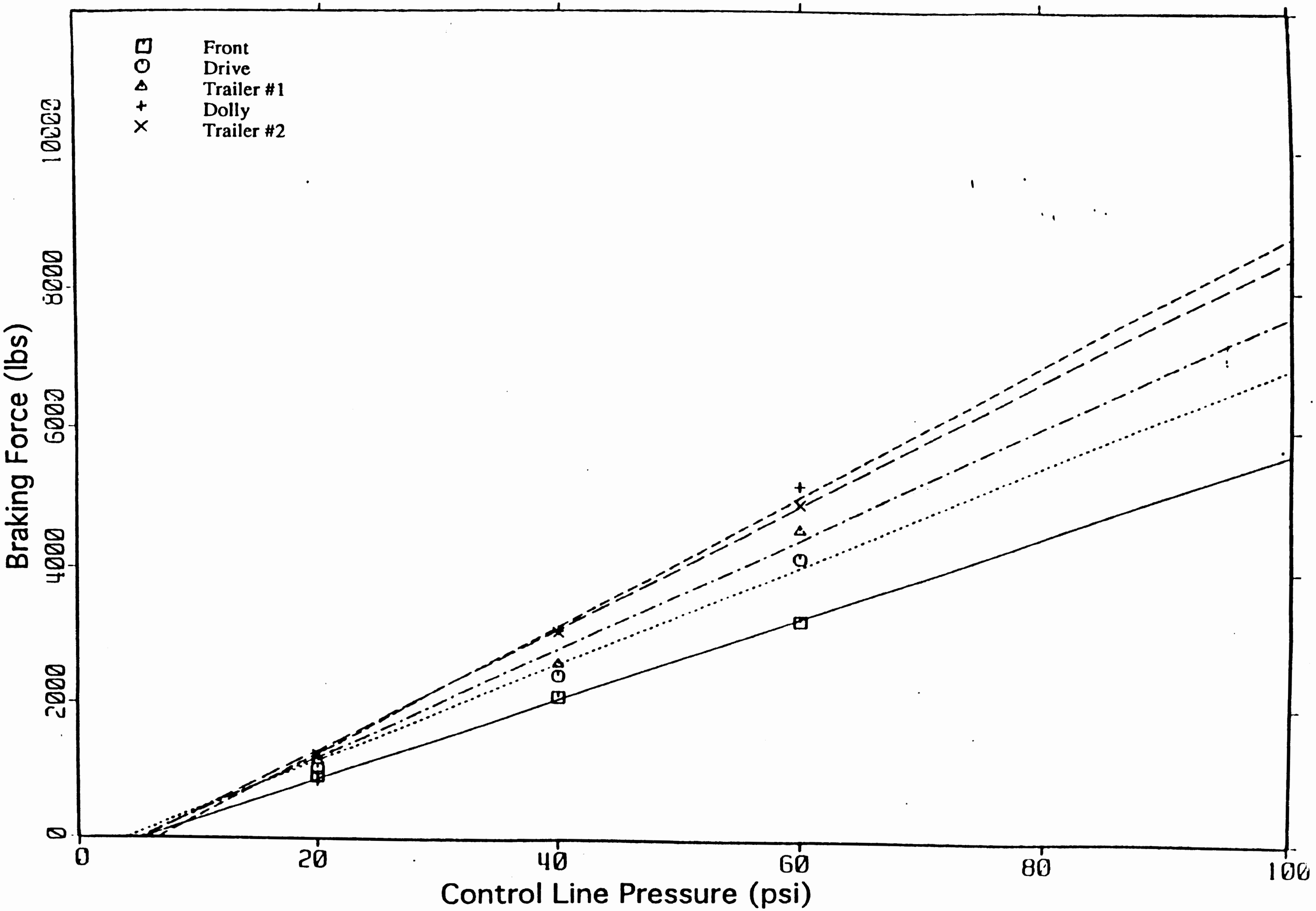
NOTE: **Average of two stops
***Average of three stops

TABLE 8
Doubles Combination Straight Line Stopping Distance Test Results

Condition		Key	20 mph Stop Dist (ft)	20 mph Line Pres (psi)	60 mph Stop Dist (ft)	60 mph Line Pres (psi)
Fully Adjusted		1	43	105	315	105
#1-#2 FA, #3-#4 @ 2.25", #5-#10 FA	*	2	46	105	341	105
#1-#6 FA, #7 @ 2.25", #8-#10 FA	*	3	43	105	312	105
#1-#8 FA, #9-#10 @ 2.25"	*	4	44	105	310	105
Fully Adjusted		5	43	105	296	105
#1-#4 FA, #5-#6 @ 2.25", #7-#10 FA	*	6	45	105	307	105
#1-#2 RA, #3-#6 FA, #7-#9 RA, #10 FA	*	7	44	105	312	105
#1-#2 FA, #3-#6 RA, #7-#9 FA, #10 RA	*	8	46	105	328	105
Fully Adjusted		9	44	105	304	105
#1-#2 FA, #3-#4 @ 2.25", #5-#10 FA	*	10	46	105	324	105
#1-#6 FA, #7 @ 2.25", #8-#10 FA	*	11	45	105	309	105
Fully Adjusted		12	43	105	293	105
#1 FA, #2 @ 2", #3-#10 FA	*	13	44	105	308	105
#1-#2 @ 2.125", #3-#10 FA	*	14	44	105	315	105
No Fronts, #3-#10 FA	*	15	49	105	340	105
Fully Adjusted		16	44	105	302	105
#1-#4 RA, #5 Off, #6-#10 RA	*	17	51	105	356	105
#1-#6 FA, #7-#8 @ 2.25", #9-#10 FA	*	18	43	105	310	105
#1-#2 FA, #3-#4 Off, #5-#10 FA	*	19	48	105	380	105
#1-#10 RA	*	20	46	105	348	105
#1 FA, #2 @ 2.125", #3-#10 FA	*	21	44	105	303	105
Fully Adjusted		22	42	105	303	105
Fully Adjusted		23	43	95	329	98
#1 @ 2", #2-#10 FA	*	24	48	96	328	98
#1 @ 2.125, #2-#10 FA	*	25	43	96	324	98
#1 Off, #2-#10 FA	*	26	45	96		
Fully Adjusted		27	43	96	309	98
Fully Adjusted		28	40	91	306	94
#1-#2 FA, #3-#6 @ 2.125", #7-#10 FA	*	29	44	91	338	85
#1-#4 FA, #5-#6 @ 2.125", #7-#8 FA, #9-#10 @ 2.125"	*	30	43	92	336	84
#1 FA, #2 @ 1.75", #3-#10 FA	*	31	42	91	290	94
Fully Adjusted		32	43	90	300	94

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
RA - At Recomended Readjustment Point
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All tests were conducted with the ALV bypassed.



Doubles Combination Brake Distribution

TABLE 11
Doubles Combination Lightly Loaded Stopping Distance Test Results

Condition	Key	Stopping Distance (ft)	Line Pressure (psi)
60 mph Straight Line Tests			
#1-#10 FA	1	307	47
#1-#10 FA w/ALV	2	298	50
No Fronts, #3-#10 FA	* 3	366	42
#1-#6 FA, No Dolly Brakes, #9-#10 FA	* 4	393	42
#1-#2 @ 1.875", #3-#10 FA	5	310	48
#1-#2 @ 1.875", #3-#10 FA w/ ALV	6	324	45
#1-#10 FA	7	308	46
35 mph Wet Jennite Tests			
#1-#10 FA	1	232	16
#1-#10 FA w/ALV	2	270	16
No Fronts, #3-#10 FA	* 3	291	15
#1-#6 FA, No Dolly Brakes, #9-#10 FA	* 4	311	14
#1-#2 @ 1.875", #3-#10 FA	5	261	14
#1-#2 @ 1.875", #3-#10 FA w/ ALV	6	333	16
#1-#10 FA	7	248	16

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
Off - Backed Off
* - Conditions meeting CVSA out-of-service criteria

NOTE: All tests were conducted with the ALV bypassed except as noted.

TABLE 12
Doubles Combination High Temperature Test Results

	Key	Initial*** Fully Adj Baseline (ft)	Cool Brake Stops (ft)	1st** Hot Stops (ft)	2nd** Hot Stops (ft)	Final*** Fully Adj Baseline (ft)
Fully Adjusted	A	286		336	348	284
No Fronts, #3-#10FA	* B	287	307	382	384	278
#1-#2FA,#3-#4@2.125", #5-#6,Fa,#7-#8@2.125", #9-#10FA	* C	278	289	351	374	279
#1-#2 FA#3-#6 RA, #7-#9 FA,#10 RA	* D	279	305	388	402	270
#1-#2 @ 1.5", #3-#10 @ 1.75"	E	270	287	346	370	273
#1-#10 RA	* F	273	304	388	412	278

#1 - Left Front #3 - Left Rear #5 - First Trailer Left
#2 - Right Front #4 - Right Rear #6 - First Trailer Right
#7 - Left Dolly #9 - Second Trailer Left
#8 - Right Dolly #10 - Second Trailer Right
FA - Fully Adjusted
RA - At Recomended Readjustment Point
* - Conditions meeting CVSA out-of-service criteria

NOTE: *Average of two stops
**Average of three stops
All tests were conducted with the ALV bypassed except as noted.

APPENDIX J

EVALUATION OF CRITERIA FOR TRUCK AIR BRAKE ADJUSTMENT

SUMMARY OF THE ANALYSES

INTRODUCTION

This report describes analyses aimed at:

(1) Assessing the influences of brake adjustment levels on stopping distance performance;

(2) Evaluating whether being able to stop within the Out-of Service (OOS) limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph within OOS limits;

(3) Identifying critical adjustment thresholds beyond which heavy vehicles cannot stop within a safe margin;

(4) Identifying key factors contributing to brake OOA for manually adjusted brakes;

(5) Developing statistical measures pertaining to the relationship between the key factors identified and stopping capability; and

(6) Providing a sound quantitative basis for confirming or changing current OOS brake adjustment criteria.

The analyses use a combination of mechanical principles, experimental findings, and data from field inspections and investigations. Some of the work is based primarily upon mechanical analyses, and some involves statistical treatment of data gathered during inspections. In this sense, this examination of brake adjustment criteria employs a multidisciplinary approach in which (a) the deterministic aspects of brake system performance are used to relate stopping distance to patterns of brake adjustment levels and (b) probabilistic associations between key factors and brake adjustment levels are used to infer relationships between those key factors and stopping capability. The goal of the analyses is to provide information to use in addressing Item (6) above pertaining to developing a quantitative basis for setting satisfactory brake adjustment levels for OOS criteria.

Before proceeding to summaries of the results of the analyses, the differences between the terms "key factors" and "patterns of adjustment level" need to be distinguished and the relationships between these terms need to be explained.

The Statement of Work for this study frequently uses the term "key factors" in describing the work to be done. This term, as we interpret it, pertains to matters like vehicle configuration (number of trailers and number of axles), type of trucking operation (seasonal, for-hire, heavily-laden vehicle, etc.), the use of rented units, the use of the trailer brake valve, company policies with regard to brake maintenance (training, procedures for determining readjustment cycles, and responsibilities in the organization), the use of special equipment (retarders, automatic slack adjusters, stroke indicators, etc.), severity of service (frequency of severe braking, downhill operation, or stop-an-go delivery), etc. In the context of this study, "key factors" means any of the above matters (plus any other things) that can be determined to be associated with brakes being OOA (particularly at the OOS level) during MCSAP inspections.

A problem in this study has been to obtain tabulated (recorded) information pertaining to the relationship of brake adjustment to these key factors. To address the relationships between adjustment levels or "patterns of adjustment levels" and key factors, we have obtained and analyzed databases developed by the states of Oregon and Wisconsin. In addition, in mid-November, we obtained a very complete database (for our purposes in this study) from the National Transportation Research Board (NTSB) for a sample of nearly 1,000 trucks. The NTSB data has provided us with information that can be used to compare the stopping capability of vehicles that are OOS with those of vehicles that are non-OOS, thereby providing a means for assessing the ability for OOS criteria to separate vehicles based on the stopping capabilities of the vehicles.

By "patterns of adjustment level" we mean which brakes (by unit, axle, and side) are OOA and the amount of static stroke at each brake. We have performed mechanical analyses relating various patterns of adjustment levels to predicted measures of braking performance. However, with regard to relating patterns of adjustment levels to key factors, we have explored the Oregon, Wisconsin, and NTSB databases to find associations indicated by the available data. Here the connections do not contain the deterministic rigor of mechanical analyses, but rather rely on using statistical techniques to examine the available data. Given the distinctions that we have made here, the patterns of adjustment level will be useful in evaluating the technical adequacy of OOS criteria and the key factors will aid in associating the characteristics of trucking operations with the likelihood that vehicles will have brakes that are OOA.

SUMMARIES OF FINDINGS FROM THE ANALYSES

The findings from the analyses have been assembled in this section to provide an overview of the finding extracted from the detailed presentations of the results supporting these findings. The sections following this one (Sections numbered 1 through 6) present information on the specific results and how they were obtained as well as the finding summarized here.

—On the influences of brake adjustment levels on stopping distance

(1) The measurement of cold static stroke at 80 psi is much less demanding than measuring cold static stroke at 100 psi. This means, for example, that a stroke that is just at the readjustment limit when 80 psi is applied will be approximately 1/8" beyond the readjustment limit when 100 psi is applied. The reason for this can be seen by examining the "operating line" due to compliances in the brake superimposed upon the following set of chamber characteristics (See Figure 1.1.1). As the pressure is increased from 80 to 100 psi, additional stroke is consumed due to compression of the linings and compliance in the brake actuation system. When MCSAP decided to check stroke at 80 to 90 psi rather than at 100 psi, they could have reduced the readjustment limits (1/2 brake demerit level) by approximately 1/8" if they wanted to be as stringent as the 100 psi stroke measurement would require. On the other hand, MCSAP may have desired to make the brake adjustment criteria less demanding as well as respond to the concern that 100 psi applications may damage the brake system. Either choice seems

possible depending upon the sentiments of the decision makers concerning the implications of brake adjustment with respect to the "service worthiness" of the vehicles permitted to operate on the highway and not be put OOS.

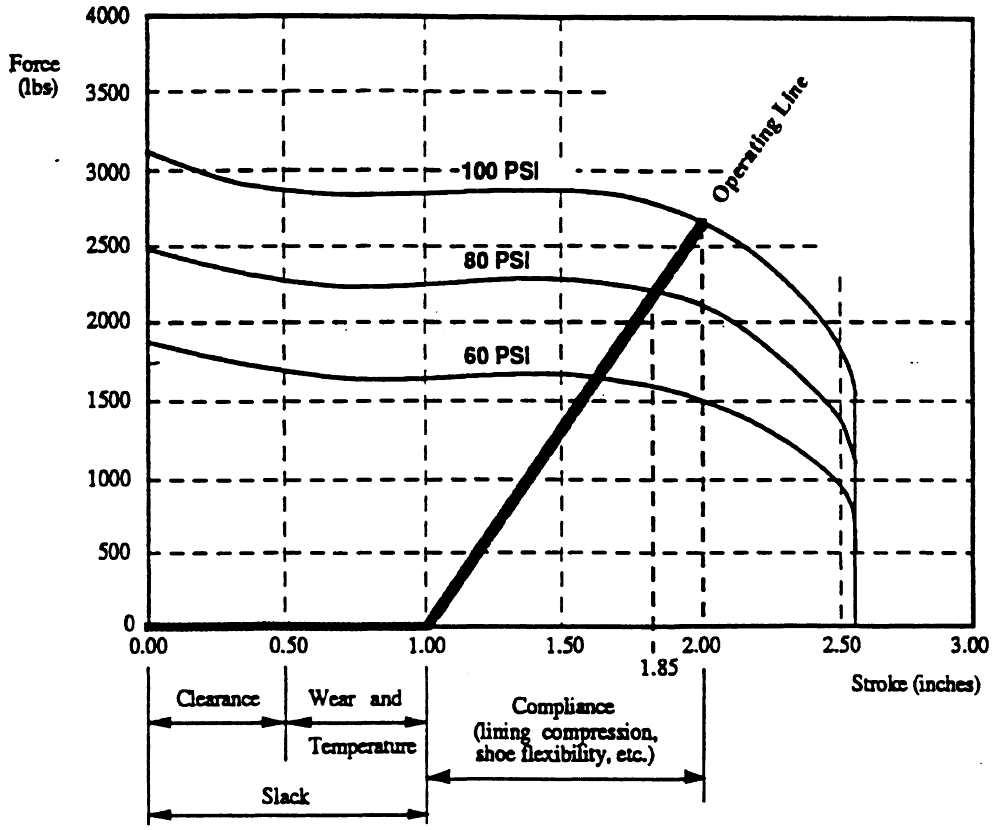


Figure 1.1.1. Operating line during braking

(2) The influences of a fully backed-off brake are considerably larger than those of a brake that is 1/8" beyond the one brake demerit level. This is particularly true for changes in stopping distance happening at low temperature levels (70°F and 200°F). This appears to be a situation which could be considered as one warranting a change in the OOS criteria.

Using the terms of Figure 1.1.1, the fully backed-off brake can be easily recognized. Such a brake is defined as one whose slack stroke is equal to the stroke required to reach the bottom of the chamber. Conceivably, such a brake can be identified during inspection relatively easily. With the absence of lining compliance to resist the motion, the stroke of the chamber will increase to the point of bottoming with a relatively small application pressure.

However, since in the course of the testing, the pressure is only applied once, and to 80 to 90 psi, identifying such a backed-off brake is not obvious. The brake inspector cannot easily tell whether a brake has worn to the point where the stroke just bottoms the chamber or if the clearance stroke (slack) is so large that the chamber has bottomed without applying the lining to the drum. (Perhaps the inspector could "ring" (tap) the drum to see if the linings were contacting the drum.) Whether the brake is backed-off or not, the inspector will measure a large stroke less than or equal to that required to bottom the chamber. And, in either case, this indicates poor maintenance and poor brake performance. Perhaps if the OOS criteria were to be changed, the inspector would be expected to apply more than one brake demerit to a brake stroke that was close to the backed-off level of stroke. The results given in Figures 1.3.2 through 1.3.11 provide the information that could form the foundation for a recommendation with regard to the level of brake demerit to use for brakes that are fully backed-off and this level of demerit would be applied to brakes that are close to being fully backed-off. (As indicated in the next item, temperature influences will lower the braking capability of brakes that are close to being backed-off, tending to cause them to approach backed-off brakes.)

(3) The results in general show a significant influence of temperature on the predicted change in stopping distance at various levels of brake adjustment beyond the readjustment limit. Given that temperature has such a large effect on the predicted change in stopping distance, there is an issue concerning the level of temperature to use in comparing and evaluating stopping capabilities. Although one could devise a means for using all of the temperature results to obtain a composite measure of the percentage change in stopping performance, the results at 400°F and 80,000 pounds appear to be representative and satisfactory for use in comparing the influences of brake adjustment on stopping capability.

—On whether being able to stop within the out-of-service (OOS) limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph with OOS limits.

(1) The results indicate that percentage changes in stopping distances due to poor brake adjustment are much larger at 60 mph than at 20 mph. There are two reasons for this. First, the influence of brake timing is much more important at 20 mph than it is at 60 mph. Even though the brake timing in the examples studied meet FMVSS 121 requirements, the maximum available torque is not applied for very long in the 20 mph stop, thereby decreasing the influence of brake adjustment compared to that during a 60 mph stop. The second reason involves the temperature rise during a stop. This is a very small effect at 20 mph but it is important at 60 mph for OOA brakes that are close to bottoming out. The basic finding from the calculations is that the increase in drum expansion due to temperature rise has an important influence on braking capability for hot poorly adjusted brakes.

(2) The finding above is based upon comparisons with available braking capability at 20 and 60 mph. The following discussion, however, involves the observation that 20 mph stopping distance standards may be set differently than 60 mph standards. For example, if the 20 mph rules were much more stringent than the 60 mph rules (or equivalently, the 60 mph rules were much more lenient), there is a possibility that passing the 20 mph stopping distance requirement would go a long way towards assuring that the vehicle will pass at 60 mph.

In order to examine the differences between stopping from 20 and 60 mph, consider the following simplified example. The current rule for 20 mph is 35 feet for some trucks and 40 feet for longer combinations. (The difference being related to brake timing considerations which will eventually come into play here also.) The basic relationship for estimating stopping distance from deceleration (ignoring or "averaging" the influences of rise times) is as follows:

$$S = V^2/2D$$

where D is the average deceleration

V is the initial velocity

and S is the stopping distance.

According to the above equation, if the deceleration capability of the braking system were to be kept equal, the stopping distance for a 60 mph stop would be nine times that for a 20 mph stop—that is, 315 feet or 360 feet corresponding to 35 or 40 feet.

However, the influences of pressure rise times vary linearly with initial velocity and amount to approximately 12 feet at 20 mph and 35 feet at 60 mph if the average rise time is approximately 0.5 seconds. This means that the 60 mph stop has an advantage over the 20 mph stop when it comes to the contribution of rise times to stopping distance, since 12 feet is a larger fraction of the stopping distance at 20 mph than 35 feet is at 60 mph. For example, if a vehicle stopped in 36 feet from 20 mph, the deceleration capability available would be approximately 0.56 g. If the deceleration available is 0.56 g, a vehicle stopping from 60 mph would be able to stop in approximately 250 feet including 35 feet as an approximation to the contribution due to rise time. The fairly obvious point of this discussion is that being able to pass a 60 mph requirement depends upon not only the braking system but the nature of the 60 mph requirement with respect to the 20 mph requirement.

People setting 60 mph requirements have included the factors discussed above if they have used empirical measurements of stopping distance capability to aid them in establishing the goals. At one time, FMVSS 121 had a 60 mph stopping distance requirement of 293 feet. Given the rough approximations above (i.e., 35 feet due to rise time and neglecting about a 4 percent reduction due to speed loss effects during the rise time), the average deceleration for a 60 mph stop would be approximately 0.47 g which would lead to a stopping distance of approximately 312 feet. So even though the reasons may be vague and obscure, the current implicit FMVSS 121 requirement on stopping distance fits in with the 315 feet derived from equation (1) which neglected not only brake timing matters, but also any in-stop fade due to heating of the brake linings or velocity sensitivity of the linings.

(3) The preceding observation needs to be supplemented with other observations for why 20 mph stops are not good indicators of what will happen at 60 mph. The reasons are (1) there are lining materials that are

temperature sensitive and the in-stop temperature rise at 60 mph will cause these materials to lose appreciable amounts of torque capability, (2) certain lining materials may have a sliding speed sensitivity that shows up at 60 mph but not at 20 mph, and (3) very good brake timing may compensate for poor adjustment or other braking torque deficiencies at 20 mph but this will not be as effective at 60 mph.

—On critical adjustment thresholds beyond which heavy vehicles cannot stop within a safe margin

(1) The raw material presented in Figures 3 through 11 shows that stopping distance versus brake adjustment results are highly dependent upon temperature conditions and the pressure level at which static stroke is measured as well as the level of adjustment. Although one could consider some composite measure of performance based upon a wide range of initial brake temperatures, vehicle loading conditions and road surface conditions; the analytical work that went into developing the calculations indicates that the influences of brake adjustment are most important with respect to stopping distance capability in situations involving high temperatures, heavy loads, and high friction at the tire/road interface. The finding here is that it is reasonable to evaluate he influences of brake adjustment criteria at chosen sets of operating conditions. Examination of the overall results suggests that calculated stopping distances from 60 mph for vehicles laden to the maximum allowable limit are appropriate for examining the influences of various brake adjustment criteria.

(2) Section 3.3.2 presents a method for adding "backed-off" brakes into a brake "demerit" system like the one used in the current 20 percent OOS criteria. The idea is to augment the current 1/2 brake and 1 brake penalties used in computing the 20 percent factor employed in the OOS criteria. If these levels of brake penalties are viewed as "demerits," a completely misadjusted or backed-off brake could be assigned a demerit value to be used in computing a 20 percent factor that would be based upon the percentage reduction in stopping distance caused by various levels of misadjustment.

The net conclusion reached is that stopping distance discrepancies due to backed-off brakes could be reduced if backed-off brakes were given a penalty equivalent to at least 1.5 brake demerits. The criteria for calling a brake "backed-off" or "completely misadjusted" would be that the cold static stroke is greater than or equal to 2.5" for a Type 30 chamber. For other types of chambers, an equivalent boundary could be set at the stroke required to reach the bottom of the chamber minus 1/8".

(3) The ideas presented in Section 3.3.3 extend the notion of using brake adjustment factors like those introduced in Section 3.3.2 for backed-off or completely misadjusted brakes. In this case, a scheme is presented for using estimated changes in stopping distance to determine OS. The methodology involves assigning "brake force adjustment factors" to various ranges of brake adjustment. The results indicate that it would be feasible to estimate changes in stopping capability using this approach although it would require knowledge of "AL" factors (chamber size and slack arm length). Also, the lower torque capabilities of front brakes would also need to be factored into the calculation of stopping capability.

Nevertheless, this method would improve the relationship of available stopping capability to OOS criteria for brake adjustment.

(4) There is already considerable sentiment for simplifying the OOS criteria. The above suggested methods for changing the OOS criteria may not appear to be simple. Nevertheless, they are much simpler than the calculation procedures used in obtaining the results presented in Sections 1 and 2. An issue to be decided is whether it is worthwhile to increase the complexity of the OOS criteria in order to reflect a more uniform relationship to stopping capability.

—On identifying key factors contributing to brake OOA for manually adjusted brakes.

(1) Our review and analysis of existing data on brake adjustment violations have produced very little information that would document a relationship between hypothesized key factors and brake adjustment. This result is primarily due to a lack of data on most of the hypothesized factors, and particularly those related to the maintenance practices of the owner/operator. However, three patterns of brake violation were observed that may a consequence of some of key factors originally identified. They are:

1. The front axle on tractors is more likely to be OOA, and when there is a brake violation on the front axle of a tractor, most of the time both brakes on the axle are in violation. This finding is consistent with a continuation of the practice of backing off the front axle brakes.

2. Semitrailers are somewhat more likely to have brake violations than tractors. However, this finding was not as strong as expected, and was not consistent in the two files examined.

3. The rear axle of tandem pairs was more frequently in violation in comparison with the front axle of the pair. This trend was evident on both tractors and semitrailers.

(2) Compared with the overall rate for brake adjustment violations for the vehicles inspected in Oregon, intrastate carriers of logs, sand, or ores (one of the categories in their database) are 14 percent overinvolved in brake adjustment violations. Intrastate carriers of general freight are 10 percent overinvolved. On the other side of the picture, intrastate private, interstate for-hire, and interstate private are all underinvolved in brake adjustment violation.

(3) The Wisconsin database indicated that for interstate hauls tractor brake violations were 55 percent of the total, while semitrailer violations only represented 35 percent of the total. On the other hand, for intrastate hauls tractors represented 31 percent and semitrailers 48 percent of the total. With regard to the location of brake violations, it was found that if one brake on an axle was OOA, the other brake on the axle was also likely to be OOA. For example, for trailers, both brakes on an axle were out-of-adjustment in 47 percent of the cases, while 21 percent of the left side brakes and 26 percent of the right side brakes were OOA alone. In

general, there were slightly more violations for the right side brakes than for the left side brakes for tractors and semitrailers.

—On developing statistical measures pertaining to the relationships between the key factors identified and stopping capability.

(1) Given that brake adjustment can be related to stopping capability, it suffices to develop relationships between key factors and OOA levels. The NTSB data set provides information that can be used to develop statistical associations between levels of OOA and the factors entered into the NTSB database. The factors studied in these analyses include automatic versus manual slack adjusters, engine brakes (retarders) versus no retarder, carrier type, tractor model year, trailer model year, axle number and location, cargo body type, and tractor make and cab style.

(2) The findings in the areas listed above are as follows. Automatic slack adjusters do very well at reducing the number of brakes that are more than 1/4" beyond the readjustment limit (one defective brake by the OOS criteria). Vehicles with engine brakes tend to have better levels of brake adjustment than vehicles without retarders. There is only a slight difference between private and for-hire vehicles with regard to brake adjustment levels in the NTSB database. In situations where the driver is responsible for brake adjustment, the drivers appear to do as well as the maintenance people in maintaining brake adjustment. Tractors with a model year before 1986 have much higher rates of defective brakes per the brake adjustment criteria. For trailers, there was no particular trend to the proportion of OOA brakes by model year. The results for axle location were that the rear tandem drive axle is more likely to be OOA and that trailer axles are more likely to be OOA than tractor axles. The differences found between different cargo body types are not great, but the tank vehicles had the lowest percentage of brakes that were properly adjusted. And, the differences between cab-over and conventional cab styles was no great, although the conventionals had a greater percentage of properly adjusted brakes that the cabovers did.

—On providing a sound quantitative basis for confirming or changing current OOS brake adjustment criteria.

(1) Only the NTSB data have the potential to provide an objective evaluation of the brake adjustment OOS criterion. This is the only source of information that includes actual slack measurements on all brakes: those that were not in violation as well as those that were. No state was found that recorded information on brakes that were *not* in violation. In addition, the NTSB data include the chamber size, which is essential for relating the slack measurement to the OOA criteria. The detail in the NTSB data is sufficient to support calculation of approximate measures of stopping performance. One such measure is the braking efficiency computed by NTSB. Comparing distributions of braking for trucks that were OOS to those that were not OOS provides a way of quantifying the way in which the current OOS criteria distinguishes the trucks that are inspected. These distributions show some overlap. Some trucks that are put OOS have higher braking efficiencies than some that were not, and vice versa. Of course, calculation of the braking efficiency of each truck inspected is probably too complicated to be part of a MCSAP vehicle inspection

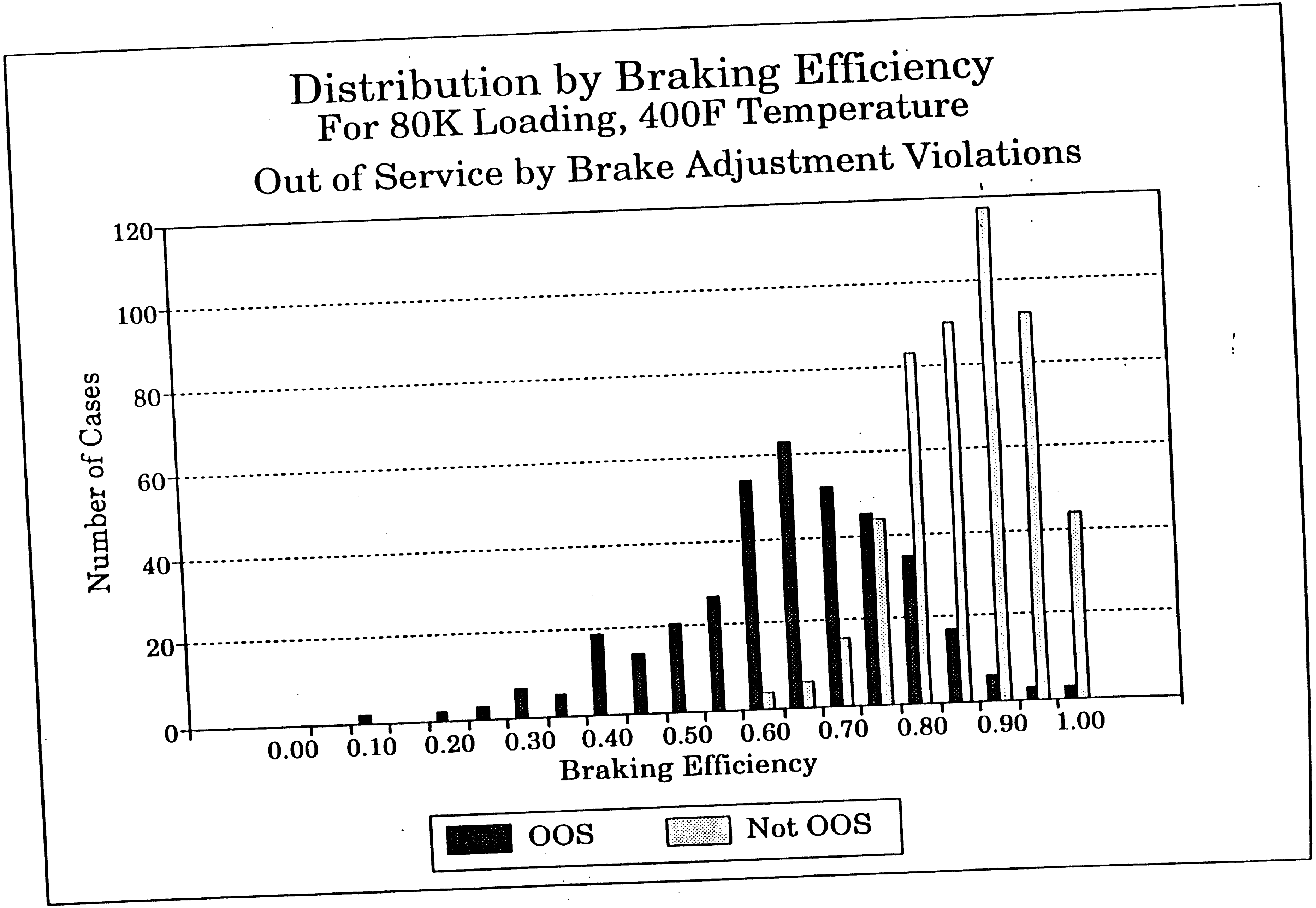
procedure. However, simple modifications and/or extensions of the existing criteria could be evaluated using the NTSB data. The effort of different criteria on the distributions of braking efficiency for OOS trucks and non-OOS trucks could be calculated from the actual slack measurements in the NTSB file.

(2) Providing a sound, quantitative basis for confirming or changing the OOS criteria is a primary goal of this project. The results obtained using the NTSB data show that the current system of assigning brake demerits for computing the "20-percent" criteria provides a reasonable separation (in terms of NTSB's calculations for braking efficiency or braking drag) between vehicles that are OOS and those that are not.

(3) We propose that further calculations by made in order to evaluate other OOS criteria suggested by this study. These calculations would employ the stopping distance factors derived in this study (and described in Section 3 of this report) in connection with the inspection database containing the NTSB data. Frequency distributions (histograms) comparing OOS vehicles under each proposed criteria would be constructed. This would provide the basis for judgments concerning the ability of various proposed OOS criteria to separate vehicles according to their stopping capabilities.

(4) The following figure shows the separation and overlap between OOS and non-OOS vehicles obtained for the vehicles inspected by NTSB. These results are labeled 80K loading and 400°F to indicate that the braking efficiencies are calculated for the vehicle if it were loaded to 80,000 pounds and the initial brake temperatures were 400°F. As indicated previously in these summary statements, this form and type of data presentation illustrates the ability of the current OOS criteria to separate vehicles by stopping capabilities.

This concludes an initial summary of the findings of the analyses. Further development of findings and recommendations regarding the appropriateness of OOS brake adjustment criteria will be presented in the Interim Report. Task F entitled, "Evaluate OOS Brake Criteria" will be completed using the information and data presented in the following sections of this report.


Distribution by Braking Efficiency
For 80K Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

1.0 THE INFLUENCES OF BRAKE ADJUSTMENT LEVELS ON STOPPING DISTANCE

1.1 Introduction

This section describes the results of analyses aimed at assessing the influences of brake adjustment levels on stopping distance performance. The purpose of these analyses is to provide information to be used later in evaluating the appropriateness of OOS brake adjustment criteria for heavy trucks.

1.2 Brief Description of the Types of Analyses Performed

The analyses consisted of predictions of brake torque capabilities and stopping distance performance from 60 mph. Calculations were made for 3, 5 and 9 axle trucks (6, 10, and 18 brakes) at selected combinations of brake adjustment levels as listed in the following table:

Table 1.2.1 Combinations of brake adjustment levels

Case	Combination	Description
Case 1	FA	•All brakes are fully adjusted
Case 2	All RA-1/8"	•All brakes stroke 1/8" before the readjustment limit
Case 3	20% RA+1/8"	•Some brakes are at half-brake demerit level (enough to constitute 20% OOS). The strokes of those brakes are 1/8" beyond the readjustment limit.
Case 4	20% RA+3/8"	•Some brakes are at 1 brake demerit level (enough to constitute 20% OOS). The strokes of those brakes are 3/8" beyond the adjustment point.
Case 5	1 Backed-off	•One brake is completely backed-off so that it does not generate any braking torque.

For these cases, all the brakes whose adjustment levels were not prescribed, were taken to be fully adjusted (FA). In addition, for the 3- and 5-axle trucks, a supplementary set of combinations were defined as Cases 3', 4', and 5'. For these cases, the brakes which were previously FA, were set to be RA-1/8". Each of the above stroke level measurements was simulated to be taken under static, cold conditions (70°F).

Since the stroke measurement depends upon the prevailing pressure in the system as regulated by the treadle valve, each of the above strokes was treated as if they were measured under 80 and 100 psi applications. Some cases were also studied with the cold static stroke being measured at 85 and 90 psi. The pressure at which the static stroke is evaluated, is an important factor in assessing the braking performance of a truck, since for a given truck with a given brake adjustment status, different strokes will be measured for different pressures. This point and its implications on the leniency of the process employed in checking brake adjustment will be further emphasized later.

During braking, the friction between the drum and the lining generates heat that in turn causes the drum to expand. In addition, in many cases, the initial temperature of the drum is hotter than 70°F. The more the drum expands, the larger the required stroke becomes, thus creating some additional "virtual" misadjustment level. This means that the chamber pushrod needs to be further extended before the lining is brought in contact with the drum. Brake chamber characteristics need to be considered in studying this phenomenon. As shown in Figure 2, when the pushrod goes beyond a certain level, it starts bottoming out. As an increasing portion of the total input force is lost against the chamber walls, leaving a decreasing portion of that force to generate braking torque.

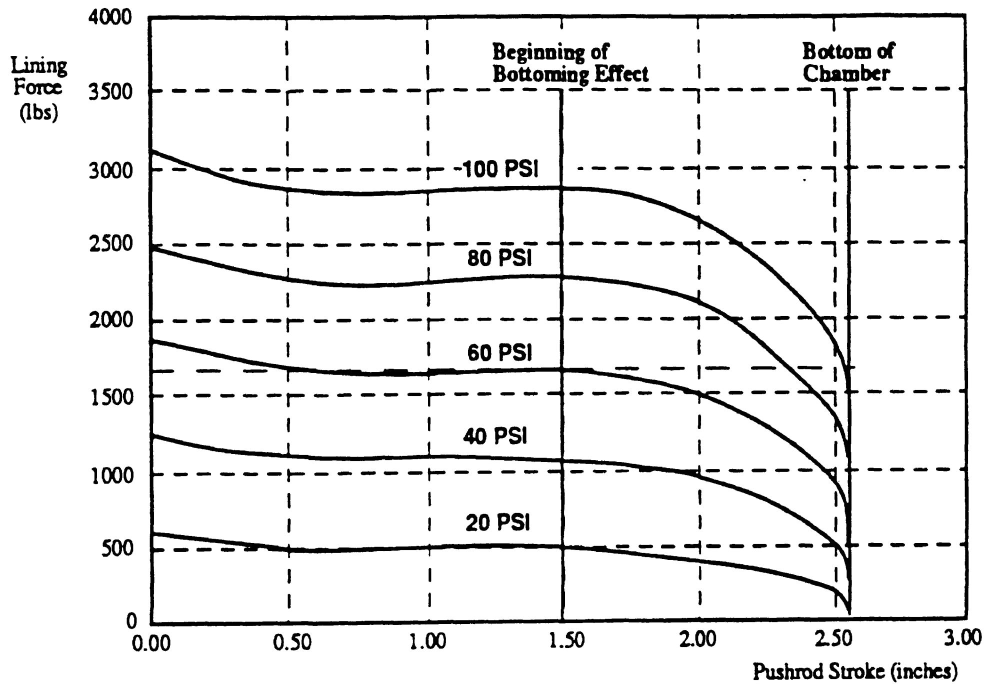


Figure 1.2.1. Chamber Type 30 characteristics

The influence of temperature on the static stroke of chambers Type 30 and 20 is shown in Figure s 1.2.2 and 1.2.3. It should be noted that the manner according to which the stroke (as measured at the chamber pushrod) changes with temperature (that causes the drum to expand), depends upon the mechanical advantage of the linkage between the lining and the chamber. The following Figures, therefore, relate to specific layouts of a front brake (15" drum and 5.5" slack arm) and a rear brake (16.5" drum and 6" slack arm).

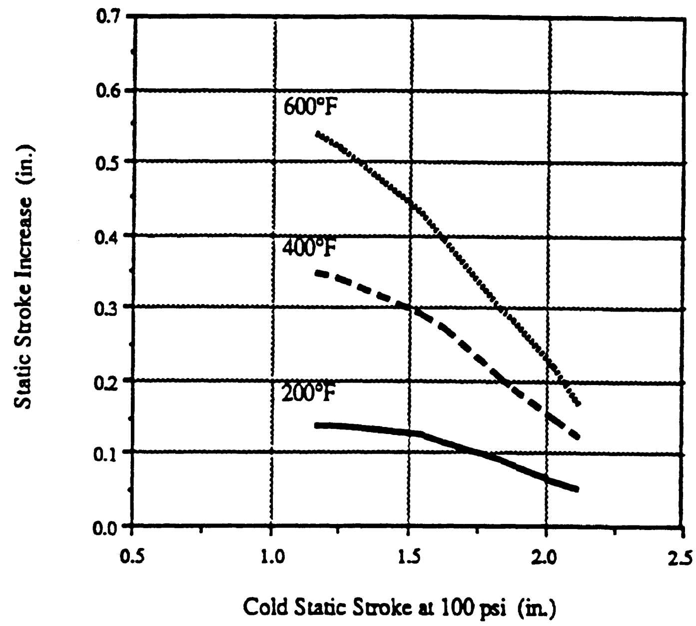


Figure 1.2.2. Increase in static stroke of chamber Type 20 due to temperature

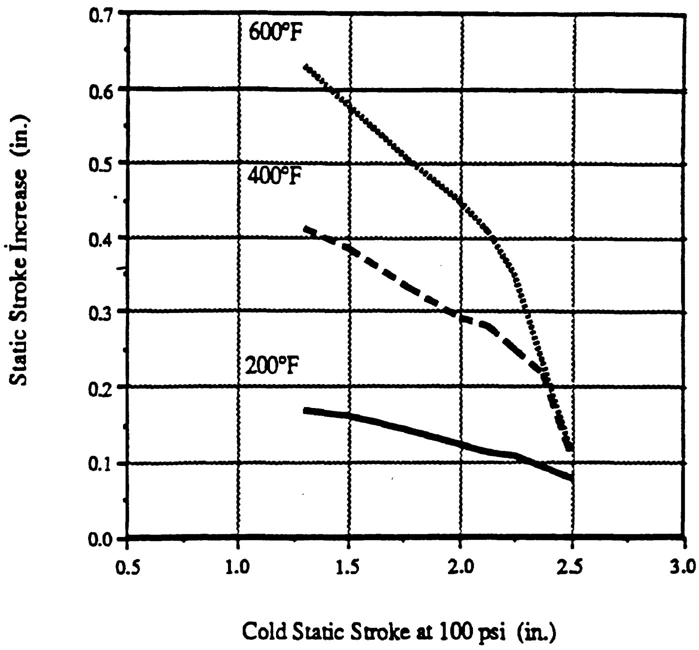


Figure 1.2.3. Increase in static stroke of chamber Type 30 due to temperature

In an emergency stop, when maximum braking capacity is required, such temperature induced stroke variations are vital considerations in assessing the braking performance of the truck. Calculations were made for an emergency stop (application of the full 100 psi) at various initial brake temperatures, and the following discussion of the results and findings demonstrates the importance of temperature induced stroke variations. In general, higher brake temperatures mean poorer performance and longer stopping distance.

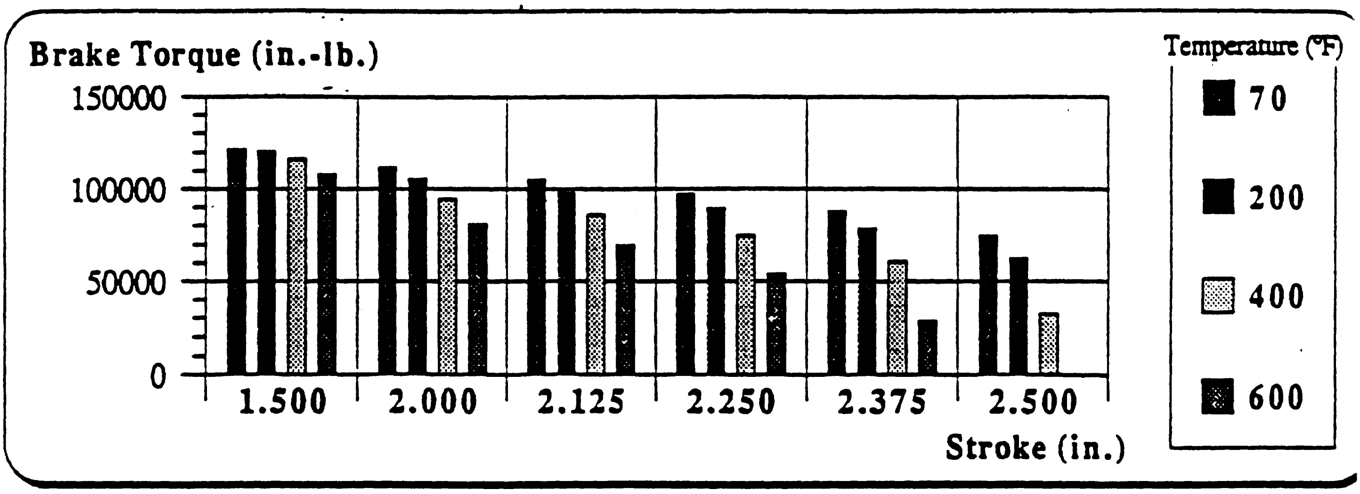
3. Concise Summary of the Results

Braking torque values that a brake can produce under different adjustment levels were used as an evaluating tool for the braking capacity at a particular adjustment state. Figure 1.3.1 shows the variations in such a braking capacity for a typical rear axle brake with Chamber Type 30, drum of 16.5" diameter, and 6" slack arm. The torque values are in pounds at a 100 psi braking application. The dramatic loss of braking capability as the static stroke increases can be easily seen. Since the "wall" of the chamber is at about 2.6" of stroke, the stroke cannot surpass 2.6". If the stroke required to "close" the clearance between the lining and the drum is higher than 2.6", contact will not be accomplished and no torque can be generated. Such is the case when the cold static stroke is 2.5". When heated to 600°F, the brake generates zero torque—drum expansion leads to a required stroke larger than 2.6".

It should be noted that the braking torque variations given in Figure 1.3.1 are for a static application. No heat is generated as the brakes are applied. If it were to be a dynamic stop with in-stop generation of heat, the losses would increase. It should also be pointed out that such an in-stop heat generation will be larger at the "tighter" levels of

Brake Torque as a Function of Temperature and Static Stroke

Temp. \ Cold Static Stroke	1.500	2.000	2.125	2.250	2.375	2.500
70	121434	111575	105091	97344	87950	74468
200	120362	105415	98047	89366	78202	62675
400	116209	94212	85805	74487	60603	32510
600	107752	80736	69315	54010	28738	0



Percent Drop in Torque as a Function of Temperature and Static Stroke

Temp. \ Cold Static Stroke	1.500	2.000	2.125	2.250	2.375	2.500
70	0	8	13	20	28	39
200	1	13	19	26	36	48
400	4	22	29	39	50	73
600	11	34	43	56	76	100

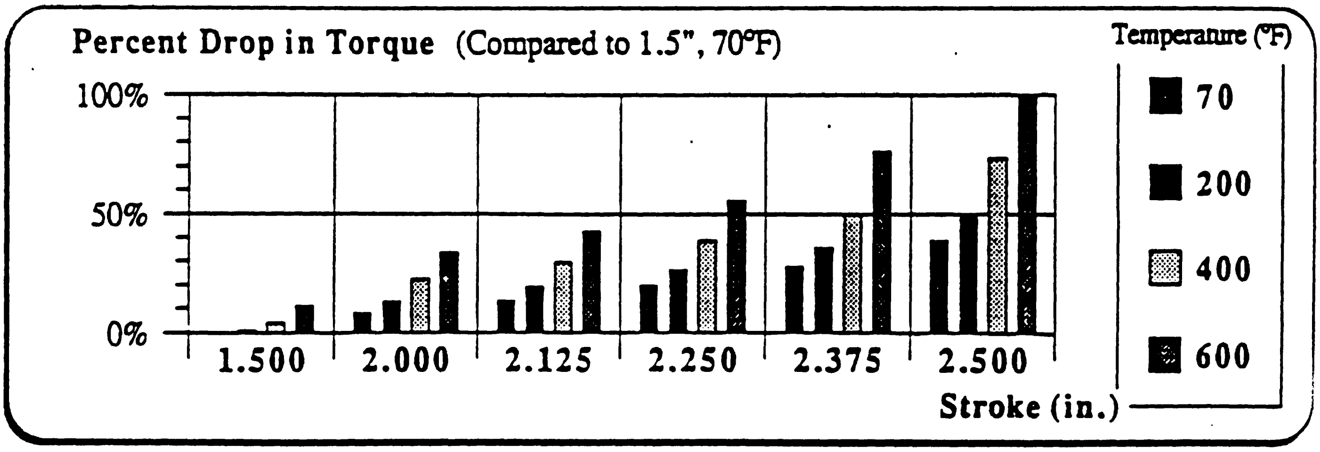


Figure 1.3.1 Influence of stroke and temperature on braking torque

adjustment (closer to FA) than at the more "loosely" adjusted brakes. That is due to the fact that the less the brake is adjusted (that is, the greater the clearance stroke), the less is the force transmitted to the lining, hence generating less heat.

The following Figures 1.3.2 through 1.3.11 show the influence of brake adjustment (as measured at different pressure levels) and initial brake temperature on the stopping distance of 3-, 5-, and 9-axle trucks.

For the purposes of this study, variations in stopping distance due to different adjustment states and temperatures are the substantial outputs. Therefore, in the following figures, although the upper tables and graphs give an estimate of the braking performance in the sense of stopping distance, the lower portion provides the percentage change in stopping distance which is a more meaningful measure to work with in comparing the influences of various levels of brake adjustment. Variations are more noticeable when compared by percentages than by comparing absolute values.

Some observations concerning the results given in the figures:

- When clearance is measured at 100 psi, there is almost no difference between the various combinations leading to 20 percent OOS. The values of percentage change in stopping distance under the two 20 percent columns in Figures 1.3.9 through 1.3.11 are rather compatible. As the measuring pressure drops, it becomes more and more noticeable that RA+1/8" and RA+3/8" cannot be equally counted towards the 20 percent OOS failure criteria. The degradation in stopping ability of a truck with 40 percent of its brakes at an adjustment level of RA+1/8" (which constitutes 20 percent OOS since each of these is at half a brake demerit), is not the same as for a truck with 20 percent of its brakes at an adjustment level of RA+3/8" (which also constitutes 20 percent OOS since each of these is at a full brake demerit). Generally speaking, the first one (40 percent at half a brake demerit each) is the worst between the two.

- Clearly, the more axles there are, the smaller is the effect of <u>one backed-off brake</u> on the braking performance. The 3-axle truck lost 21 percent of its braking capacity (increased braking distance at 70°F, Figure 1.3.2), the 5-axle truck lost 11 percent (Figure 1.3.4), and the 9-axle truck lost only 5 percent (Figure 1.3.6) due to the backed-off brake.

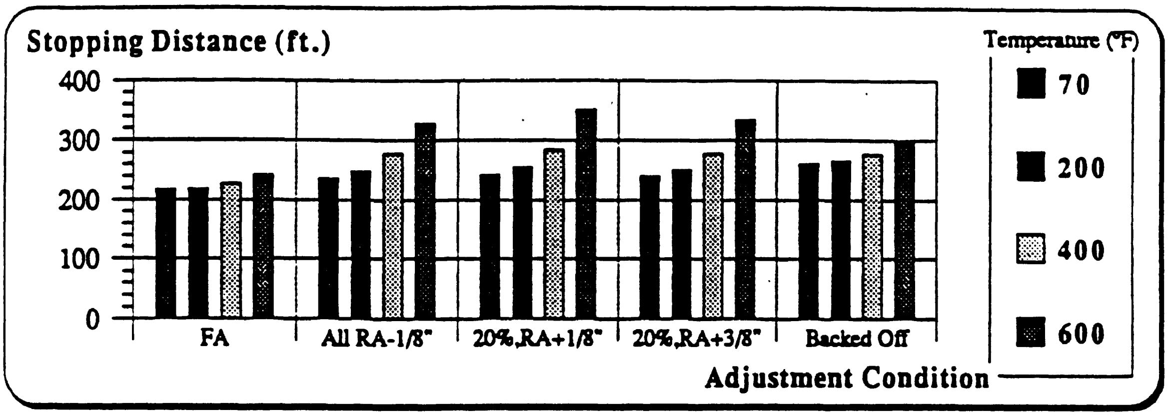
- Throughout the configurations and cases studied (except for the "prime" cases - 3', 4', and 5'), categorization of adequately adjusted trucks and ones that are OOA according to the present rules, could not be rationalized for the pathological cases examined. (To some extent, this is to be expected since the cases were selected with the idea that they would challenge the OOS criteria).

The 20-percent OOS rule did not work well in the cases studied for the 3-axle truck (Figure 1.3.2). At 70°F, Cases 3 and 4 are defined as out-of-service, but they are only slightly worse than Case 2 which is considered adjusted (12 and 11 percent increased stopping distance versus 9 percent). This small margin is maintained throughout the temperature range.

The acuteness of the discrepancy in stopping capability grows with the number of axles and even results in reversed categorization. Examination of the 5-axle truck results (Figure 1.3.4), shows that Case 2 (RA-1/8") performs poorer than the two OOS cases (10 percent increased stopping distance versus only 9 and 8 percent), but it will still be passed. A similar situation exists for the 9-axle

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%.RA+1/8"	Case 4 20%.RA+3/8"	Case 5 Backed Off
70	217	237	244	241	262
200	219	249	256	251	266
400	227	278	285	279	277
600	242	328	351	334	297



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case1 FA	Case 2 All RA-1/8"	Case 3 20%.RA+1/8"	Case 4 20%.RA+3/8"	Case 5 Backed Off
70	0	9	12	11	21
200	1	15	18	16	23
400	5	28	31	29	28
600	12	51	62	54	37

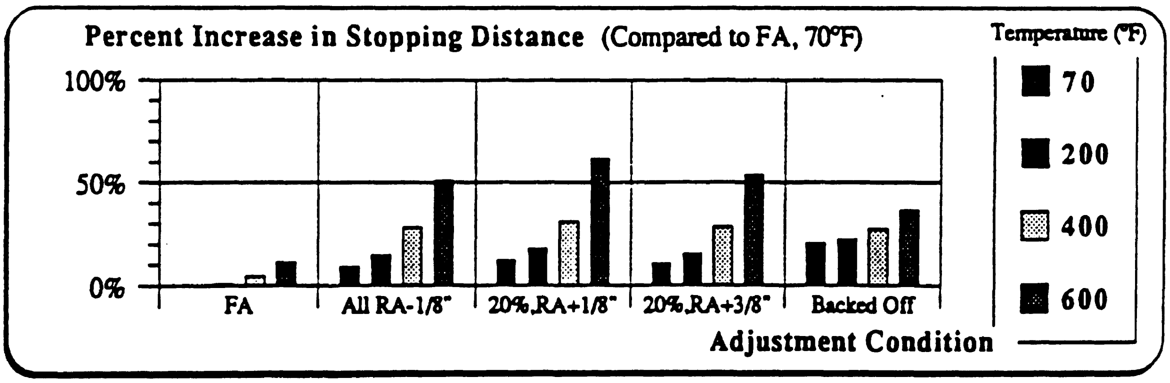
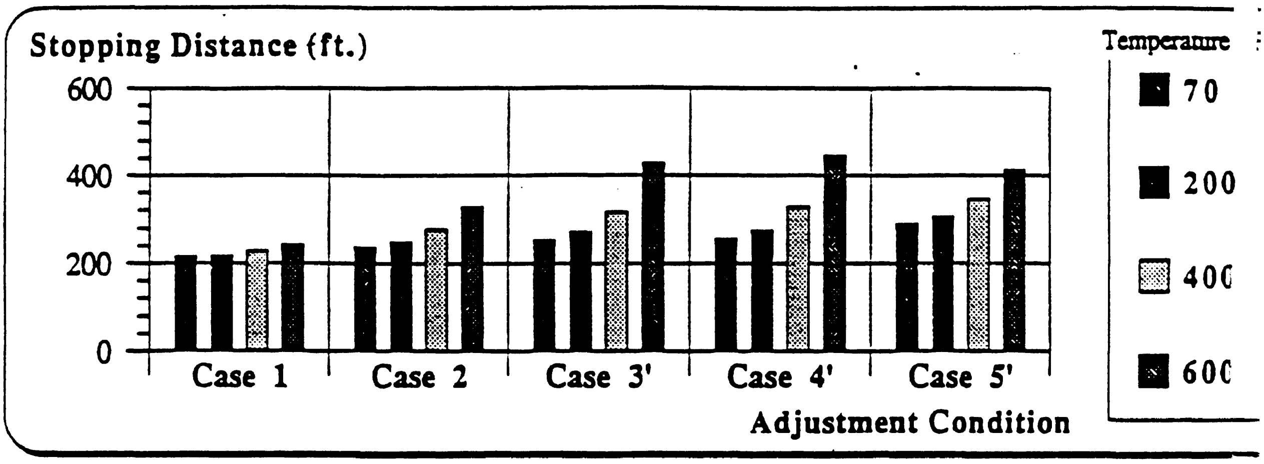


Figure 1.3.2 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 60 mph

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case 1	Case 2	Case 3'	Case 4'	Case 5'
70	217	237	253	256	290
200	219	249	271	275	306
400	227	278	316	328	345
600	242	328	427	444	412



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case 2	Case 3'	Case 4'	Case 5'
70	9	17	18	34
200	15	25	27	41
400	28	46	51	59
600	51	97	105	90

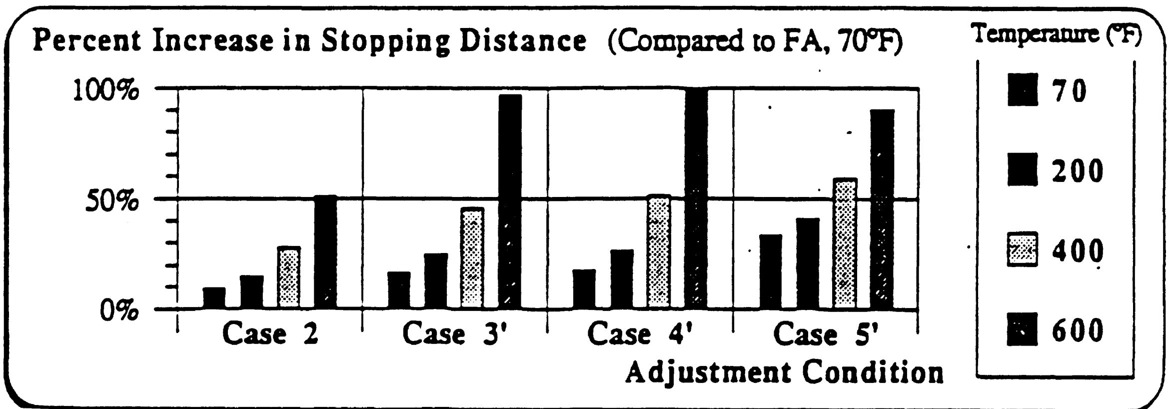
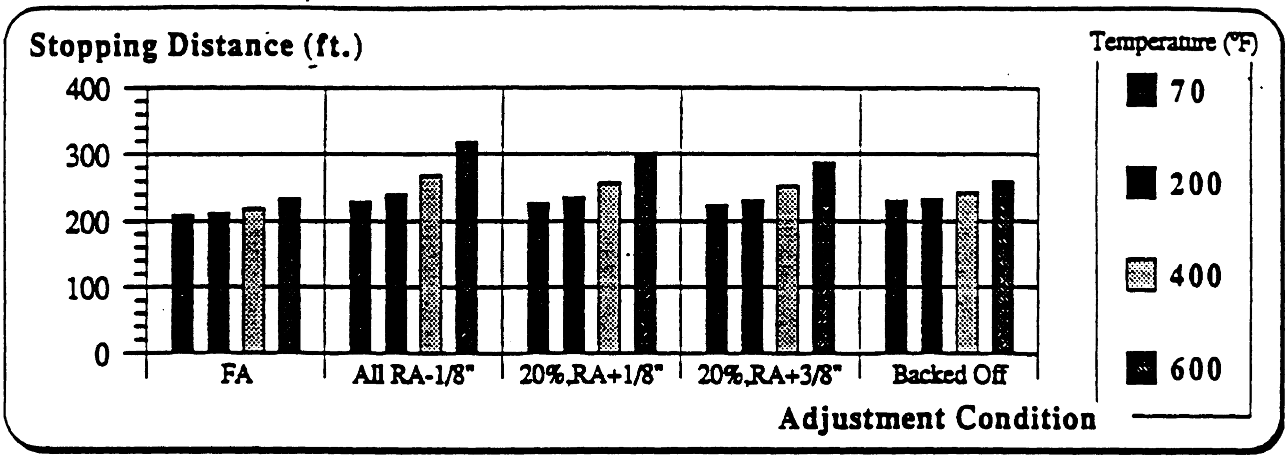


Figure 1.3.3 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 60 mph (modified adjustment cases)

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	229	227	225	231
200	212	241	236	231	234
400	219	269	257	252	243
600	234	318	301	288	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	10	9	8	11
200	1	15	13	11	12
400	5	29	23	21	16
600	12	52	44	38	24

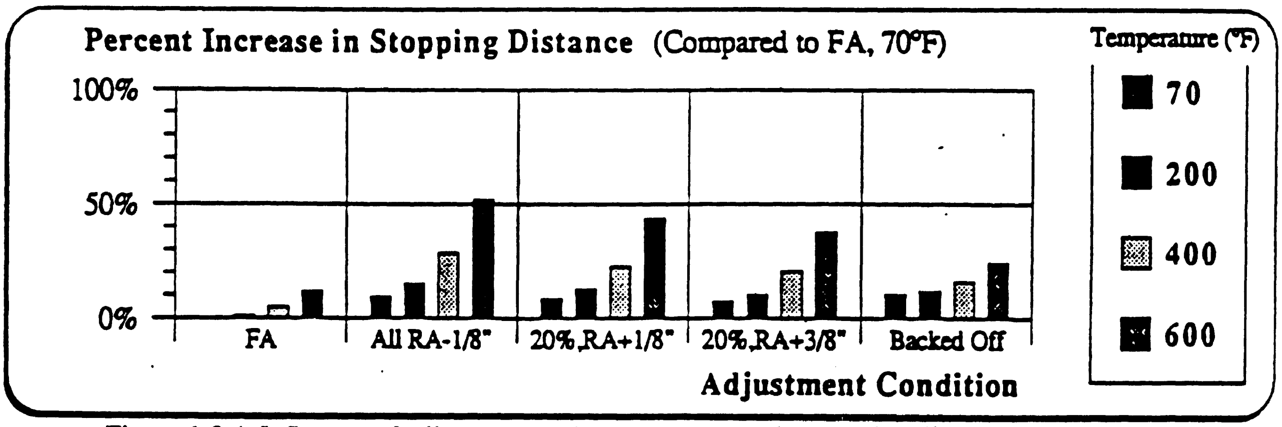
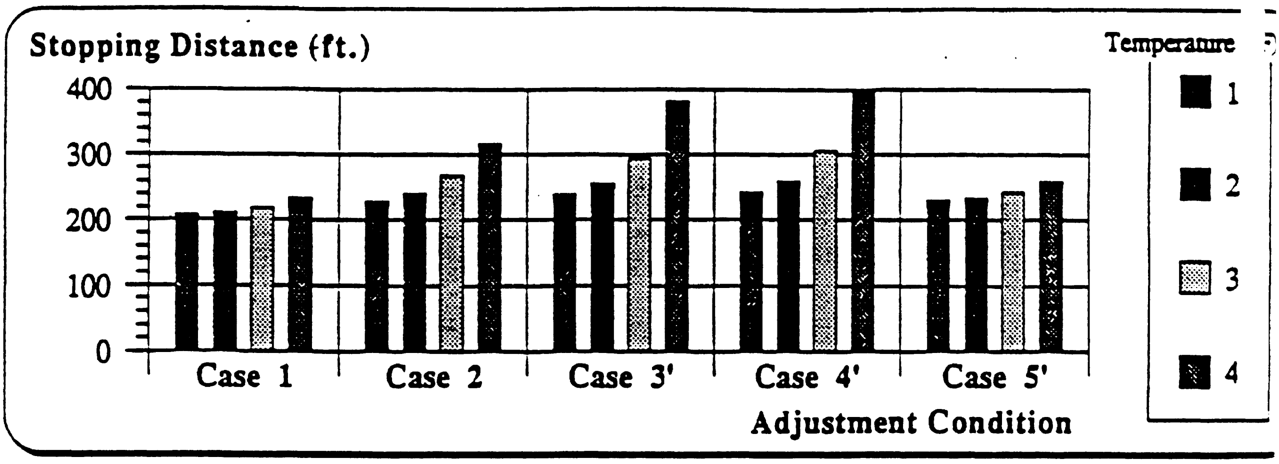


Figure 1.3.4 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 60 mph

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	Case 1	Case 2	Case 3'	Case 4'	Case 5'
70	209	229	240	243	231
200	212	241	256	260	234
400	219	269	295	306	243
600	234	318	382	399	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	Case 2	Case 3'	Case 4'	Case 5'
70	10	15	16	11
200	15	22	24	12
400	29	41	46	16
600	52	83	91	24

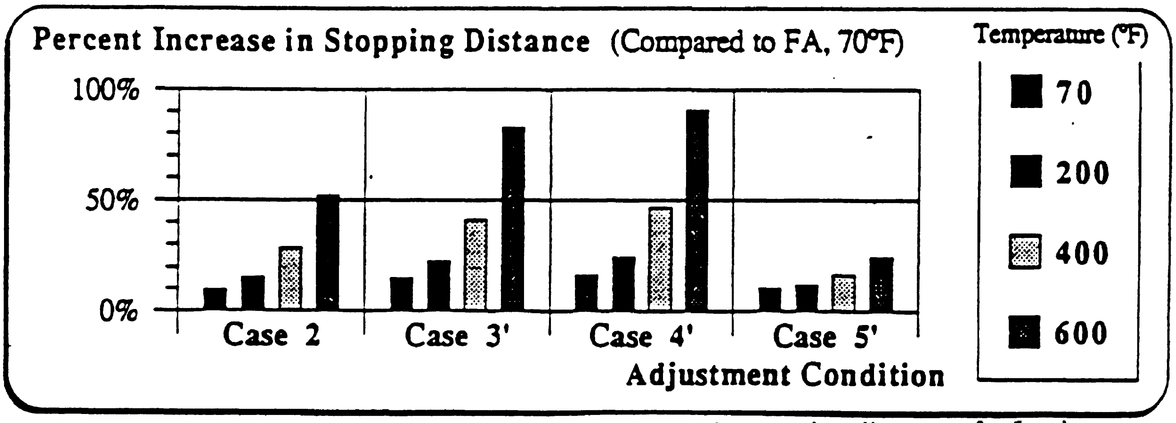
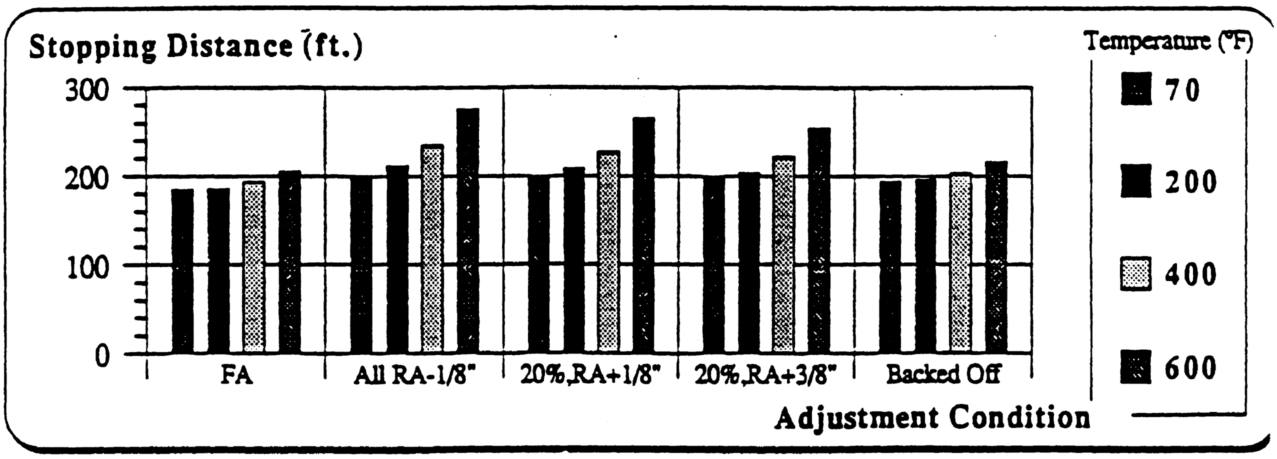


Figure 1.3.5 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 60 mph (modified adjustment case)

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	201	200	198	194
200	186	211	208	204	196
400	193	234	226	222	203
600	205	275	264	254	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	9	8	7	5
200	1	14	12	10	6
400	4	26	22	20	10
600	11	49	43	37	17

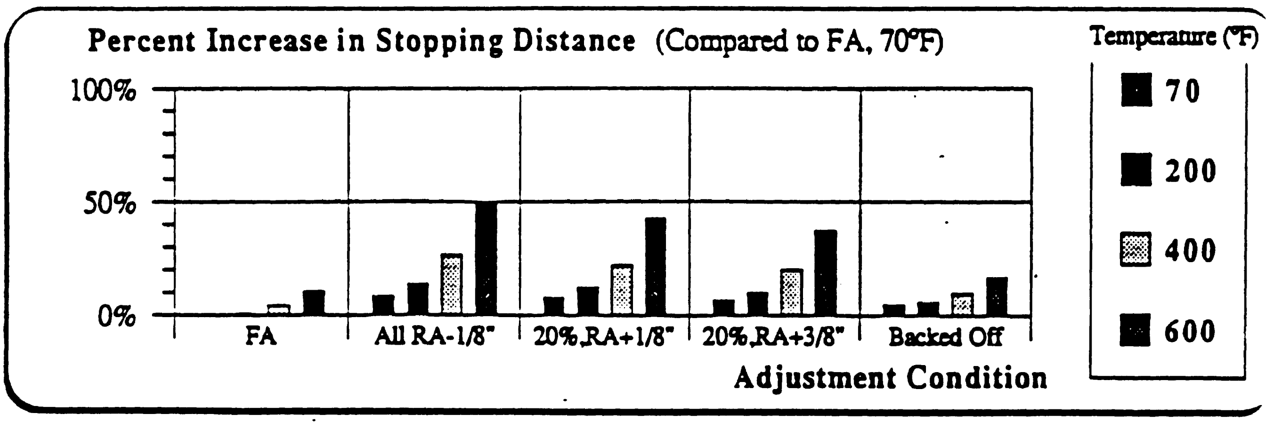
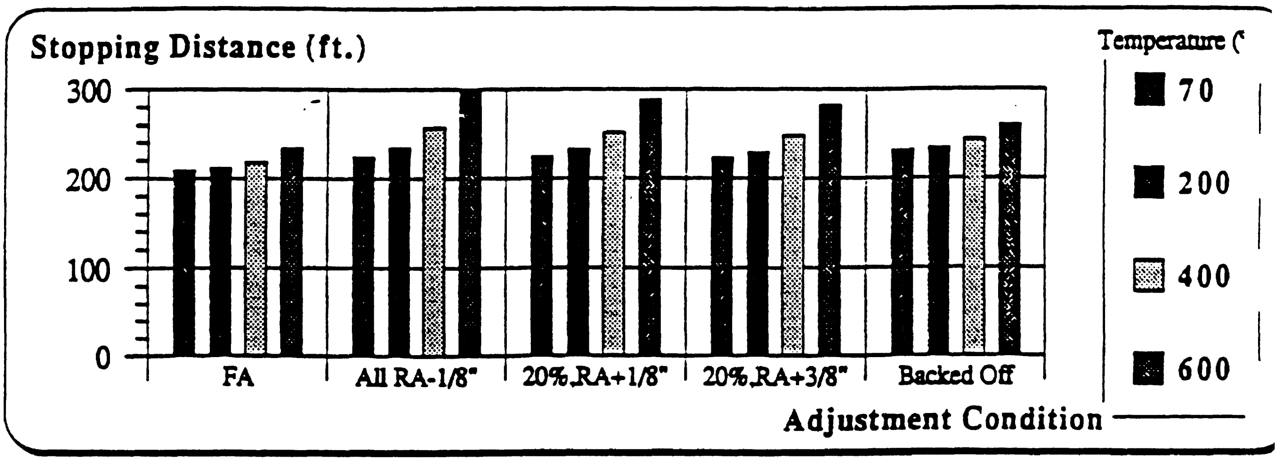


Figure 1.3.6 Influence of adjustment and temperature on the stopping distance of a 9-axle truck at 60 mph

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	224	225	223	231
200	212	234	233	229	234
400	219	258	252	248	243
600	234	298	289	282	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	7	7	7	11
200	1	12	11	10	12
400	5	23	20	19	16
600	12	42	38	35	24

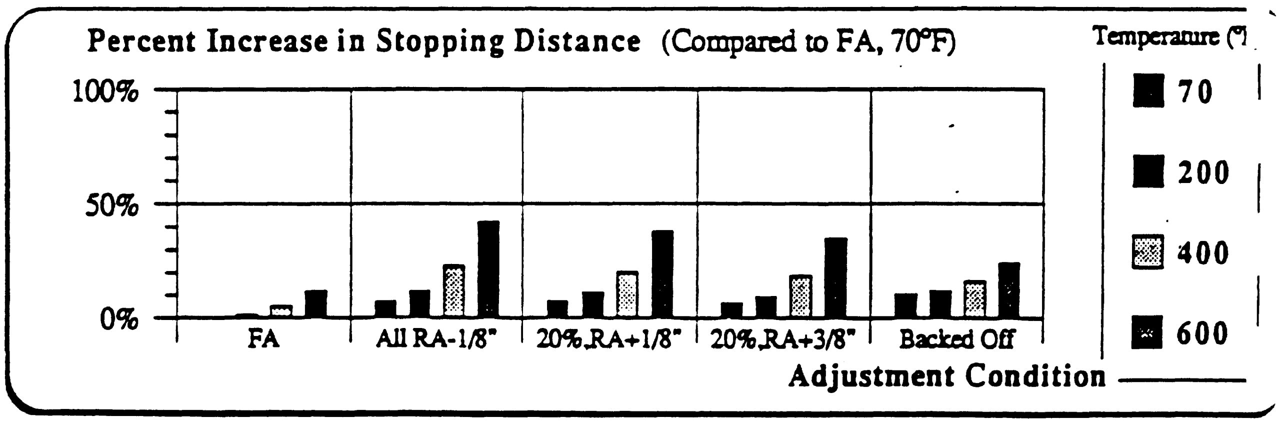
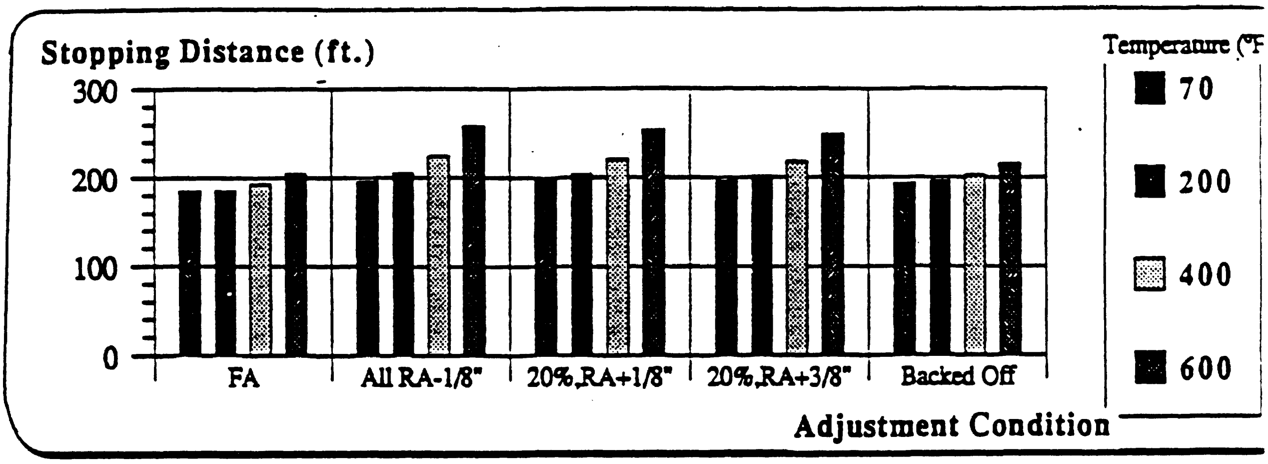


Figure 1.3.7 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 60 mph

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	197	198	197	194
200	186	205	205	202	196
400	193	225	221	218	203
600	205	258	253	249	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	6	7	6	5
200	1	11	11	9	6
400	4	21	19	18	10
600	11	39	37	34	17

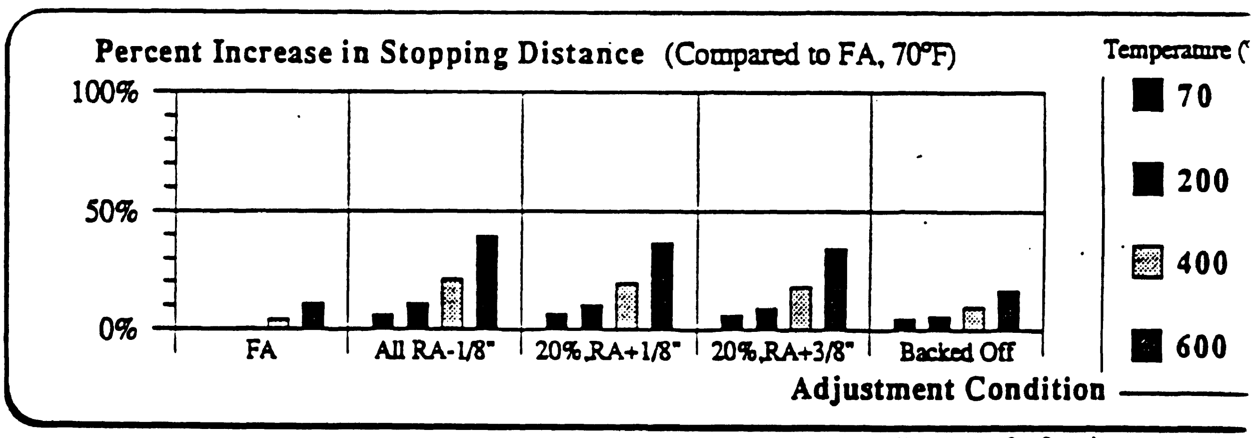
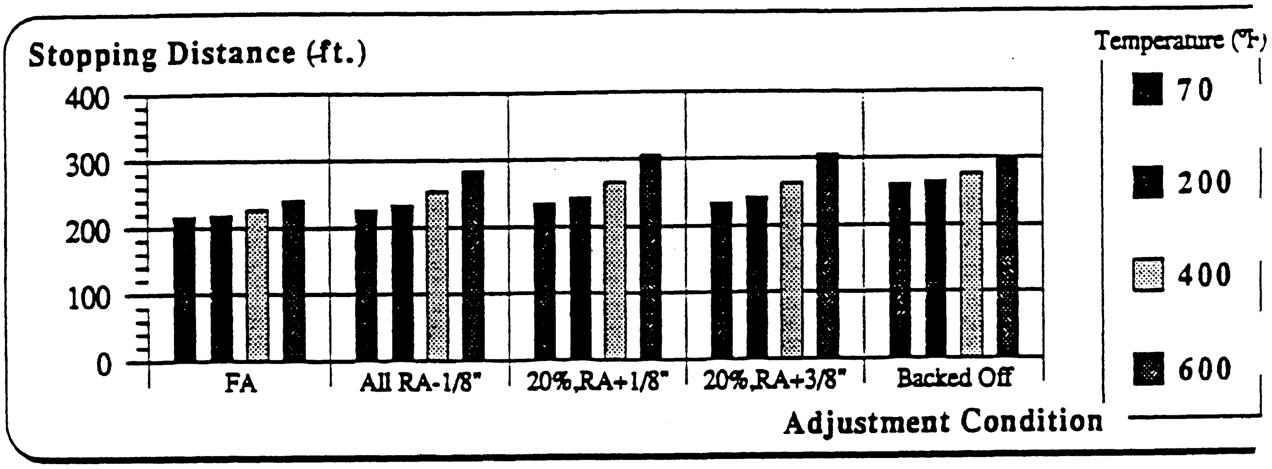


Figure 1.3.8 Influence of adjustment and temperature on the stopping distance of a 9-axle truck at 60 mph

Stopping Distances (60mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Adjustment Case / Temp.	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	217	226	235	234	262
200	219	234	244	243	266
400	227	254	267	264	277
600	242	285	306	306	297



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Adjustment Case / Temp.	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	8	8	21
200	1	8	12	12	23
400	5	17	23	22	28
600	12	31	41	41	37

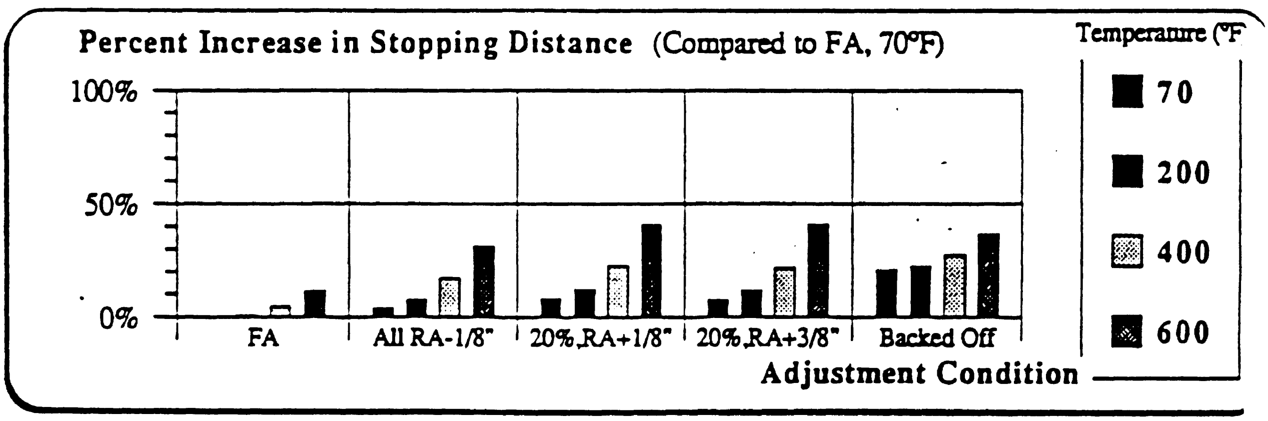
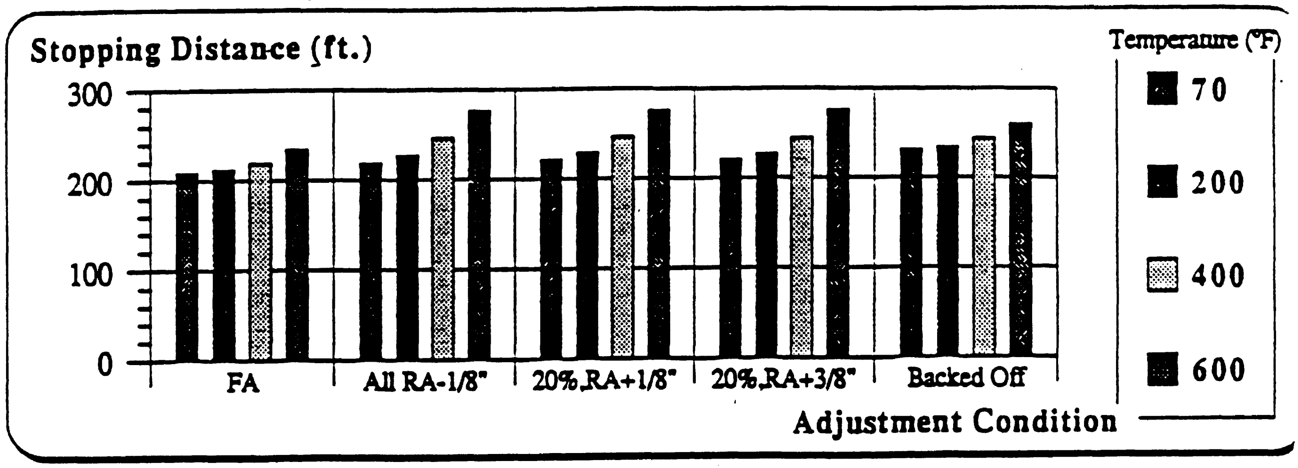


Figure 1.3.9 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 60 mph

Stopping Distances (60mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	209	219	222	221	231
200	212	227	229	227	234
400	219	246	246	244	243
600	234	277	276	276	260



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	5	6	6	11
200	1	9	10	9	12
400	5	18	18	17	16
600	12	33	32	32	24

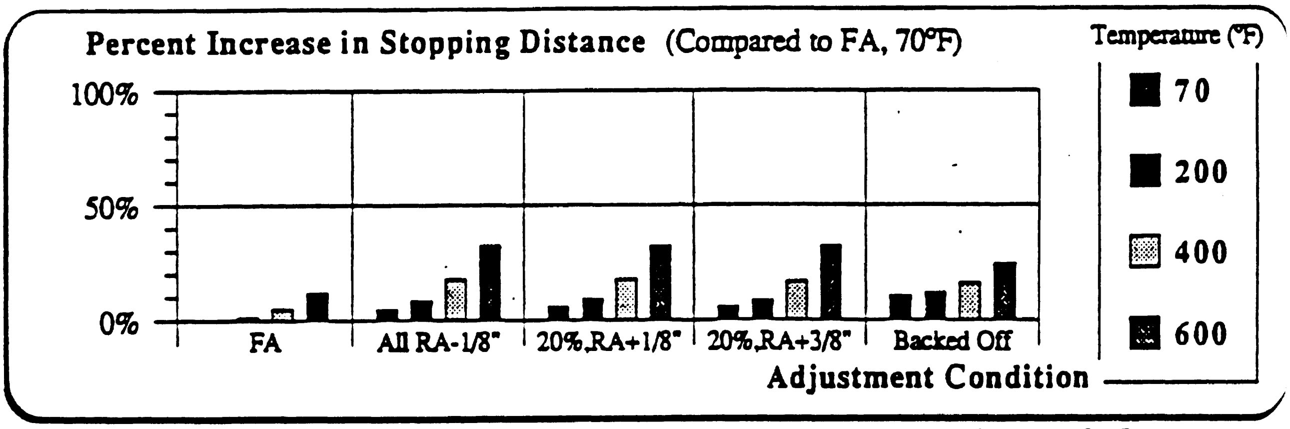
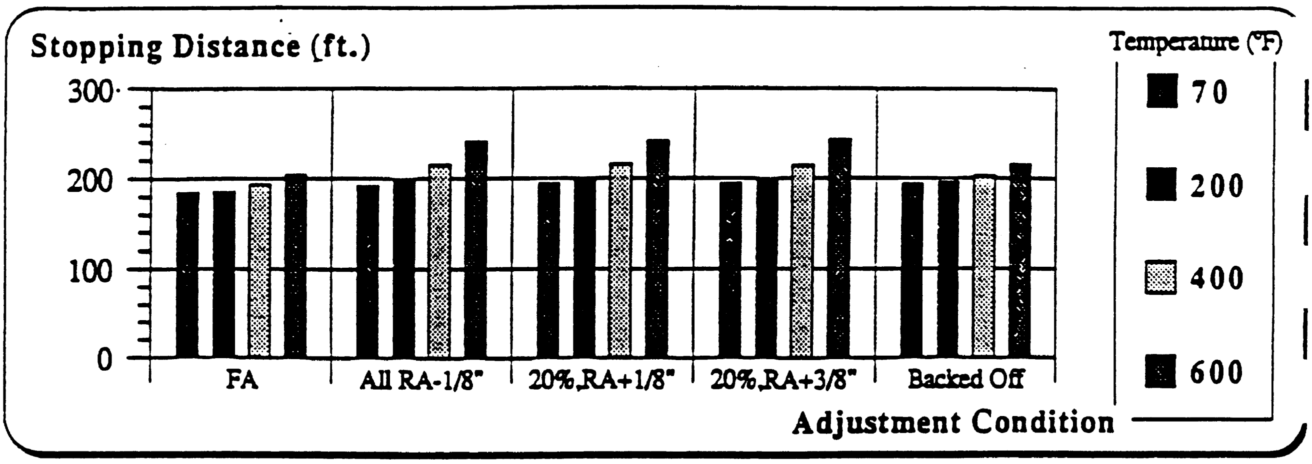


Figure 1.3.10 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 60 mph

Stopping Distances (60mph) of a 9 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	185	192	195	195	194
200	186	199	201	200	196
400	193	215	216	214	203
600	205	241	242	243	216



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	5	5	5
200	1	8	9	8	6
400	4	16	17	16	10
600	11	30	31	31	17

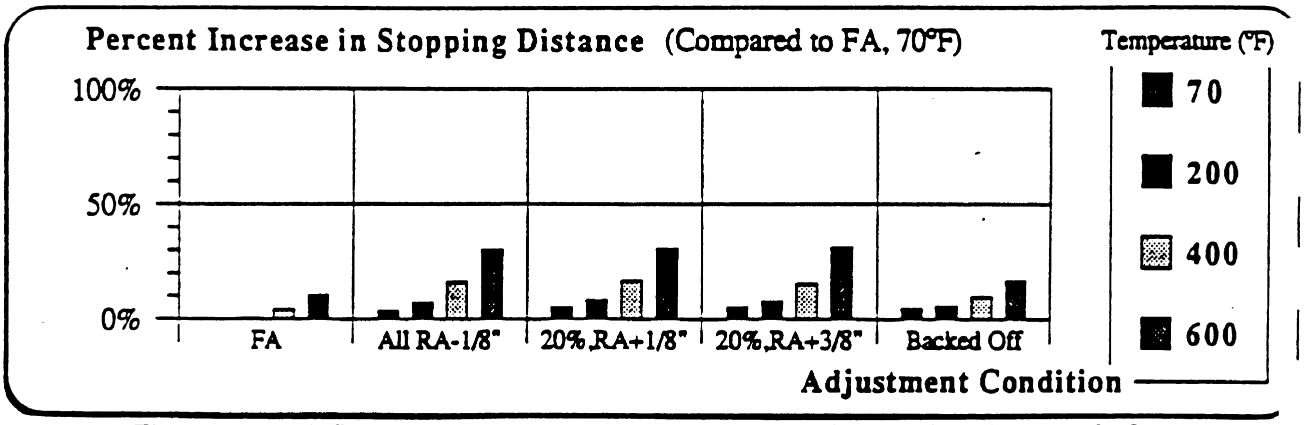


Figure 1.3.11 Influence of adjustment and temperature on the stopping distance of a 9-axle truck at 60 mph

truck. On the other hand, if the adjustment status of the truck is as defined by the "prime" cases (3', 4', 5'), the 20-percent OOS rule can be considered adequate. for the 3-axle truck (figure 1.3.5), the 20-percent OOS rule serves equally well. Cases 3' and 4' take 15 and 16 percent more to stop, significantly more than 10 percent for Case 2 which just passes.

Perhaps Cases 3' and 4' are more representative of vehicles in-service than Cases 3 and 4 because vehicles with mixes of fully-adjusted and misadjusted brakes might not occur frequently in service. Clearly, data from in-service vehicles are needed to address the issue.

- When a brake is completely backed-off in a 3-axle truck, by itself it will not cause it to be defined as OOS even though it degraded its braking performance more than any 20 percent OOS adjustment combination (Figure 1.3.3). That fact might motivate counting a backed-off brake as more than one brake demerit. In that figure, it is interesting to observe the temperature influence: Up to and including 400°F, Case 5' was worse than Cases 3' and 4'. At 600°F, since there were more OOA brakes in Cases 3' and 4' than in Case 5', the expansion of the drums caused more chambers to "bottom" in 3' and 4', therefore, these cases performed poorer than 5' at 600°F. The influence of a single completely backed-off brake decreases with the number of axles. Its influence is most significant in Case 5' of a 3-axle truck (Figure 1.3.3), but is much smaller in the same case (5') with the 5-axle truck (Figure 1.3.5).

- The use of a pressure which is lower than 100 psi to examine the adjustment status of a truck while maintaining the same pass/fail criteria levels will result in allowing trucks with poorer braking performance on the road. That fact also serves as a "magnifying glass" to distinguish between different cases. The results of the 5-axle truck can demonstrate the point. In Figure 1.3.10, under 100 psi test pressure, Cases 2 through 4 are almost the same (70°F) at 5, 6, and 6 percent degradation in braking performance. Reading the same strokes under 80 psi, Figure 1.3.4 shows a worse level of performance: 10, 9, and 8 percent degradation while the differences between the cases were magnified. At a higher temperature level, that phenomenon is more noticeable. At 600°F, under 100 psi, the degradation in braking performance for Cases 2, 3, 4 were 18, 18 and 17 percent, respectively. On the other hand, under 80 psi with the same conditions and stroke readings, the degradation in braking performance for those cases were 52, 44, and 38 percent. Clearly, if emergency braking is required, the truck that was inspected under 80 psi will perform significantly poorer than a similar vehicle tested under 100 psi. It should be emphasized that the above is true only if the stroke levels that determine OOS adjustment status are kept the same for both cases.

1.4. Findings and Observations

1.4.1 The measurement of cold static stroke at 80 psi is much less demanding than measuring cold static stroke at 100 psi. This means, for example, that a stroke that is just at the readjustment limit when 80 psi is applied will be approximately 1/8" beyond the readjustment limit when 100 psi is applied. The reason for this can be seen by examining the "operating line" due to compliances in the brake superimposed upon the following set of chamber characteristics. (See Figure 1.4.1) As the pressure is increased from 80 to 100 psi, additional stroke is consumed due to compression of the linings and compliances in the brake actuation system. When MCSAP decided to check stroke at 80 to 90 psi rather than at 100 psi, they could have reduced the readjustment limits (1/2 brake demerit level) by approximately 1/8" if they wanted to be as stringent as the 100 psi stroke measurement would require. On the other hand, MCSAP may have desired to make the brake adjustment criteria less demanding as well as respond to the concern that 100 psi applications may damage the brake system. Either choice seems possible depending upon the sentiments of the decision makers concerning the implications of brake adjustment with respect to the "service worthiness" of the vehicles permitted to operate on the highway and not be put OOS.

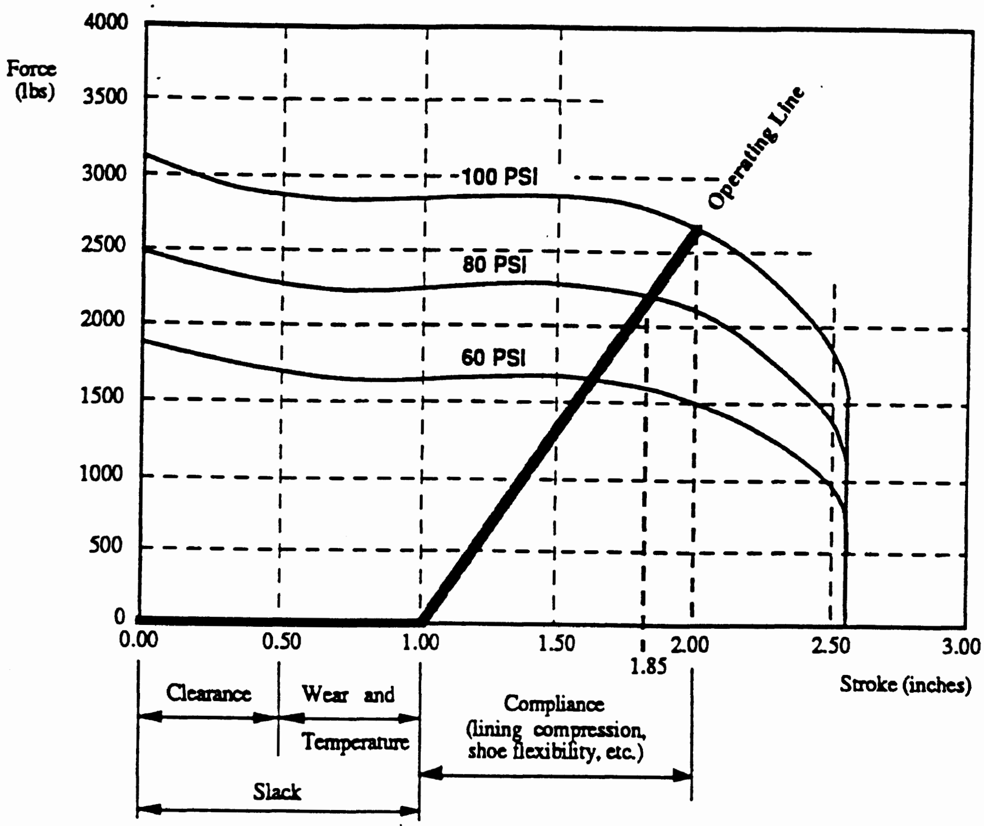


Figure 1.4.1. Operating line during braking

1.4.2 The influences of a fully backed-off brake are considerably larger than those of a brake that is 1/8" beyond the one brake demerit level. This is particularly true for changes in stopping distance happening at low temperature levels (70°F and 200°F). This appears to be a situation which could be considered as one warranting a change in the OOS criteria.

Using the terms of Figure 1.4.1, the fully backed-off brake can be easily recognized. Such a brake is defined as one whose slack stroke is equal to the stroke required to reach the bottom of the chamber. Conceivably, such a brake can be identified during inspection relatively easily. With the absence of lining compliance to resist the motion, the stroke of the chamber will increase to the point of bottoming with a relatively small application pressure.

However, since in the course of the testing the pressure is only applied once, and to 80 to 90 psi, identifying a backed-off brake is not obvious. The brake inspector cannot easily tell whether a brake has worn to the point where the stroke just bottoms the chamber or if the clearance stroke (slack) is so large that the chamber has bottomed without applying the lining to the drum. (Perhaps the inspector could "ring" (tap) the drum to see if the linings were contacting the drum.) Whether the brake is backed-off or not, the inspector will measure a large stroke less than or equal to that required to bottom the chamber. And, in either case, this indicates poor maintenance and poor brake performance. Perhaps, if the OOS criteria were to be changed, the inspector would be expected to apply more than one brake demerit to a brake stroke that was close to the backed-off level of stroke. The results given in Figures 1.3.2 through 1.3.11 provide the information that could form the foundation for a recommendation with regard to the level of brake demerit to use for brakes that are fully backed-off and this level of demerit would be applied to brakes that are close to being fully backed-off. (As indicated in the next item, temperature influences will lower the braking capability of brakes that are close to being backed-off, tending to cause them to approach backed-off brakes.)

1.4.3 The results in general show a significant influence of temperature on the predicted change in stopping distance at various levels of brake adjustment beyond the readjustment limit. Given that temperature has such a large effect on the predicted change in stopping distance, there is an issue concerning the level of temperature to use in comparing and evaluating stopping capabilities. Although one could devise a means for using all of the temperature results to obtain a composite measure of the percentage change in stopping performance, the results at 400°F and 80,000 pounds appear to be representative and satisfactory for use in comparing the influences of brake adjustment on stopping distance.

2.0 WHETHER BEING ABLE TO STOP WITHIN OUT-OF-SERVICE LIMITS AT 20 MPH IS A RELIABLE INDICATOR OF BEING ABLE TO STOP SAFELY AT 60 MPH WITHIN OOS LIMITS

2.1 Introduction

This section describes the results of analyses and observations aimed at evaluating whether being able to stop within OOS limits at 20 mph is a reliable indicator of being able to stop safely at 60 mph within OOS limits.

2.2 Brief Description of the Types of the Calculations Performed

The analyses consist of predictions of stopping distance performance from 20 mph using vehicles and levels of brake adjustment that are comparable to those used in some of the calculations of stopping performance from 60 mph. (See the previous section.) Calculations were made for at 20 mph stop at various levels of brake adjustment for the following combinations of vehicle types:

- 3-axle truck—with the cold static stroke measured at 80 and 100 psi (See Figures 2.2.1 and 2.2.2)

- 5-axle truck—with the cold static stroke measured at 80, 90, and 100 psi (See Figures 2.2.3, 2.2.4, and 2.2.5)

2.3 Concise Summary of the Results

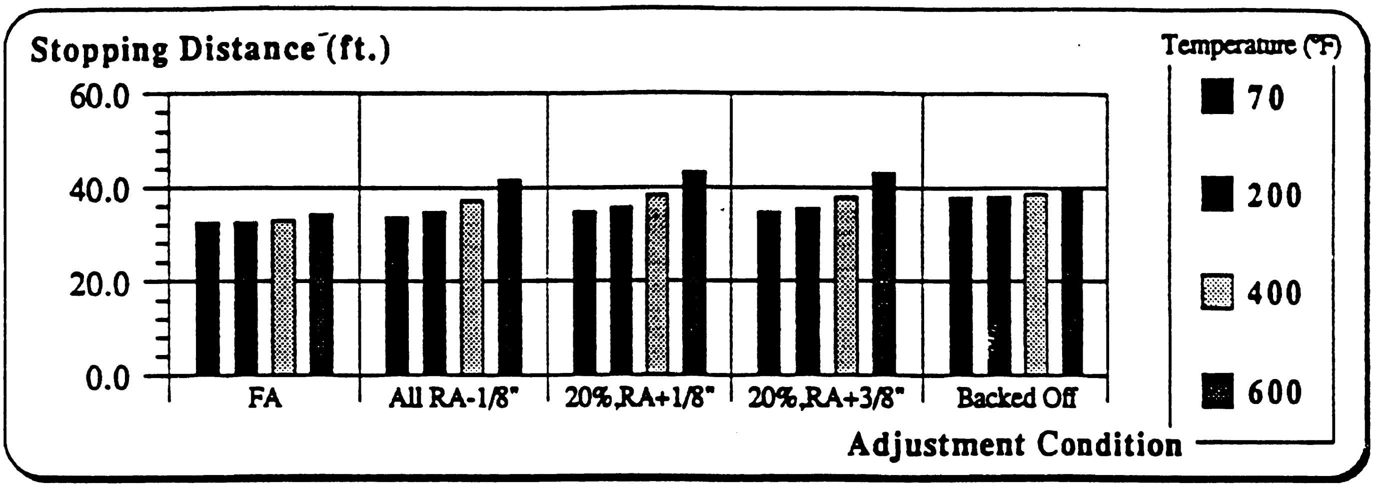
Although calculations were made at conditions when cold static stroke was measured at other than 80 psi, it is sufficient to examine the results at 80 psi. (Nevertheless, the results for all of the 20 mph calculations are presented in Figures 2.2.1 to 2.2.5. These charts and tables are in the format explained in the previous section.) As with the calculations made at 60 mph, these results indicate the influences of brake adjustment and do not indicate the influences of changes in brake properties such as timing, lining fade, and speed sensitivity of brake torque capability on stopping distance.

For purposes of comparing the results at 20 mph with those at 60 mph, the tables of percent increase in stopping distance can be compared directly. We wish to point out that, in general, predictions for stopping distance are for ideal conditions that would not ordinarily be expected in service. Accordingly, the predicted distances are shorter than those to be expected from vehicle tests. Nevertheless, we believe that the percentage changes in stopping distance due to brake adjustment are representative of the percentage changes to be found in service for various levels of brake adjustment with everything else held equal. In other words, the percentage changes in stopping performance are preferred for use in making evaluations and comparisons.

In order to facilitate the comparison between 60 mph and 20 mph stops, Figure 2.3.1 shows the percentage changes in stopping distance for a 3-axle truck making brake-limited stops from both 60 and 20 mph. In general, these results show that brake adjustment is much more important at 60 mph than it is at 20 mph. For example, in Case 3, where the vehicle would be OOS because a minimum number of rear brakes are 1/8" beyond the readjustment limit, the percentage increase in stopping distance at an initial brake temperature of 400°F is 31 percent at 60 mph and 18 percent at 20 mph. Figure 2.3.2 shows similar results for a 5-axle vehicle. As will be explained further, the

Stopping Distances (20mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	32.5	33.8	34.7	34.7	37.9
200	32.6	34.8	35.8	35.6	38.1
400	33.0	37.3	38.4	38.0	38.7
600	34.2	41.6	43.3	43.1	40.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	7	7	17
200	0	7	10	10	17
400	2	15	18	17	19
600	5	28	33	33	24

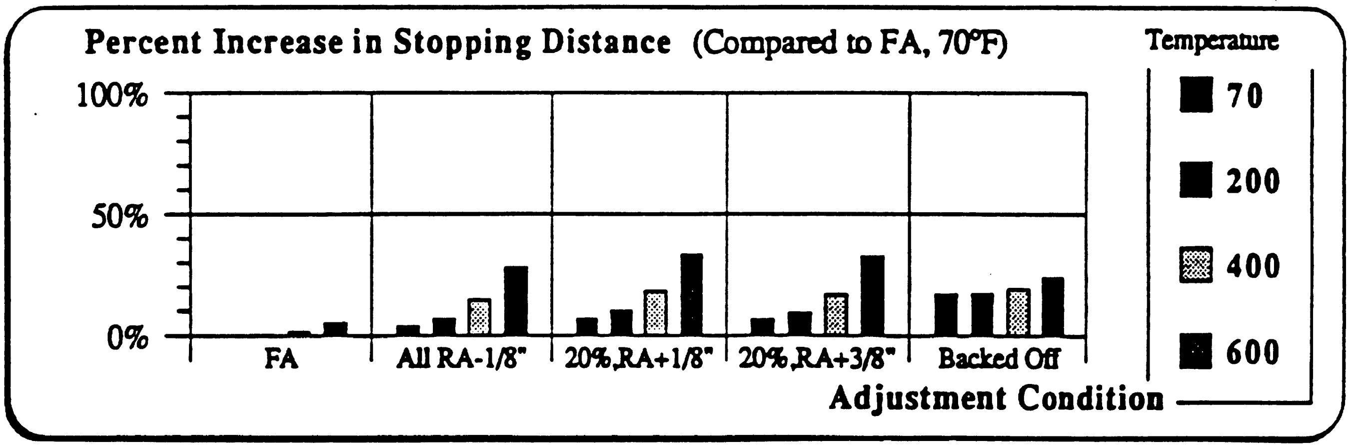
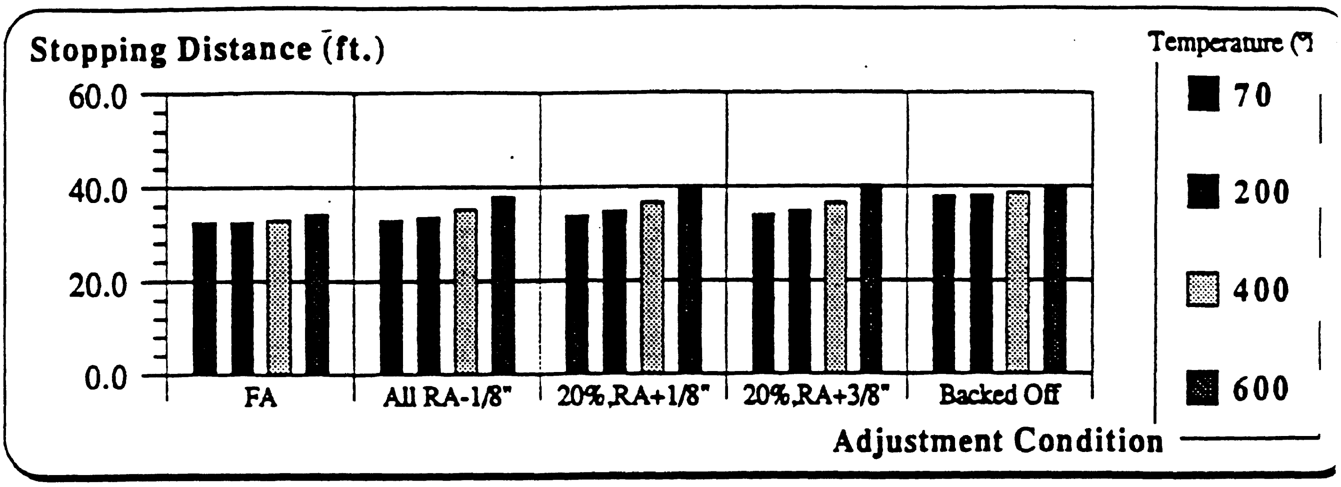


Figure 2.2.1 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 20 mph

Stopping Distances (20mph) of a 3 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	32.5	33.0	33.8	34.0	37.9
200	32.6	33.6	34.7	34.8	38.1
400	33.0	35.2	36.7	36.5	38.7
600	34.2	38.0	40.1	40.3	40.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	2	4	5	17
200	0	3	7	7	17
400	2	8	13	12	19
600	5	17	23	24	24

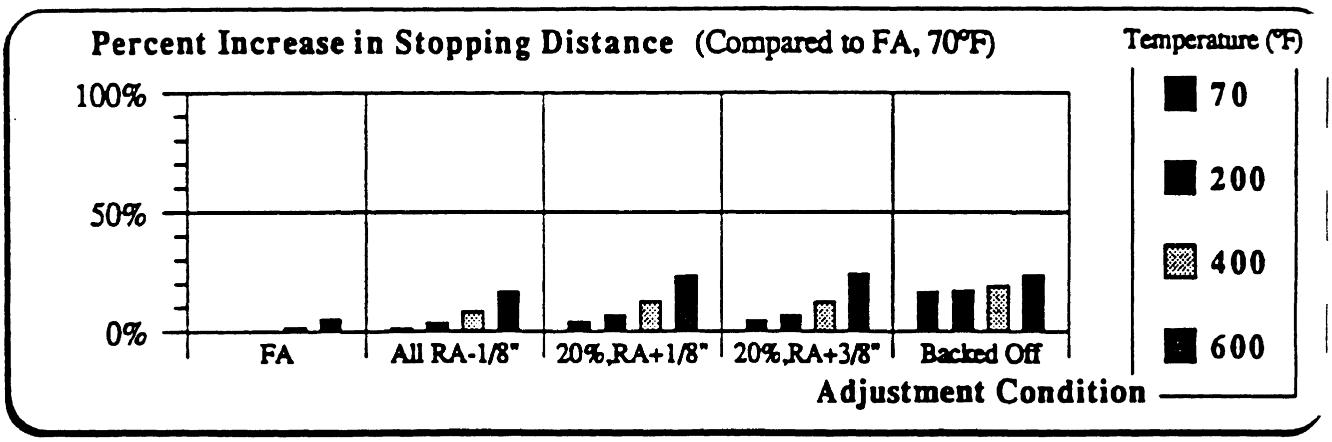
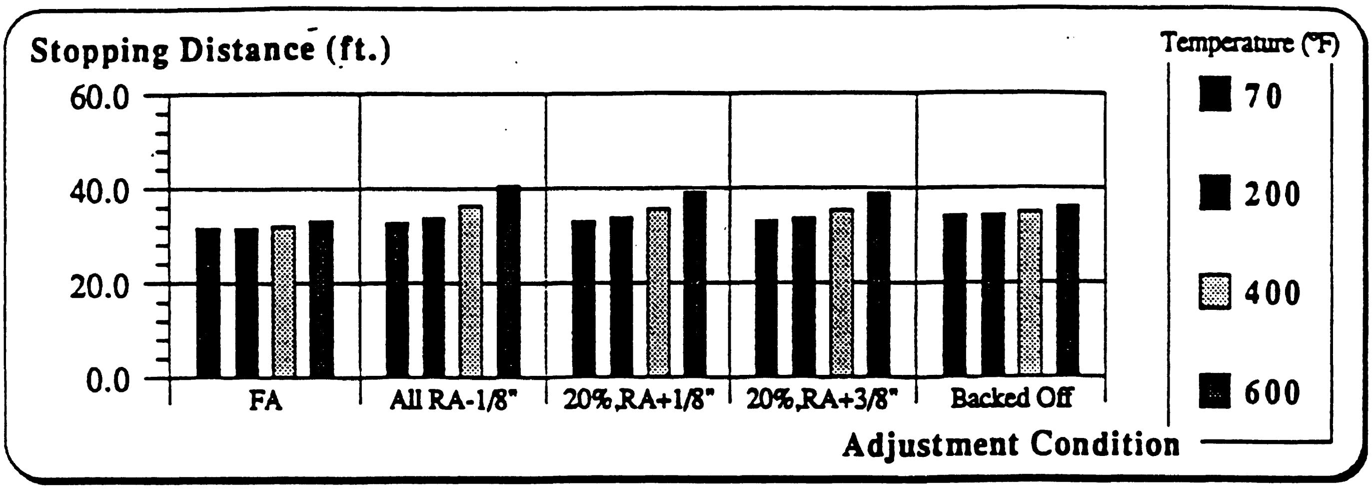


Figure 2.2.2 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 20 mph

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 80 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.9	33.1	33.1	34.2
200	31.7	33.9	33.9	33.7	34.3
400	32.1	36.4	35.7	35.3	34.9
600	33.3	40.6	39.1	39.0	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	4	5	5	8
200	0	7	7	7	9
400	2	15	13	12	10
600	5	28	24	23	14

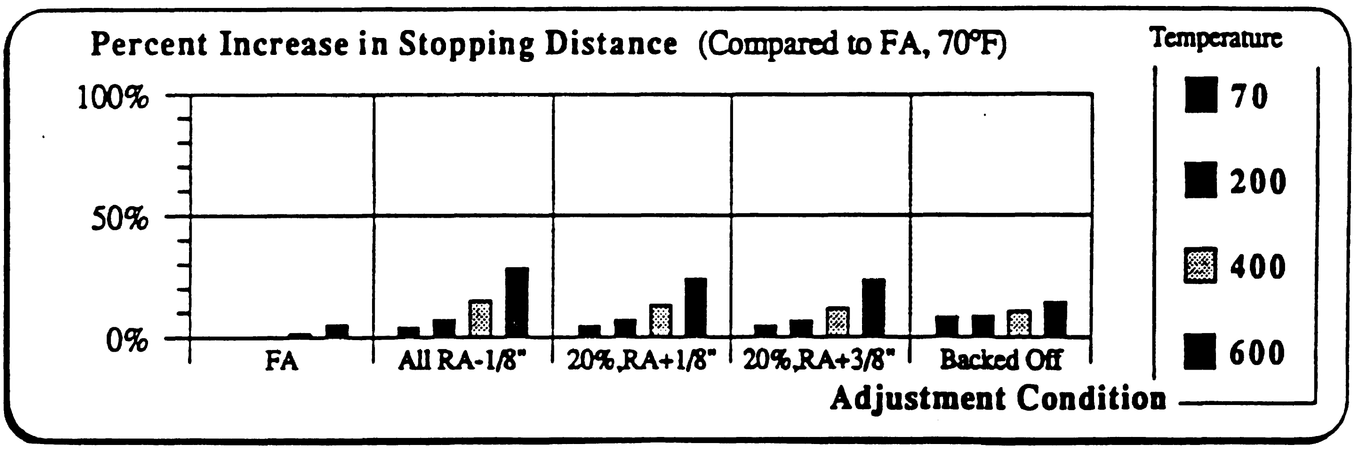
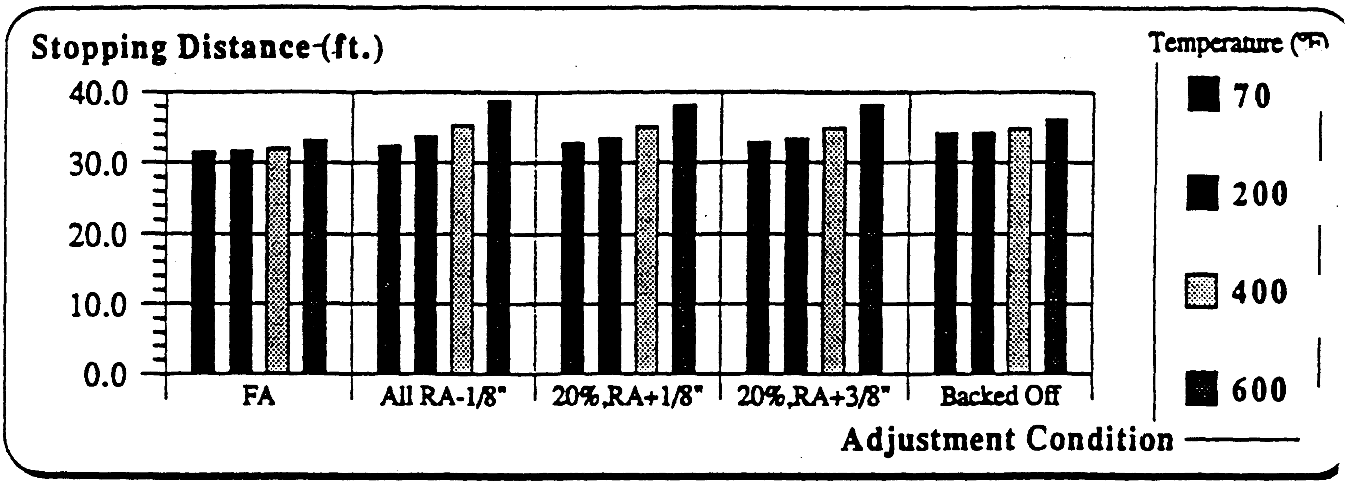


Figure 2.2.3 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 20 mph

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 90 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.5	32.8	32.9	34.2
200	31.7	33.8	33.5	33.4	34.3
400	32.1	35.4	35.1	34.9	34.9
600	33.3	38.8	38.2	38.2	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	3	4	4	8
200	0	7	6	6	9
400	2	12	11	10	10
600	5	23	21	21	14

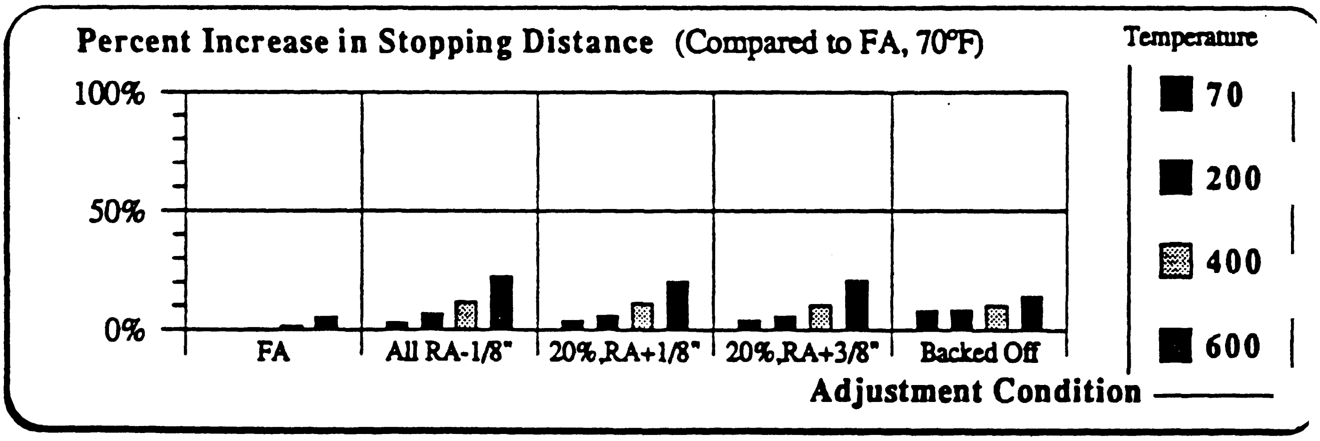
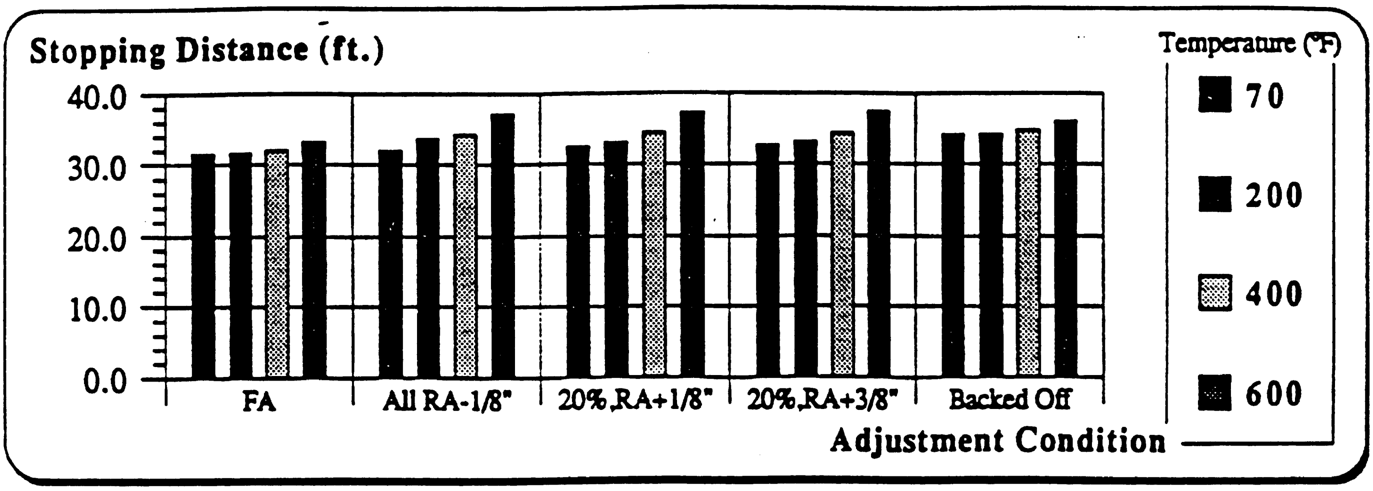


Figure 2.2.4 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 20 mph

Stopping Distances (20mph) of a 5 Axle Truck With Various Adjustment Conditions (Measured at 100 psi) as a Function of Temperature

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	31.6	32.1	32.5	32.7	34.2
200	31.7	33.7	33.1	33.2	34.3
400	32.1	34.4	34.6	34.5	34.9
600	33.3	37.1	37.2	37.4	36.2



Percent Increase in Stopping Distance as a Function of Temperature and Adjustment Conditions

Temp. \ Adjustment Case	FA	All RA-1/8"	20%,RA+1/8"	20%,RA+3/8"	Backed Off
70	0	2	3	4	8
200	0	7	5	5	9
400	2	9	9	9	10
600	5	17	18	18	14

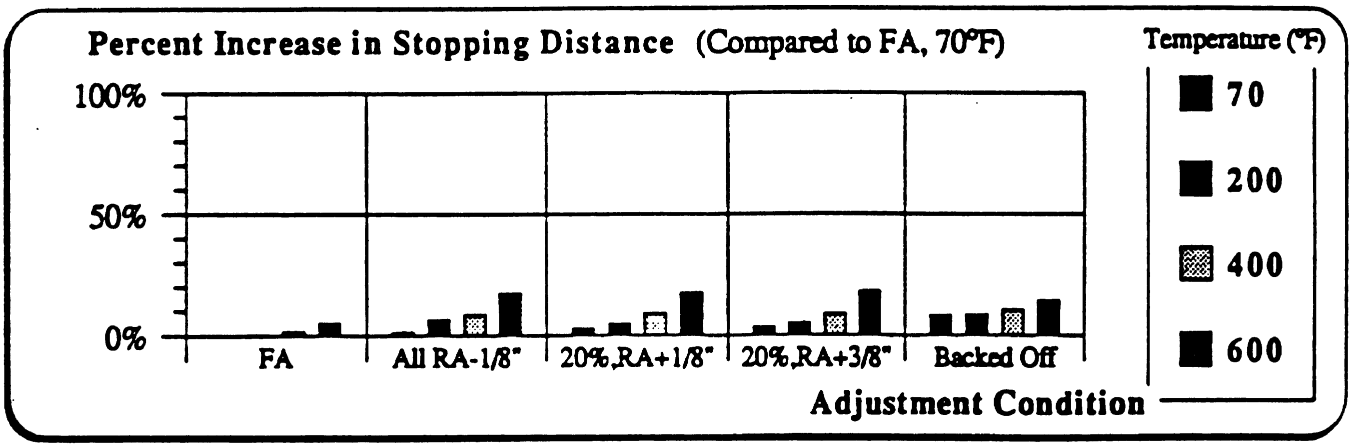


Figure 2.2.5 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 20 mph

numerical data show that 60 mph results are much more sensitive to brake adjustment than the 20 mph results are.

Another outcome of the fact that brake adjustment is less important at 20 mph, is the way the results change with pressure. As discussed in the first section, stopping distance calculations for cases categorized by stroke measurements conducted at the higher pressure (100 psi), will vary significantly from cases categorized at the lower pressure (80 psi). This is less noticeable at the 20 mph stopping distance than the 60 mph cases. For the 3-axle truck at 60 mph and stopping with an initial brake temperature of 400°F, the 80 psi results (Figure 1.3.2) for Cases 2, 3, and 4 varied from the 100 psi results (Figure 1.3.9) by 9, 8, and 7 percent, respectively. The same cases, this time from 20 mph, varied between 80 and 100 psi only by 7, 5, and 5 percent (See Figures 2.2.1 and 2.2.2).

Unlike the 60 mph stopping distance situations, the 20 mph cases do not have "dramatic" variations between the various adjustment cases and truck configurations. At 400°F, the values of percent increase in stopping distance from 20 mph do not go above 19 percent, and mostly they are at the proximity of 15 percent (see the lower part of Figures 2.3.1 and 2.3.2). The same values for the 60 mph stop go as high at 31 percent, and from the most part, they are at the proximity of 26 percent (upper part of Figures 2.3.1 and 2.3.2). For a 5-axle truck under the more stringent adjustment test (100 psi) and at a high initial brake temperature of 400°F , the braking performance for a 20 mph stop does not degrade more than 10 percent for the worst case (Figure 2.2.5). The same truck, when performing the 60 mph stopping distance test, will encounter a performance degradation of up to 18 percent (Figure 1.3.10).

In contrast to the higher sensitivity of the 60 mph results to brake adjustment, the calculated results are less sensitive at 60 mph than at 20 mph due to timing characteristics of the braking system. The higher slope of the 20 mph lines in Figures 2.3.3 and 2.3.4 demonstrates that fact. Furthermore, under timing values that meet the FMVSS 121 requirements, the braking performance is more susceptible (with an order of magnitude) to variations in chamber pressure rise time (Figure 2.3.3) than to variations in chamber pressure rise (Figure 2.3.3) than to variations in the rise time of the air lines of the system (Figure 2.3.4).

2.4 Findings and Observations

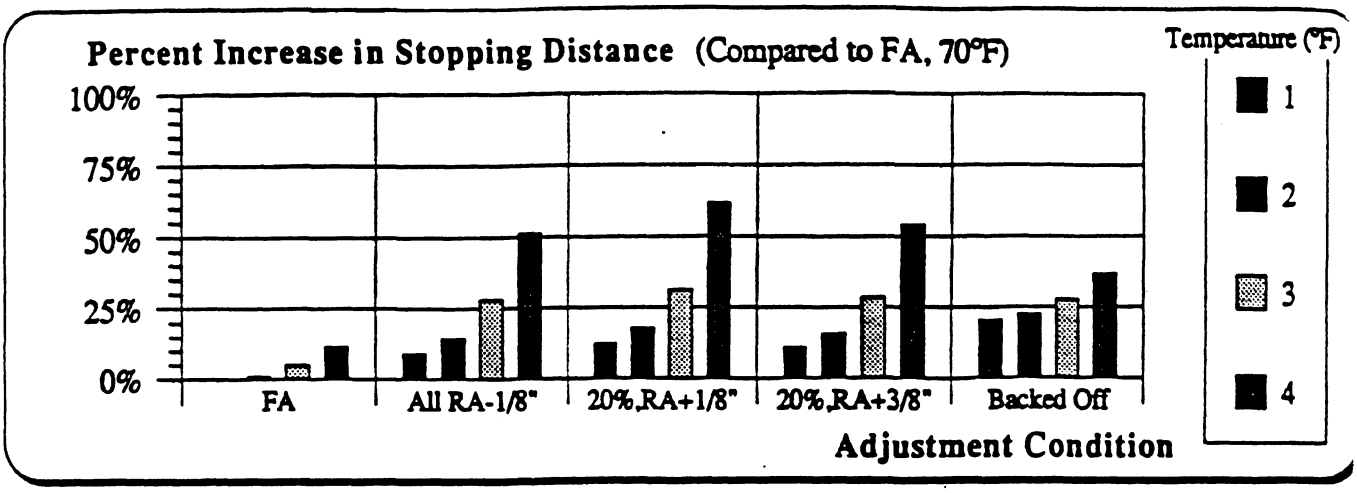
2.4.1 The results indicate that percentage changes in stopping distances due to poor brake adjustment are much larger at 60 mph than at 20 mph. There are two reasons for this. First, the influence of brake timing is much more important at 20 mph than it is at 60 mph. Even though the brake timing in the examples studied meet FMVSS 121 requirements, the maximum available torque is not applied for very long in the 20 mph stop, thereby decreasing the influence of brake adjustment compared to that during a 60 mph. stop. The second reason involves the temperature rise during a stop. This is a very small effect at 20 mph, but it is important at 60 mph for OOA brakes that are close to bottoming out. The basic finding from the calculations is that the increase in drum expansion due to temperature rise has an important influence on braking capability for hot, poorly adjusted brakes.

2.4.2 The finding above is based upon comparisons with available braking capability at 20 and 60 mph. The following discussion, however, involves the observation that 20 mph stopping distance standards may be set differently than 60 mph standards. For example, if the 20 mph rules were much more stringent than the 60 mph

3 AXLE TRUCK

Percent Increase in Stopping Distances (60mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	9	12	11	21
200	1	15	18	16	23
400	5	28	31	29	28
600	12	51	62	54	37



Percent Increase in Stopping Distances (20mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	4	7	7	17
200	0	7	10	10	17
400	2	15	18	17	19
600	5	28	33	33	24

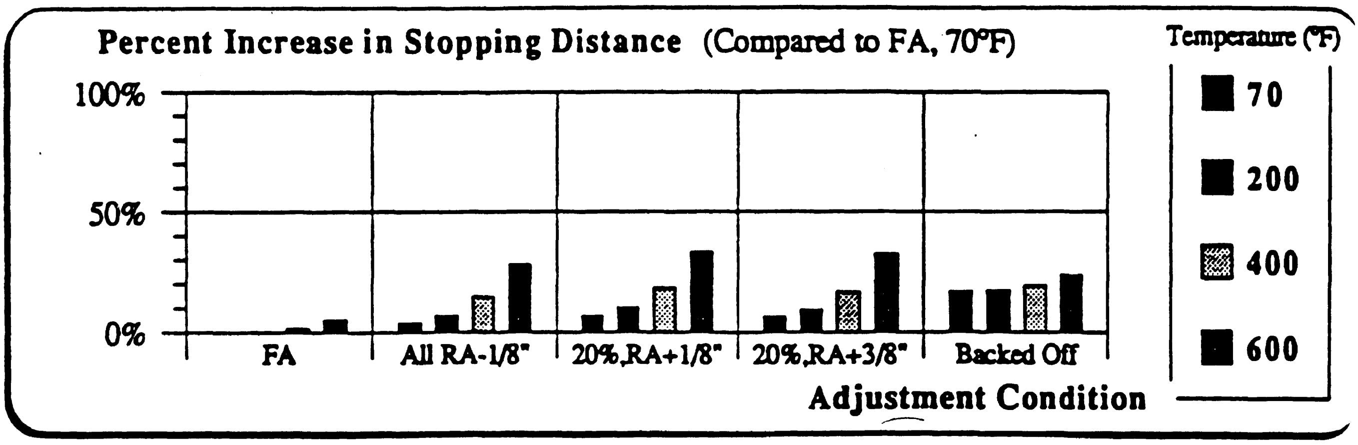
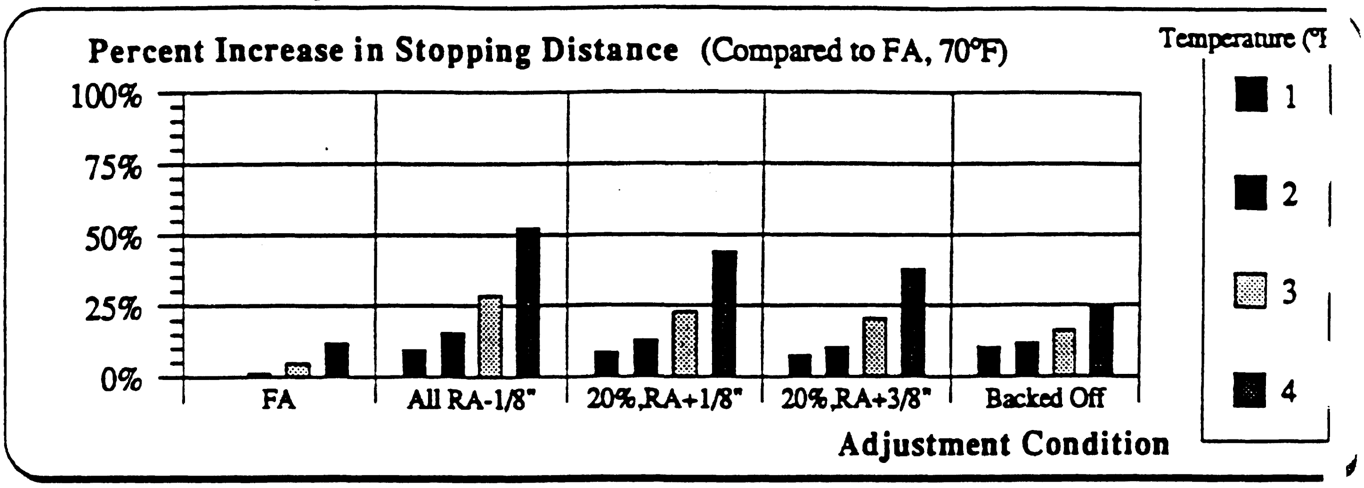


Figure 2.3.1 Influence of adjustment and temperature on the stopping distance of a 3-axle truck at 30 and 20 mph

5 AXLE TRUCK

Percent Increase in Stopping Distances (60mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	10	9	8	11
200	1	15	13	11	12
400	5	29	23	21	16
600	12.	52	44	38	24



Percent Increase in Stopping Distances (20mph) as a Function of Temperature and Various Adjustment Conditions (Measured at 80 psi)

Adjustment Case / Temp.	Case1 FA	Case 2 All RA-1/8"	Case 3 20%,RA+1/8"	Case 4 20%,RA+3/8"	Case 5 Backed Off
70	0	4	5	5	8
200	0	7	7	7	9
400	2	15	13	12	10
600	5	28	24	23	14

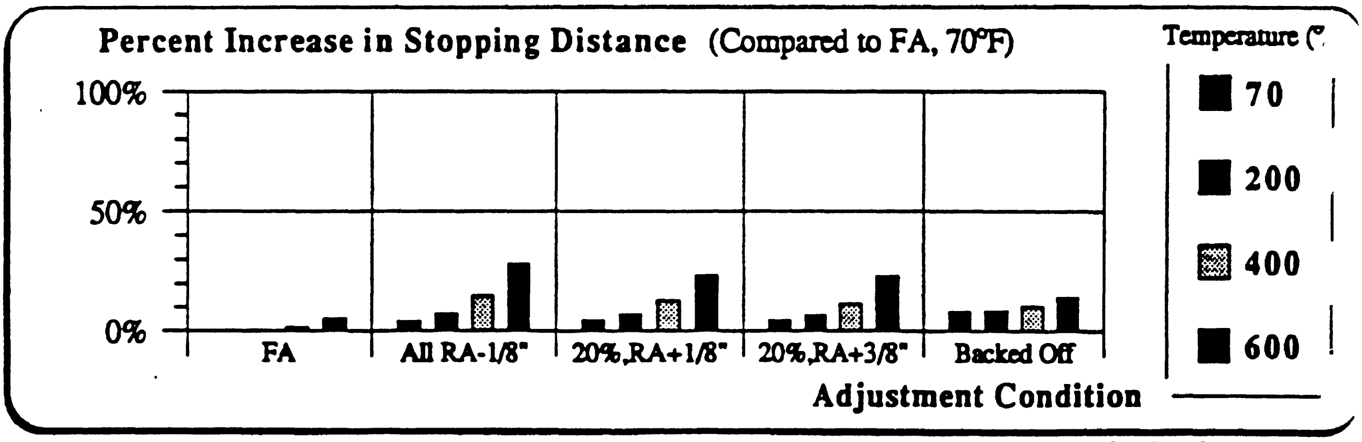


Figure 2.3.2 Influence of adjustment and temperature on the stopping distance of a 5-axle truck at 60 and 20 mph.

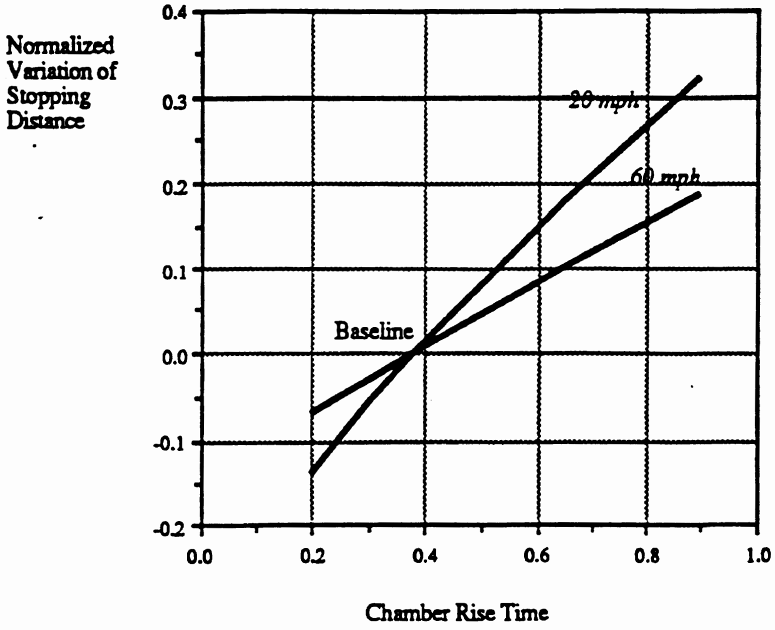


Figure 2.3.3 Influence of chamber rise time on stopping distance from 20 and 60 mph

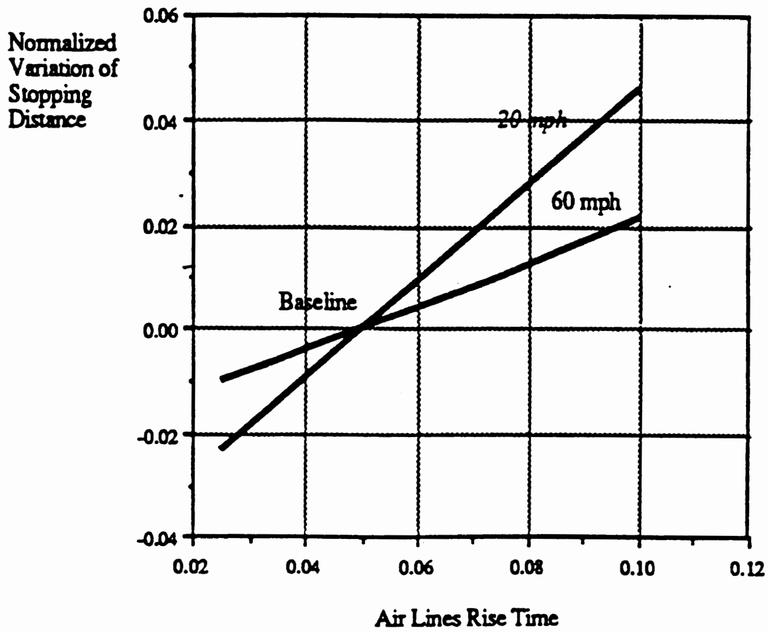


Figure 2.3.4 Influence of air lines rise time on stopping distance from 20 and 60 mph

rules (or equivalently, the 60 mph rules were much more lenient), there is a possibility that passing the 20 mph stopping distance requirement would go a long way towards assuring that the vehicle will pass at 60 mph.

In order to examine the differences between stopping from 20 and 60 mph, consider the following simplified example. The current rule for 20 mph is 35 feet for some trucks and 40 feet for longer combinations. (The difference being related to brake timing considerations which will eventually come into play here also.) The basic relationship for estimating stopping distance from deceleration (ignoring or "averaging" the influences of rise times) is as follows:

$$S = V^2/2D$$

where D is the average deceleration

V is the initial velocity

and S is the stopping distance.

According to the above equation, if the deceleration capability of the braking system were to be kept equal, the stopping distance for a 60 mph stop would be nine times that for a 20 mph stop—that is, 315 feet or 360 feet corresponding to 35 or 40 feet.

However, the influences of pressure-rise times vary linearly with initial velocity and amount to approximately 12 feet at 20 mph and 35 feet at 60 mph if the average rise time is approximately 0.5 seconds. This means that the 60 mph stop has the advantage over the 20 mph stop when it comes to the contribution of rise time to stopping distance, since 12 feet is a larger fraction of the stopping distance at 20 mph than 35 feet is at 60 mph. For example, if a vehicle stopped in 36 feet from 20 mph, the deceleration capability available would be approximately 0.56 g. If the deceleration available is 0.56 g, a vehicle stopping from 60 mph would be able to stop in approximately 250 feet including 35 feet as an approximation of the contribution due to rise time. The fairly obvious point of this discussion is that being able to pass a 60 mph requirement depends upon not only the braking system, but the nature of the 60 mph requirement with respect to the 20 mph requirement.

People setting 60 mph requirements have included the factors discussed above if they have used empirical measurement of stopping distance capability to aid them in establishing the goals. At one time, FMVSS 121 had a 60 mph stopping distance requirement of 293 feet. Given the rough approximations above (i.e., 35 feet due to rise time and neglecting about a 4 percent reduction due to speed loss effects during the rise time), the average deceleration for a 60 mph stop would be approximately 0.47 g. The current dynamometer tests in FMVSS 121 require approximately 0.435 g which would lead to a stopping distance of approximately 312 feet. So even though the reasons may be vague and obscure, the current implicit FMVSS 121 requirement on stopping distance fits in withthe 315 feet derived from equation (1) which neglected not only brake timing matters, but also any in-stop fade due to heating of the brake linings or velocity sensitivity of the linings.

2.4.3 The preceding observation needs to be supplemented with other observations for why 20 mph stops are not good indicators of what will happen at 60 mph. The reasons are (1) there are lining materials that are temperature-sensitive and the in-stop temperature rise at 60 mph will cause these materials to lose appreciable amounts of torque capability, (2) certain lining materials may have a sliding speed sensitivity that shows up at 60 mph, but not at 20 mph, and (3) very good brake timing may compensate for poor adjustment or other braking torque deficiencies at 20 mph, but this will not be as effective at 60 mph.

3.0 CRITICAL ADJUSTMENT THRESHOLDS BEYOND WHICH HEAVY TRUCKS CANNOT STOP WITHIN A SAFE MARGIN.

3.1 Introduction

This section describes results pertaining to identifying critical adjustment thresholds beyond which heavy trucks cannot stop within a safe margin.

3.2 Brief Description of the Type of Analysis Performed

The analyses presented previously consisted of predictions of brake-torque capabilities and stopping-distance performance for selected combinations of brake adjustment levels as listed in Table 1.2.1. In this section, those results are examined from the perspective of using them in evaluating OOS criteria.

The difficulty here is in determining what is meant by being able to "stop within a safe margin." In work by NHTSA (Reference [1]), they chose to use a 20 percent increase in stopping distance as a "bogie" for emphasizing conditions not covered by the current OOS criteria. A general scanning of an informal, but extensive, document entitled, "History of CVSA Brake Out-of-Service Criteria," (supplied by Mr. L. Strawhorn) indicates that people tend to use stopping-distance calculations to show that either some condition of brake adjustment is worse than the OOS criteria, and therefore, ought to be included in the OOS or, depending upon their attitude, that some OOS condition is no worse than some acceptable condition, and therefore, ought to be removed from the OOS category. In either case, stopping-distance predictions for some set of operating conditions are used in making the evaluations. The calculations performed in this study and described in Section 1 provide the "raw material:" regarding stopping distance for "pathological" cases that were selected for use in making critical assessments of the stopping capabilities and safety margins of heavy trucks with various types and levels of misadjustment. These cases are representative of situations that challenge the OOS criteria with regard to distinguishing between various out-of-adjustment situations on the basis of percentage changes in stopping distance.

Given the above description, the analysis in this section has a more abstract and philosophical tone in a straightforward analysis of stopping distance. The results summarized in the next section are based on concepts and ideas related to selecting levels of stopping distance degradations and reductions in safety margins with respect to those stopping distances available to trucks with excellent maintenance making stops under very favorable operating conditions. The logic and rationale for this approach is that the current OOS criteria represent the combined judgment of many knowledgeable people, thereby providing a reasonable starting point for considering the implications and meanings of changes in defining critical adjustment thresholds or combinations of adjustment thresholds from brake to brake on a vehicle.

In summary, the current OOS criteria provide an initial indication of the amount of loss in stopping capability and safety margin that is currently deemed acceptable by the CVSA/MCSAP community. Perhaps higher goals may be acceptable in the future, but the current indications from MCSAP inspections are that many trucks are having difficulty meeting the current goals for brake adjustment, given the hardware and maintenance practices currently employed. The following results emphasize means by which stopping-distance goals as derived from current criteria might be applied more uniformly across the spectrum of possible brake adjustment situations.

3.3 Concise Summary of the Results and Findings

3.3.1 The raw material presented in Figures 1.3.2 through 1.2.11 shows that stopping distance versus brake adjustment results are highly dependent upon temperature conditions and the pressure level at which static stroke is measured as well as the level of adjustment. Although one could consider some composite measure of performance based upon a wide range of initial brake temperatures, vehicle loading conditions, and road surface conditions; the analytical work that went into developing the calculations indicates that the influences of brake adjustment are most important with respect to stopping-distance capability in situations involving high temperatures, heavy loads, and high friction at the tire/road interface. The finding here is that it is reasonable to evaluate the influences of brake adjustment criteria at chosen sets of operating conditions. Examination of the overall results suggests that calculated stopping-distances for vehicles laden to the maximum allowable limit are suitable for examining the influences of various brake adjustment criteria.

Clearly, the results depend importantly on initial brake temperature. The choice of fully-laden and 400°F represents a judgment concerning a likely state of operation. Higher temperatures such at 600°F emphasize the influences of the level of degradation involved, however, 600°F is a high temperature that is representative of demanding service. We have used results calculated at 400°F to illustrate our ideas.

Once a brake becomes backed-off, temperature does not influence the amount of degradation involved (of that particular brake) and important levels of degradation can be obtained without the influences of temperatures being a contributing factor in this case. Hence, a backed-off brake, or a brake that might be called "completely OOA," is a specially bad situation.

3.3.2 This section presents a method for adding "backed-off" brakes into a brake "demerit system like the one used in the current 20 percent OOS criteria. The idea here is to augment the current 1/2 brake and one brake penalties used in computing the 20 percent factor employed in the OOS criteria. If these levels of brake penalties are viewed as "demerits," a completely misadjusted or backed-off brake could be assigned a demerit value to be used in computing a 20 percent factor that would be based upon the percentage reduction in stopping distance caused by various levels of misadjustment. The following material provides an explanation of a methodology leading to incorporating a penalty of 1.5 or 2.0 for a completely misadjusted brake.

The method is based upon studying brake chamber characteristics to determine "adjustment factors" that can be used to estimate the influences of various levels of brake adjustment or misadjustment. The chamber characteristics are examined as illustrated in Figure 3.3.1 to determine the loss in actuating force due to the level of brake adjustment. This loss is expressed as a fraction of the actuating force that would be available if the brake were fully-adjusted. The following table summarizes a set of adjustment factors determined for various states of adjustment as a function of cold static stroke values.

Table 3.3.1 Brake adjustment factors at 400°F for a Type 30 chamber

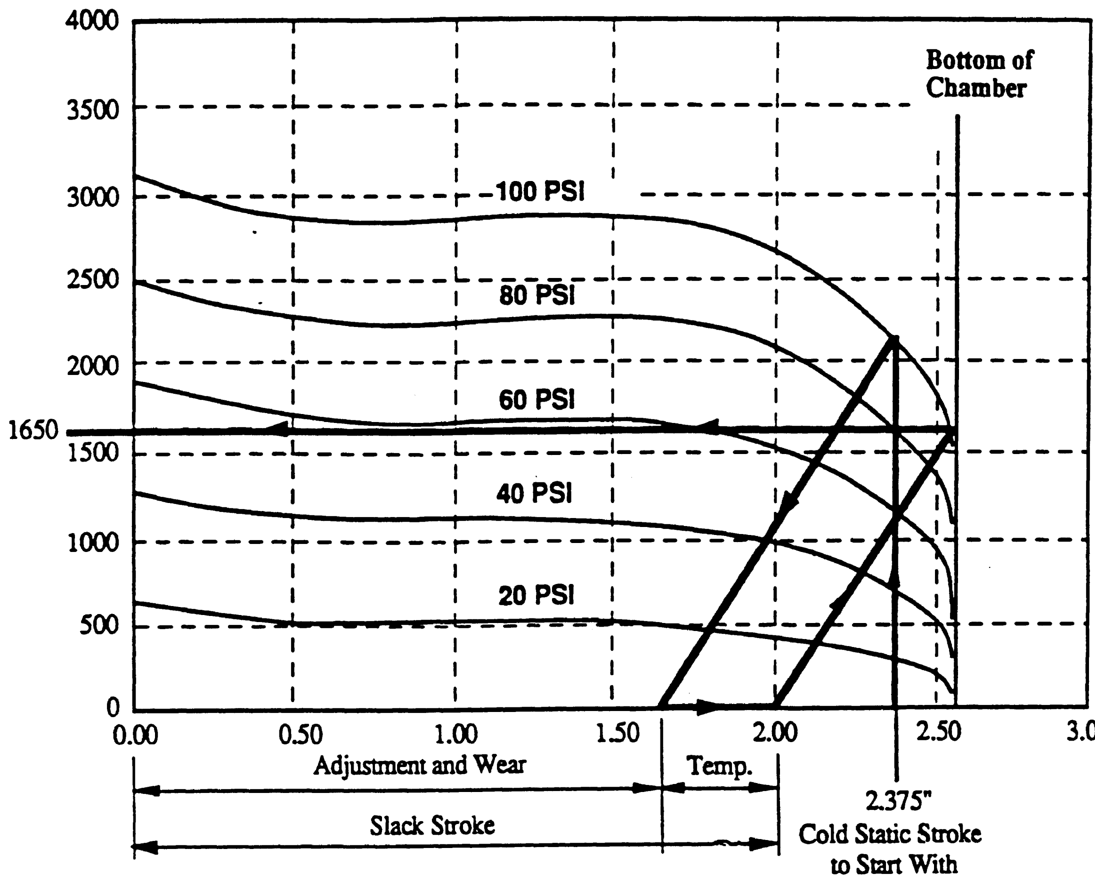
Conditions at which stroke was measured	2.125" of cold static stroke	2.375" of cold static stroke
measured at 100 psi and 70°F	0.77	0.58
measured at 80 psi and 70°F	0.68	0.39
measured at 80 psi and 70°F plus 0.1" of in-stop stroke increase	0.63	0.30

These adjustment factors are proportional to the available braking capability in the ranges of brake adjustment corresponding to a brake penalty of 0.5 and a full brake penalty (1.0) in the current OOS criteria. If we were to extrapolate the factors given in the first row of Table 3.3.1 to a completely backed-off brake which would have an adjustment factor of 0.0, we would conclude that a completely misadjusted brake should be given a penalty or demerit of approximately 2.0 to be in concert with the penalties of 0.5 and 1.0 given the current criteria. When stroke is measured at 80 psi, the factors given in the last row of Table 3.3.1 extrapolate to a penalty value of approximately 1.5 for a fully backed-off brake. (The lower value in this case is due to the fact that the levels of misadjustment are actually greater at 2.125" and 2.375" when measured at 80 psi than when the strokes are measured at 100 psi.)

The net conclusion that is implied by this work is that stopping distance discrepancies due to backed off brakes could be reduced if backed off brakes were given a penalty equivalent to at least 1.5 brake demerits. The criteria for calling a brake "backed-off" or "completely misadjusted" might be that the cold static stroke is greater than or equal to 2.5" for a Type 30 chamber. For other types of chambers, an equivalent boundary might be set at the stroke required to reach the bottom of the chamber minus 1/8".

3.3.3 The ideas presented in this section extend the notion of using brake adjustment factors like those introduced in the previous section. In this case, a scheme is presented for using estimated changes in stopping distance to determine OOS.

The methodology involves assigning adjustment factors to various ranges of brake adjustment. To illustrate the concept, brake chamber characteristics have been examined at several levels of brake adjustment and values of adjustment factors have been determined per the procedure illustrated in Figure 3.3.1. (Although these factors were derived for a particular type of chamber and set of brake properties, we have generalized their use to be representative or typical of a broad range of brakes.) A tentatively proposed set of factors suitable for introducing the procedure is given in Table 3.3.2. These adjustment factors represent the contribution to changes in stopping distance with brakes at 400°F and with cold static stroke measured at 80 psi.



$$\frac{F}{F_{ref}} = \frac{1650}{2850} = 0.579 \longrightarrow$$

Net Result: 58% of the Fully Adjusted Braking Force

Figure 3.3.1 Limit on actuation force due to brake adjustment level

Table 3.3.2 Brake adjustment factors at 400°F

Range of strokes with respect to the readjustment limit RA	Brake adjustment factor representing the stroke range
"fully adjusted" strokes	1.0
RA-1/8≤s<RA	0.77
RA≤s<RA+1/4	0.63
RA+1/4<s<RA+1/2*	0.30
RA+1/2*≤s *use for Type 30 chambers and bottom -1/8 for other types	0.0

There is a caveat that needs to be considered when applying adjustment factors. The factors are keyed to what a fully-adjusted brake will do. If different brakes have different torque capabilities in the fully-adjusted state, these differences need to be taken into account. A common situation is that front brakes have approximately 50 percent of the torque capability of rear brakes. Also, when slack arm lengths and/or chamber areas differ from tractor rear brakes to trailer brakes, then the "AL" factors need to be included in the procedure for estimating changes in stopping distance due to brake adjustment. The following example presented in Table 3.3.3 illustrates the computation for a situation in which a 3-axle (6-brake) truck has all brakes fully-adjusted except one rear brake is at a cold stroke of RA+1/8 and another is at RA+3/8.

Table 3.3.3 Example calculation of the change in stopping capability

brake #	adjustment level	adjust. factor	relative AL etc.	relative torque
1	FA	1.0	0.5	0.5
2	FA	1.0	0.5	0.5
3	FA	1.0	1.0	1.0
4	FA	1.0	1.0	1.0
5	RA+1/8	0.63	1.0	0.63
6	RA+3/8	0.30	1.0	0.30
		totals	5.0	3.93

To first approximation, the stopping distance is inversely proportional to the braking force. This means that in the above example (Table 3.3.3) the change in stopping distance due to brake adjustment is approximately given by 5.0/3/93 which equals 1.27. In other words, the estimated stopping distance is 27 percent longer with the arrangement of brake adjustment levels given in Table 3.3.3 than it would be if all brakes were fully-adjusted.

A question that naturally arises at this point, concerns the validity of the results. "How close are the results of such an approximated calculation of stopping distance variation, to those of the more elaborated, detailed computational method used in the previous sections?" Table 3.3.3 presents a 3-axle truck with brakes at 40°F and with cold static stroke measured at 80 psi. The elaborated calculations results for such a truck, under the same conditions in Figure 1.3.2 (case 4, RA+3/8"—29 percent) do not deviate significantly from the approximated result of 27 percent.

The methods presented here, and in the following section for approximating degradation of braking performance by means of increased stopping distance, are based on reduced braking capability due to brake adjustment. As discussed in Section 2 (60 versus 20 mph), brake adjustment is mostly influential when evaluating brake performance at high speed. Therefore, it should be emphasized that such an approximate approach can be adopted rather confidently at high speeds. It should be regarded cautiously at low speeds. This fact can be demonstrated by examining the results for a 20 mph stop presented in Figure 2.2.1. While the approximated result was quite close to the detailed one for the 60 mph stop at 27 and 29 percent, it deviates significantly from the result of the 20 mph stop—17 percent.

The above procedure can be applied to brake adjustment situations in general to provide a measure of the associated change in stopping distance capability. The following Table 3.3.5 gives results for several examples for vehicles with six and ten brakes. The concept portrayed here is as follows: if the OOS criteria were related to a target level of allowable reduction in stopping capability, a more uniform consideration of the importance of various states of OOA would be obtained.

Table 3.3.5 Examples showing the influence of brake adjustment on stopping capability

Example	number of brakes	adjustment condition	total relative torque	change in stopping capability
1	6	RA-1/8, 6 brakes	3.85	1.30
2	6	RA+1/8, 3 brakes	3.89	1.29
3	6	RA+1/8, 1 brake RA+3/8, 1 brake	3.93	1.27
4	6	RA+1/2, 1 backed-off	4.0	1.25
5	6	RA+1/8, 1 front RA+3/8, 1 front	4.465	1.12
6	10	RA-1/8, all brakes	6.94	1.30
7	10	RA+1/8, 4 brakes	7.52	1.20
8	10	RA+3/8, 2 brakes	7.69	1.18
9	10	RA+1/2, 1 backed-off	8.0	1.13
10	10	1 backed off and 1 at RA+1/8	7.63	1.18
11	10	RA+3/8, 2 fronts	8.3	1.08

As with the 3-axle truck in Table 3.3.4, some of the example trucks above were also calculated using the detailed computational method. Results based upon using the approximate and detailed methods are compared in Table 3.3.6 below. It should be noted that such a comparison is made only for qualitative assessment of the simplified approximation, and not for a quantitative analysis of its accuracy.

Table 3.3.6 Example comparisons of detailed and approximate calculations

Approx Example (above)	Corresponding Figure of Detailed Comp.	Adjustment Condition/Case	Approximated Increased Stopping Distance	Detailed Increased Stopping Distance
1	1.3.2	All RA-1/8", Case 2	30%	28%
2	1.3.2	20% RA+1/8", Case 3	29%	31%
6	1.3.4	All RA-1/8", Case 2	30%	29%
7	1.3.4	20% RA+1/8", Case 3	20%	23%
8	1.3.4	20% RA+3/8", Case 4	18%	21%

It is clearly seen from the above table that the results of the approximate method agree with those of the detailed one. If the detailed method is looked upon as accurate, the simplified method provides a good approximation for the degradation in the braking capabilities. Furthermore, it can be observed that the more axles there are, the better the agreement between the results.

3.4 Observations and Concluding Remarks

3.4.1 There is already considerable sentiment for simplifying the OOS criteria. The methods suggested above for changing the OOS criteria may not appear to be simple. Nevertheless, they are much simpler than the calculation procedures used in obtaining the results presented in Section 1 and 2. An issue to be decided is whether it is worthwhile to increase the complexity of the OOS criteria in order to reflect a more uniform relationship to stopping capability.

3.4.2 One matter to be observed derives from the importance of front brakes as currently configured. Front brakes are less effective than rear brakes, and hence, they contribute less to the stopping capability of the vehicle than do rear brakes. This means that if a stopping distance rule were to be adopted, front brake degradation would be less important than it currently is under the present OOS criteria. (However, there are a number of other OOS matters that apply to the front brakes so they would receive special attention anyhow.)

Perhaps more effective front brakes will come into style as it is noticed that brake wear and maintenance costs may be reduced by the use of more effective front brakes. In any event, the stopping distance estimation method would account for the effectiveness of each brake including the front brakes because if requires knowledge of the relative effectiveness of each brake as determined by chamber size, slack arm length, drum radius, and tire radius. A source of this type of information for a sample of vehicles is given in the data obtained from NTSB (see Section 4). In later stages of this study, we would like to use the NTSB data to evaluate the effectiveness of proposed OOS criteria in separating OOS vehicles from acceptable vehicles based on stopping capability estimates.

In particular, an OOS criteria based upon brake adjustment factors like those given in Table 3.3.2 could be evaluated using the data collected by NTSB.

3.4.3 The stopping distance approach is readily amenable to the use of on-line computers at weigh stations. For example, in Wisconsin the inspectors enter vehicle description and measurement data into an on-line computer system. In the future, the computer system could be programmed to compute the relative change in stopping distance for the measured state of brake adjustment. However, there would be an additional burden of entering the relative torque effectiveness for each brake.

It seems that knowledge of the "AL factor" for each brake would need to be readily available if a stopping distance approach were to be used. If the relative AL factors were available or standard values were chosen, a simple computation could be used to estimate the relative change in stopping distance even if a computer were not available (see Table 3.3.3). In essence, the stopping distance calculation would amount to a refined version of the 20-percent rule. Its virtue would be that it provided an indication of the loss in stopping capability and based an OOS decision directly on this measure of the degradation in stopping capability caused by the level of brake adjustment.

4.0 IDENTIFYING KEY FACTORS CONTRIBUTING TO BRAKE OUT-OF-ADJUSTMENT FOR MANUALLY ADJUSTED BRAKES.

(Analysis of Brake Inspection Data from Oregon and Wisconsin)

The overall objective of this analysis is to identify factors that are associated with brake OOA based on MCSAP data from individual states. The review of computerized inspection data identified only two states, Oregon and Wisconsin, with data elements that appeared to address the objective of this task. Information recorded during CVSA inspections were obtained on magnetic tape from Oregon and Wisconsin. The data on magnetic tape were converted into an appropriate format for analysis by the OSIRIS database package of programs available on the University of Michigan mainframe computer. This section describes the results of the analyses of the Oregon and Wisconsin files.

Oregon Data. A magnetic tape with 20,233 records containing coded inspection data was obtained from the State of Oregon. These data covered all CVSA inspections in 1989. The format of the Oregon data was better suited to a structured, or hierarchical, file. In this application, the file structure includes two different types of records. At the first level, there is one record for each vehicle inspected. These records include trucks with no violations, trucks with brake violations, and trucks with other violations. The records at Level 1 describe the carriers' operating authority and the configuration of the truck. The configuration is described in a series of fields for up to six units (tractor, semitrailer, etc.). Each unit is characterized in terms of the unit type, CVSA decal, make, state of registration, and whether it was placed OOS. The unit type codes are the following:

Power Unit		Trailer	
BU	Bus	ST	Semitrailer
TT	Tractor	FT	Full trailer
TR	Truck	PT	Pole trailer
		OT	Other trailer
		DC	Dolly converter

The second level of records describe individual brake violations. Each record identifies the unit having the violation, the type of unit, and whether the violation put the unit OOS. The available brake violation codes include the following:

Brake Violation Codes

B20	Defective brakes exceed 20-percent
BBA	Brake adjustment
BPR	Pushrod (on steering axle)
BSA	Slack adjuster (on steering axle)
BSB	No steering axle brakes

The BP20 code, defective brakes exceed 20 percent, seems redundant since subsequent BBA (brake adjustment) codes follow for each of the brakes individually. A number of other codes describe brake violations not related to adjustment.

The configuration of the vehicle can be determined from the combination of units identified. For each configuration, the violation codes listed above can be located by unit number. No actual pushrod travel measurements are recorded, and violations cannot be located with regard to axle or axle-end.

Results from the 1989 Oregon inspection data are summarized in the following tables. Of the 20,233 vehicles inspected 22.1 percent had no violations; 45.7 percent had brake violations; and the remaining 32.1 percent had other violations. Overall, 34.4 percent of the trucks inspected were put OOS, and brake violations were responsible for about 80 percent of the vehicles put OOS. Focusing on the 45.7 percent (9,250 vehicles) that had one or more brake violations, 59.6 percent of these were put OOS. There were a total of 29,021 brake violations on the 9,250 vehicles having one ore more brake violations. In other words, trucks with brake violations in Oregon have an average of about three brake violations per vehicle. These statistics are shown in Tables 0.1 and 0.2

Table O.1. Oregon brake data

6,491	(32.1%)	cases with no brake violations
4,492	(22.2%)	cases with no violations at all
9,250	(45.7%)	cases with brake violations
20,233	(100.0%)	total cases

29,021 brake violations total
1.43/vehicle inspected
3.14/vehicle with brake violations

Table O.2. Out-of-service (OOS) distribution for all trucks inspected and brake violators

	Not OOS	OOS	Total
All Trucks	13,280	6,9552	20,232
(%)	65.6	34.4	100.0
Brake Violators	3,739	5,511	9,250
(%)	40.4	59.6	100.0

Approximately two-thirds of the brake violations are for adjustment when the "defective brakes exceed 20-percent" code is omitted. Looking at the distribution of brake violations among combination units by type of unit, r44 percent are on semitrailers and 30 percent are on tractors, for a total of 75 percent of the brake adjustment violations. the proportion of brake violations on tractors and semitrailers drops to 68.4 percent when single-unit trucks are included, as illustrated in the Tables O.3 through O.5.

Table O.3. Distribution of brake violations by violation type (excludes "defective brakes exceed 20 percent because that is in addition to the violations themselves)

	N	Percent
Brake adjustment	16,542	64.79%
Pushrod	70	0.27%
Slack adjustment	78	0.31%
No steering axle brakes	41	0.16%
Other/unknown	8,799	34.47%
Total	25,530	100.0%

Table O.4 Distribution of brake adjustment violations by unit type (excludes non-combination vehicles)

	Brake Adjust	Percentage
Straight	757	5.04%
Tractor	4,552	30.32%
Semi	6,581	43.84%
Pole	1,472	9.80%
Full	1,263	8.41%
Dolly	228	1.52%
Other	145	0.97%
Unknown	15	0.10%
Total	15,013	100.00%

Table O.5 Distribution of brake adjustment violations by unit type (includes non-combination vehicles)

	Brake Adjust	No Steer Brake	Brake Adjust	No Steer Brake
Straight	2,016	7	12.14%	17.07%
Tractor	4,772	31	28.73%	75.61%
Semi	6,603	1	39.75%	2.44%
Pole	1,473	0	8.87%	0.00%
Full	1,282	0	7.72%	0.00%
Dolly	255	1	1.54%	2.44%
Other	145	0	0.87%	0.00%
Unknown	65	1	0.39%	2.44%
Total	16,611	41	100.00%	100.00%

Other coding is available to identify the carrier type. The emphasis is on Oregon PUC authorization, but interstate operating authority is also identified in a separate field. The intrastate authority may be of interest because it includes information on the commodity carried in the following codes.

Carrier Classification	
Class A	General commodities
Class B	Local cartage
Class D	Sand, gravel, etc.
Class L	Logs, poles, or pilings
Class M	Metallic ores and concentrates
Class P	Passengers
Class SP	Small parcel

Table O.6 compares the percentage of brake violations with the percentage of vehicles for each carrier type. Intrastate carriers hauling logs, sand, and ore have about 14 percent more brake violations than the average vehicle inspected. This figure is based on the table below which shows the intrastate log, sand, and ore group to be 21.9 percent of the trucks inspected and 24.9 percent of the brake violations. The ratio of these two percentages is 1.14, or 14 percent more than the average for all carriers. However, this comparison does not take into account the number of axles and brakes per vehicle. This group of carriers might have more brake violations per vehicle because they have more axles. Information on the number of axles is not available in the Oregon data.

Table 0.6 Brake adjustment violators versus all vehicles inspected by company type Oregon inspection data.

Company Type Normalized	Brake Adj. Viol.		All Vehicles Inspected		
	N	%	N	%	Rate
Intra Gen Freight	1718	28.08	5152	25.46	1.10
Intra Logs, Sand, Ore	1526	24.94	4433	21.91	1.14
Intra Other For-hire	12	0.20	88	0.43	0.45
Intra Private	1046	17.09	4130	20.41	0.84
Inter For-hire	1356	22.16	4789	23.67	0.94
Inter Exempt	166	2.71	557	2.75	0.99
Inter Private	284	4.64	995	4.92	0.94
		0.00			
Unknown	11	0.18	88	0.43	0.41
Total	6119	100.00	20232	100.00	1.00

Wisconsin Data. A magnetic tape containing coded information on all brake violations in 1989 was provided by the State of Wisconsin. Wisconsin inspects both intrastate and interstate trucks, and a code is available to distinguish the two. Coding is also available to identify the location of each brake violation in terms of the unit number, the axle number, and axle end (left or right). In addition, the following three character codes identify the nature of the brake violation.

Violation Codes
BP1 Pushrod travel exceeds 1.75"
BP2 Pushrod travel exceeds 2"
BPN No pushrod movement when brake applied
BPA Pushrod travel is improper
BPU Difference in pushrod travel (L/R) exceeds 0.5 inch

Each unit of the vehicle is described separately, and is identified as unit "one of two" (1/2), or "two of two" (2/2). Unit type is coded as truck, tractor, semitrailer, or full trailer. Axles are numbered within each unit, and axle ends are identified as left or right. Thus, the available information is adequate to determine the distribution of violations by unit of the vehicle, and by axle location on each unit.

The Wisconsin data has information on 4,156 trucks, each with one or more brake violations, for a total of 8,725 violations. The average number of brake violations per truck having one or more violations is 2.1 in Wisconsin, as compared to 3.14 from the Oregon data. The largest percentage of brake violations is on the tractor in Wisconsin, 55.2 percent, with 42 percent on trailers. This result is the reverse of the situation in Oregon. The distribution of brake violations by violation type is shown in Table W.3. OOA violations account for 87.9 percent. These overall statistics are presented in Table s W.1 through W.3.

Table W.1 Wisconsin brake violation statistics

4,156 vehicles with brake violations
2,721 (65%) put OOS
8,725 total violations (2.10 per vehicle)

3,558 had violations on just one unit (as opposed to both tractor and trailer).
597 had violations on more than one unit.

2,624 (55.2%) truck tractors had brake violations
130 (2.7%) straight trucks
1,998 (42.0%) trailers, including semi, had violations.

Table W.2 Number of violations per vehicle

	1	2	3	4	5	6	7	8	9	10	Total
Frequency	1,722	1,319	473	435	103	63	22	13	5	1	4,156
Percent	41.4	31.7	11.4	10.5	2.5	1.5	0.5	0.3	0.1	0.0	100.0

Table W.3 Brake violations by violation type

	>1.7	>2.0	Improper	L/R Diff	Bent Rod	Unk	Totals
Frequency	1,611	6,054	373	463	26	198	8,725
(percent)	(18.50)	(69.40)	(4.3)	(5.3)	(0.3)	(2.3)	(100.0)

Key:
">1.7"	Pushrod travel exceeds 1.75".
">2.0"	Pushrod travel exceeds 2.0".
"Improper"	Pushrod adjustment is improper.
"L/R Diff"	Difference in pushrod travel (L/R) exceeds .5".
"Bent"	Pushrod is bent.

The next series of tables looks at the distribution of brake violations by axle and axle end (left or right). The first table (W.4) is limited to tractors. The greatest percentage of violations (38.9 percent) is on the front axle of the tractor. Over half of the time, both of the front axle brakes are in violation. On the second and third axles, both brakes are in violation about one-third of the time. When only one side is in violation on the drive axles, it is a little more likely to be the right side. It may be particularly significant that 32.1 percent of the brake violations are on the third tractor axle, and only 21.2 percent on the second axle. these statistics do not take into account the number of tractors that had only two axles. This number of 2-axle tractors would tend to decrease the percentage of violations on a third axle, since there would be none. Thus, the elevated percentage on the third axle, since there would be none. Thus, the elevated percentage on the third axle can be interpreted as an indication of a greater likelihood for the second drive axle to be in violation, although not quite as high as the front axle. This interpretation is consistent with the impressions of some of the inspectors interviewed.

Table W.4 Brake violations by location—tractors (column percents sum to 100)

	Axle				
Location	1	2	3	Unk	Total
Left	188 (15.7)	172 (26.4)	282 (28.6)	17 (7.1)	659 (21.5)
Right	176 (14.7)	225 (34.5)	348 (35.3)	23 (9.7)	772 (25.2)
Both	640 (53.6)	238 (36.5)	335 (34.0)	56 (23.50	1,269 (41.3)
Unknown	190 (15.90	17 (2.60	20 (2.0)	142 (59.7)	369 (12.0)
Total	190 (100.0)	17 (100.0)	20 (100.0)	142 (100.0)	369 (100.0)
(row percent)	(38:9)	(21.2)	(32.1)	(7.8)	(100.0)

Table W.5 shows the location of the brake violations on trailers. As would be expected, 89.8 percent are on either the first or second axle since few trailers have more than two axles. As with the drive axles on the tractors, the second axle is somewhat more likely to be in violation. Both axle ends are in violation about half of the time with the right being slightly more frequent that the left when only one end is in violation. Straight trucks are only a small percentage of the vehicles inspected, and only a small percentage of the brake violations. The distribution of brake violations by axle and axle end is shown for straight trucks in Table W.6. There is little difference in the percentage of brake violations on the first, second, and third axles. However, the majority of brake violations on the front axle involve both ends, as was observed on the tractors.

Table W.5 Brake violations by location—trailers (column percents sum to 100)

	Axle								
Location	1	2	3	4	5	6	7	unk	total
Left	268	207	10	14	15	3	1	8	526
	(24.1)	(17.7)	(20.8)	(30.4)	(31.3)	(50.0)	(50.0)	(7.2)	(20.7)
Right	295	310	7	15	18	9	9	12	657
	(26.5)	(26.5)	(14.6)	(32..6)	(37.5)	(0.0)	(0.0)	(10.8)	(25.8)
Both	523	611	29	13	9	3	1	10	1,199
	(47.0)	(52.2)	(60.4)	(28.3)	(18.8)	(50.0)	(50.0)	(9.0)	(47.1)
Unk	27	42	2	4	6	0	0	81	162
	(2.4)	(3.6)	(4.2)	(8.7)	(12.5)	(0.0)	(0.0)	(73.0)	(6.4)
Total	1,113	1,170	48	46	448	6	2	111	2,544
	(100.0)	(100.0)	(100.0	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
row %	(43.8)	(46.0)	(1.9)	(1.8)	(1.9)	(0.2)	(0.1)	(4.4)	(100.0)

Table W.6 Brake violations by location—straight trucks (column percents sum to 100)

	Axle						
Location	1	2	3	4	5	Unk	Total
Left	8	14	12	3	1	1	39
	(18.6)	(31.1)	(24.0)	(23.1)	(50.0)	(4.5)	(22.3)
Right	6	14	11	5	0	0	36
	(14.0)	(31.1)	(22.0)	(38.5)	(0.0)	(0.0)	(20.6)
Both	27	15	23	4	1	1	71
	(62.8)	(33.3)	(46.0)	(30.8)	(50.0)	(4.5)	(40.6)
Unknown	2	2	4	1	0	20	29
	(4.7)	(4.4)	(8.0)	(7.7)	(0.0)	(90.9)	(16.6)
Total	43	45	50	13	2	22	175
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
(row percent)	(24.6)	(25.7)	(28.6)	(7.4)	(1.1)	(12.6)	(100.0)

Brake violations could also be broken down by inter- and intrastate carriers in the Wisconsin data. Table W.7 breaks down the brake violations by carrier type unit of the truck to see if there is any difference in this pattern. As would be expected, most of the straight trucks are operated by intrastate carriers. Of primary interest is the finding that the intrastate carriers have a greater proportion of violations on the semitrailers as compared with tractors. This intrastate subset of the Wisconsin data is consistent with the overall statistics form Oregon in this regard. It is only the interstate carriers in Wisconsin that show a greater percentage of brake violations on the tractor than on the semitrailer

Table W.7 Brake violations by unit—interstate versus intrastate hauls

	Tractor	Truck	Trailer	Semi	Totals
Interstate	4,209	94	681	2,667	7,651
(percent)	(55.0)	(1.2)	(8.9)	(34.9)	(100.0)
Intrastate	304	154	51	464	973
(percent)	(31.2)	(15.8)	(5.2)	(47.6)	(100.0)
Total	4,513	248	732	3,131	8,624
(percent)	(52.3)	(2.9)	(8.5)	(36.3)	(100.0)

<u>Summary.</u> The Oregon and Wisconsin inspection data were examined for evidence of key factors associated with brake adjustment violations and patterns in brake adjustment violations that might suggest key factors. In general, the available information did not include many of the factors originally identified. Some coding was available in each state to identify different carrier types. however, there were not marked differences in the patterns of brake violations among different carrier types. Unit of the truck was identified in each file also. Here the results were somewhat mixed. The Oregon data tended to support the inspectors impressions that trailers were somewhat more likely to have brake violations. However, only the smaller group of intrastate carriers in Wisconsin showed a similar result. The interstate carriers in Wisconsin showed more violations on the tractors. A shortcoming of the Wisconsin data is that we did not get information on all trucks that were inspected. Some o f the tractors with brake violation may have been operating bobtail so that there could not be any trailer violations for these tractors. However, it is unlikely that appreciable numbers of bobtail tractors were inspected.

Wisconsin was the only state inspection file that we found that included coding that identified the unit, axle, and axle end of the violation. This information allowed us to look for patterns in brake violations by unit, axle, and axle end. Two observations made by many of the inspectors interviewed were confirmed by this data. The first was a greater incidence of OOA brakes on the front axle. Usually, both brakes on the front axle were OOA, and very few violations were for the side-to-side difference in brake adjustment. This result is consistent with a situation where the front axle brakes are backed-off. The other observation supported by the Wisconsin data is a greater tendency for the rear axle of a tandem pair to be OOA. On many trucks, the brakes on the rear axle are somewhat harder to access for adjustment. With regard to left/right side differences, the most common situation on any axle is for both brakes to be in violation. However, when only one end is in violation, the right side is in violation a little more often than the left.

5.0. DEVELOPING STATISTICAL MEASURES PERTAINING TO THE RELATIONSHIPS BETWEEN THE KEY FACTORS IDENTIFIED AND BRAKE ADJUSTMENT

(Preliminary Analysis of NTSB Brake Data)

The tables presented below are limited to 5-axle, tractor/single-trailer combinations. This eliminates the tractor/double-trailer combinations, but those units accounted for only 36 combinations of the 910 inspected. Thus, excluding the doubles does not significantly limit the amount of data available for analysis. On the other hand, limiting the analysis to singles simplifies the discussion since all the units involved consist of a 3-axle tractor pulling a 2-axle trailer.

FACTORS ASSOCIATED WITH BRAKES OOA

In all of the tables, the brake adjustment criteria as stated in the North American Uniform Vehicle Out-of-Service Criteria Policy Statement were followed. That is to say, for each brake, the stroke, given the chamber size, was compared with the figures in the chart on Page 8 of the Statement and classified as either OOA or defective. Brakes at, or 0.25" over the "maximum stroke at which brakes must be readjusted," were categorized as OOA. Brakes with strokes 0.25 percent or more over the readjustment limit were categorized as defective. Brakes were also counted as defective if they were inoperative. (A separate variable for each brake gives the inoperative status.) The tables are organized around a few broad influences on brake adjustment. Several categories of factors which may be associated with brake adjustment problems were identified and then variables in the NTSB data were examined for their relevance to those factors. First, there is the mechanical design of the brake and any braking aids that may be part of the trucks design. The NTSB data includes data on slack type and the use of retarders. Next, here is the general category of trucking operations and the business and regulatory environment. This category has to do with the extent to which competitive pressures may affect maintenance practices, and how servicing is done. Another broad category has to do with how the equipment is used and the effect of age and use on brake adjustment. In this category, we were able to look at model year for both the tractor and trailer, and cargo body style. A final general category has to do with truck design, the extent to which different cab styles, and even makes, are associated with brake adjustment problems.

BRAKE DESIGN RELATED FACTORS

Slack Type

The first table shows slack type by the OOA status. The top half of the table shows the raw numbers. These are counts of brakes. Only brakes with automatic or manual slacks are included in this table. Wedge-type and other brakes are excluded. For the column headings, "ok" means that the brake is properly adjusted. "OOA" means that the brake exceeds the maximum stroke at which it must be readjusted, but by less than 0.25". "Defect means that the brake exceeds the maximum stroke by at least 0.25", and thus, constitutes a defective brake for the purposes of the OOS criteria. "Unk" means the adjustment status could not be determined.

Out-of-adjustment status by slack type, singles only

	ok	1/2-DEF	DEF	unk	total
auto	1771	219	75	0	2065
manual	4809	838	896	4	6547
total	6580	1057	971	4	8612

	ok	1/2-DEF	DEF	unk	total
auto	85.76%	10.61%	3.63%	0.00%	100.00%
manual	73.45%	12.80%	13.69%	0.06%	100.00%
total	76.41%	12.27%	11.27%	0.05%	100.00%

It seems that the advantage of the automatic slack is in preventing a brake from getting so far out-of-adjustment that is constitutes a defective brake. Both slack types had similar proportions of brakes that were out-of-adjustment, though the manual proportion was about 2 percent higher. And overall, the proportion of automatic slacks with properly adjusted brakes was only about 12 percent higher than that of manual slacks. Almost a quarter of the brakes in the NTSB data had automatic slacks, so these differences are certainly statistically reliable.

Retarders

Among the data gathered as part of the NTSB survey was whether the sample vehicles were equipped with retarders. This includes any sort of drive line, transmission, or engine retarder. It appears that the use of retarders has some effect on brake adjustment. Combinations equipped with such brakes had lower proportions of OOA and defective brakes. Overall, almost 80 percent of the brakes on such units were within the adjustment standards, while 72.4 percent of the brakes on combinations without retarders were adjusted.

Brake adjustment status by retarder use

	ok	OOA	defect	unk	total
yes	2610	336	278	66	3290
no	2643	499	466	42	3650
unk	1327	222	233	18	1800
total	6580	1057	977	126	8740

	ok	OOA	defect	unk	total
yes	79.33%	10.21%	8.45%	2.01%	100.00%
no	72.41%	13.67%	12.77%	1.15%	100.00%
unk	73.72%	12.33%	12.94%	1.00%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

FACTORS RELATED TO THE OPERATING ENVIRONMENT

Carrier Type

NTSB data include information about fleet size, whether the carrier operates inter- or intrastate, and whether the carrier is a private or for-hire carrier. Fleet size information is difficult to get and is missing in about half of the cases. Only 90 of the 910 vehicles inspected were operated by intrastate carriers, probably due to the fact that the inspection sites were all on interstates.[1]

Brake adjustment status by carrier type

	ok	OOA	defect	unk	total
for-hire	5147	794	727	102	6770
private	1370	235	231	24	1860
unk	63	28	19	0	110
total	6580	1057	977	126	8740

	ok	OOA	defect	unk	total
for-hire	76.03%	11.73%	10.74%	1.51%	100.00%
private	73.66%	12.63%	12.42%	1.29%	100.00%
unk	57.27%	25.45%	17.27%	0.00%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

Responsibility for Brake Adjustment

In a related question, the NTSB data also includes information on whether the driver is responsible for the adjustment of the brakes. Perhaps surprisingly, in 520 of the 874 cases of singles, the driver was responsible for brake adjustment. But this appears to make no difference. The proportion of OOA and defective brakes is about the same for both trucks in which the driver is responsible for keeping the brakes in adjustment and in which that responsibility lies elsewhere. The proportion of brakes within adjustment standards is higher by 2 percent for the drivers than for the others, but that difference is not great enough to be meaningful.

Brake adjustment status by driver responsibility for adjustment

	ok	OOA	defect	unk	total
yes	3934	588	600	78	5200
no	2165	396	333	46	2940
unk	481	73	44	2	600
total	6580	1057	977	126	8740

	ok	OOA	defect	unk	total
yes	75.65%	11.31%	11.54%	1.50%	100.00%
no	73.64%	13.47%	11.33%	1.56%	100.00%
unk	80.17%	12.17%	7.33%	0.33%	100.00%
total	75.29%	12.09%	11.18%	1.44%	100.00%

Thus, it appears that the main variables which might distinguish different approaches to truck operations do not appear to be associated with success in keeping brakes properly adjusted. But the new data from inspection sites off the interstates and the fleet size data remain to be examined.

[1] A second round of data collection was conducted at sites off the interstates. This data should be available for analysis soon. It is likely that the data will cover a different mix of company types, cargo bodies, and operations, which will be very useful in this analysis.

FACTORS RELATED TO THE AGE AND USE OF THE EQUIPMENT

Tractor Model Year

Brake adjustment was considered by the model year of the tractor. Only the brakes on the power unit's axles were used in the analysis. Pre-1983 model years were lumped together. Later model years are shown separately.

Brake adjustment status by tractor model year

year	ok	OOA	defect	unk	total
<1983	580	95	166	107	948
1983	143	16	21	0	180
1984	307	53	59	1	420
1985	405	64	65	6	540
1986	301	31	28	0	360
1987	425	58	39	0	522
1988	532	96	20	0	648
1989	766	78	50	0	894
1990	542	56	44	0	642
1991	19	4	7	0	30
unk	51	7	2	0	60
total	4071	558	501	114	5244

year	ok	OOA	defect	unk	total
>1983	61.18%	10.02%	17.51%	11.29%	100.00%
1983	79.44%	8.89%	11.67%	0.00%	100.00%
1984	73.10%	12.62%	14.05%	0.24%	100.0%
1985	75.00%	11.85%	12.04%	1.11%	100.00%
1986	83.61%	8.61%	7.78%	0.00%	100.00%
1987	81.42%	11.11%	7.47%	0.00%	100.00%
1988	82.10%	14.81%	3.09%	0.00%	100.00%
1989	85.68%	8.72%	5.59%	0.00%	100.00%
1990	84.42%	8.72%	6.85%	0.00%	100.00%
1991	63.33%	13.33%	23.33%	0.00%	100.00%
unk	85.00%	11.67%	3.33%	0.00%	100.00%
total	77.63%	10.64%	9.55%	2.17%	100.00%

Tractors with a model year before 1986 have much higher rates of brakes so OOA as to count as defective brakes. They also appear to have higher rates of brakes OOA, though the differences are not so striking. The poor showing of the 1991 model is based on just thirty brakes, which is five variables, so that is not a reliable indication of the performance of the newest model year. On the other and, all of the other categories have more than enough data to be reliable.

Trailer Model Year

The model of the trailer was also considered to see if the same pattern was shown. Instead, there was no particular trend to the proportions of OOA and defective brakes by model year. Pre-1983 model year trailers had the lowest proportion of fully-adjusted brakes, but the second lowest model year was 1985, and 1990 was the third lowest. There was a reasonable number of trailers for all the model year categories in the accompanying table.

Brake adjustment status by trailer model year

	ok	OOA	defect	unk	total
<1983	494	110	136	8	748
1983	125	17	18	0	160
1984	203	36	41	0	280
1985	190	51	39	0	280
1986	216	32	28	0	276
1987	216	37	47	0	300
1988	281	55	44	0	380
1989	299	72	53	0	424
1990	103	23	22	0	148
unk	382	66	48	4	500
total	2509	499	476	12	3496

	ok	OOA	defect	unk	total
<1983	66.04%	14.71%	18.18%	1.07%	100.00%
1983	78.13%	10.63%	11.25%	0.00%	100.00%
1984	72.50%	12.86%	14.64%	0.00%	100.00%
1985	67.86%	18.21%	13.93%	0.00%	100.00%
1986	78.26%	11.59%	10.14%	0.00%	100.00%
1987	72.00%	12.33%	15.67%	0.00%	100.00%
1988	73.95%	14.47%	11.58%	0.00%	100.00%
1989	70.52%	16.98%	12.50%	0.00%	100.00%
1990	69.59%	15.54%	14.86%	0.00%	100.00%
unk	76.40%	13.20%	9.60%	0.80%	100.00%
total	71.77%	14.27%	13.62%	0.34%	100.00%

Considering this table and the last, it seems that trailer brakes are more likely to be OOA. A table that addresses that issue explicitly is presented below.

Axle Number and Location

The following table shows only OOA problems and defective brakes. ("Defective" is defined as a brake so far OOA as to count as a defective brake for the purposes of the brake inspection OOS criteria.) The percentages in the cells are the percentages of brakes at a particular axle number and location which are OOA or defective. Thus, 10.3 percent of the brakes on the left side of axle number one were OOA and 9.95 percent were defective. Axle 1 is the steering axle, 2 and 3 are the drive axles on the tractor. Axles 4 and 5 are the trailer's axles.

Brake adjustment by axle number and location

	Right		Left	
axle	OOA	Defect	OOA	defect
1	90	87	95	84
2	86	65	77	89
3	108	85	102	91
4	118	120	137	108
5	119	118	125	130
total	521	475	536	502

	Right		Left	

axle	OOA	defect	OOA	defect
1	10.30%	9.95%	10.87%	9.61%
2	9.84%	7.44%	8.81%	10.18%
3	12.36%	9.73%	11.67%	10.41%
4	13.50%	13.73%	15.68%	12.36%
5	13.62%	13.50%	14.30%	14.87%
total	11.92%	10.87%	12.27%	11.49%

Overall, trailer axles are more likely to be either out-of-adjustment or defective. From 27 percent to 29 percent of trailer axles have adjustment problems, while 20 percent to 21 percent of tractor axles are either OOA or defective. The steering axle appears to have about the same proportion of adjustment problems as the other axles on the tractor.

Cargo Body Type

Cargo body type might be expected to have a large impact on brake adjustment. Dumps and tanks typically carry very heavy loads which put greater stress on the brakes. Vans are more often used for general freight hauling and lighter loads. Moreover, cargo bodies are associated with different types of carriers and operations, dumps with private carriers and local hauling, vans with for-hire interstate carriers and tanks with both services.

The differences found between different cargo body types are not great. Overall, the proportion of properly-adjusted brakes ranges from a low of 67.5 percent for the tanks to 74.7 percent for flatbeds. Tanks and dumps have the highest proportion of brakes so far OOA as to be counted as defective. Vans have the lowest proportion of defective brakes, but the highest proportion of OOA brakes. It may be a little surprising to see that flatbeds do the best. Since tanks so often haul hazardous materials, and consequently are subject to more rigorous inspections, one might have expected that their brakes would be in better shape.

TRACTOR MAKE AND CAB STYLE

Tractor Make

Brake adjustment problems by tractor make were also examined. Only the tractor's axles were considered for this analysis. The idea was to determine if any particular makes were associated with higher rates of adjustment problems. As it happens, most makes have about the same proportion of OOA and defective brakes. But both Freightliner and White/Volvo have strikingly lower rates of defective brakes. About 5.5 percent of Freightliner brakes were defective, compared with 9.5 percent for all makes. White/Volvo had 1.2 percent defective brakes. The sample size for White/Volvo is only eighty-four brakes (twenty-four tractors), but Freightliners were the second most common tractor make.

Brake adjustment status by tractor make

	ok	OOA	defect	unk	total
Freightliner	1027	107	66	12	1212
Ford	160	28	20	2	210
GMC	162	17	25	6	210
Navistar	982	182	146	16	1326
Kenworth	535	75	79	37	726
Mack	347	43	46	14	450
Pete	523	67	81	13	684
Wh/GMC	123	18	15	0	156
Wh/Volvo	73	10	1	0	84
White	80	5	11	6	102
Other	59	6	11	8	84
Total	4071	558	501	114	5244

	ok	OOA	defect	unk	total
Freightliner	84.74%	8.83%	5.45%	0.99%	100.00%
Ford	76.19%	13.33%	9.52%	0.95%	100.00%
GMC	77.14%	8.10%	11.90%	2.86%	100.00%
Navistar	74.06%	13.73%	11.01%	1.21%	100.00%
Kenworth	73.69%	10.33%	10.88%	5.10%	100.00%
Mack	77.11%	9.56%	10.22%	3.11%	100.00%
Pete	76.46%	9.80%	11.84%	1.90%	100.00%
Wh/Volvo	78.85%	11.54%	9.62%	0.00%	100.00%
Wh/Volvo	86.90%	11.90%	1.19%	0.00%	100.00%
White	78.43%	4.90%	10.78%	5.88%	100.00%
Other	0.24%	7.14%	13.10%	9.52%	100.00%
Total	77.63%	10.64%	9.55%	2.17%	100.00%

This pattern is suggestive rather than conclusive. The explanation could be the design of the vehicle or brake manufacturer or the type of brake typically installed. There may be other explanations. In any case, the difference is intriguing and warrants further examination.

Cab Style

Another possible influence on brake adjustment is the design of the cab. Some designs may make the brakes more accessible and consequently more easily adjusted. But when brake adjustments were examined by cab style, the differences between conventional and cabovers were slight. Conventionals had lower proportions of OOA and defective brakes than cabovers. Only 8.8 percent of conventionals' brakes were defective, compared with 10.9 percent for cabovers. And conventionals were 4 percent higher in the proportion of brakes within adjustment limits (79 percent to 75 percent). The differences are real, but the size of the effect is not sufficient to have a major impact.

Brake adjustment status by cab style

	ok	OOA	defect	unk	total
conv	2636	342	293	65	3336
coe	1429	216	208	49	1902
unk	6	0	0	0	6
total	4071	558	501	114	5244

	ok	OOA	defect	unk	total
conv	79.02%	10.25%	8.78%	1.95%	100.00%
coe	75.13%	11.36%	10.94%	2.58%	100.00%
unk	100.00%	0.00%	0.00%	0.00%	100.00%
total	77.63%	10.64%	9.55%	2.17%	100.00%

6.0 PROVIDING A SOUND QUANTITATIVE BASIS FOR CONFIRMING OR CHANGING CURRENT OOS BRAKE ADJUSTMENT CRITERIA.

(Braking Efficiencies and Out-of-Service Criteria Using the NTSB Data)

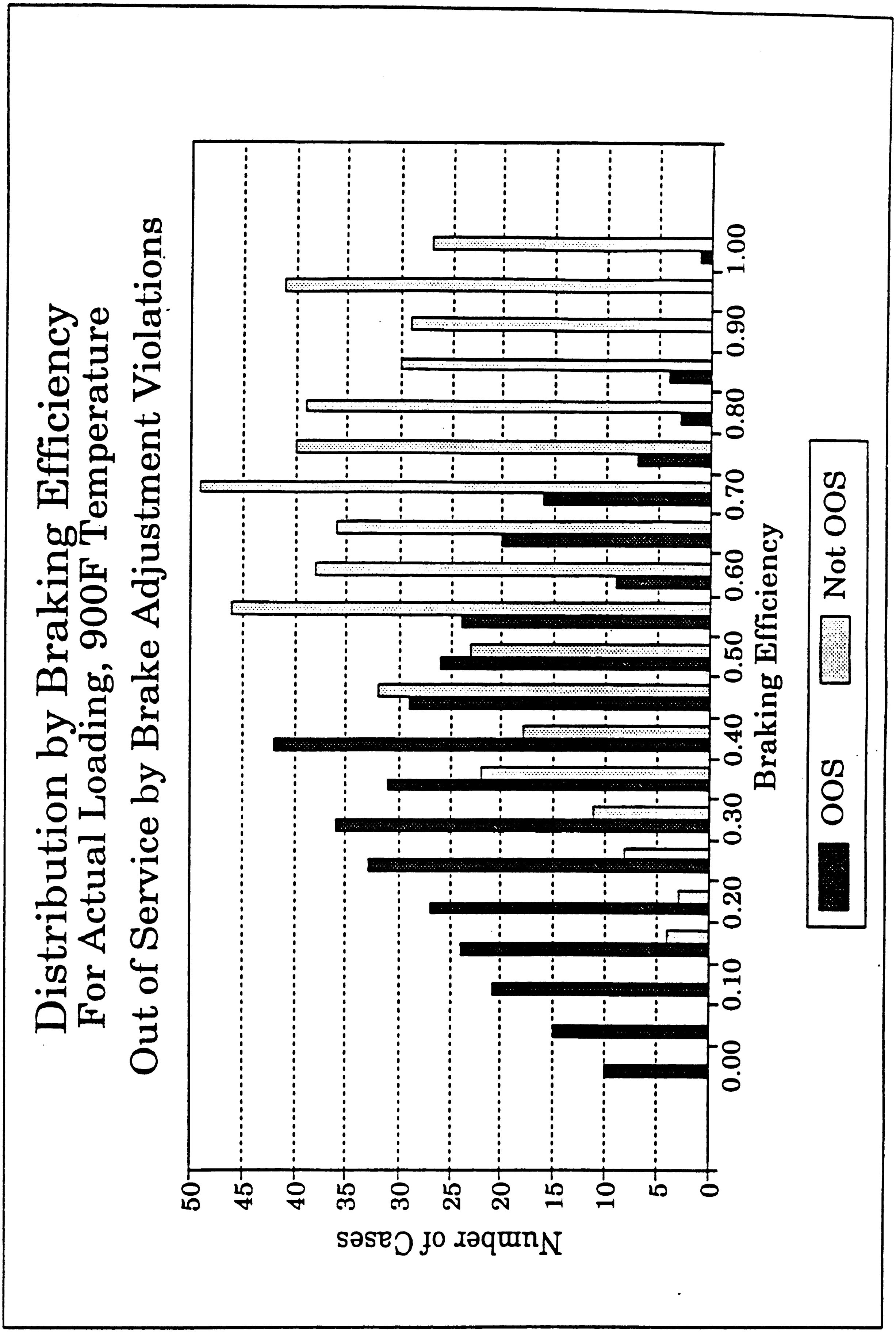
The appended charts examine the distribution of calculated braking efficiencies for different loadings and brake temperatures for vehicles put OOS for brake adjustment violations and those that were not put OOS for brake adjustment violations. Calculated brake efficiencies are from the NTSB data. They were determined for the actual loading of the vehicle and for the vehicle if it were loaded to 80,000 pounds. There are two sets of four charts, one set for the actual loading of the vehicle and one for the vehicle if loaded to 80,000 pounds. Within each set, the four charts represent the baseline case with no temperature-related expansion and then with the brakes at 400°F, 600°F, and 900°F. Only 5-axle, tractor-trailer units are included in the comparison.

OOS is restricted just to vehicles put OOS due to brake adjustment problems. The rules relating to brake adjustment as outlined in the North American Uniform Vehicle Out-of-Service Criteria Policy Statement were applied to the vehicles in the NTSB data. Brakes were classified as defective if they were inoperative, or if the stroke exceeded the maximum readjustment length by 0.25" or more. Brakes were classified as OOA if the stroke exceeded the readjustment length by less than 0.25", and two OOA brakes count as one defective brake. If the total of defective brakes on a combination was 20 percent or more of the brakes, the vehicle was classified as OOS. A defective brake on the steering axle also put a vehicle OOS.

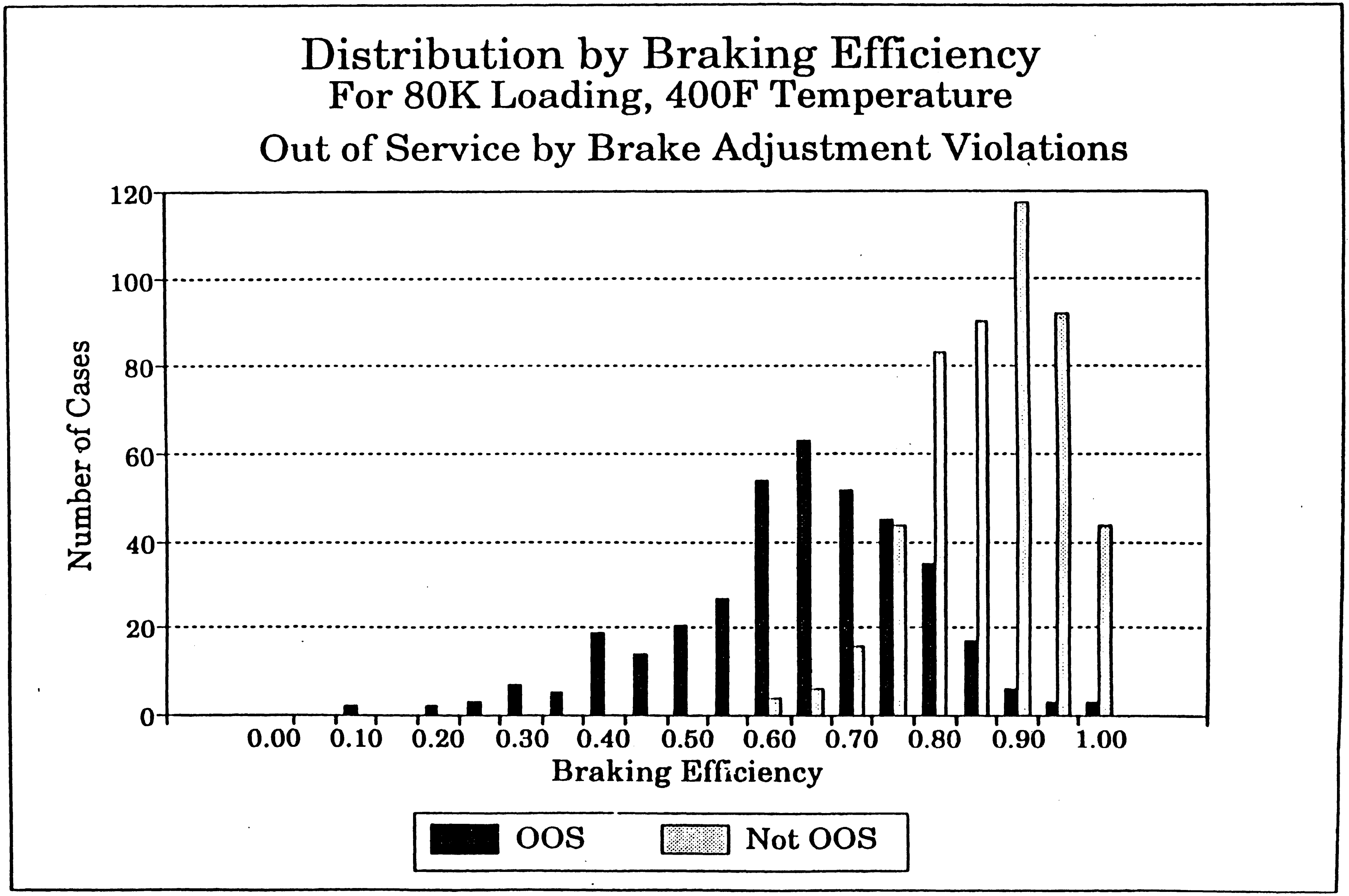
The appended charts show how well the brake adjustment OOS criteria discriminate between braking efficiencies. From one point of view, the charts for the 80K loadings are the fairest comparison since they compare braking efficiencies given the same gross weight. For both the default case and the 400°F, the OOS criteria do a good job of separating the two populations. There is some overlap in the tails, but the means of the two populations are clearly separated.

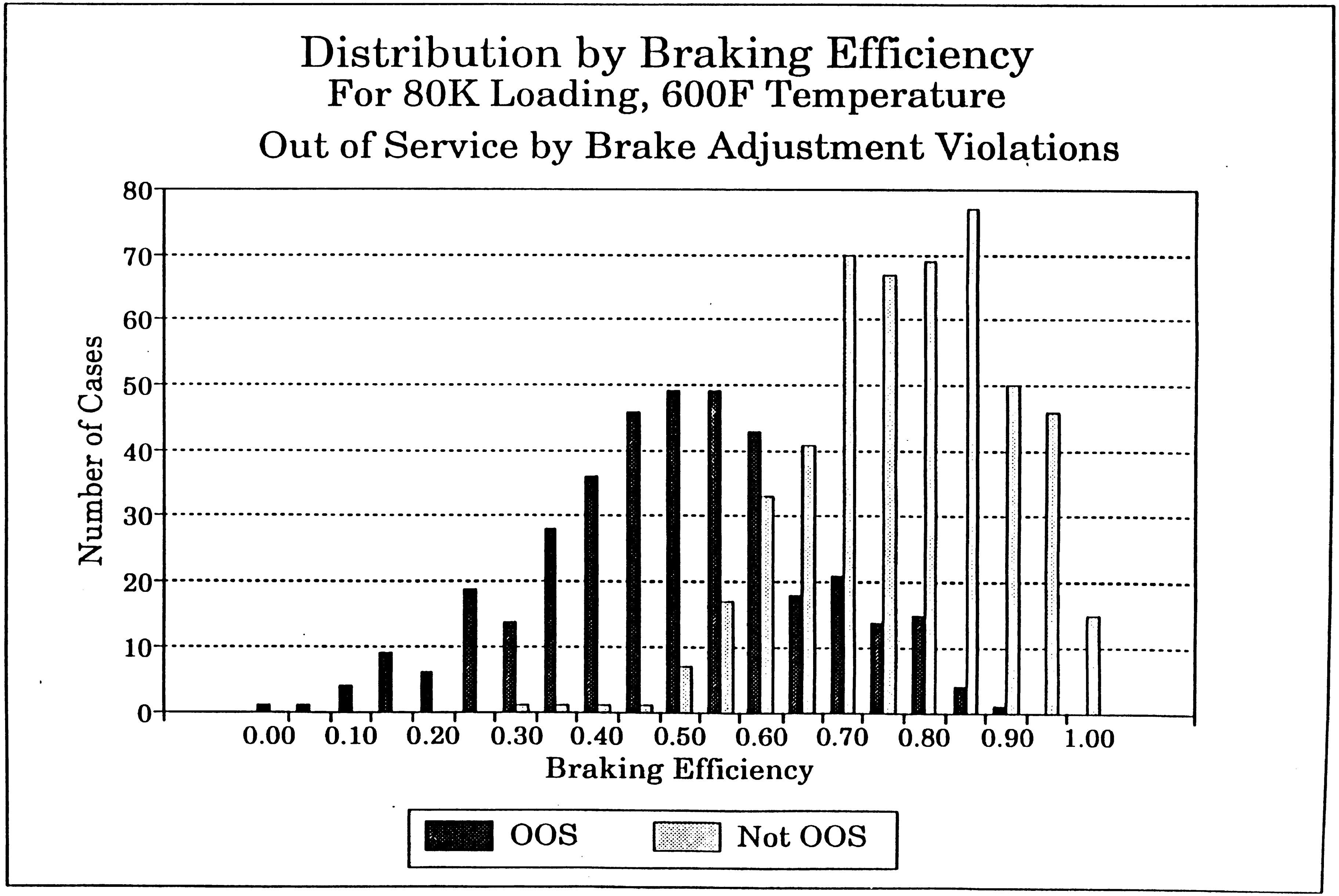
The charts for the actual loading are also of interest. These efficiencies were calculated for the gross weight of the vehicle at the time of the inspection and so show braking efficiencies for the two populations as they actually operate. For the default and 400°F case, there is somewhat more overlap. There is a significant number of cases which were put OOS, yet whose braking efficiencies are 1.00. Though their braking would have been significantly degraded if they had been loaded to 80K, their braking efficiency was at 1.00 as they were actually loaded.

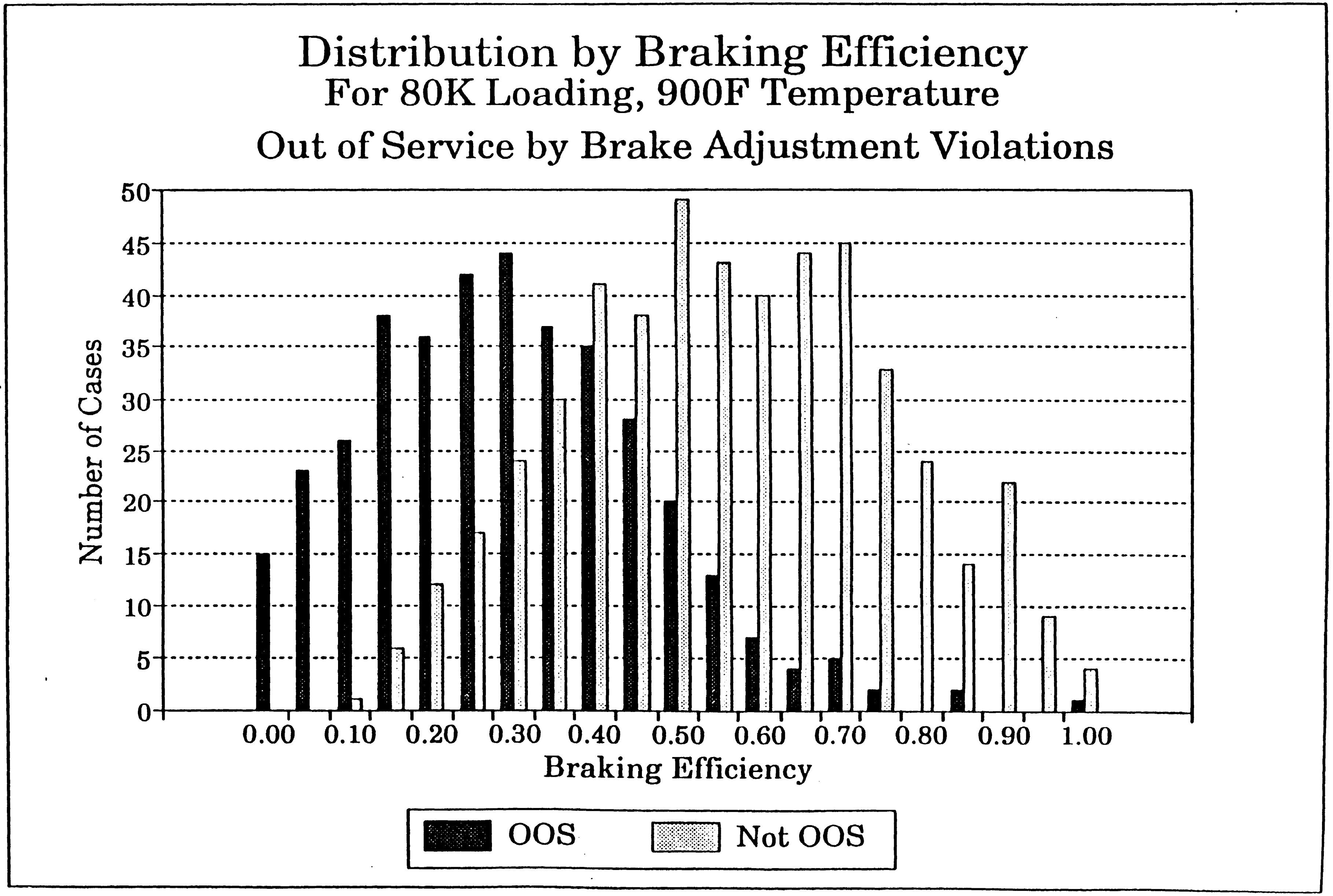
At higher temperatures, the two distributions broaden and overlap to a much greater extent.



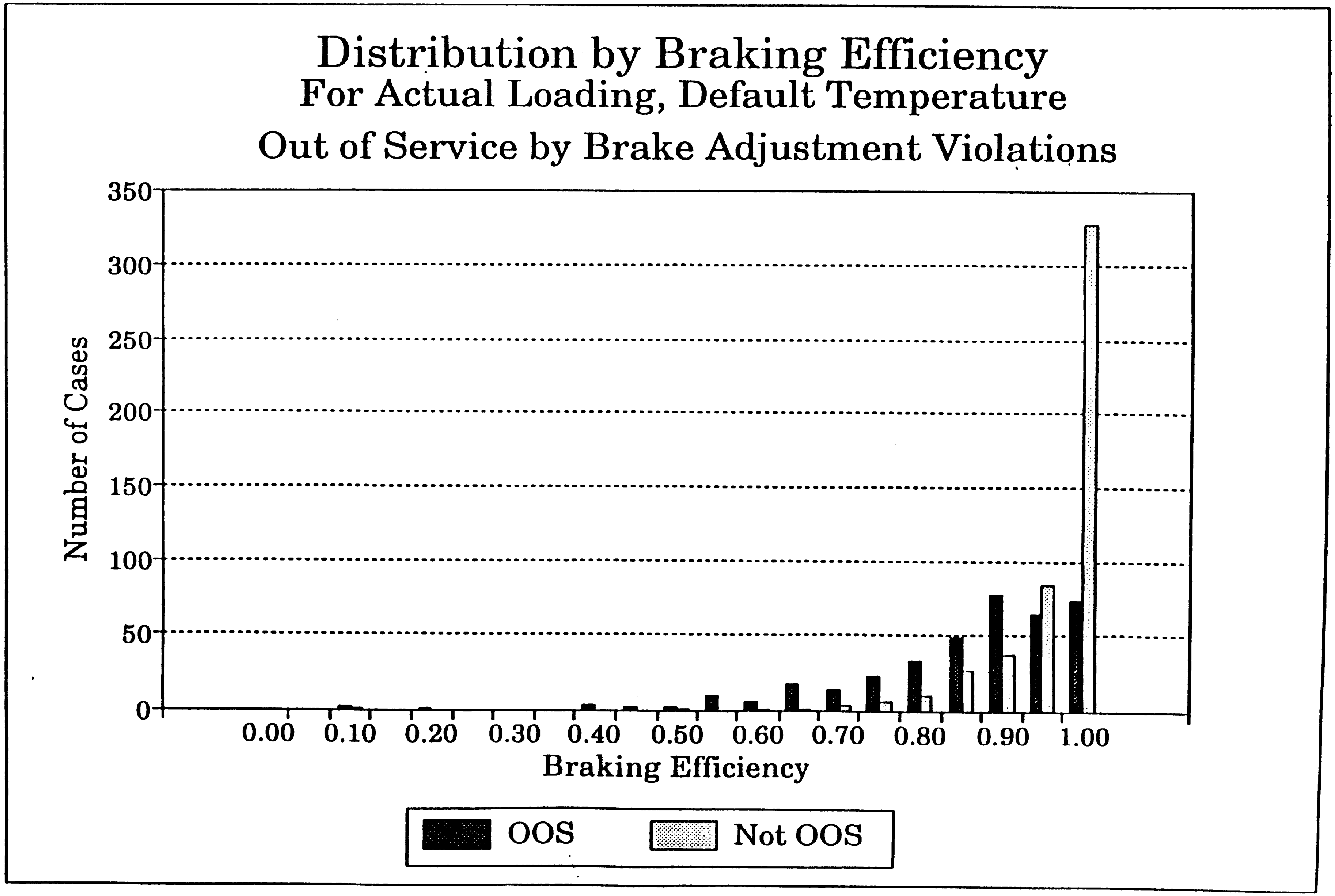
Distribution by Braking Efficiency
For Actual Loading, 900F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

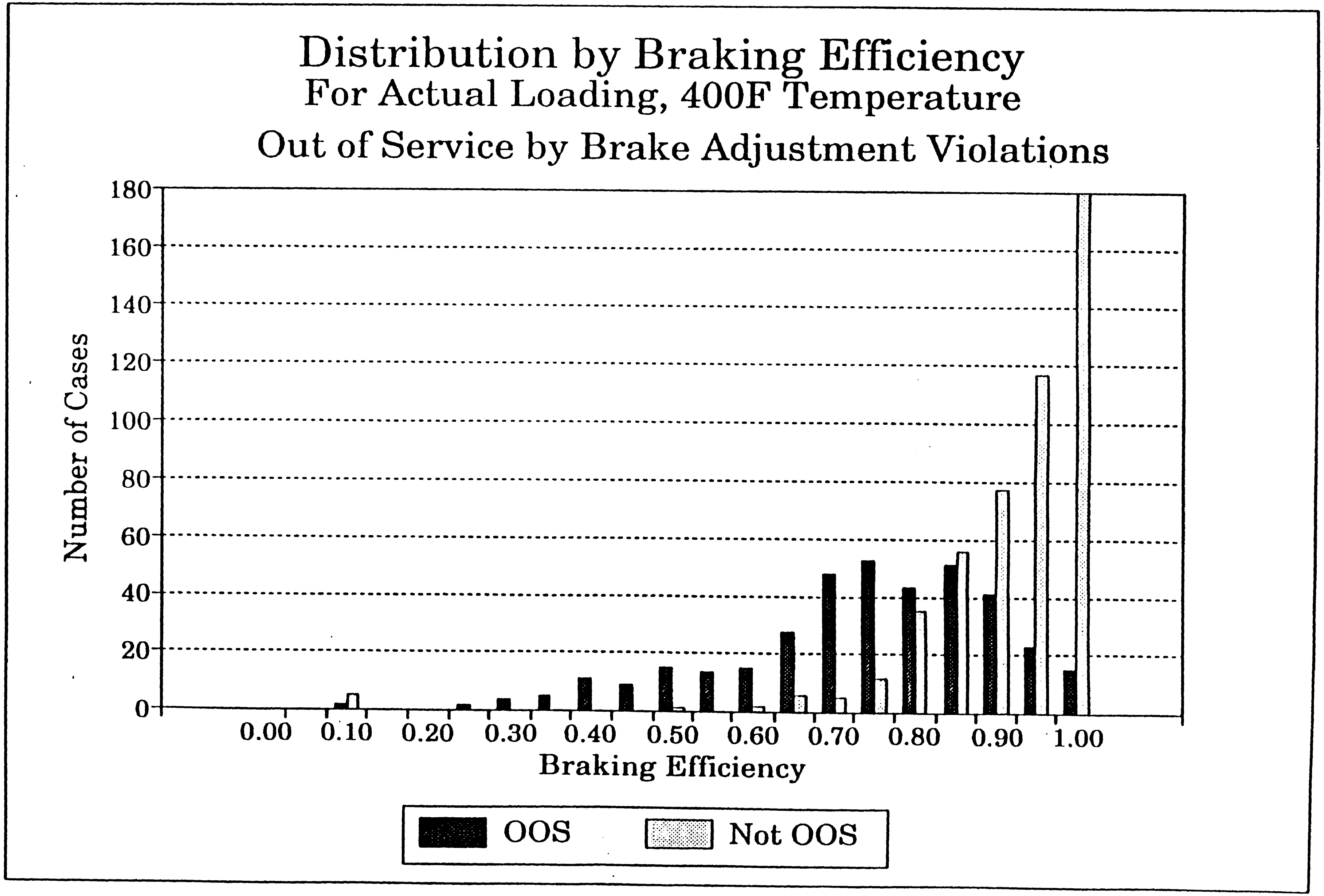

Distribution by Braking Efficiency
For 80K Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

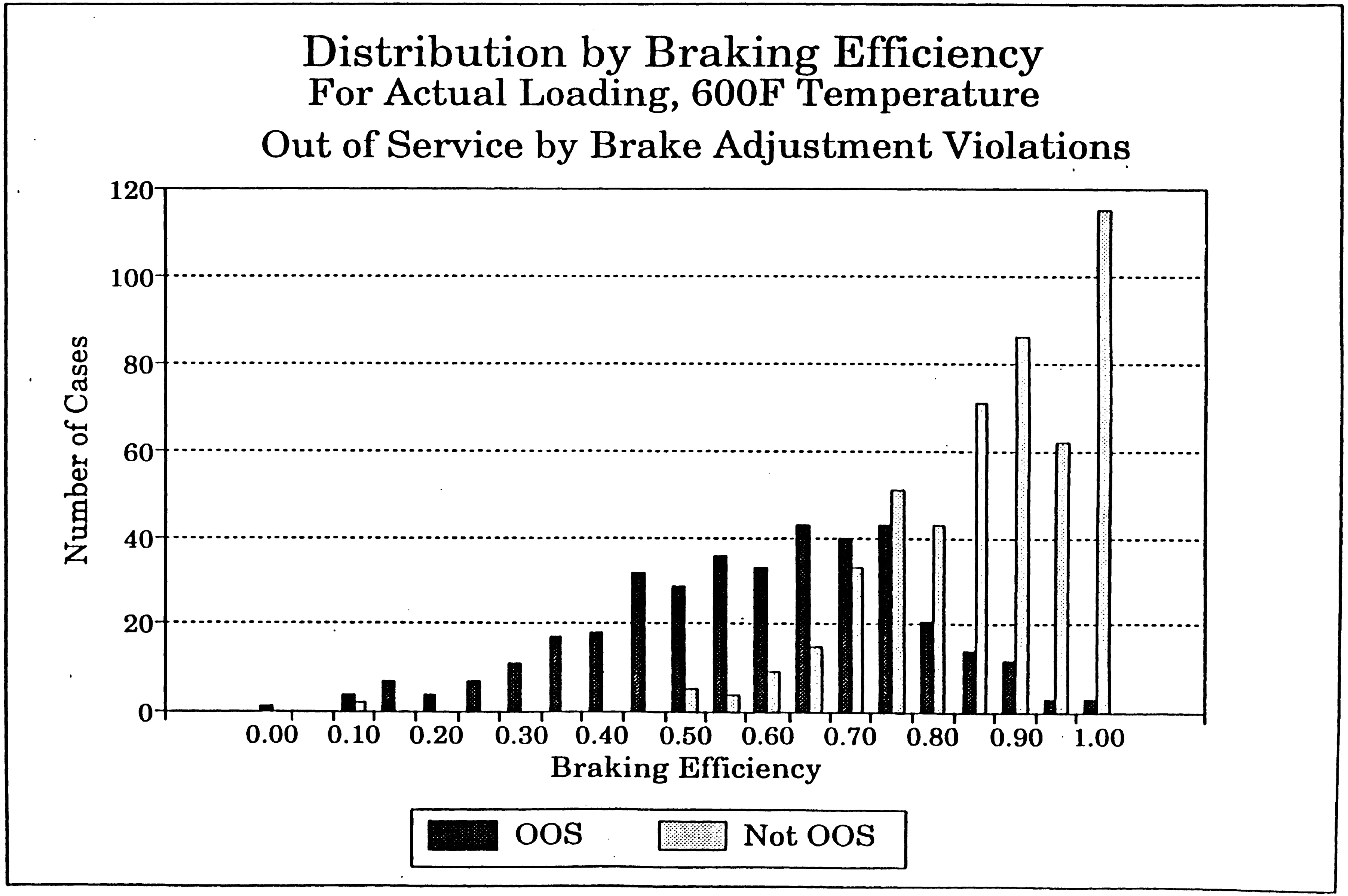

Distribution by Braking Efficiency
For 80K Loading, 600F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
10
20
30
40
50
60
70
80
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS

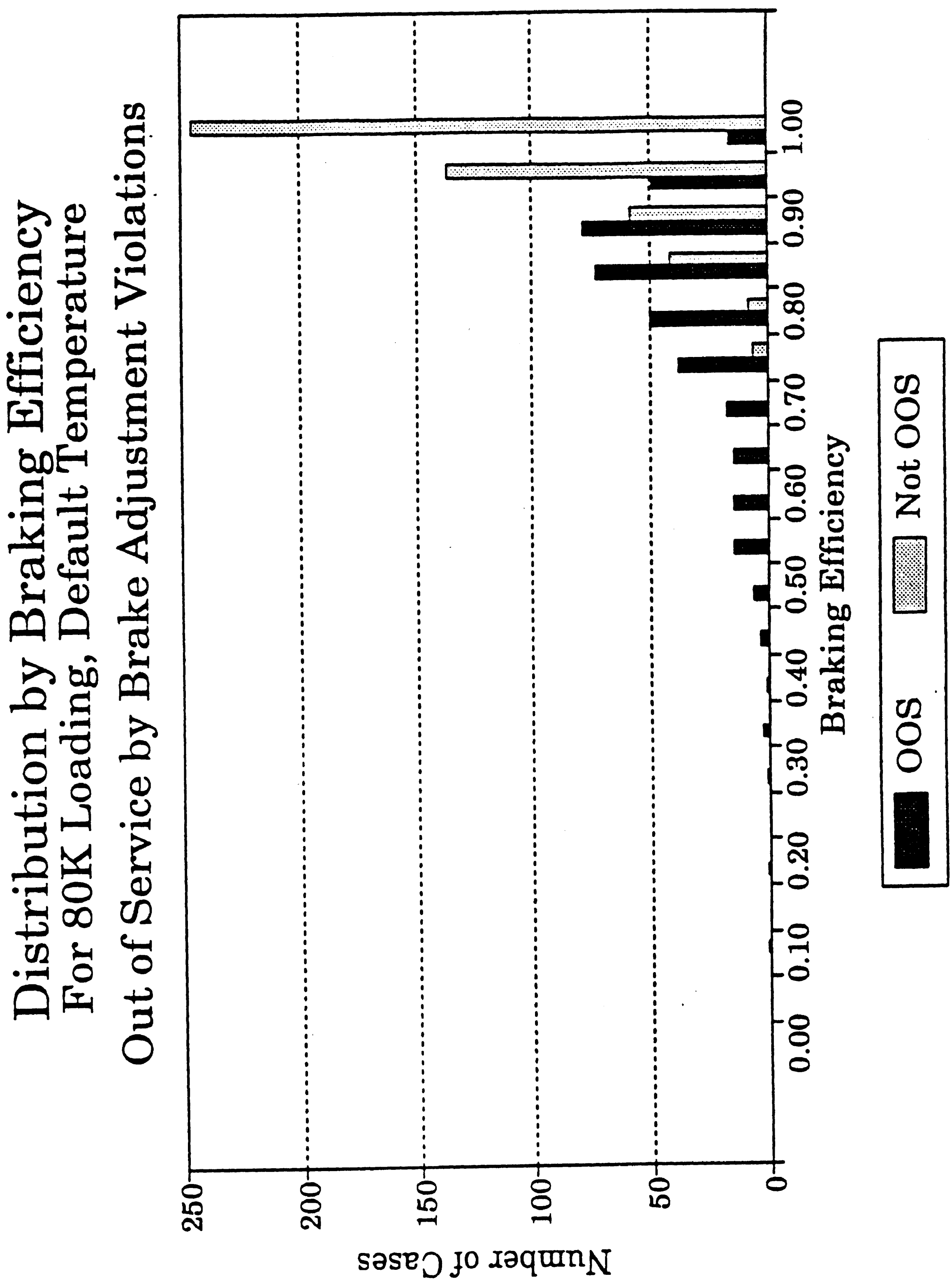


Distribution by Braking Efficiency
For 80K Loading, 900F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, Default Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
350
300
250
200
150
100
50
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, 400F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
180
160
140
120
100
80
60
40
20
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS


Distribution by Braking Efficiency
For Actual Loading, 600F Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
0
20
40
60
80
100
120
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS



Distribution by Braking Efficiency
For 80K Loading, Default Temperature
Out of Service by Brake Adjustment Violations
Number of Cases
250
200
150
100
50
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Braking Efficiency
OOS
Not OOS