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Assessment of the Effect of Automatic Slack Adjusters on Brake Adjustment

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National Research Council of Canada, Centre for Surface Transportation Technology

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16. Abstract

A requirement for automatic slack adjusters on airbrakes was introduced into Canadian Motor Vehicle Safety Standard 121 in 1996. Transport Canada needed to conduct an assessment of the effectiveness of the regulatory change.

This report presents that assessment. It uses brake chamber size, slack adjuster type and stroke data collected by Ontario Ministry of Transportation in 1999, 2000 and 2001 during Operation Airbrake enforcement blitzes. The work includes an assessment of compliance to the regulatory requirement, and the effectiveness of automatic slack adjusters in maintaining brake adjustment in comparison with manual slack adjusters.

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16. Résumé

En 1996, une exigence relative aux dispositifs automatiques de rattrapage d'usure des garnitures sur les freins à air comprimé a été ajoutée dans la Norme de sécurité des véhicules automobiles du Canada n°121. Transports Canada se devait d'évaluer l'efficacité de cette modification de la réglementation.

Le présent document expose les résultats de cette étude d'évaluation. Les données utilisées sur la dimension des cylindres de freins, le type de dispositif de rattrapage d'usure des garnitures et la course des cylindres ont été recueillies par le ministère des Transports de l'Ontario en 1999, 2000 et 2001 au cours de campagnes-éclairs de contrôles routiers effectués dans le cadre de l'Opération freins pneumatiques. L'étude comprend une évaluation de la conformité des véhicules à l'exigence et de l'efficacité des dispositifs automatiques de rattrapage sur le maintien du réglage des freins, en comparaison avec les dispositifs manuels de rattrapage.

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Assessment of the Effect of Automatic Slack Adjusters on Brake Adjustment

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ASSESSMENT OF THE EFFECT OF AUTOMATIC SLACK ADJUSTERS ON BRAKE ADJUSTMENT

ÉVALUATION DE L'EFFET DES RÈGLEURS DE SEMELLE DE FREIN AUTOMATIQUES SUR L'AJUSTEMENT DES FREINS

J.R. Billing

Centre for Surface
Transportation Technology

Centre de technologie
des transports de surface

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DISCLAIMER

This report deals with brake strokes, which the manufacturing and operating industries, and provincial enforcement staff, customarily still measure and report in inches. This report presents brake strokes solely in inches. Other quantities are presented in SI units, with the Imperial equivalent following in parentheses.

EXECUTIVE SUMMARY

All provinces and states across North America inspect heavy vehicles following standard procedures agreed under the auspices of the Commercial Vehicle Safety Alliance (CVSA). A vehicle may be put out-of-service if it has any of many specified defects defined by objective inspection criteria. Airbrake defects have been the principal reason for vehicles to be put out-of-service, and airbrake pushrod stroke in excess of the prescribed limit has been the principal airbrake defect. CVSA inspections conducted at random over the last ten years or so have consistently resulted in 25 to 45% of all vehicles inspected being put out-of-service. A vehicle with some airbrakes out of adjustment may not have a consistent and reliable capability to stop, so a requirement for automatic slack adjusters was introduced to improve the reliability of airbrake stroke. U.S. Federal Motor Vehicle Safety Standard 121 was amended to require automatic slack adjusters, and a simple visual means of checking brake stroke, on vehicles built from 20 October 1994. Ontario introduced this requirement for certain vehicles with the same effective date, and extended it to all vehicles from 30 April 1995. Transport Canada amended Canadian Motor Vehicle Safety Standard 121 to introduce this requirement for vehicles built from 31 May 1996. Five years have now passed, and Transport Canada wished to assess the effect of the regulatory change on the state of brake adjustment on vehicles with airbrakes. The objectives of the work were to determine:

1. The fitment rate of automatic slack adjusters on vehicles with airbrakes;
2. The extent to which original equipment automatic slack adjusters may have been replaced by manual slack adjusters; and
3. The effectiveness of automatic slack adjusters in maintaining airbrake adjustment.

Transport Canada engaged the Centre for Surface Transportation Technology of the National Research Council of Canada (NRC/CSTT) to conduct this work. NRC/CSTT identified that Ontario Ministry of Transportation (MTO) had detailed roadside inspection reports on large numbers of heavy trucks, which included vehicle type, number of axles, model year, license plate jurisdiction, brake chamber type, slack adjuster type and brake stroke. MTO graciously provided access to about 4,500 records collected from CVSA brake inspections during Operation Airbrake in 1999, 2000 and 2001. Operation Airbrake consists of three days of inspections in all provinces and some states, with the objective of focusing drivers and carriers on airbrake issues and gathering data to assess the state of airbrake adjustment. Vehicles were selected at random in all parts of Ontario.

The sample of vehicles for each of the three years appeared to be representative of traffic in Ontario. Fitment of automatic slack adjusters on power units jumped to over 90% when the U.S. mandated them in 1994. Automatic slack adjusters were found on about 93% of all tractors in 2001. This number will rise gradually as older vehicles equipped with manual slack adjusters disappear from service, and may reach about 98% by 2010. Automatic slack adjusters were found on about 85% of all straight trucks in 2001. Fitment of automatic slack adjusters on Canadian trailers did not increase significantly until they were mandated in Canada in 1996. They were found on about 75% of all trailers in 2001. The fitment rate of automatic slack adjusters on straight trucks and trailers is lower than for tractors, because straight trucks and trailers tend to be kept in service longer than tractors.

Thus, a larger proportion of the fleets of both straight trucks and trailers that pre-date the requirement for automatic slack adjusters are still on the highway than tractors. These older vehicles predominantly have manual slack adjusters. About 30% of older straight trucks, tractors and trailers that pre-date the requirement for automatic slack adjusters are nevertheless fitted with them. Some may have been fitted as original equipment, because these devices have been available for at least 25 years. It is also possible that some carriers believe that the value of retrofit outweighs its cost. Overall, in 2001, almost 90% of all vehicle units (tractors, straight trucks, trailers and converter dollies) on the highway in Ontario were fitted with automatic slack adjusters. Small numbers of older vehicles fitted with manual slack adjusters may still be operating well beyond 2020, though most of these will be in local use for limited travel.

The survey showed that about 4.2% of power units and U.S. registered trailers built since 1994, which would have been expected to have been built with automatic slack adjusters, were reported as fitted with manual slack adjusters. It is not possible to identify from the data whether these vehicles were built with manual slack adjusters, or the automatic slack adjusters fitted in the factory had been replaced with manual slack adjusters, or whether there were errors in identification of the slack adjuster, or in recording the inspection data. If it is assumed that all the vehicles were built in compliance with regulations, then this establishes an upper bound for an inspection and reporting error rate. However, 9.4% of Canadian registered trailers built since 1996, which would have been expected to have been built with automatic slack adjusters, were reported as fitted with manual slack adjusters. There is no reason to expect a different inspection and reporting error rate between power units and trailers, so this suggests that at least 5.2% of Canadian registered trailers were either not built with automatic slack adjusters, or have been retrofitted with manual slack adjusters. If U.S. built trailers are assumed in compliance and are removed from the sample, it is possible that as many as 10% of Canadian trailers that should have automatic slack adjusters do not have them. The level of non-compliance for all vehicles will be higher if the inspection and recording error rate is less than 4.2%. Transport Canada could address this issue, by working with the provinces in future editions of Operation Airbrake, to conduct a careful assessment of each vehicle unit that should have been fitted with automatic slack adjusters but is reported as fitted with manual slack adjusters. It could either be done on-site, or by following up from the paper inspection reports.

The distribution of stroke in the normal operating range appears very similar for both manual and automatic slack adjusters for a brake chamber of a particular size, regardless of whether it is standard stroke or long stroke. However, a higher number of manual slack adjusters end up with a stroke outside the prescribed adjustment range. While manual and automatic slack adjusters each manage to maintain about the same mean stroke, the standard deviation of stroke is slightly larger for manual slack adjusters. Estimates of the probability that brakes would be out of adjustment using these statistics were reasonably consistent with the results from the survey.

Vehicles with manual slack adjusters were put out-of-service at a rate 150% higher than their population, simply because there is a higher probability that a brake with a manual slack adjuster would be out of adjustment. Ontario impounds vehicles with defined critical defects significantly beyond the threshold for putting a vehicle out-of-service. The impounded vehicles also match the provincial fleet profile reasonably well. About 97% of all vehicles had been impounded for brake system defects, and about 90% of impounded vehicles have manual slack adjusters.

Long stroke brake chambers began to appear about 1997, and the rate of fitment is increasing rapidly. It was about 13% for Canadian registered tractors, and 21% for U.S. registered tractors, in the 2001 model year, with lesser rates for trailers. A long stroke brake chamber with a typical automatic slack adjuster as seen in this study should virtually never be out of adjustment, as long as the slack adjuster is functioning.

The process of integration of automatic slack adjusters into Canada's truck fleet is about 90% complete, though the last manual slack adjuster may not disappear for another 35 years or so. There is no doubt that current models of automatic slack adjuster are able to maintain brake stroke more reliably than manual slack adjusters, though it must be recognized that automatic slack adjusters are predominantly on relatively new vehicles and manual slack adjusters are on older vehicles. Trucks are put out-of-service in Ontario mostly for brake system defects, and the principal defect has always been brakes out of adjustment. The out-of-service rate has diminished by about half over the last ten years. The introduction of the automatic slack adjuster has undoubtedly played a significant role in this, but so also have other initiatives, such as MTO's focus on the responsibility of the carrier to inspect and maintain vehicles, allowing drivers to adjust brakes, and providing brake adjustment training to drivers and mechanics.

The work described here has developed an approach and data processing methodology that could be applied to similar data that may be available from other provinces.

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Introduction

All provinces and states across North America inspect heavy vehicles following standard procedures agreed under the auspices of the Commercial Vehicle Safety Alliance (CVSA). The Level 1 inspection includes a detailed check of the mechanical condition of a vehicle. Level 1 CVSA inspections conducted at random over the last ten years or so have resulted in 25 to 45% of all vehicles inspected being put out-of-service. This represents roughly the mechanical condition of all vehicles on the highway at any instant in time. Inspection blitzes that focus on vehicles likely to be in poor condition usually result in over 70% of all vehicles inspected being put out-of-service. Airbrake defects are responsible for about half of all vehicles put out-of-service in either random inspections or blitzes, predominantly because brakes are out of adjustment. An inspector may require a vehicle with minor deficiencies to be repaired at the earliest opportunity. If a vehicle has certain specific objective deficiencies, the vehicle may be put out-of-service, and must be repaired at the inspection location, or towed away. In Ontario, a vehicle with specific objective deficiencies substantially worse than the out-of-service standard may be impounded.

The role of airbrake adjustment in ensuring adequate heavy vehicle stopping performance has long been established [1]. The U.S. National Highway Traffic Safety Administration (NHTSA) conducted an extensive field trial of automatic slack adjusters, and concluded that they were more reliable in maintaining airbrake adjustment than manual slack adjusters [2]. The U.S. National Transportation Safety Board (NTSB) examined the effect of poor airbrake adjustment on crashes in the early 1990's, and in 1992 recommended (among other things) that automatic slack adjusters should be required on all vehicles with airbrakes [3]. U.S. Federal Motor Vehicle Safety Standard (FMVSS) 121 was amended to require automatic slack adjusters, and a simple visual means of checking brake stroke, on new vehicles built from 20 October 1994 [4]. Ontario introduced the same requirement for automatic slack adjusters on all vehicles in a combination, when the combination includes a semitrailer longer than 14.65 m (48 ft), is a double longer than 23 m (75 ft 6 in), or is a double with a box length over 18.5 m (60 ft 6 in), with the same effective date [5], and subsequently extended this to all airbraked vehicles, effective 30 April 1995 [6]. Transport Canada conducted two assessments of automatic slack adjusters, and other braking system components [7, 8], and amended Canadian Motor Vehicle Safety Standard (CMVSS) 121 to mirror FMVSS 121 from 31 May 1996 [9].

There has been a fairly steady decline in the out-of-service rate from random vehicle inspections since about 1995. Brakes out of adjustment has been by far the single largest reason that vehicles have been put out-of-service, so it might be surmised that the reduction in the out-of-service rate means that automatic slack adjusters are better able to keep stroke within range than manual slack adjusters. However, this is not the only change that has occurred. Jurisdictions have focused intensively on vehicle mechanical condition over the last five years or so, through additional requirements made in legislation and regulation, on-highway inspections and facility audits. The jurisdictions have also focused on the operator's responsibility to put a vehicle on the highway only if it is in a safe mechanical condition. The operating industry has developed a range of programs to

respond to these pressures, which should result in more inspection and maintenance of vehicles. The outcome of all these efforts does seem to have been a reduction in the out-of-service rate in Ontario, and a general observation that the condition of many of the worst vehicles on the highway has improved.

Five years have passed since Transport Canada introduced the requirement for automatic slack adjusters into CMVSS 121. Their objective was to improve the reliability of airbrake stroke, so that vehicles with airbrakes had a consistent and reliable capability to stop. Transport Canada engaged the Centre for Surface Transportation Technology of the National Research Council of Canada (NRC/CSTT) to conduct an assessment of this regulatory change on brake adjustment. The objectives of the work were to determine:

1. The fitment rate of automatic slack adjusters on vehicles with airbrakes;
2. The extent to which original equipment automatic slack adjusters may have been replaced by manual slack adjusters; and
3. The effectiveness of automatic slack adjusters in maintaining airbrake adjustment.

This report summarizes the results of this work.

1. EQUIPMENT REQUIREMENTS

1.1 Federal Requirements

Canadian Motor Vehicle Safety Standard (CMVSS) 121 sets the requirements for airbrakes that must be fitted to a vehicle at the time it is manufactured [9]. A requirement for automatic brake adjustment is found in Technical Standards Document 121 [10], which essentially replicates the corresponding U.S. Federal Motor Vehicle Safety Standard (FMVSS) 121 [4]. Both require that:

1. "Any tractor or trailer must be equipped with a service brake system acting on all wheels.

2. Wear of the service brakes must be compensated for by means of a system of automatic adjustment that maintains the adjustment of the service brakes shall be within the limits recommended by the vehicle manufacturer.

3. Each brake equipped with an external automatic adjustment mechanism and having an exposed push rod, the condition of service brake under-adjustment shall be displayed by a brake adjustment indicator in a manner that is discernible when viewed with 20/40 vision from a location adjacent to or underneath the vehicle."

The U.S. requirement became effective October 20 1994. The corresponding Canadian requirement became effective on 31 May 1996.

1.2 Ontario Requirements

Ontario Regulation 587 on Equipment sets the standards for a vehicle that will operate on highways within the province [6]. Section 5 of this regulation specifies the following requirements for brakes:

(1) "The push rod stroke of the service brake chamber of a vehicle equipped with wheel brake air chambers shall be not more than the push rod stroke listed in Column 2 of the Schedule for the type of chamber listed in Column 1 of the Schedule if the wheel brake has cam or disc type brakes.

(2) The push rod stroke of the service brake chamber of a vehicle equipped with wheel brake air chambers shall be not more than the vehicle manufacturer's maximum push rod stroke if the brake chamber type does not appear in Column 1 of the Schedule.

(3) If the wheel brakes of a vehicle equipped with wheel brake air chambers have wedge type brakes, the combined movement of both brake shoe linings shall not exceed one-eighth of an inch.

(4) Measurements of wheel brakes under subsections (1), (2) and (3) shall be taken with the vehicle engine turned off, an initial air system pressure between 90 and 100 psi, the park brakes released and the service brake actuator fully applied.

(5) All the wheels of a vehicle manufactured after April 30, 1995 that is equipped with wheel brake air chambers shall have wheel brakes each of which is automatically adjustable.

(6) Each wheel brake referred to in subsection (5) that is equipped with an external adjustment mechanism and has an exposed push rod shall have an indicator that indicates the condition of service brake under-adjustment.

(7) The indicator referred to in subsection (6) must be visible to a person with 20/40 vision who is adjacent to or underneath the vehicle.

(8) No wheel brake shall be removed, rendered partly or wholly inoperable, modified so as to reduce its effectiveness or shall operate improperly

(9) Brakes shall be adjusted so that the braking power is applied as equally as possible to the wheels on opposite sides of the vehicle."

Table 1 below reproduces the Schedule from the regulation, referred to from items (1) and (2) above, for the allowable pushrod travel for clamp type brake chambers [6].

Table 1: Schedule of Allowable Push Rod Travel

Column 1 Service Brake Chamber		Column 2
Type	**Outside Diameter**	**Push Rod Travel**
6	4½″ (114.30 mm)	1¼″ (31.75 mm)
9	5¼″ (133.35 mm)	$1\frac{3}{8}$″ (34.93 mm)
12	$5\frac{11}{16}$″ (144.46 mm)	$1\frac{3}{8}$″ (34.93 mm)
12 Long Stroke	$5\frac{11}{16}$″ (144.46 mm)	1¾″ (44.45 mm)
16	$6\frac{3}{8}$″ (161.93 mm)	1¾″ (44.45 mm)
16 Long Stroke	$6\frac{3}{8}$″ (161.93 mm)	2″ (50.80 mm)
20	$6\frac{25}{32}$″ (172.24 mm)	1¾″ (44.45 mm)
20 Long Stroke	$6\frac{25}{32}$″ (172.24 mm)	2″ (50.80 mm)
24	$7\frac{7}{32}$″ (183.36 mm)	1¾″ (44.45 mm)
24 Long Stroke	$7\frac{7}{32}$″ (183.36 mm)	2″ (50.80 mm)
24 Long Stroke *	$7\frac{7}{32}$″ (183.36 mm)	2½″ (63.50 mm)
30	$8\frac{3}{32}$″ (205.58 mm)	2″ (50.80 mm)
30 Long Stroke *	$8\frac{3}{32}$″ (205.58 mm)	2½″ (63.50 mm)
36	9″ (228.60 mm)	2¼″ (57.15 mm)

* With square inlet port, or with square raised embossment on lid.

In addition, Ontario Regulation 32/94 requires that when a combination of vehicles includes

a semitrailer longer than 14.65 m (48 ft), is a double longer than 23 m (75 ft 6 in), or is a double with a box length over 18.5 m (60 ft 6 in), then any vehicle in the combination built after 19 October 1994 must be fitted with a system of automatic brake adjustment and brake adjustment indicators, in accordance with U.S. FMVSS 121 S5.1.8 or S5.2.2, or with the corresponding requirements in CMVSS 121 that became effective on 31 May 1996 [5].

1.3 Implications of the Equipment Requirements

The U.S. Federal requirement implies that all vehicles owned by a U.S. carrier and built from 20 October 1994 should have automatic slack adjusters. The Canadian Federal requirement implies that all vehicles owned by a Canadian carrier and built since 31 May 1996 should have automatic slack adjusters. The Ontario provincial requirement implies certain vehicles owned by a Canadian carrier and built since 19 October 1994, or all vehicles built since 30 April 1995, should have automatic slack adjusters. Other provinces may have similar requirements, to the extent that they introduced the same vehicles as Ontario between 20 October 1994 and 31 May 1996.

2. METHODOLOGY

2.1 Data Sources

Ontario Ministry of Transportation (MTO) conducts large numbers of inspections of commercial vehicles operating on highways in Ontario. Inspections are conducted at Truck Inspection Stations, which are fixed facilities located on major highways, and by roving patrols on other highways and at other locations. These inspections address the mechanical condition of the vehicle, securement of cargo, and vehicle, driver and carrier status. Inspections are conducted following a standardized procedure developed by the Commercial Vehicle Safety Alliance (CVSA), a cooperative association of the motor carrier enforcement arms of all provinces and territories, states, and Mexico. MTO staff record each inspection on a Commercial Vehicle Inspection Report (CVIR), a standard paper form used by the vehicle inspector to record the outcome of an inspection. The CVIR has fields to identify the inspection, the vehicle, the driver, the carrier, and the inspector, and allows any defects found to be noted. Inspection records are sent to MTO's office in St. Catharines, where the data are entered into various databases, and are summarized in various ways to assess compliance. The paper records are then stored in archives. MTO has at least five separate commercial vehicle inspection programs, each of which results in a detailed and complete CVIR for each inspection.

MTO conducts about 68,000 CVSA Level 1 inspections each year under its daily enforcement mandate. Level 1 is the most detailed CVSA inspection procedure. If a vehicle has deficiencies that exceed specific criteria set by CVSA, the inspector can put the vehicle out-of-service, and require that it must be repaired before it is moved. This program aims to find vehicles with defects, so many vehicles are selected for inspection because the inspector has reason to believe that an inspection is warranted. However, a vehicle with a valid CVSA sticker indicating it has passed an inspection in any jurisdiction in the preceding 90 days is not normally re-inspected.

MTO participates in the CVSA Roadcheck Program, a coordinated three-day blitz by all jurisdictions in North America that has run in June each year since 1988. MTO selects vehicles at random at Truck Inspection Stations across Ontario, and also at other convenient locations, using a methodology designed so that the sample can be expanded to represent all traffic on the principal highways in the province. MTO conducts between 2,000 and 3,000 Level 1 inspections on vehicles each year during Roadcheck.

MTO also participates in the CVSA Operation Air Brake Program, a coordinated series of three one-day blitzes per year, two announced and one un-announced, that is carried out simultaneously in all provinces and territories, and some states in the U.S., and has run since 1998. The objectives are to increase drivers' and carriers' knowledge of brake compliance and brake performance, and to make sure all applicable brake system inspection requirements are followed. MTO selects vehicles at random, using the same methodology as for Roadcheck, but conducts only a Level 4 inspection, which addresses only the braking system. MTO has a sample of about 2,000 vehicles from 2001, 1,300 vehicles from 2000, and about 1,000 vehicles from 1999.

MTO gained authority for the Commercial Vehicle Impoundment Program (CVIP), which began in February 1998 [11]. This allows MTO to impound a vehicle for 15 days if the vehicle is found with one or more critical defects, serious and immediate safety deficiencies that are significantly beyond the level at which it would be put out-of-service. These are spelled out in regulation [11]. MTO has impounded about 750 vehicles since the program began, principally for airbrake defects.

In addition, MTO also conducts a wide range of other enforcement activities, from blitzes focused on a particular carrier, sector or location, to educational and other activities. All vehicle inspections are carried out to the same CVSA standard, and all inspection reports, the CVIR, are filled in the same manner, regardless of the purpose of the inspection. The motor carrier industry has through the years raised issues regarding inspection procedures. MTO has striven to ensure that the inspection process and criteria are applied consistently across the province, and vehicles are put out-of-service to a consistent standard.

The CVIR includes the date, time and location of the inspection, the carrier's Commercial Vehicle Operator Registration (CVOR) number, the year of manufacture, license plate number and province of registration for each vehicle unit, and the brake chamber type and size, and stroke, for each brake on the vehicle unit. It also includes a considerable amount of other data not relevant to this work, including some designated by MTO as personal information. There are no fields on the CVIR for the type of slack adjuster, so these data are written by hand when the report is filled.

2.2 Data Collection

The existence of the inspection data within MTO presented an opportunity to conduct this work without going into the field to capture original data, which would have been time-consuming and very expensive. MTO graciously agreed to provide access to inspection records in their files.

The selection bias inherent in the daily inspection records ensures that this dataset does not represent a proper cross-section of vehicles on the highway. It was considered unsuitable for this work. Roadcheck and Operation Airbrake both generate high-quality data for vehicles selected at random. Operation Airbrake was selected simply because it focused entirely on vehicles equipped with airbrakes, while Roadcheck addresses all vehicles and may include vehicles with hydraulic brakes. Ontario traffic at the survey sites used on the primary highway system typically includes about one third of trucks from other jurisdictions, with about 13% from the U.S., about 10% from Quebec, and 10% from the other eight provinces and the territories. It actually represents a reasonable cross-section of trucks across North America. In addition, data were selected from the Commercial Vehicle Impoundment Program, because almost all these vehicles were impounded for serious brake deficiencies. It was expected that these data would provide detailed insights into the group of vehicles in the worst condition on the highway.

Table 2: Scope of Data

Year	Operation Airbrake Records	CVIP Records
1999	1,001	86
2000	1,297	90
2001	2,176	90
Total	4,474	267

Data were selected from Operation Airbrake files as indicated in Table 2. It was intended to supplement these data with data from Roadcheck for years prior to 1999, but these data had been lost by accidental activation of the sprinkler system in the area where the data were stored. The Commercial Vehicle Impoundment Program records obtained represent about one third of all such records since the inception of the program in 1998.

A completed inspection record contains certain fields in which data considered personal are entered. The personal data were not relevant to this project, and would not have been coded. However, the personal data were collected for specific purposes, and this project went beyond those purposes. It was determined that only MTO staff had the right of access to such personal data. A thin paper mask was therefore constructed that obscured all fields on an inspection record other than those directly required for this work. The mask was taped beneath a thin sheet of transparent plastic. The plastic was placed on the document glass of a copying machine, and was pushed under the plastic moulding at the end of the glass where an automatically fed document entered the glass. This ensured the document would not catch on the plastic sheet as it moved onto the glass for copying. MTO staff then copied original inspection forms using the automatic document feed of the copying machine. This procedure addressed all the concerns about privacy, and provided an efficient means to capture a large number of CVIR's.

2.3 Data Entry

The following data were extracted from an inspection record:

1. Date of inspection;
2. Location of inspection;
3. Inspection record number;
4. Carriers CVOR number, for inspections conducted in 2001 only;
5. Number of axles on each vehicle unit;
6. Type of each vehicle unit;
7. Year of manufacture of each vehicle unit;
8. Province of registration of each vehicle unit;
9. License plate number of any vehicle unit registered in Ontario without a year of manufacture;
10. Brake type and chamber size for each brake;
11. Slack adjuster type for each brake; and
12. Stroke for each brake.

Data from each inspection record was entered into a Microsoft Excel spreadsheet. A "smart" data entry form was developed using the Visual Basic forms utility. It was evident during early trials of this data entry procedure that the most common vehicle was a 3-axle tractor registered in Ontario towing a 2-axle semitrailer, also registered in Ontario, with Type 20 brake chambers on the front axle, Type 30 chambers on all other axles, and automatic slack adjusters on all axles. Each new record was therefore pre-filled with this combination of values in the appropriate fields. Some fields depended on data entered in earlier fields, and data were filled in or removed from later fields depending on the data entered in the earlier fields. This dynamic process simplified data entry by minimizing the number of keystrokes and mouse clicks required to enter each record.

2.4 Comments on Data

The data entered on most inspection records appears to have been entered in a relatively consistent manner, and was substantially complete.

The records included one bus. This was excluded from the final tabulation of vehicles.

A number of records were filled with all brake strokes at 1 in. These typically occurred in an isolated batch of a small number of consecutive records. This may have been suitable for the Operation Airbrake purpose, to indicate that all brakes were within their specified stroke. However, for the purpose of this work, the values appeared spurious, so these records were discarded. A small number of records were filled with a check mark for all brake strokes, also to indicate that all brakes were within their specified stroke. These were also discarded.

There were a small number of records where brake chamber sizes were not entered. The default chamber sizes, Type 20 for the front axle and Type 30 for all other axles, were assumed in these cases. These were the predominant brake chamber sizes.

There were some numbers of records, particularly in 1999, where the type of slack adjuster was not recorded. The data were entered, but were excluded from the analysis of stroke. There were a number of cases where the slack adjuster type was identified for the tractor, but not for the trailer. In these cases, it was assumed that the trailer slack adjusters were of the other type than the tractor slack adjusters.

There were a number of cases where the inspection record claimed that a late model vehicle was fitted with manual slack adjusters, or an old vehicle was fitted with automatic slack adjusters. There was no basis to make any change to these data, so they were entered strictly as recorded on the inspection record, regardless of plausibility.

A small number of stroke measurements were entered on the CVIR form in sixteenths of an inch. These were rounded down to the nearest eighth of an inch, except that a stroke of 2 1/16 in was rounded up to 2 1/8 in, to ensure that a Type 30 chamber would still be out of adjustment.

Small numbers of vehicles had axles fitted with electric, hydraulic or wedge brakes. The brake type was recorded, but no stroke was recorded. The stroke was also not recorded for a small number of other brakes, because the brakes were inaccessible and measurements could not be made, or because the brakes were inoperative.

There were a small number of anomalies in the data, which are believed to be real from the way the inspection report was filled out. Four cases were observed where brake chambers of different sizes were installed on the same axle. Three cases were observed where one axle of a vehicle was fitted with one manual and one automatic slack adjuster.

The make and model of slack adjuster was never reported, so the extent to which slack adjusters of different makes or models may be fitted on any axle, and the relative performance of different makes and models, could not be determined.

3. RESULTS FROM OPERATION AIRBRAKE

3.1 Scope

This chapter presents the results from the Operation Airbrake data. It provides an overall view of the use of automatic slack adjusters, and the state of brake adjustment, for heavy truck traffic on the principal highways in Ontario.

3.2 Vehicles

The first step was to validate the Operation Airbrake data captured in this survey against the best alternative data source, the CCMTA 1999 National Roadside Survey (NRS) [12].

Table 3 summarizes the percentage of vehicles by configuration and number of axles, for each of the three years of data, and compares it with the NRS results for Ontario. Table 4 summarizes the jurisdiction of registration of power units, for each of the three years of data, and compares it with the NRS results for Ontario. It was not possible to look at trailers, because the NRS did not capture the jurisdiction of registration of trailers. These two tables include all vehicles for each sample year, regardless of whether slack adjusters were properly identified. The sample of vehicles appears relatively consistent over the three years of Operation Airbrake data, and is also relatively consistent with the NRS data.

Table 3: Comparison of Configurations

Configuration	No of Axles	1999	2000	2001	NRS
Straight truck	2	4.1%	7.1%	6.3%	10.2%
	3	5.7%	6.9%	6.3%	2.9%
	4 or more	1.8%	4.2%	3.9%	1.0%
Tractor-semitrailer	4 or less	2.3%	2.4%	2.5%	1.2%
	5	55.8%	50.8%	55.0%	61.2%
	6	13.5%	12.4%	11.4%	9.6%
	7	4.8%	4.6%	5.4%	4.2%
	8	2.6%	2.2%	1.9%	1.5%
	9 or more	0.1%	0.8%	0.5%	0.8%
Double	5 or less	0.2%	0.3%	0.3%	0.3%
	6	0.2%	0.5%	0.1%	0.2%
	7	0.9%	0.5%	0.1%	0.3%
	8	4.6%	2.7%	3.3%	3.5%
	9 or more	1.0%	1.3%	1.1%	0.7%
Truck-trailer	5 or less	0.3%	0.3%	0.4%	0.4%
	6 or 7	0.5%	0.5%	0.7%	0.3%
	8 or more	0.4%	0.3%	0.2%	0.1%
Bobtail tractor		1.5%	2.0%	0.5%	1.6%

Table 4: Comparison of Jurisdiction of Power Unit Front License Plate

Jurisdiction	1999	2000	2001	NRS
Ontario	69.3%	71.4%	70.6%	66.5%
Quebec	9.9%	8.4%	13.8%	10.6%
Alberta	4.7%	5.6%	2.4%	4.2%
Illinois	1.7%	1.5%	1.7%	3.1%
Manitoba	3.8%	3.3%	2.8%	2.3%
Michigan	0.9%	0.5%	0.6%	2.1%
New York	0.8%	0.3%	0.7%	2.0%
New Brunswick	1.4%	1.3%	1.5%	1.1%
Other provinces	3.8%	2.4%	2.1%	2.1%
Other states	3.7%	5.3%	3.8%	6.0%

Table 5: Vehicles by Model Year and Registration

Year	Canadian Registered			US Registered	
	Truck	Tractor	Trailer	Tractor	Trailer
2002	8	22	8	2	0
2001	48	168	126	23	9
2000	56	469	296	36	26
1999	82	422	399	49	32
1998	81	359	405	29	21
1997	32	198	294	16	18
1996	40	203	211	14	14
1995	57	209	249	25	20
1994	36	124	193	9	12
1993	19	67	133	6	5
1992	8	18	62	4	5
1991	11	8	39	1	1
1990	31	27	115	2	6
1989	31	40	120	0	2
1988	21	39	130	0	4
1987	21	32	115	1	4
1986	8	16	56	0	2
<1986	16	21	182	3	11
No of vehicles	606	2442	3133	220	192

3.3 Equipment

Table 5 shows the count of vehicles by model year, vehicle type and license plate jurisdiction for those vehicles for which these data and type of automatic slack adjuster were available, and Table 6 shows the same data expressed as a percentage of each column total. The latter data are also plotted in Figure 1, as the cumulative percentage of each class of vehicle built since the model year. These data show that about 75% of tractors have been built since 1995, and 90% have been built since 1993, whereas about 75% of trailers have been built since 1992, and 90% have been built since 1988. This reflects the longer life of trailers over tractors. U.S. registered tractors and trailers that travel in Ontario are slightly younger than Canadian tractors and trailers. Older vehicles tend to be relegated to local uses, and few local-use U.S. vehicles would be expected in Ontario. Straight trucks have a similar age distribution to trailers, because many are not used as intensively as tractors, so their mechanical components last longer. The oldest vehicles were two trailers built in 1957, and the oldest power unit was built in 1968. The survey found 9 power units (0.3%) and 78 trailers (2.3%) built before 1980.

Table 6: Percentage of Vehicles by Model Year and Registration

Year	Canadian Registered			US Registered	
	Truck	Tractor	Trailer	Tractor	Trailer
2002	1.3%	0.9%	0.3%	0.9%	0.0%
2001	7.9%	6.9%	4.0%	10.5%	4.7%
2000	9.2%	19.2%	9.4%	16.4%	13.5%
1999	13.5%	17.3%	12.7%	22.3%	16.7%
1998	13.4%	14.7%	12.9%	13.2%	10.9%
1997	5.3%	8.1%	9.4%	7.3%	9.4%
1996	6.6%	8.3%	6.7%	6.4%	7.3%
1995	9.4%	8.6%	7.9%	11.4%	10.4%
1994	5.9%	5.1%	6.2%	4.1%	6.3%
1993	3.1%	2.7%	4.2%	2.7%	2.6%
1992	1.3%	0.7%	2.0%	1.8%	2.6%
1991	1.8%	0.3%	1.2%	0.5%	0.5%
1990	5.1%	1.1%	3.7%	0.9%	3.1%
1989	5.1%	1.6%	3.8%	0.0%	1.0%
1988	3.5%	1.6%	4.1%	0.0%	2.1%
1987	3.5%	1.3%	3.7%	0.5%	2.1%
1986	1.3%	0.7%	1.8%	0.0%	1.0%
<1986	2.6%	0.9%	5.8%	1.4%	5.7%
No of vehicles	606	2442	3133	220	192

Figure 1: Cumulative Percentage of Vehicles Built Since Model Year

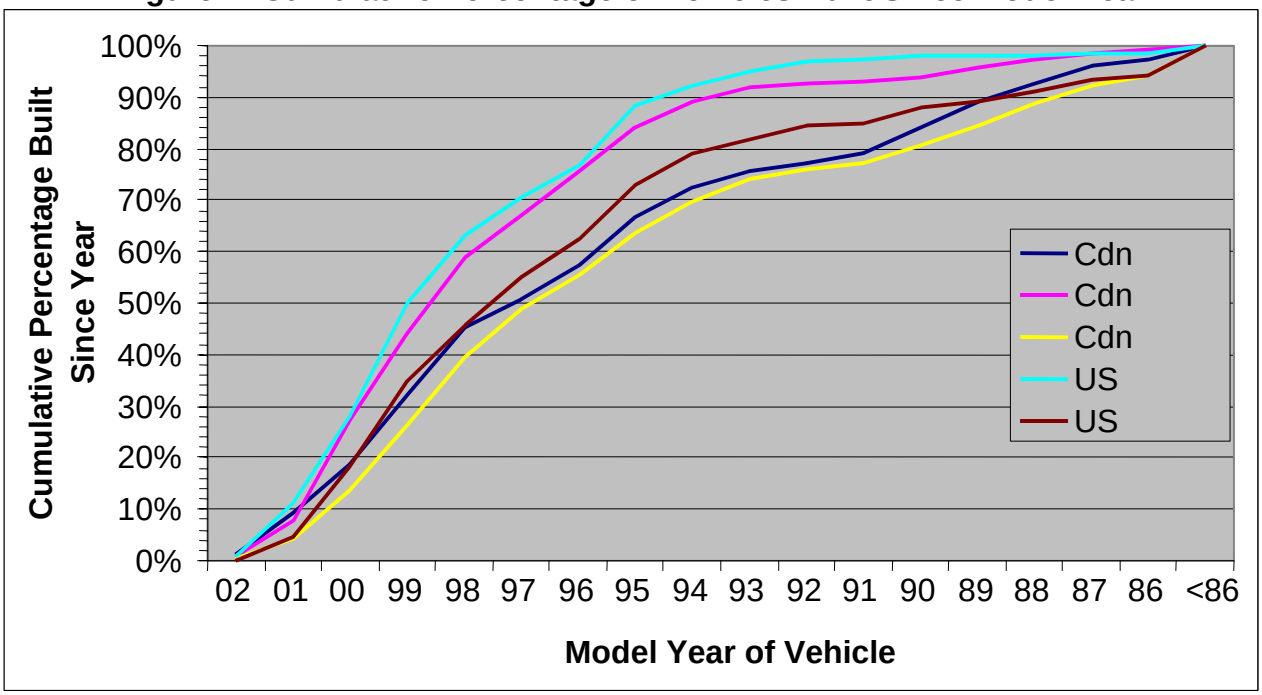


Table 7: Number of Vehicles with Automatic Slack Adjusters

Year	Canadian Registered			US Registered	
	Truck	Tractor	Trailer	Tractor	Trailer
2002	8 / 8	22 / 22	7 / 8	2 / 2	0 / 0
2001	48 / 48	163 / 168	119 / 126	23 / 23	9 / 9
2000	55 / 56	458 / 469	269 / 296	33 / 36	26 / 26
1999	81 / 82	408 / 422	371 / 399	47 / 49	31 / 32
1998	77 / 81	347 / 359	366 / 405	28 / 29	20 / 21
1997	32 / 32	182 / 198	252 / 294	15 / 16	17 / 18
1996	39 / 40	195 / 203	186 / 211	14 / 14	13 / 14
1995	51 / 57	188 / 209	200 / 249	22 / 25	18 / 20
1994	30 /36	102 / 124	113 / 193	9 / 9	10 / 12
1993	18 / 19	50 / 67	70 / 133	4 / 6	3 / 5
1992	6 / 8	12 / 18	28 / 62	3 / 4	3 / 5
1991	4 / 11	6 / 8	12 / 39	1 / 1	1 / 1
1990	9 / 31	9 / 27	48 / 115	1 / 2	3 / 6
1989	14 / 31	14 / 40	28 / 120	0 / 1	1 / 2
1988	2 / 21	13 / 39	40 / 130	0 / 1	4 / 4
1987	7 / 21	9 / 32	28 / 115	0 / 1	3 / 4
1986	2 / 8	5 / 32	13 / 56	0 / 0	1 / 2
<1986	8 / 16	2 / 21	58 / 182	1 / 3	2 / 11
Overall	491 / 606	2185 / 2442	2208 / 3133	203 / 220	165 / 192

Table 8: Percentage of Vehicles with Automatic Slack Adjusters

Year	Canadian Registered			US Registered	
	Truck	Tractor	Trailer	Tractor	Trailer
2002	100.0%	100.0%	87.5%	100.0%	100.0%
2001	100.0%	97.0%	94.4%	100.0%	100.0%
2000	98.2%	97.7%	90.9%	91.7%	100.0%
1999	98.8%	96.7%	93.0%	95.9%	96.9%
1998	95.1%	96.7%	90.4%	96.6%	95.2%
1997	100.0%	91.9%	85.7%	93.8%	94.4%
1996	97.5%	96.1%	88.2%	100.0%	92.9%
1995	89.5%	90.0%	80.3%	88.0%	90.0%
1994	83.3%	82.3%	58.5%	100.0%	83.3%
1993	94.7%	74.6%	52.6%	66.7%	60.0%
1992	75.0%	66.7%	45.2%	75.0%	60.0%
1991	36.4%	75.0%	30.8%	100.0%	100.0%
1990	29.0%	33.3%	41.7%	50.0%	50.0%
1989	45.2%	35.0%	23.3%	0.0%	50.0%
1988	9.5%	33.3%	30.8%	0.0%	100.0%
1987	33.3%	28.1%	24.3%	0.0%	75.0%
1986	25.0%	31.3%	23.2%	0.0%	50.0%
<1986	50.0%	9.5%	31.9%	33.3%	18.2%
Overall	81.0%	89.5%	70.5%	92.3%	85.9%

Figure 2: Percentage of Vehicles with Automatic Slack Adjusters by Model Year

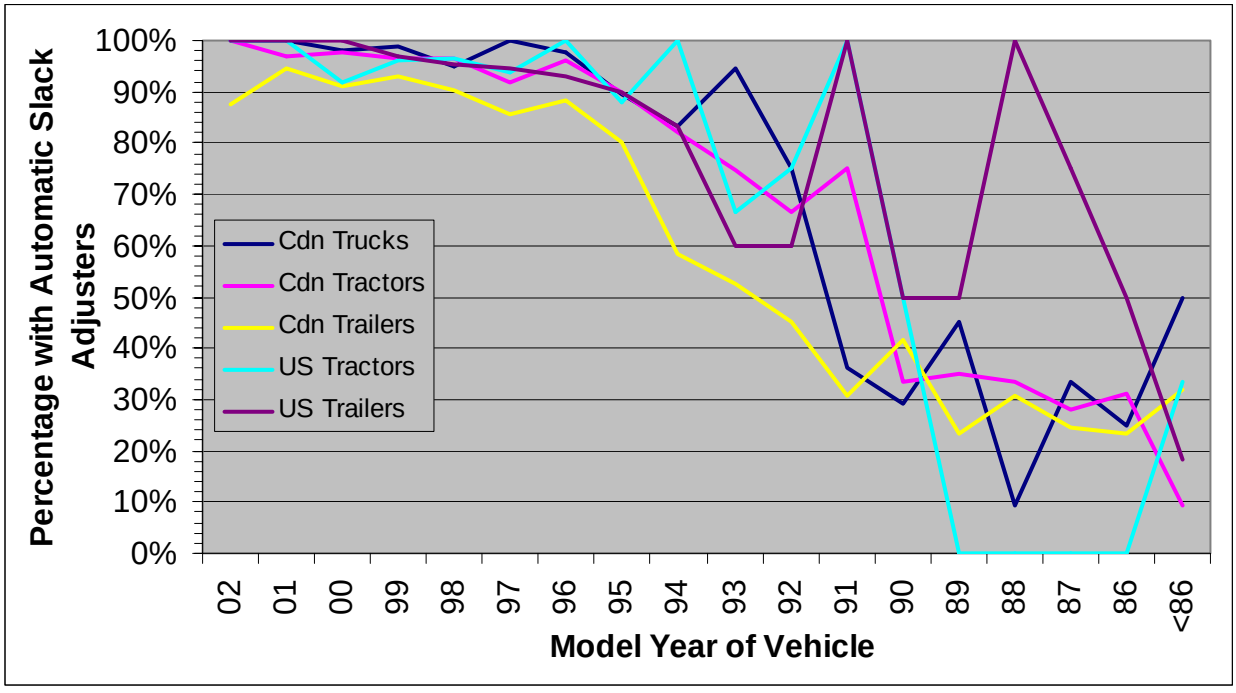


Table 7 shows the percentage of vehicles with automatic slack adjusters by model year, vehicle type and license plate jurisdiction for the same set of vehicles as Table 5. For each entry, “x / y” should be read as “x of y vehicles were fitted with automatic slack adjusters”. Table 8 shows the data from Table 7 expressed as percentages, and these data are also plotted in Figure 2. Note that some of the entries in Table 7 contain relatively small numbers of vehicles, so there are substantial fluctuations in percentages from year to year.

The fitment rate for automatic slack adjusters shown in Table 8 would be expected to be 100% for U.S. registered vehicles built since 1994, and for Canadian registered vehicles built since 1996. Canadian and U.S. federal regulations do provide exemptions from the requirement for automatic slack adjusters for any vehicle fitted with an axle with a gross axle weight rating over 13,154 kg (29,000 lb), any heavy hauler trailer with a gross vehicle weight rating over 54,432 kg (120,000 lb), and certain other cases [4, 10]. These provisions are intended to exempt certain specialized heavy haul vehicles in the U.S., but because of the high weights and particular configurations allowed in Ontario, some vehicles in the survey might technically have been exempt from the federal requirement for automatic slack adjusters. However, the Ontario regulation does not provide the same exemptions [6], so it is likely that a manufacturer building such legal vehicle for Ontario would not build it differently than any other legal vehicle.

Tables 7 and 8 show less than the expected 100% fitment of automatic slack adjusters for vehicles built in the U.S. since 1994, or in Canada since 1996. Four immediately obvious causes for the difference can be postulated:

- Manufacturers may have fitted manual slack adjusters as original equipment when automatic slack adjusters were required; or
- Owners may have replaced automatic slack adjusters fitted as original equipment with manual slack adjusters; or
- MTO inspectors incorrectly identified or recorded the type of slack adjuster, or
- MTO inspectors incorrectly identified or recorded the model year of the vehicle.

There is no immediate way of telling from the data the extent that any of these factors accounts for differences between expected and actual fitment of automatic slack adjusters. Resolving this would take some additional work beyond the scope of this assignment.

It is likely that all, or almost all, power units built since the U.S. requirement for automatic slack adjusters in 1994 (i.e. in or after 1995) would have been fitted with automatic slack adjusters in the factory. Table 7 shows that 2538 of 2648 such power units, or 95.8%, were reported as fitted with automatic slack adjusters. It is not possible to be certain whether a vehicle that should have had automatic slack adjusters by its reported year of construction actually had manual slack adjusters or not. A significant proportion of power units and trailers registered in Canada are built in the U.S., and they should have been fitted with automatic slack adjusters in the plant in accordance with the U.S. requirement effective in 1994. During the period from the effective date of the U.S. requirement to the Canadian requirement, some Canadian customers may have requested the U.S. vehicle manufacturer to fit manual slack adjusters. If a manufacturer was not prepared to do this, some vehicle owners may have changed the slack adjusters after delivery. Some may not

have been prepared to absorb the cost. It is possible that the MTO inspector may have made an error in identification or recording of either the type of slack adjuster or the model year of the vehicle. There is at least one model of automatic slack adjuster that does not have the distinctive separate adjuster link that many other models have, and a cursory glance at such a design could result in an incorrect identification as a manual slack adjuster. If it is assumed that no manual slack adjusters were incorrectly identified as automatic slack adjusters, and the discrepancy is entirely due to recognition or recording errors by MTO inspectors, then the error rate would be about 4.2%. If the error rate is actually half of this, then about 2% of power units would have had their original automatic slack adjusters replaced with manual slack adjusters.

The data in Table 7 show that 134 of 140 U.S. registered trailers built since 1994, or 95.7%, were reported as fitted with automatic slack adjusters. This is compatible with the error rate for power units, noted above. It is likely that most such trailers would have been built by large manufacturers, so 100% fitment of automatic slack adjusters would be expected. However, the same data show that only 1384 of 1528 of Canadian registered trailers, or 90.6%, built since 1996 were actually fitted with automatic slack adjusters. There is no reason why MTO inspectors should commit a significantly higher error rate in recognition or recording of slack adjuster type for these trailers compared to power units. Power units and trailers of different ages are coupled together and are inspected together, so any errors would be expected to be distributed relatively uniformly among them. There are also approximately the same numbers of power units and trailers. If anything, trailers are more carefully inspected, because they tend to be in poorer condition than power units, so are more frequently put out-of-service. Many Canadian trailer manufacturers are small, and some may have been slow to respond to the requirement for automatic slack adjusters, so a lower fitment rate for 1997 and maybe 1998 vehicles might be possible. However, manufacturers should know the requirements by now. While it seems possible to rationalize the difference in trend for Canadian trailers compared to other vehicles, there is no clear way to account for a continuing automatic slack adjuster fitment rate of about 90% on Canadian trailers. It can only be concluded that this is substantially real, and either some trailers that require automatic slack adjusters are not being fitted with them when they are built, or their owners are replacing them with manual slack adjusters. In fact, the numbers quoted in this paragraph may be a little optimistic. Many of the Canadian registered trailers were actually built by large manufacturers in the U.S., so would be expected to have been built with automatic slack adjusters. The origin of the samples of trailers is not known. If it is assumed that half the Canadian registered trailers were built in the U.S. and were actually fitted with automatic slack adjusters, and the error rate is 4.2%, then the actual automatic slack adjuster fitment rate for Canadian manufactured trailers drops to about 85%.

At the other end of the scale, about 30% of Canadian registered power units and trailers that were manufactured prior to any requirement for automatic slack adjusters were fitted with automatic slack adjusters. A few such older vehicles have an automatic slack adjuster on a single wheel, or automatic slack adjusters on a single axle, which suggests a replacement during maintenance. All other older vehicles with automatic slack adjusters had them on all axles. This suggests they were either built that way, although there was no requirement, or their owners have elected to make a complete change. The fitment rates

for such older U.S. vehicles shown in Tables 7 and 8 are not considered reliable, because there are often fewer than 6 vehicles of one model year.

Overall, just over 90% of tractors and 81% of straight trucks have automatic slack adjusters, but only 70% of Canadian registered trailers, and 86% of U.S registered trailers have them. Inspection of Figure 1 suggests that the natural attrition and replacement of tractors should result in about 98% of tractors having automatic slack adjuster's by about 2010. The rates for straight trucks and trailers would be about 97% and 94% respectively at this time. These fitment rates might be achieved earlier if there should be a higher rate of retrofit of automatic slack adjuster's, such as would happen if manual slack adjusters began to disappear from the replacement parts market.

Table 9 shows the distribution of brake chambers by type. The design of brake chamber was not consistently recorded on the inspection records, so was not coded. Brake chambers are principally clamp type design. The numbers of standard stroke and long stroke brake chambers are listed, together with the percentage of these fitted with automatic slack adjusters. The numbers of brake chambers would be expected to be even numbers, because there are two brakes on each axle. However, these data exclude those brakes that were inoperative, and a small number of axles identified with chambers of other types. No chambers smaller than Type 12 or larger than Type 30 were found. Types 12, 16, 20 and 24 were used on front axles, and Type 30 was used on power unit drive axles and trailer axles. A small number of vehicles were fitted with Type 20 or 24 chambers on a liftable axle or a converter dolly. Brakes have been required on all axles on vehicles built in the U.S. since 1982, and on vehicles built in Canada since 1993. Small numbers of vehicles built prior to these dates were found without brakes on some axles. These included power units with no front axle brakes, trailers without brakes on a liftable axle, and converter dollies without brakes. There were also a small number of vehicles with wedge brakes, usually on the front axle of the power unit, or with hydraulic or electric brakes on a trailer. These were all older vehicles, built prior to 1990. "Small number" in each case means less than ten, sometimes only one or two, out of a total of 3,268 power units and 3,325 trailers.

Table 9: Distribution of Brake Chambers

Chamber size	Standard stroke	% ASA	Long stroke	% ASA	Total	% ASA
12	92	54.3%	0	0.0%	92	54.3%
16	286	56.3%	0	0.0%	286	56.3%
20	6,085	90.9%	296	98.6%	6,381	91.2%
24	795	89.6%	66	100.0%	861	90.4%
30	30,212	83.0%	956	96.4%	31,168	83.4%
Overall	37,470	84.2%	1,318	97.1%	38,788	84.6%

Table 10: Percentage of Long stroke brake chambers by Vehicle and Registration

Year	Canadian Registered			US Registered	
	Truck	Tractor	Trailer	Tractor	Trailer
2002	0.0%	13.6%	0.0%	100.0%	0.0%
2001	0.0%	13.7%	5.6%	21.7%	11.1%
2000	0.0%	8.3%	2.4%	16.7%	3.8%
1999	1.2%	13.0%	2.8%	20.4%	6.3%
1998	0.0%	6.1%	0.2%	6.9%	4.8%
1997	3.1%	2.0%	1.7%	0.0%	0.0%
1996	0.0%	0.5%	0.5%	0.0%	0.0%
Overall	0.3%	6.0%	1.2%	11.4%	2.6%

Table 11: Percentage of Vehicles with Automatic Slack Adjusters

Year	Canadian Registered			US Registered		Total
	Truck	Tractor	Trailer	Tractor	Trailer	
1999	70.8%	38.3%	60.7%	83.3%	77.3%	59.3%
2000	76.1%	90.6%	68.5%	94.5%	78.0%	79.3%
2001	85.2%	92.9%	74.7%	92.9%	89.9%	89.1%
Overall	81.0%	89.5%	70.5%	92.3%	85.9%	79.7%

The moderate fitment rate of automatic slack adjusters on Type 12 and 16 chambers seen in Table 9 reflects use of chambers of these sizes predominantly on older vehicles. Newer vehicles mostly use Types 20 and 24. Long stroke brake chambers make up only 3.4% of all brakes, because they are still in the early stages of adoption. However, because of this, they are fitted almost entirely with automatic slack adjusters.

Table 10 shows the percentage of vehicles in each model year with long stroke brake chambers, by vehicle type and license plate jurisdiction, using the same dataset as for Tables 5 and 7. The bottom row shows the overall rate of fitment of long stroke brake chambers. Almost no vehicles of a model year prior to 1996 use long stroke brake chambers. The data suggests a trend is definitely underway for both tractors and trailers, though not yet apparently for straight trucks.

Table 11 shows the trend in automatic slack adjuster fitment rate by vehicle type and jurisdiction of registration for the three years for which Operation Airbrake data were available. The 1999 data are a little sparse, but only the 1999 figure for Canadian registered tractors seems significantly out of line. These data show that 89.1% of vehicles with airbrakes operating in Ontario in 2001 were fitted with automatic slack adjusters. The truck fleet is in the final stage of its transition to automatic slack adjusters. However, that final stage will be slow and long drawn-out. It may take until about 2010 to reach an overall automatic slack adjuster fitment rate over 98%, and the last manual slack adjuster may still be on the highway well after 2020.

3.4 Performance of Slack Adjusters

This section reviews the performance of slack adjusters in terms of their ability to maintain stroke within the ranges outlined in Table 1.

Table 12 is a summary of brake adjustment for all vehicles whose brake chambers and slack adjusters were reliably identified, and whose brake adjustments were credible. The table omits direct mention of Type 12 chambers, which were few in number, and groups Types 16, 20 and 24 together, because they have the same adjustment limit. The first two columns of data are for Types 16, 20 and 24 for manual and automatic slack adjusters, and the next two are for Type 30 for manual and automatic slack adjusters. The next two are for long stroke brake chambers of Types 16, 20 and 24, and Type 30, for automatic slack adjusters only, because virtually none of these chambers was fitted with a manual slack adjuster. The last two columns summarize the results for all brake chambers, including Type 12, for manual and automatic slack adjusters. The first row of data gives the total number of chambers of the given size and slack adjuster, and the next row gives this value as a percentage of the total number of brakes. The third row of data gives the total number of brakes out of adjustment, and the next row gives this as a percentage of that type of brake. The fifth and sixth rows give the mean and standard deviation of stroke for all brakes in that column, and the last row gives the probability that a brake will be out of adjustment assuming that the mean and standard deviation represent a normal distribution. The last row gives the adjustment limit, for reference.

Table 12 shows that Types 16, 20 and 24 chambers have a relatively low rate of out of adjustment. These are predominantly front axle brakes, and it is generally believed that the state of brake adjustment on power units is better than that on trailers. The average strokes for manual and automatic slack adjusters are similar, but the standard deviation is

larger for manual slack adjusters, which results in a probability about 50% higher that a brake with manual slack adjusters will be out of adjustment. Similar data are presented for Type 30 chambers, which are a mixture of power unit drive axles and trailer axles. Again, the average strokes for manual and automatic slack adjusters are similar, but the standard deviation is larger for manual slack adjusters, which results in a probability about 200% higher that a brake with a manual slack adjuster will be out of adjustment. These data suggest that automatic slack adjusters do indeed reduce the probability that a brake will be out of adjustment. The results for long stroke chambers give mean values and standard deviations of brake adjustment close to those for standard stroke chambers. However, the

additional stroke available from a long stroke brake chamber is sufficient to reduce significantly the probability that such a brake will be out of adjustment. The additional 0.25 in of stroke for a Type 16, 20 or 24 long stroke chamber is not as effective as the additional 0.5 in of stroke of a Type 30 chamber. It is apparent that the probability of a brake being out of adjustment derived by assuming a normal distribution with the mean and standard deviation derived from the data corresponds quite well with the percentage of brakes actually found out of adjustment. Overall, 4.9% of brakes with manual slack adjusters were out of adjustment, while only 1.5% of brakes with automatic slack adjusters were out of adjustment. These results are substantially dominated by the results for Type 30 chambers.

Table 12: Summary of Brake Adjustment

	Type 16 - 24		Type 30		Type 16-24LS	Type 30LS	All	
	MSA	ASA	MSA	ASA	ASA	ASA	MSA	ASA
Number	763	6403	5126	25086	358	922	5969	32819
% of all	2.0%	16.5%	13.2%	64.7%	0.9%	2.4%	15.4%	84.6%
No OOA	14	72	285	466	0	3	291	506
% OOA	1.8%	1.1%	5.6%	1.9%	0.0%	0.3%	4.9%	1.5%
Av Stroke	1.02 in	1.09 in	1.35 in	1.34 in	1.10 in	1.37 in		
Std Dev	0.35 in	0.29 in	0.41 in	0.33 in	0.34 in	0.34 in		
Prob OOA	1.9%	1.3%	5.8%	2.4%	0.4%	0.0%		
Adj Limit	1.75 in	1.75 in	2.00 in	2.00 in	2.00 in	2.50 in		

Table 13 shows the brake adjustment results for just Type 30 standard (i.e. not long stroke) brake chambers for the three years, for manual and automatic slack adjusters separately, and combined, in the same format as Table 10. The table shows the steady increase in the proportion of automatic slack adjusters. It also shows that manual slack adjusters are consistently out of adjustment at more than twice the rate of automatic slack adjusters, even though each has about the same mean stroke. The standard deviation of stroke is consistently higher for manual slack adjusters, and that small but consistent difference is sufficient to increase the rate that brakes are out of adjustment. The important thing from these data is that automatic slack adjusters seem to be able to provide a consistent standard deviation of stroke of about 0.34 in, while the standard deviation for manual slack adjusters is larger and may also be inconsistent.

Table 13: Summary of Brake Adjustment for Type 30 Chambers by Year

	1999			2000			2001		
	MSA	ASA	Both	MSA	ASA	Both	MSA	ASA	Both
Number	1290	3981	5271	1435	6614	8049	2401	14491	16892
% of all	24.5%	75.5%	100.0%	17.8%	82.2%	100.0%	14.2%	85.8%	100.0%
No OOA	67	64	131	87	127	214	131	275	406
% OOA	5.2%	1.6%	2.5%	6.1%	1.9%	2.7%	5.5%	1.9%	2.4%
Av Stroke	1.34 in	1.32 in	1.33 in	1.38 in	1.34 in	1.34 in	1.34 in	1.35 in	1.35 in
Std Dev	0.39 in	0.34 in	0.35 in	0.44 in	0.34 in	0.36 in	0.41 in	0.33 in	0.34 in
Prob OOA	4.5%	2.2%	2.8%	7.8%	2.7%	3.5%	5.3%	2.4%	2.8%

Figure 3: Probable Percentage of Brakes Out of Adjustment

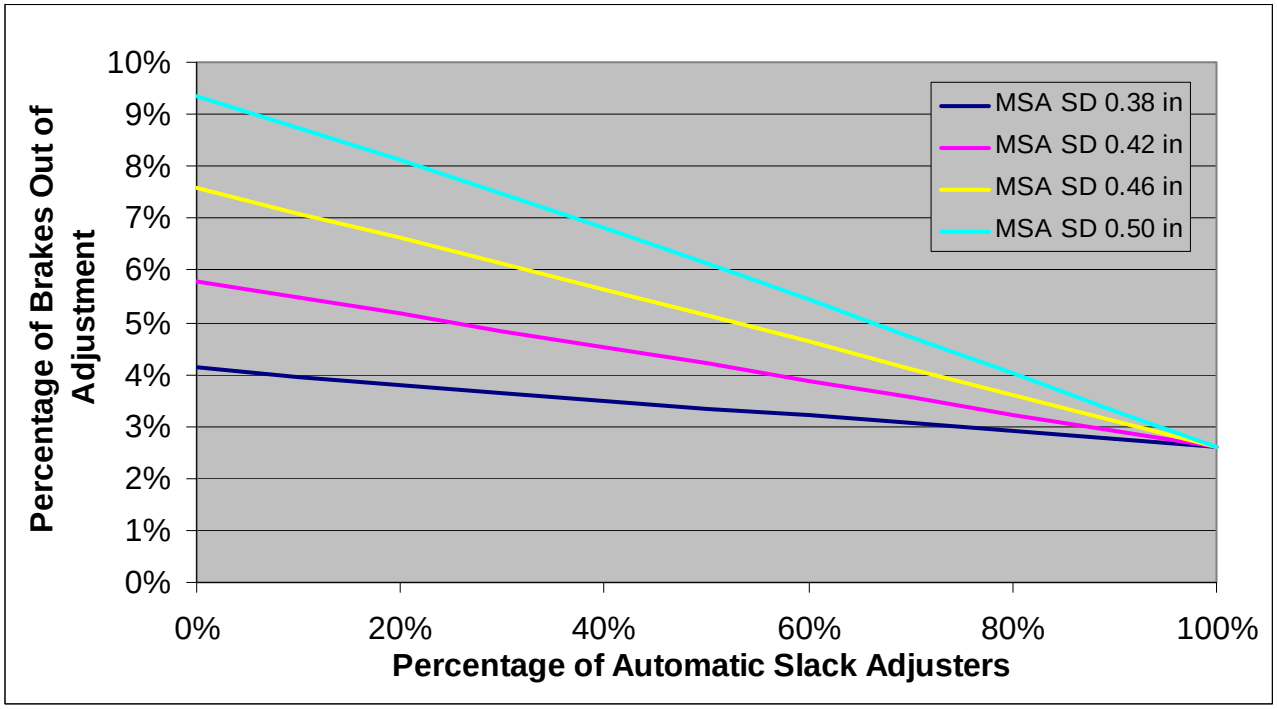


Figure 3 presents a theoretical extension of the data in Tables 12 and 13. It shows the percentage of brakes with Type 30 standard stroke chambers expected to be out of adjustment as functions of the percentage of brakes with automatic slack adjusters and the standard deviation of stroke for manual slack adjusters. The mean stroke is assumed constant at 1.34 in for both manual and automatic slack adjusters, and the standard deviation for automatic slack adjusters is assumed constant at 0.34 in. The standard deviation for manual slack adjusters takes arbitrary values from 0.38 to 0.50 in for this exercise. Figure 3 shows clearly that the percentage of brakes out of adjustment diminishes as the proportion of automatic slack adjusters increases, and it also diminishes as the standard deviation of stroke for manual slack adjusters decreases. Tables 12 and

13 show that the standard deviation of automatic slack adjuster stroke is consistent at about 0.34 in. This should be simply a function of the adjustment mechanism, assuming that the mechanism is working properly. However, manual slack adjusters require continuous attention to maintain stroke, and without this attention both the mean stroke and the standard deviation of stroke will increase, when an even higher percentage of brakes would be out of adjustment than suggested in Figure 3.

Figure 4 shows the distribution of brake stroke for standard brake chambers, again grouping Types 16, 20 and 24 together, and Type 30, for both manual and automatic slack adjusters. The peaky nature of the graph is due to the propensity of MTO vehicle inspectors to measure or record sub-critical strokes to the nearest quarter of an inch. Some measurements were recorded to the nearest eighth or sixteenth of an inch, but

Figure 4: Distribution of Brake Stroke for Standard Brake Chambers

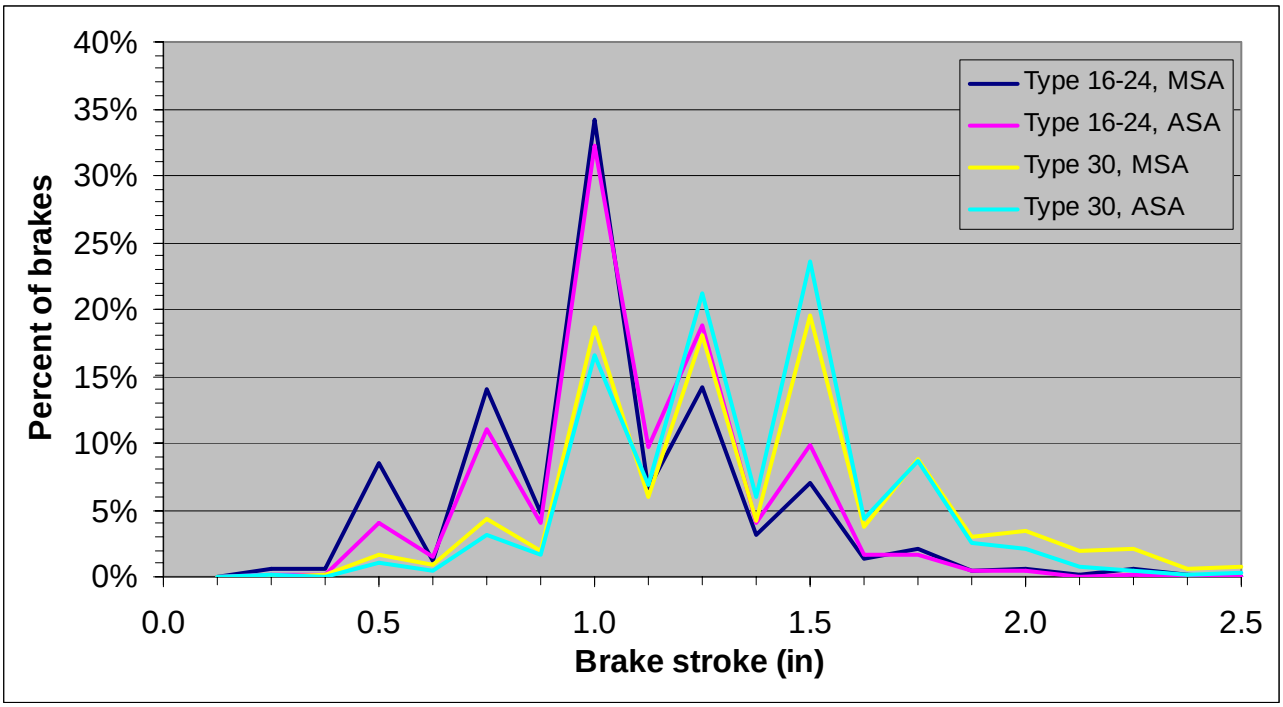
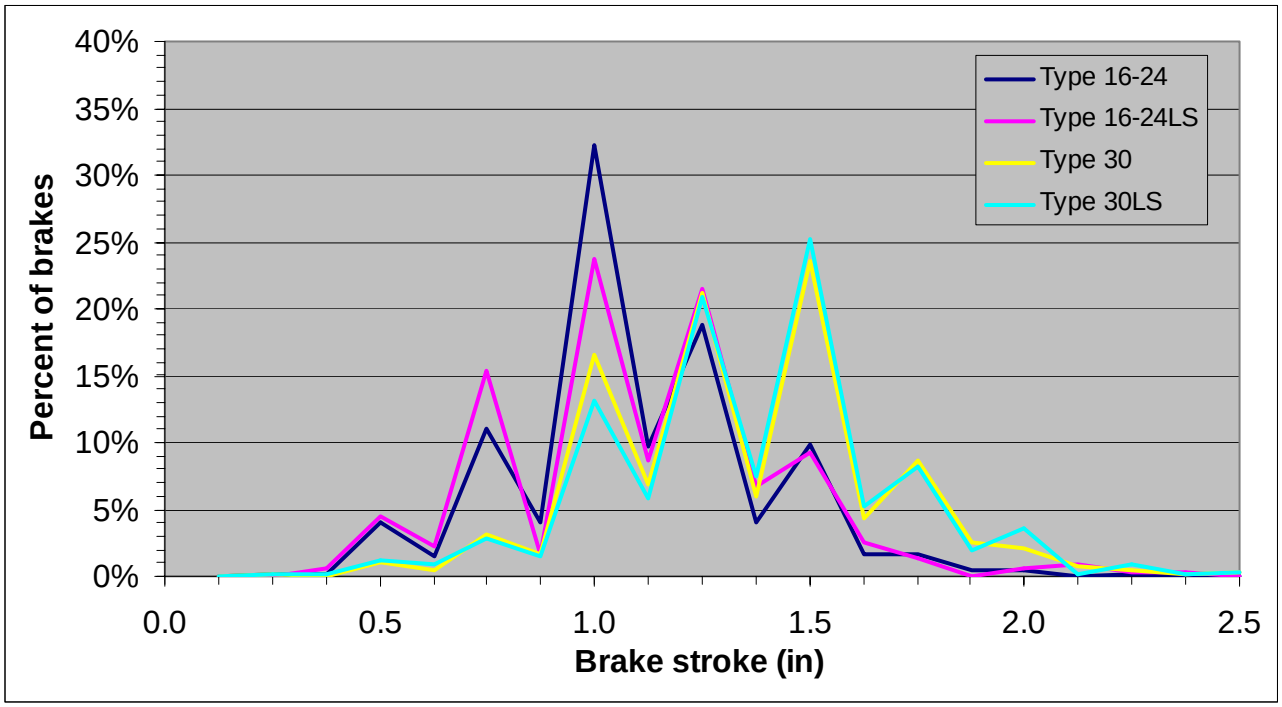


Figure 5: Distribution of Brake Stroke for Standard Brake Chambers



predominantly measurements were to the nearest quarter. The distributions of stroke for manual and automatic slack adjusters are rather similar for each type of chamber, though there is a significant difference in the tail beyond 2 in stroke for Type 30 chambers between manual and automatic slack adjusters. It is this difference that results in the increase in standard deviation of stroke for manual slack adjusters. The stroke for Type 16, 20 and 24 chambers clearly peaks at a stroke of 1 in, which is compatible with the mean just over that value presented in Table 11. The stroke for Type 30 chambers apparently peaks at a stroke of 1.5 in, but the actual mean from Table 9 is about 1.34 in. By and large, stroke is being controlled well within the adjustment limit of 1.75 in for Type 16, 20 and 24 chambers, or 2 in for Type 30 chambers.

Figure 5 shows the distribution of brake stroke for standard and long stroke brake chambers, again grouping Types 16, 20 and 24 together, and Type 30, for automatic slack adjusters only. The strokes for each type of chamber are rather similar, as in each case the slack adjuster is the same and is trying to do the same task. Table 11 shows there is little difference in either mean value or standard deviation of stroke for the two types of chamber of each size.

MTO puts a vehicle out-of-service if it fails one of many criteria established by the CVSA. MTO puts a vehicle unit out-of-service if more than 20% of its brakes are out of adjustment. This differs from the CVSA standard, which is 20% of the brakes on the entire vehicle out of adjustment. This may be satisfactory where most vehicles do not have more than five axles, but MTO consider it unsatisfactory when vehicles may have eight or more axles. A

tractor with three brakes out of adjustment, half its brakes, would get put out-of-service under the CVSA criteria on a 5-axle vehicle, but would not on an 8-axle vehicle. The tractor will face an equal risk in either case if it is coupled to a trailer under the alternative MTO criterion.

Table 14 shows the number of vehicles that would have been put out-of-service by MTO criteria, and the percentage of those vehicles with manual slack adjusters, by vehicle type and year. Table 15 shows the actual numbers of vehicles of each type, and the percentage of those vehicles with manual slack adjusters. Table 15 shows a steady decline in the portion of the fleet with manual slack adjusters. However, Table 14 shows that the proportion of vehicles fitted with manual slack adjusters that would have been put out-of-service is about 150% higher than their presence in the fleet as a whole. As noted above, manual slack adjusters are now found predominantly on older vehicles.

Table 16 shows the rate that vehicles would have been put out-of-service because their brakes were out of adjustment. Tractors are the most recent vehicles on the highway, with the highest proportion of automatic slack adjusters and long stroke brake chambers. They also allegedly get better maintenance, on average, than trailers. This table suggests that when the fitment rate of automatic slack adjusters on trailers approaches that on tractors, a further significant reduction in the out-of-service rate is possible, with the proper combination of circumstances and maintenance.

Table 14: Vehicles Out-of-service for Brakes Out of Adjustment

Year	Truck		Tractor		Trailer		Overall	
	No	% MSA	No	% MSA	No	% MSA	No	% MSA
1999	11	36.4%	6	66.7%	33	54.5%	50	52.0%
2000	11	54.5%	9	44.4%	63	38.1%	83	41.0%
2001	28	14.3%	18	50.0%	121	34.7%	167	32.9%
Total	50	28.0%	33	51.5%	217	38.7%	300	38.3%

Table 15: Distribution of Manual Slack Adjusters

Year	Truck		Tractor		Trailer		Overall	
	No	% MSA	No	% MSA	No	% MSA	No	% MSA
1999	65	29.2%	537	14.5%	537	29.4%	1139	22.4%
2000	176	23.9%	807	9.2%	748	20.3%	1731	15.5%
2001	365	14.8%	1712	7.1%	1715	16.9%	3792	12.3%
Total	606	19.0%	3056	9.0%	3000	20.0%	6662	14.8%

Table 16: Rate of Out-of-service for Brakes Out of Adjustment

Year	Truck	Tractor	Trailer	Overall
1999	16.9%	1.1%	6.1%	4.4%
2000	6.3%	1.1%	8.4%	4.8%
2001	7.7%	1.1%	7.1%	4.4%
Total	8.3%	1.1%	7.2%	4.5%

3.5 Performance of Carriers

The CVOR system provides a safety rating for carriers, based on the carrier's fleet size, accident history, on-road performance and audit results.

Table 17 shows the incidence of brake defects by carrier safety rating. Note that the Excellent and Satisfactory ratings, and the Conditional and Unsatisfactory ratings, have been combined, because there were small numbers of vehicles from carriers with an Excellent or Unsatisfactory rating. The third and fourth columns give the number and percentage of vehicles with one or more brakes out of adjustment, and the fifth and sixth columns give the number and percentage of vehicles where one or more vehicle units would have been put out-of-service using the MTO criterion.

Carriers with an Excellent or Satisfactory rating appear to maintain brakes better than carriers with a Conditional or Unsatisfactory rating. Carriers with a Satisfactory - Unaudited rating appear to perform about average. This group could include some carriers on the verge of a Conditional or Unsatisfactory rating, but is more likely to include some carriers that would receive an Excellent or Satisfactory rating if they would be audited. There appears little difference in the out-of-service rate by carrier safety rating. This may be because Ontario places any vehicle unit in a combination out-of-service if it has more than 20% of its brakes out of adjustment, so a tandem axle semitrailer, the most common trailer, will be put out-of-service if it has only one brake out of adjustment.

Table 18 shows the incidence of brake defects by carrier fleet size, in the same format as Table 17. Smaller carriers appear significantly more likely to have vehicles with brakes out of adjustment, but less likely to have vehicles put out-of-service due to brake adjustment. This may be because this group includes most of the straight trucks. Larger carriers appear less likely to have vehicles with brakes out of adjustment, but more likely to have vehicles put out-of-service due to brake adjustment. This may be because this group includes large numbers of tandem axle semitrailers, which could be put out-of-service with just one brake out of adjustment.

Table 17: Incidence of Brake Defects by Carrier Safety Rating

Carrier Safety Rating	Number of Vehicles	Brakes out of Adjustment		Vehicles Out of Service	
		Number	%	Number	%
Excellent or Satisfactory	239	28	11.7%	19	7.9%
Satisfactory - Unaudited	1572	206	13.1%	110	7.0%
Conditional or Unsatisfactory	145	25	17.2%	15	10.3%
Not available	220	28	12.7%	16	7.3%
Total	2176	287	13.2%	160	7.4%

Table 18: Incidence of Brake Defects by Fleet Size

Fleet Size	Number of Vehicles	Brakes out of Adjustment		Vehicles Out of Service	
		Number	%	Number	%
1 - 10	578	94	19.7%	38	6.6%
11 - 50	478	62	13.0%	44	9.2%
51 - 200	459	53	11.5%	27	5.9%
201 - 500	216	25	11.6%	15	6.9%
Over 500	237	25	10.5%	19	8.0%
Unknown	216	28	13.0%	17	7.9%
Total	2176	287	13.2%	160	7.4%

4. RESULTS FOR IMPOUNDED VEHICLES

MTO has the authority to impound any vehicle, a power unit or trailer, if it has one or more critical defects [11]. The impoundment criterion for brake adjustment is that more than 50% of the brakes on the vehicle are out of adjustment. For example, this requires three or more brakes out of adjustment on a vehicle with two axles and brakes on all axles, or four or more brakes out of adjustment on a vehicle with three axles and brakes on all axles.

A sample of 267 inspection records of impounded vehicles was gathered, which included 267 power units and 286 trailers. Sufficient brakes were out of adjustment to warrant impoundment of one or more units of 257 of these vehicles, or 94.8% of the sample. The other ten vehicles may also have had some brakes out of adjustment, but were impounded for other reasons. 17 power units and 253 trailers were impounded, so for 13 vehicles either the power unit and a trailer, or two trailers, were impounded. In many cases when sufficient brakes were out of adjustment to warrant impoundment, the impounded vehicle unit also had a number of other defects, like air leaks, or loose, worn, broken or cracked components. Some of these defects may have been sufficiently severe to warrant impoundment, even if all brakes had been within adjustment limits.

Table 19 shows the distribution of configuration of vehicles impounded in comparison with the 1999 National Roadside Survey (NRS) [12]. In the NRS, straight trucks made up 14.1% of the trucks at MTO inspection sites, but were only 1.1% of impounded vehicles. There is no obvious reason to account for the low impoundment rate of straight trucks. Consequently, most other configurations had a higher impoundment rate than their proportion of the population.

Table 20 shows the distribution of impounded vehicles by jurisdiction of power unit front license plate, also in comparison with the NRS [12]. The impounded vehicle was most often the trailer, and the jurisdiction of the trailer license plate was not always the same as that of the power unit. Nevertheless, this table provides some insight into the source of impounded vehicles. Ontario registered vehicles have been impounded at a distinctly lower rate than their occurrence in the population, while vehicles from most provinces, other than Quebec, and most states, are impounded at about double their occurrence in the population.

Unfortunately, the type of slack adjuster was identified on only 73 of the 267 CVIR's, comprised of one straight truck, 61 tractor-semitrailers and 11 B-train doubles. These included six instances where both trailers of a B-train double were impounded, so a total of 79 vehicles were impounded where the type of slack adjuster was positively identified. Table 21 shows the numbers of vehicles and impounds with manual slack adjusters for this group of 73 vehicles. There were 73 power units, of which 14 were fitted with manual slack adjusters. Six power units were impounded, and one of these was fitted with manual slack adjusters. There were 83 semitrailers, of which 74 were fitted with manual slack adjusters. 73 semitrailers were impounded, and 66 of these were fitted with manual slack adjusters.

Table 19: Distribution of Configurations of Impounded Vehicles

Configuration	No of Axles	CVIP	NRS
Straight truck	2	0.7%	10.2%
	3	0.4%	2.9%
	4 or more	0.0%	1.0%
Tractor-semitrailer	4 or less	6.7%	1.2%
	5	68.2%	61.2%
	6	10.8%	9.6%
	7	2.2%	4.2%
	8	0.0%	1.5%
	9 or more	0.0%	0.8%
Double	5 or less	0.0%	0.3%
	6	0.4%	0.2%
	7	0.8%	0.3%
	8	6.4%	3.5%
	9 or more	1.9%	0.7%
Truck-trailer	5 or less	0.0%	0.4%
	6 or 7	0.8%	0.3%
	8 or more	0.4%	0.1%
Bobtail tractor		0.4%	1.6%

Table 20: Comparison of Jurisdiction of Power Unit Front License Plate of Impounded Vehicles

Jurisdiction	CVIP	NRS
Ontario	55.1%	66.5%
Quebec	10.6%	10.6%
Alberta	4.9%	4.2%
Illinois	3.8%	3.1%
Manitoba	2.3%	2.3%
Michigan	2.3%	2.1%
New York	3.8%	2.0%
New Brunswick	2.3%	1.1%
Other provinces	4.6%	2.1%
Other states	10.3%	6.0%

Table 21: Fitment of Manual Slack Adjusters on Impounded Vehicles

Vehicle Unit	All Vehicles			Impounded Vehicles		
	Vehicles	MSA	%	Vehicles	MSA	%
Tractor	73	14	19.2%	6	1	16.6%
Trailer	83	74	89.2%	73	66	90.4%

Table 22: Age Ranges of Vehicles Impounded for Brakes Out of Adjustment

Vehicle Unit	Pre-1994			1994-96			Post-1996		
	Impound	Total	%	Impound	Total	%	Impound	Total	%
Tractor	9	71	12.7%	7	75	9.3%	1	121	0.8%
Trailer	182	204	89.2%	57	68	83.8%	14	14	100%

The typical vehicle in this sample consisted of a late-model tractor, built since 1996, with (usually) all brakes within specified stroke limits, and an old semitrailer or trailers, built prior to 1994, with most of its brakes out of adjustment. In situations like this, the trailer with brakes out of adjustment was impounded, and the tractor remained free.

Table 22 shows the ranges of age of vehicles in the impound file. So, for example, 9 of 71 tractors (12.7%) built prior to 1994 were impounded for brakes out of adjustment, while only 1 of 121 (0.8%) tractors built since 1996 was impounded. The pre-1994 vehicles were predominantly built without automatic slack adjusters, while all vehicles built since 1996 should have automatic slack adjusters. The group in between may or may not have been built with automatic slack adjusters.

It would be easy to read more into the results presented in Tables 19 and 20 than is warranted. It was stated that:

> "Of the … vehicles impounded to date, … 97.8% were for brakes out-of-adjustment… In 100% of cases, trip reports noted no brake defects." [14]

A majority of these vehicles are old, and are apparently operated by carriers who are not doing any inspections or maintenance. It is certain that if a manual slack adjuster is ignored for long enough while the vehicle is being driven, it will end up out of adjustment. An automatic slack adjuster may maintain proper stroke for a longer time than a manual slack adjuster, but ultimately without any maintenance, it will also end up out of adjustment. The transition to automatic slack adjusters apparently will help maintain brake stroke for carriers who are maintaining their vehicles. They cannot be expected to make any significant difference for carriers who are not prepared to maintain their vehicles.

5. DISCUSSION

5.1 Background

In the early 1990's about 42% of all trucks inspected in Ontario during Roadcheck were put out-of-service for at least three consecutive years, principally for brake defects, most of which were because brakes were out of adjustment. The negative publicity arising from this became intolerable to the trucking industry, and a joint MTO-Ontario Trucking Association (OTA) Blue Ribbon Task Force on Brake Adjustment was formed to address the issue. This established that the out-of-service rates were real numbers, and industry learned that some very shabby trucks on the highway were responsible for these numbers. MTO's inspection staff gained considerable credibility from this exercise. It also showed that an automatic slack adjuster would be a more reliable device for maintaining brake stroke than a manual slack adjuster. From this, eventually came the changes to Ontario regulations that now allow drivers to adjust brakes, and the OTA developed a training course on brake adjustment that has now been widely delivered. During 1995-96, a rash of wheels lost from heavy trucks resulted in three deaths in Ontario. It was clearly established that the state of vehicle maintenance was the major factor in these incidents. MTO has focused strongly on the operator's responsibility to maintain the vehicle, and on the requirements for Periodic Motor Vehicle Inspection and pre-trip inspection.

The Roadcheck out-of-service rate in Ontario has steadily diminished over the last ten years, to 25% in 1999 and just over 22% in each of 2000 and 2001. However, brake defects still remain the single largest reason for trucks being put out-of-service, and brakes out of adjustment remains the most common brake defect. MTO has focused its enforcement activity squarely on the carrier's responsibility to inspect and maintain vehicles so that only vehicles in satisfactory mechanical condition are operated on a highway. One result is that much of the very shabby equipment is no longer in operation. Carriers have responded with additional training for their staff. The trend to 16.2 m (53 ft) semitrailers and 25 m (82 ft) long B-trains has resulted in replacement of previously existing equipment with new equipment. The requirement for automatic slack adjusters caught this wave of new equipment, which has hastened penetration of automatic slack adjusters into the market. All of these, and many other factors, have all resulted in a general improvement in the standard of highway equipment over the last ten years, which has reflected in the improvement in the out-of-service rate.

5.2 Consideration for Retrofit of Automatic Slack Adjusters

When governments impose a new safety standard, it is typically applied to all new vehicles manufactured after the effective date. There have been few instances where vehicles manufactured prior to the effective date of a new standard must be retrofitted to the new standard. The most recent case is where the U.S. Federal Motor Carrier Safety Administration has required that conspicuity markings in accordance with FMVSS 108 must be applied to vehicles built before the effective date of the requirement.

One of the issues to arise from this work is whether the results create a case for considering retrofit of automatic slack adjusters to vehicles that were not required to have them when they were manufactured. Table 6 shows the percentage of straight trucks, tractors and trailers by year of manufacture, and Table 8 shows the percentage with automatic slack adjusters.

Figure 1 shows that over 90% of tractors have been manufactured since 1993. Table 11 shows that almost 93% of tractors have automatic slack adjusters, which includes those built prior to 1994 that may have been built or retrofitted with automatic slack adjusters. Suppose it takes three years to pass a requirement to retrofit automatic slack adjusters, and make it effective. The automatic slack adjuster fitment rate on tractors should be over 97% in three years, by extrapolating from Figure 1 and Table 11. The owners of the remaining tractors either know how to keep manual slack adjusters in adjustment, as seen by the rather modest out-of-service rate for tractors in Table 16, or do little maintenance on their equipment. The latter group may not respond significantly even if manual slack adjusters must be replaced. Thus, a retrofit requirement for tractors will have little additional effect over the simple passage of time on brake adjustment for tractors.

The situation for straight trucks and trailers is slightly different. These vehicles tend to last longer than tractors, and their fitment rate with automatic slack adjusters is lower than for tractors, about 85% for trucks and 83% for trailers, from Table 11. Time will also take care of these vehicles, but it will take longer, by 2010 or beyond, before the overall fitment rate would be over 97%. It is known that the median age of farm-use trailers in Ontario is over 20 years. Thus, if a trailer built in 1995 without automatic slack adjusters is never retrofitted with them and ultimately becomes a farm-use vehicle, it could still see occasional use on the highway from 2035-2040. Most such vehicles are only used occasionally, so see little highway travel each year.

The issue of retrofit would presumably need to be addressed by all provinces in concert. It would also need to address U.S. vehicles. While these tend to be slightly newer than Canadian vehicles, the survey found a few rather elderly U.S. vehicles in Ontario.

5.3 Improved Inspection Effectiveness

The probability of brake defects, including brakes out of adjustment, has been shown to increase steadily both with the age of the vehicle, and the time since its last mechanical inspection [14]. It is clear from the data presented in Chapters 4 and 5 that vehicles with manual slack adjusters are more likely to have brakes out of adjustment than vehicles with automatic slack adjusters. At this time, when the transition from manual to automatic slack adjusters is in its later stages, these vehicles are predominantly straight trucks and trailers built before about 1997.

5.4 Maintenance Experience with Automatic Slack Adjusters

The effectiveness of automatic slack adjusters depends on a number of factors relating to installation, inspection, service and use.

Automatic slack adjusters are not all interchangeable. Different makes and models have different installation, set-up and service requirements, and they operate using different principles and mechanisms. Not all mechanics may be fully aware of all aspects of installation and maintenance of a particular make and model of automatic slack adjuster, so it is not uncommon for a particular slack adjuster to be installed or set up wrongly

A worn cam or bushings, an off-centre drum, a loose clevis pin, a pushrod dragging on the chamber, and other situations can all modify the actual brake stroke. The slack adjuster will sense the modified stroke, and the adjustment mechanism will respond to this. It will not necessarily produce the correct adjustment. The foundation brakes must be properly maintained for an automatic slack adjuster to function properly. A slack adjuster assumes the foundation brakes are properly maintained, but has no way to assess this assumption. It will not necessarily be able to maintain proper stroke if the assumption is not correct.

There is internal friction and hysteresis within the adjustment mechanism of an automatic slack adjuster. The adjustment mechanism will not make any required adjustment if successive brake applications are so gentle that the adjustment mechanism cannot overcome the internal friction and hysteresis. The careful, defensive driver, who slows to each stop by gearing down, with only the lightest touch on the treadle, may not generate sufficient force to activate the adjustment mechanism. Slack adjustment requires the driver to make occasional positive brake applications each day that overcome internal friction and hysteresis in the adjustment mechanism, so that adjustment actually takes place.

There are now five principal manufacturers of automatic slack adjusters, and there have been others in the past. Some manufacturers may have had more than one model, and not all are currently in production. Each model has undoubtedly evolved through a series of product improvements. Different makes and models of automatic slack adjuster are not necessarily interchangeable. Different makes and models operate on different mechanical principles, and have different installation, set-up and maintenance requirements. It is believed that some automatic slack adjusters are being replaced during maintenance with a device of a different make or model, so that the slack adjusters on one axle are not compatible. The inspection records did not record the manufacturer or model of any of the slack adjusters, so it is not possible to comment on the extent that incompatible automatic slack adjusters may used on the same axle, or within an axle group.

5.5 Recommendations from the North American Brake Safety Conference

The recent North American Brake Safety Conference made twelve recommendations that would provide the knowledge, motivation and hardware to improve brake system compliance [14]. The findings of this work relate most directly to the following three recommendations, which coincidentally were the top three in the prioritized list:

- Raise the level of knowledge of drivers and carriers regarding brake compliance matters and the brake performance of their vehicles;
- Increase the use of effective visual stroke indicators; and
- Increase the use of long-stroke brake chambers.

Checking and adjusting brakes takes time and effort, and is not a lot of fun at any time, especially outdoors in the winter. Checking strokes takes the same amount of time whether manual or automatic slack adjusters are used. However, an automatic slack adjuster should require adjustment very infrequently, which significantly reduces the effort compared to a manual slack adjuster. The time to check is reduced with effective visual stroke indicators, which are required by CMVSS 121 and FMVSS 121. This work shows that automatic slack adjusters provide greater assurance that brakes will be in adjustment than manual slack adjusters. Carriers should consider retrofitting manual slack adjuster-equipped vehicles with automatic slack adjusters and effective visual stroke indicators both to increase the reliability of brake stroke control, and reduce their time and effort in checking brake strokes.

The results presented in Chapter 4 show clearly that use of long stroke brake chambers with automatic slack adjusters should essentially eliminate brakes getting out of adjustment for Type 30 chambers, and should come close to this for Type 16, 20 and 24 chambers, as long as the slack adjuster itself continues to function properly. Vehicle manufacturers should consider long stroke brake chambers as standard equipment.

Airbrakes are designed to stop vehicles, and they need to work reliably when the vehicle needs to stop. Drivers need this for their personal safety, and the safety of others on the road with them. Carriers need this so they can provide reliable service to their customers. Unfortunately, reliability is attained through diligent work attending to a mess of details. It seems that the current generation of automatic slack adjuster may be close to the point where, with reasonable inspection and maintenance when necessary, it can hold a modest level of brakes out of adjustment compared to the high levels experienced in the recent past. Drivers and carriers may need to raise their knowledge of the details to maintain this new plateau, or improve on it. Long stroke brake chambers provide an easy way to increase the reliability of brake adjustment. Disc brakes have the potential to eliminate many of the mechanical compliances that are the basis of the adjustment issue for drum brakes. Over the longer term, electronic braking systems provide a range of options to improve the reliability of the braking system, to make much more consistent use of tire-road friction, and to enhance the stability of vehicles.

5.6 Broader Applicability of Results

The results discussed here are based on data captured on primary highways in Ontario. It is of interest to consider the extent to which these results apply more widely.

Operation Airbrake gives a snapshot of the state of long-haul trucking, because it captures vehicles on the primary highway system. The vehicles are predominantly tractor-semitrailers and doubles, and the tractors and trailers tend to be newer than those that operate in urban areas or on secondary roads. There is also a much larger population of straight trucks in urban areas and on secondary roads. Vehicles that travel on the primary highway system are responsible for the bulk of the vehicle-kilometres of travel, and may face CVSA inspections daily, but often make relatively little use of their brakes. Vehicles that are used only in urban areas or on secondary roads may never have a CVSA inspection, and may make much more frequent use of their brakes. However, all vehicles are required to have an annual inspection. It is beyond the scope of this work to try and make estimates of the impacts that arise from this situation. It is merely surmised that the results presented here might be expected to over-estimate the use of automatic slack adjusters, and to under-estimate the state of brake adjustment. This situation will gradually be rectified as older vehicles not fitted with automatic slack adjusters are replaced.

It is also of interest to try and understand how these results would apply to the rest of Canada. The data discussed here does include about 20% of vehicles from provinces other than Ontario, and about 13% of vehicles from the U.S. There is no reason an automatic slack adjuster installed in one jurisdiction should function any differently in another jurisdiction. However, if a vehicle is from a jurisdiction with significantly different (more intense or more lax) enforcement than Ontario, then the state of brake adjustment in that jurisdiction may differ from that in Ontario. However, it seems that the rate at which brakes with manual slack adjusters are out of adjustment is fairly consistently about 150% higher than with automatic slack adjusters [15]. It is clear that a vehicle that operates in the mountains of western Canada has much greater demand on its braking system than when it operates in the relatively flat terrain of central Canada. These differences would not be expected to show up in this survey. However, both British Columbia and Alberta recently reported brake out of adjustment rates similar to those found here [15]. The higher demands of mountain operation may be countered by mandatory requirements for drivers to check brake adjustment.

Ontario has about 50% of Canada's truck traffic, and Ontario and Quebec together have about 75%. Even if one province was substantially out of line with the Ontario results discussed here, it would not have a significant effect on the overall statistics for Canada as a whole. Crude estimates could be made by taking overall results for each province, then re-weighting to represent the traffic in each province using data from the 1999 National Roadside Survey. This step was beyond the scope of this work.

It is likely that data similar to that used in this work should be available in other provinces. However, it is believed that each province uses a different inspection report form, that may capture different personal information, and each province may have a different interpretation of what is considered personal information.

6. CONCLUSIONS

This work has assessed the state of brake adjustment on heavy trucks in Ontario using detailed airbrake stroke data available from about 4,500 records collected from Level 4 vehicle inspections during Operation Airbrake in 1999, 2000 and 2001. The sample of vehicle configurations and origins appears representative of traffic in Ontario.

Fitment of automatic slack adjusters on Canadian power units jumped over 90% when the U.S. mandated them in 1994. They were found on about 93% of tractors in 2001, and this number should be over 98% by 2010 as older vehicles are removed from service. Automatic slack adjusters were found on about 85% of straight trucks, because these vehicles tend to be kept in service longer than tractors. Fitment of automatic slack adjusters on Canadian trailers did not take off until they were mandated in Canada in 1996. They were found on about 75% of trailers in 2001, because these are also kept in service longer than tractors. About 30% of older straight trucks, tractors and trailers built prior to the requirements for automatic slack adjusters are now fitted with them. While some may have been fitted as original equipment, it also suggests that some carriers believe that the value of retrofit outweighs its cost. Overall, almost 90% of the vehicle units on the highway in Ontario in 2001 were fitted with automatic slack adjusters.

The distribution of stroke in the normal operating range appears very similar for both manual and automatic slack adjusters on a brake chamber of a particular size, regardless of whether it is standard stroke or long stroke. However, a higher number of manual slack adjusters stroke outside the normal adjustment range. While manual and automatic slack adjusters each manage to maintain about the same mean stroke, the standard deviation of stroke is slightly larger for manual slack adjusters, which results in a higher probability they will be out of adjustment. Estimates of the probability that brakes would be out of adjustment using the statistics from this work were reasonably consistent with actual rates found from the survey.

Vehicles with manual slack adjusters would be put out-of-service at a rate about 150% higher than their population, because simply there was a higher probability that a brake with a manual slack adjuster would be out of adjustment. Ontario impounds vehicles with defined critical defects significantly beyond the threshold for putting a vehicle out-of-service. The impounded vehicles also matched the provincial fleet profile reasonably well. About 97% of all vehicles had been impounded for brake system defects, and about 90% of impounded vehicles have manual slack adjusters.

Long stroke brake chambers began to appear in about 1997, and the rate of fitment is increasing fast. It was about 13% for Canadian registered tractors, and 21% for U.S. registered tractors, of the 2001 model year, with lesser rates for trailers. A long stroke brake chamber with a typical automatic slack adjuster as seen in this study should result in a brake that is virtually never out of adjustment, as long as the slack adjuster is functioning.

The process of integration of automatic slack adjusters into Canada's truck fleet is about 90% complete, though the last manual slack adjuster may not disappear for another 35 years or so. There is no doubt that current models of automatic slack adjuster are able to maintain brake stroke more reliably than manual slack adjusters, though it must be recognized that automatic slack adjusters are predominantly on relatively new vehicles and manual slack adjusters are on older vehicles. Trucks are put out-of-service in Ontario mostly for brake system defects, and the principal defect has always been brakes out of adjustment. The out-of-service rate has come down by about half over the last ten years. The introduction of the automatic slack adjuster has undoubtedly played a significant role in this, but so also have other initiatives, such as MTO's focus on the responsibility of the carrier to inspect and maintain vehicles, and allowing drivers to adjust brakes, and providing training to drivers and mechanics.

A small number of late model vehicles were reported with manual slack adjusters when they should have been built with automatic slack adjusters. There appears to be a particular deficiency with Canadian registered trailers. It was not possible to identify from the data whether the vehicles were built with manual slack adjusters, the carriers have replaced automatic slack adjusters with manual slack adjusters, or whether there were errors in identification and recording of inspection data. Transport Canada could address this issue, by working with the provinces in future editions of Operation Airbrake, to conduct a careful assessment of each vehicle unit that should have been fitted with automatic slack adjusters but is reported as fitted with manual slack adjusters. It could either be done on-site, or by following up from the paper inspection reports.

The work described here has developed an approach and data processing methodology that could be applied to similar data that may be available from other provinces. However, other provinces may take different approaches to the issue of personal information, and will certainly use different inspection forms.

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APPENDIX 1

Operation Air Brake
Inspection Procedure - 2000

Inspection Items

1. Driver License
2. Registration
3. Low Air Warning Device
4. Push Rod Travel (Adjustment)
5. Brake Linings/Drums
6. Air Loss Rate (if leak detected)

Basic Inspection Procedure

1. Vehicle will be chosen randomly for inspection (i.e. next available vehicle will be handled by the next available team)
2. Obtain driver's license and registration – complete inspection form.
3. Install the wheel chocks – have the driver release all the brakes.
4. Have the driver fan down the brakes and check the low air warning device
5. Have the driver build the air pressure to 100 psi.
6. Have the driver shut down the engine.
7. Inform the driver that an inspector is going under the vehicle.
8. Mark the push rods and check components (i.e. brake linings)
9. Have the driver make a full application – measure push rod travel.
10. If a leak is detected, check the air loss rate.
11. Finalize paperwork, and provide the results to the driver. (i.e. Out-of-service, etc)

Note

The statistics will require a count of automatic slack adjuster vs. manual slack adjuster brakes and their respective adjustment (or out of adjustment). Jurisdictions will need to capture this information on their CVSA inspection sheets or on some other form in order to compile the statistics. If the jurisdiction doesn't normally capture this information on their inspection sheet, officers will need to know ahead of time that they are required to record this somewhere on the sheet.