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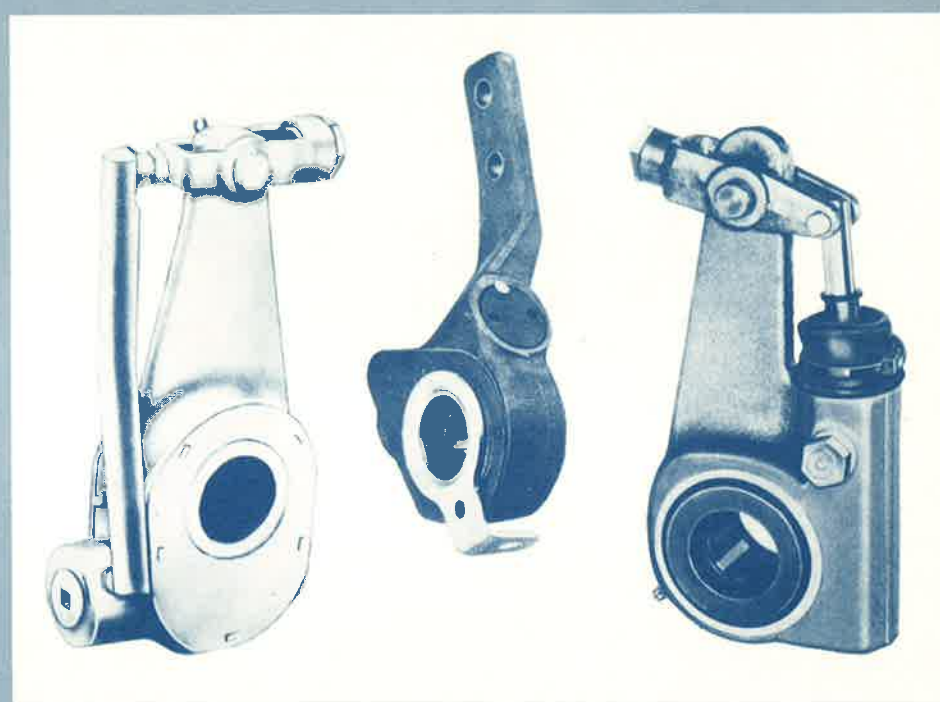
U.S. Department of Transportation

Urban Mass Transportation Administration

Automatic Brake Slack Adjusters on Transit Buses

Prepared by:
Transportation Systems Center
Cambridge MA 02142

Final Report
April 1985



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16. Abstract
The purpose of this report is to provide transit bus agencies with current information on automatic brake slack adjusters. Rather than a comprehensive statistical survey, this report is intended to provide an overview of the states of automatic slack adjusters in the transit industry. It documents an investigation of current transit experiences with automatic slack adjusters in order to establish the potential range of maintenance cost savings associated with this equipment. Brake slack adjusters are mechanical devices which operate automatically or manually and are used to control the distance the brake shoes must travel before the brake linings contact the brake drums. The scope of this report includes information on use, problems, benefits and costs of automatic slack adjusters in the transit bus industry. The report points out that automatic slack adjusters have been sold to over 90 transit agencies across the United States and are currently in use on 15 percent of all U.S. transit buses. Of the 22 transit agencies contacted (each reported to have over 100 buses with automatic slack adjusters), one third reported that they had reduced their brake maintenance costs by using automatic slack adjusters. An outer bound estimate of cost saving based on manufacturer supplied data was calculated to be $440.00 per bus per year.

This report indicates that the safety implications of automatic slack adjusters on transit buses may be a topic for further investigation and that another topic which may be of interest for future work would be the effect of automatic slack adjusters on brake lining, road calls and defect report.

17. Key Words
Automatic Brake Slack Adjusters; Brakes; S-CAM Brakes; Transit Buses

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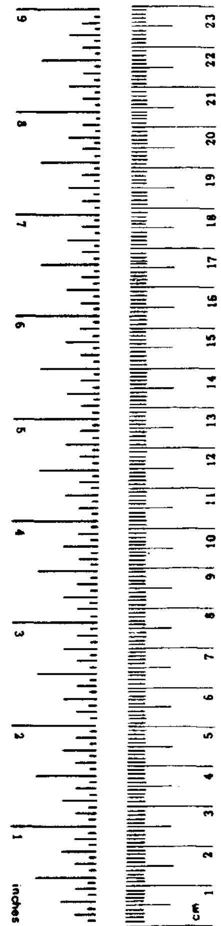
Preface

This document was sponsored by the Urban Mass Transportation Administration's (UMTA) Office of Technical Assistance to present information on designs of automatic brake slack adjusters currently available for use by the transit community. The information in this report was prepared by the Office of Systems Assessment of the Transportation Systems Center to increase the transit community's awareness and understanding of current experiences and maintenance cost savings which may result from use of automatic slack adjusters.

METRIC CONVERSION FACTORS

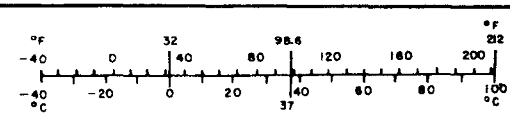
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Executive Summary

This report documents an investigation of current transit experiences with automatic slack adjusters in order to establish the potential range of maintenance cost savings associated with this equipment. Interest in reducing brake maintenance has been growing since the late 1970s when the introduction of the advanced design bus brought an increase in brake lining wear. In response to this industry problem UMTA initiated a series of projects aimed at reducing brake maintenance costs without sacrificing braking performance or safety. These projects include engineering and cost assessments of brake retarders, bonded brake linings, alternate lining materials and automatic brake slack adjusters. Brake slack adjusters are mechanical devices which operate automatically or manually and are used to control the distance the brake shoes must travel before the brake linings contact the brake drums.

Automatic slack adjusters have been sold to over 90 transit agencies across the United States and are currently in use on 15% of all U.S. transit buses. Since another 25% of transit buses in the U.S. are General Motors RTS buses which have self-adjusting wedge brakes, this leaves approximately 60% of transit buses across the U.S. which have the potential to reduce brake maintenance by replacing their manual slack adjusters with automatic slack adjusters.

Two manufacturers, Rockwell and SAB, sell automatic slack adjusters for use on transit buses. Bendix also manufactures an automatic slack adjuster which is currently being tested for transit bus use. Information from transit agencies indicates that current designs of automatic slack adjusters appear to be relatively free of the problems associated with earlier designs.

Of the 22 transit agencies contacted (each reported to have over 100 buses with automatic slack adjusters) one-third reported that they had reduced their brake maintenance costs by using automatic slack adjusters. An outer bound estimate of cost saving based on manufacturer-supplied data was calculated to be $440 per bus per year. Actual cost saving will depend on the degree to which maintenance policies and procedures are able to be implemented. Some transit agencies continue to use automatic slack adjusters despite a lack of cost saving because they believe there is an increase in safety.

1. Introduction

The purpose of this report is to provide transit bus agencies with current information on automatic brake slack adjusters. Rather than a comprehensive statistical survey, this report is intended to provide an overview of the status of automatic slack adjusters in the transit industry. This information is available for use by transit bus agencies in their OEM and retrofit procurement efforts and should also aid UMTA in deciding whether it is reasonable to pursue a more detailed analysis of automatic slack adjusters.

The scope of this report includes information on use, problems, benefits, and costs of automatic slack adjusters in the transit bus industry. The report begins with a background section which discusses government involvement. The next section, the project approach, provides an explanation of how the information for the report was developed. A general discussion of the function of automatic slack adjusters is followed by information on current designs. The report looks at use of automatic slack adjusters in the U.S. both from a geographic perspective and according to bus manufacturers. Finally, experiences of various transit agencies are discussed and potential cost savings are calculated.

1.1 Background

With the introduction of the advanced design bus in the 1970s brake maintenance increased. The improved acceleration and increased weight of the advanced design bus caused additional brake wear. Today, a substantial part of the total bus maintenance is contributed by the brake subsystem. UMTA is currently involved in a series of projects aimed at reducing maintenance costs associated with the brake area.

As one of these projects, this study investigates the use of automatic slack adjusters on transit buses. Additional projects analyze the use of bonded brakes and retarders. Slack adjusters are mechanical devices which are used to control the distance brake shoes travel before brake linings contact the brake drums. They are operated either automatically or by hand. Automatic slack adjusters have the potential to reduce maintenance costs primarily by reducing the frequency of brake relines due to more even lining wear, reducing the number of brake inspections, and reducing adjustment time.

Approximately 75% of the transit buses in the U.S. utilize S-cam brakes which, in turn, have the potential to use automatic slack adjusters. The other 25% are GM RTS buses which have the wedge brake design with a built-in self-adjusting mechanism.

Although this report focuses on the maintenance cost savings from automatic slack adjusters, other government projects in the brake adjustment area were motivated by safety concerns. A 1982 NHTSA study [1] revealed the importance of brake adjustment in providing a safe stopping distance. Currently a NHTSA study of automatic brake slack adjusters in the trucking industry is being conducted by the consulting firm of Bolt, Beranek and Newman.

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[1] R. W. Radlinski, S. F. Williams, J. M. Machey "The Importance of Maintaining Air Brake Adjustment." SAE Technical Paper Series #821263, Truck & Bus Meeting Exposition, Indianapolis, Indiana, Nov. 8-11, 1982

1.2 Approach

The approach to this investigation of automatic brake slack adjusters in the domestic transit industry involved 1) an identification of the technology and the suppliers, 2) an identification of the users, 3) an assessment of transit experiences with the equipment and 4) an analysis of potential cost savings by using the equipment.

Information sources used to develop information for this project included:

- discussions with U.S. bus manufacturers and suppliers
- review of literature from the three manufacturers of bus automatic slack adjusters and discussions with company representatives
- telephone conversations with numerous transit agencies who have tried this technology as well as selected site visits
- review of related literature and on-going studies involving trucking applications of automatic slack adjusters

2. Technology and Suppliers

Automatic slack adjusters have been tried repeatedly by transit agencies over the past twenty years. (See Figure 1.) Early designs met with little success and their use was discontinued. The sustained use of current designs seems to indicate an improvement in performance.

SAB and Rockwell are the manufacturers of automatic slack adjusters sold today for use on transit buses. Bendix automatic slack adjusters are currently being tested for transit applications. Company profiles of SAB, Rockwell and Bendix can be found in Appendix A. SAB automatic slack adjusters have been manufactured and sold in Europe since 1970. A few of the European manufactured SABs were sold in the U.S. and performed satisfactorily. During the late 1970s and early 1980s Borg and Beck was licensed to manufacture the SAB design in the U.S. but its product did not duplicate the original SAB performance and was removed at many transit agencies. Rockwell also entered the automatic slack adjuster market in the late 1970s. SAB began to manufacture automatic slack adjusters in the U.S. in Missouri in 1983. Today transit agencies utilize primarily SAB and Rockwell designs although use of a few Borg and Beck automatic slack adjusters is reported.

<u>SAB</u>	Sold for transit buses 1982-84, manufactured in U.S. Sold for transit buses in 1970s, manufactured in Sweden.
<u>Rockwell</u>	Sold for transit buses since 1979. Sold for trucks since 1976
<u>Bendix</u>	Tentative plans to enter transit bus market if tests successful. Sold currently for use other than on transit buses.
<u>Kelsey Hayes</u>	Sold currently for use other than on transit buses.
<u>Borg & Beck</u>	(SAB design) - Sold from 1975 - 1982 approximately, no longer manufactured.
<u>Eaton</u>	Sold from 1970 - 1975 approximately, no longer manufactured.
<u>Baker</u>	Sold approximately 10 years ago, no longer manufactured.
<u>McGregor</u>	Sold approximately 20 years ago, no longer manufactured.

FIGURE 1. MANUFACTURERS OF AUTOMATIC SLACK ADJUSTERS

2.1 Function of Automatic and Manual Slack Adjusters

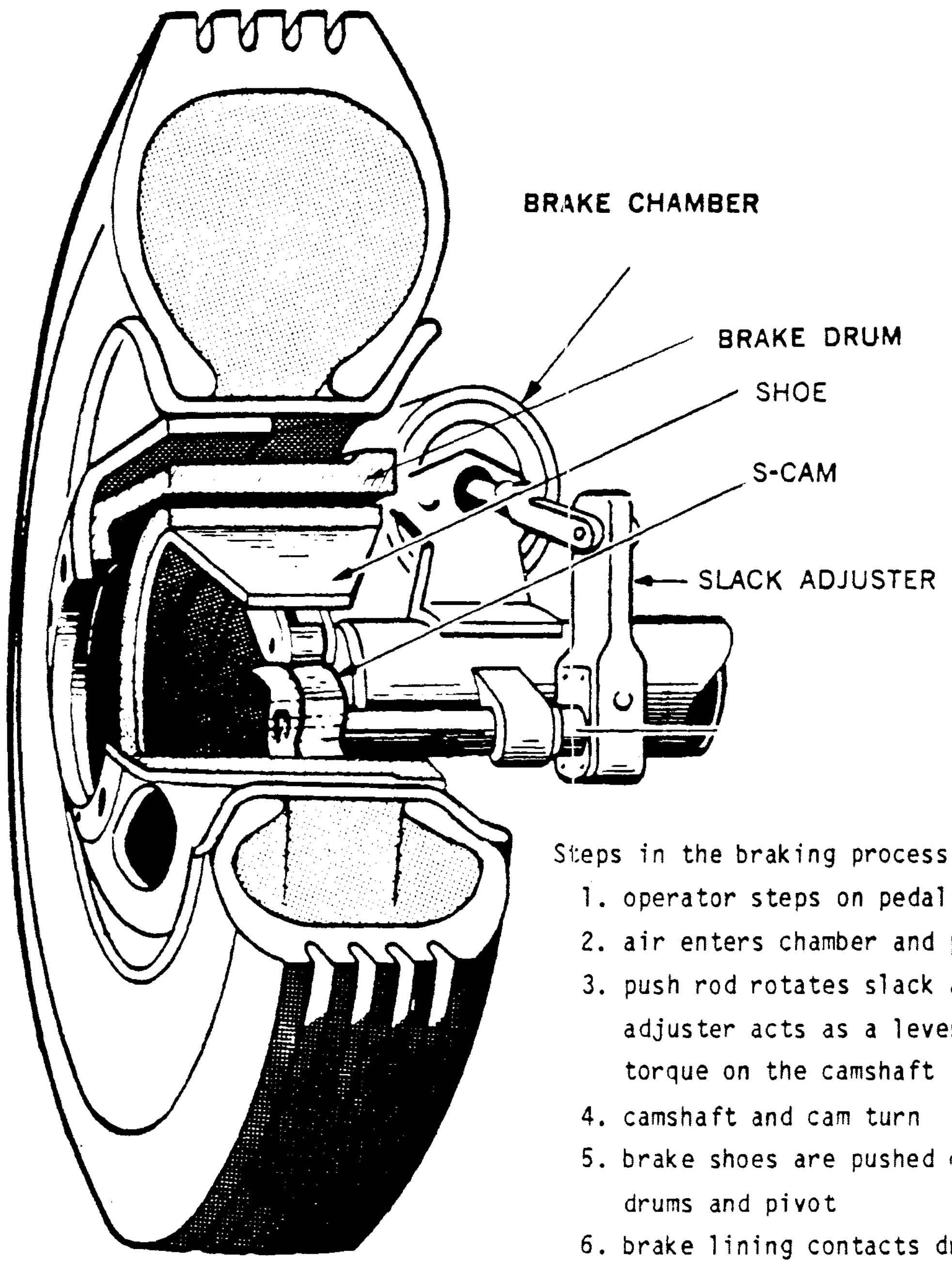
Before looking at the specific designs of automatic slack adjusters, it is helpful to understand the brake system in general. Automatic slack adjusters are used with S-cam foundation brakes which are found on about 75% of the transit buses in the U.S. The remaining 25% are General Motors RTS buses which have wedge brakes with an internal self-adjustment mechanism. The focus of this report, therefore, is on this larger segment of buses with S-cam brakes which currently use manual slack adjusters and could benefit from using automatic slack adjusters.

Figure 2 illustrates the operation of the S-cam brake system. When the brake pedal is not activated, the brake linings are held away from the brake drums. When the operator applies the brake, air is released into the brake chamber. The air pushes on a diaphragm inside the brake chamber causing it to move which, in turn, activates a push rod. The other end of the push rod is connected to the slack adjuster which can be of the manual or automatic type. The slack adjuster is attached to the camshaft in such a way that movement from the push rod causes them both to rotate. The rotating motion of the S-cam is translated through a set of rollers into movement of the brake shoes out against the brake drum which eventually slows down the bus.

As the brake linings wear, with the manual slack adjuster, the push rod travels through a greater distance until it reaches its limit, which is determined by the length of the air chamber. At this point it no longer moves the slack adjuster and braking is diminished.

The S-cam is designed in such a way that the more it is rotated the farther out the brake shoes will be pushed. Adjustment of the brakes with both the automatic and manual slack adjuster, changes the position of the camshaft and cam relative to the slack adjuster so that the brake shoes, with their worn linings are moved outward towards the drums to an optimum clearance distance. The brake linings will now be able to contact the drums within the throw of the pushrod.

Manual and automatic slack adjusters are similar in appearance. The main difference is the additional presence of a control arm or external linkage on

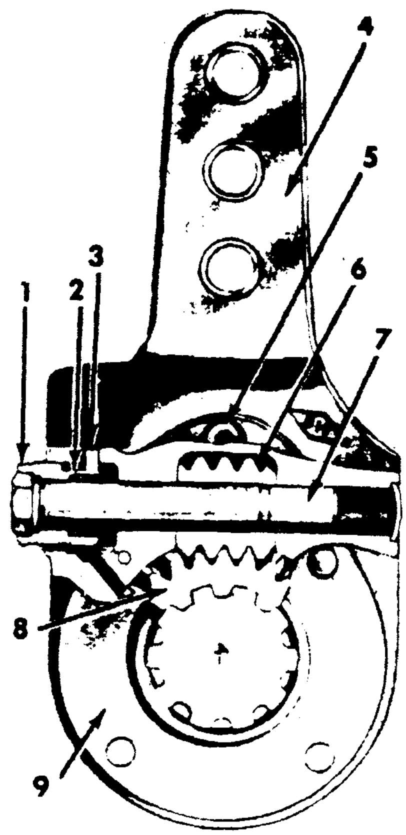


Steps in the braking process:

1. operator steps on pedal
2. air enters chamber and pushes on rod
3. push rod rotates slack adjuster, slack adjuster acts as a lever and exerts a torque on the camshaft
4. camshaft and cam turn
5. brake shoes are pushed out against drums and pivot
6. brake lining contacts drums
7. friction slows and stops brake drum and wheel (kinetic energy of bus changed to heat)

FIGURE 2. THE S-CAM BRAKE

the automatic slack adjusters. Both manual and automatic slack adjusters contain a worm gear which is turned to adjust the brakes. (See Figure 3.) After the worm gear is turned, the slack adjuster and cam continue to rotate through the same angle but their relative positions are changed. This has the effect of advancing the cam slightly and moving the brake shoes closer to the drum. In the automatic slack adjuster the worm gear is turned by a mechanical device which senses the push rod throw or the slack adjuster movement and turns the worm screw a corresponding amount. In the manual slack adjuster a mechanic turns the worm screw to adjust the brakes. The following sections of this report will address individual designs of automatic slack adjusters and their specific mechanisms for automatically adjusting brakes.



1 Lock Sleeve
2 Spring
3 Dowel
4 Lever
5 Rubber Plug
6 Worm
7 Worm Shaft
8 Gear
9 Cover Plate

FIGURE 3. MANUAL SLACK ADJUSTER

2.2 Rockwell Design

The Rockwell Automatic slack adjuster (Figure 4) adjusts on the return stroke. (The worm screw turns on the return stroke.) As the brake pedal is depressed and air enters the brake chamber the push rod and slack adjuster advance. This has the effect of causing the adjusting sleeve to travel up. The helical serrations on the outside of the adjusting sleeve travel up over the serrations on the one-way adjusting pawl. On the return stroke the sleeve is pushed against the pawl but instead of travelling down across the serrations the pawl is designed so that the sleeve slips along the serrations, causing the sleeve to turn and the worm screw to turn with it. The farther the push rod travels, the more grooves the sleeve travels over and the larger the adjusting turn. The Rockwell design senses the push rod travel and adjusts the brakes accordingly.

Rockwell stresses inspection of the serrations in the pawl and sleeve. Some wear may be experienced here as the parts travel over one another. Rockwell sells a kit for rebuilding automatic slack adjusters which contain these parts. The Rockwell automatic slack adjuster is guaranteed for one year. This automatic slack adjuster was originally designed for trucks. The angle at which the Rockwell automatic slack adjuster is installed is critical for it to function properly. Damage can be done by turning the worm screw in the opposite direction. Rockwell recommends that its automatic slack adjuster be lubricated every four months.

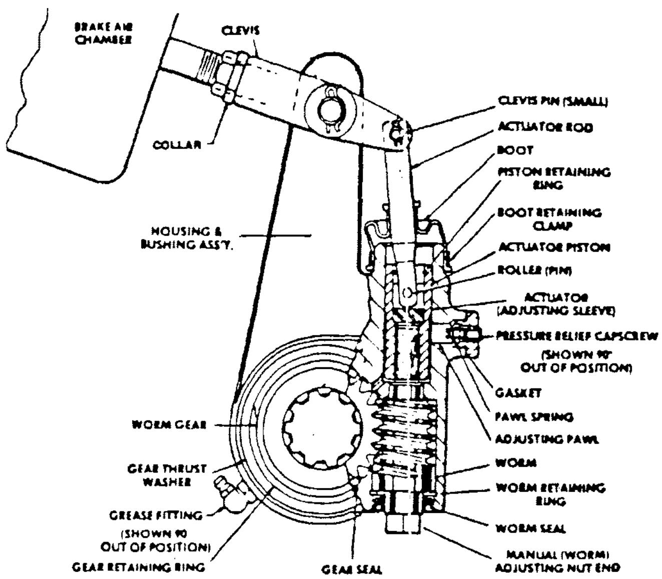


FIGURE 4. ROCKWELL AUTOMATIC SLACK ADJUSTER

2.3 SAB Design

The SAB automatic slack adjuster (Figure 5) adjusts on the return stroke. It has a control bracket which is fixed and has a rigidly attached disc. The disc pushes on the rack which moves up according to the amount of travel of the slack adjuster. As the torque increases the rack continues to travel but the worm screw clutch disengages due to the coil spring. On the return stroke the rack moves down but does not begin adjustment until the torque lets up and the adjuster has travelled through a calibrated notch length. The torque sensing clutch prevents adjustment due to elasticity in the brake linings. The SAB automatic slack adjuster is described as a clearance sensing design but can also be described as a torque sensing design with clearance determined by a notch in the control disc.

Wear is expected in the SAB slack adjuster in the serrations at the clutch end of the worm shaft. Inspection and lubrication are suggested at the normal chassis lube interval. The SAB automatic slack adjuster is warranteed for 50,000 miles or one year.

The SAB automatic slack adjuster was initially designed for buses and has had extensive use in Europe. The control arm bracket needs to be anchored and properly aligned.

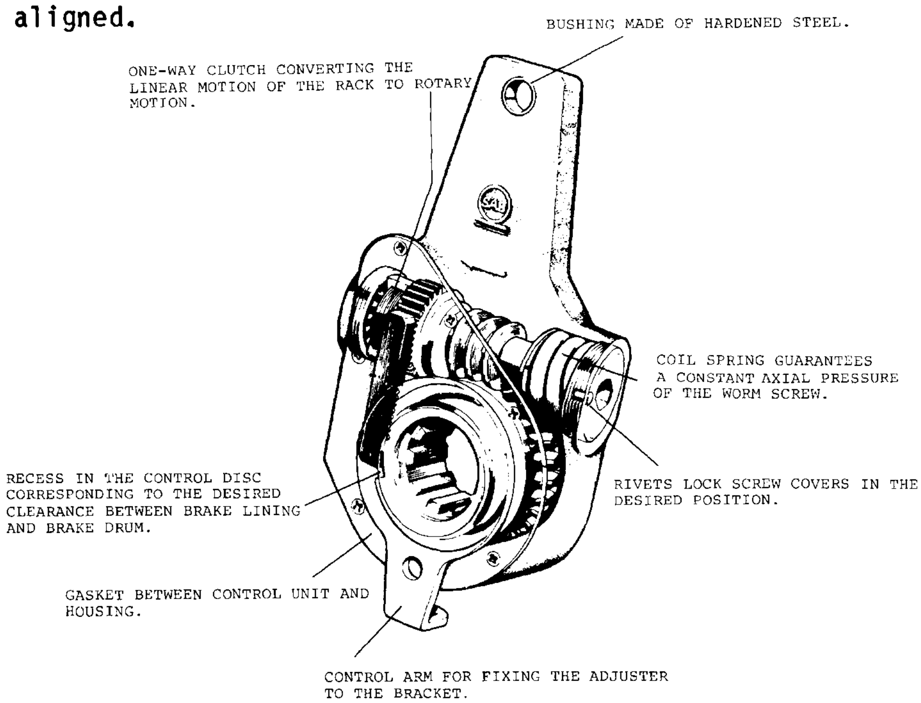


FIGURE 5. SAB AUTOMATIC SLACK ADJUSTER

2.4 Bendix Design

The Bendix automatic slack adjuster (Figure 6) adjusts during the applied stroke. It has an adjusting crank which turns until the torque causes the spring clutch to begin to slip. An anti-reverse spring keeps it from adjusting on the return stroke. A notched mechanism on the adjusting crank provides an allowance beyond which the mechanism should not adjust. This is to prevent overadjustment.

The Bendix automatic slack adjuster was originally designed for trucks and is currently being tested for transit bus applications. It is called a clearance sensing design but can also be described as a torque sensing design. Wear is experienced primarily in the joints in the linkage.

Bendix recommends that its automatic slack adjuster be inspected and lubricated every 50,000 miles or six months or 1,000 operating hours. It is warranteed for 100,000 miles.

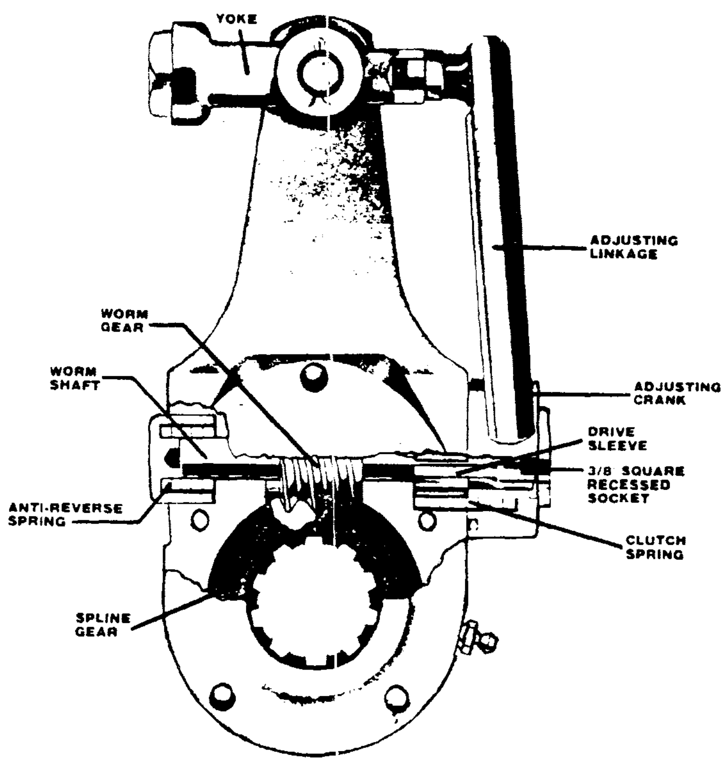


FIGURE 6. BENDIX AUTOMATIC SLACK ADJUSTER

3. Extent of Transit Use

In order to find out where the three designs of automatic slack adjusters are currently in use, the following bus manufacturers were contacted for sales information:

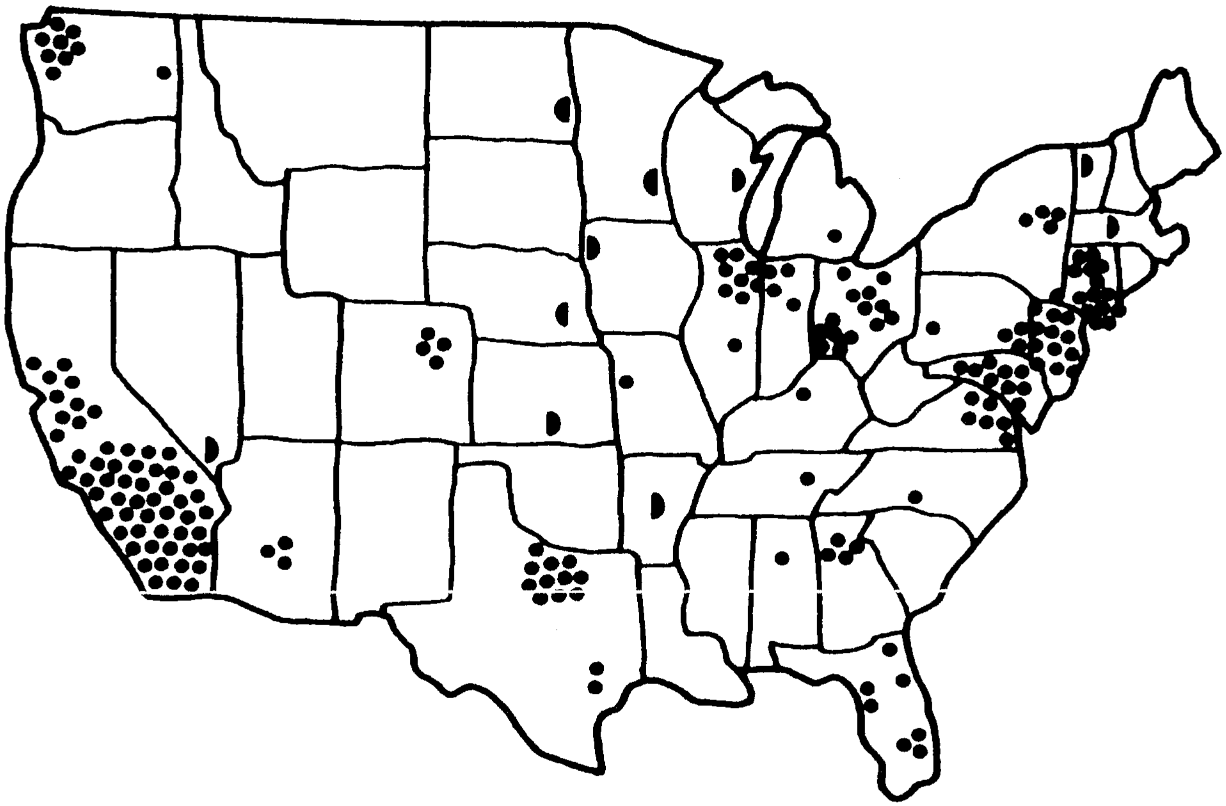
1. M.A.N.
2. Grumman Flxible Corporation
3. Neoplan
4. Flyer Industries
5. Gillig Corporation
6. MCI
7. GMC

The bus suppliers listed below were also contacted for information on possible retrofit purchases:

1. Interstate Manufacturing and Supply Co.
2. Muncie Reclamation and Supply Co.
3. Stone Nycal Corporation
4. Motor Devices Corporation

From these sources it was found that automatic slack adjusters were sold to approximately 90 transit agencies during the years 1977-1984. These agencies are distributed throughout the U.S. (Figure 7). The numbers sold, as reported by the manufacturers, transit agencies and suppliers totalled approximately 9,000 bus sets. A bus set consists of four automatic slack adjusters per transit bus or six automatic slack adjusters per articulated bus. A complete listing of information from manufacturers by states and agencies can be found in Appendix B.

Use of the automatic slack adjusters in the U.S. has not been limited to one geographical location or particular climate. The heaviest concentrations of use appear to be in Southern California and along the Northeast Corridor but all regions of the country have some transit agencies which are currently using automatic slack adjusters on their buses.



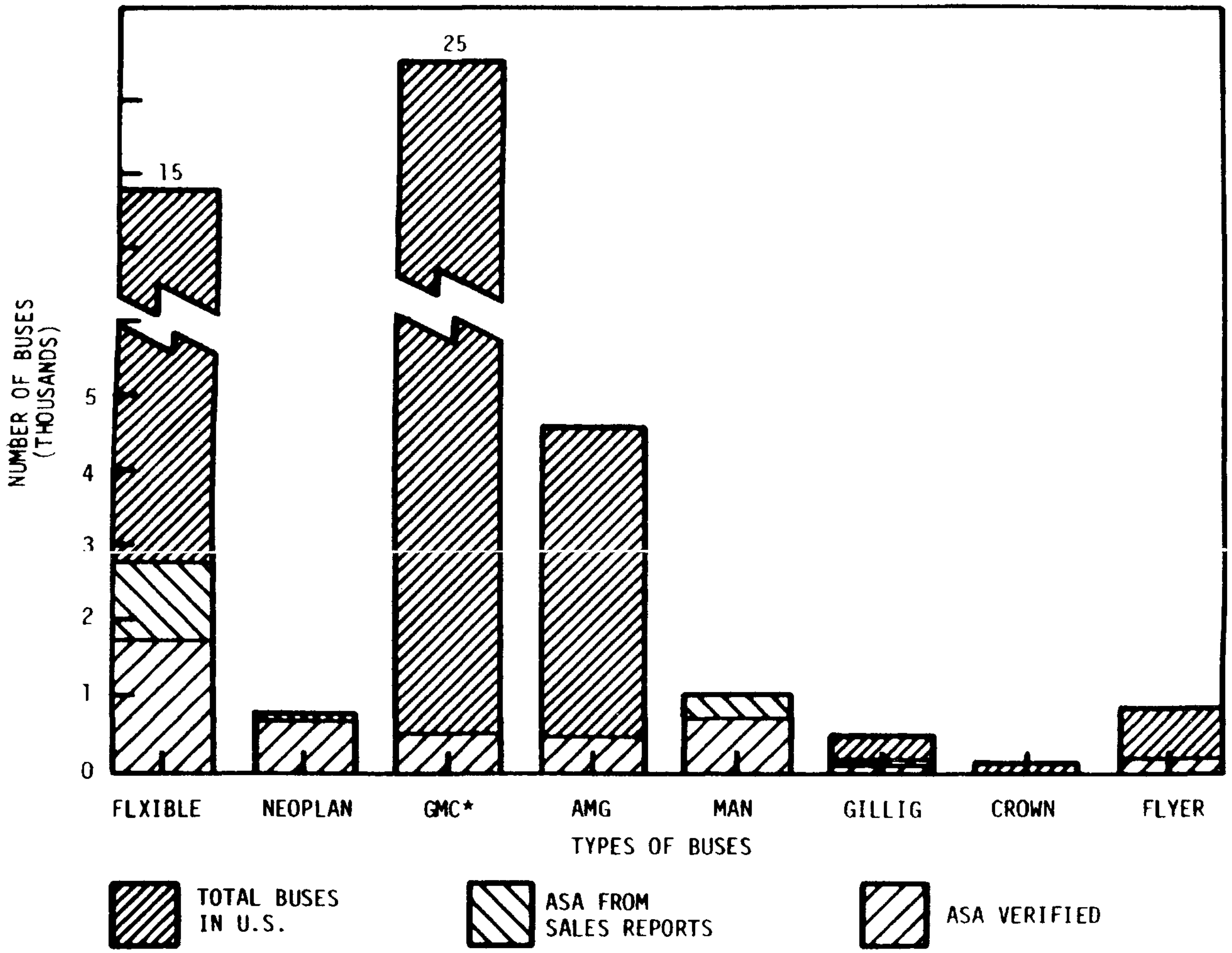
●= APPROXIMATELY 50 BUS SETS OF AUTOMATIC SLACK ADJUSTERS

This distribution represents a total of approximately 9,000 bus sets (4 or 6 per bus) sold in the U.S. Random contact with 22 agencies reports that 2,551 sets of automatic slack adjusters were removed. It appears that the slack adjusters removed were Borg and Beck only.

FIGURE 7. SALES OF AUTOMATIC SLACK ADJUSTERS IN THE U.S.

Sixteen out of twenty-two agencies contacted had used Borg and Beck automatic slack adjusters on buses in the past. Twelve of the sixteen had the Borg and Beck automatic slack adjusters removed and two of the twelve agencies no longer use automatic slack adjusters.

The information that was gathered in this project shows that use of automatic slack adjusters has not been limited to a single manufacturer or type of bus. Transit agencies reported use of automatic slack adjusters on new look, advanced design and articulated buses. Automatic slack adjusters are currently in use on transit buses of eight manufacturers in the U.S. Figure 8 shows the numbers of buses with automatic slack adjusters according to bus manufacturer.



*10,000 OF GMC TOTAL BUSES ARE RTS BUSES WITH SELF ADJUSTING WEDGE BRAKES

FIGURE 8. TYPES OF TRANSIT BUSES WITH AUTOMATIC SLACK ADJUSTERS

4. Experiences to Date

Telephone discussions were held with transit agencies to identify advantages and problems associated with use of automatic slack adjusters. Of the approximately 90 transit agencies identified by the bus manufacturers, 22 were contacted by telephone because they reportedly had purchased 100 buses or more with automatic slack adjusters.

Persons contacted were primarily from the areas of transit bus maintenance and equipment engineering. Transit agencies were asked to verify the numbers of buses using automatic slack adjusters at their location and to discuss in a general way problems and benefits associated with their experiences using automatic slack adjusters. Information gained in this way tends to be subjective. Because quantitative data was not available, responses often were opinions, insights or feelings. Also, since specific questions were not targeted at exact areas, there may be further benefits and problems which were not discussed in the telephone conversations.

The problems and advantages mentioned in conversations with the transit agencies are shown in Figure 9. Few or no problems with automatic slack adjusters currently in use were reported by 15 transit agencies.[2] This would seem to indicate that the automatic slack adjusters currently in use are performing well.

Problems reported by the remaining agencies could be categorized as non-uniform braking, over-adjustments, under-adjustments and increased brake lining wear. A short lifetime for automatic slack adjusters was mentioned as

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[2] Oakland, WMATA, Denver, Seattle, Dallas, San Diego, MARTA, Columbus, Houston, CTA, SCRTD, Orange County, Pheonix, Nassau, Miami. Dallas has automatic slack adjusters on their entire fleet and Denver is retrofitting their entire fleet.

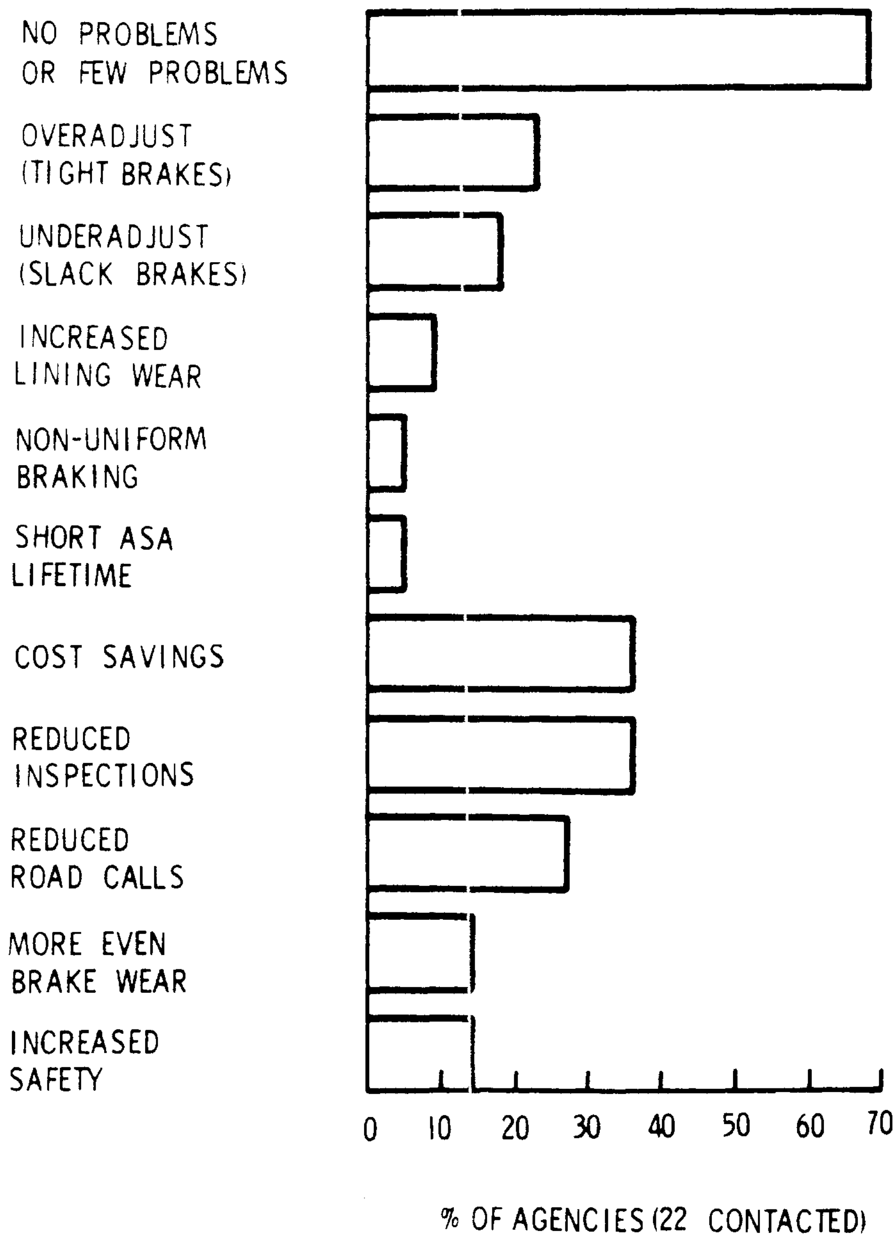

FIGURE 9. TRANSIT EXPERIENCES WITH AUTOMATIC SLACK ADJUSTERS

a problem by one agency. The reported lifetime of automatic slack adjusters varied between 22,000 miles and 60,000 miles with lifetimes of up to 100,000 miles experienced on vehicles which also had retarders. Problems could not be correlated to one particular manufacturer of automatic slack adjusters or to use on one particular manufacturer or type of bus. Nor could problems be correlated to a particular geographical area.

The brake inspection frequency that was reported ranged from every other night to every 6,000 miles. While the agencies who reported problems seemed to inspect their brakes more frequently, not every agency with frequent inspections reported problems with their automatic slack adjusters. At seven agencies manual slack adjusters are inspected more frequently than automatic slack adjusters. At ten agencies automatic and manual slack adjusters are inspected at the same frequency. Some agencies with a mixed fleet found it impractical to have two different inspection intervals.

Eight agencies reported cost savings due to automatic slack adjusters; three reported no cost saving and the rest were not sure. Policies rather than use of the automatic slack adjuster equipment were mentioned as a cause for lack of cost saving. Other advantages reported were reduced road calls, more even brake wear, reduced inspections and increased safety due to the fact that with automatic slack adjusters the bus brakes are in adjustment more often.

These responses are cited as examples of possible advantages or problems that a transit agency may experience when using automatic slack adjusters. They are intended to reflect a general picture of automatic slack adjusters from the users' point of view.

5. Potential Cost Saving

In order to establish an upper bound for cost savings with automatic slack adjusters, information was obtained from the manufacturers of automatic slack adjusters and a yearly cost saving per bus was estimated. The data and formulae used for the cost saving analysis is shown in Figure 10. This type

			Average	% Variation	
A.	Initial cost of Automatic S.A.	($)	64.61	± 14	Manufacturers' Estimates
B.	Initial cost of Manual S.A.	($)	25.00	± 20	
C.	Lifetime of Automatic S.A.	(Mi.)	78,750	± 25	
D.	Lifetime of Manual S.A.	(Mi.)	125,000	± 20	
E.	Brake Inspection freq., Auto. S.A.	(Mi.)	8,767	± 139	
F.	Brake Inspection freq., Manual S.A.	(Mi.)	524	± 71	

G. # miles per bus per year = 40,000 mi.

H. # of automatic or manual slack adjusters per bus = 4

I. Time for brake inspection and adjustment = 15 min. = .25 hr.

J. Labor rate (including overhead and fringe benefits) = \$30.00 per hour

$$\text{Yearly Cost Saving per Bus} = \left[\begin{array}{l}\text{Purchase and}\\ \text{Maintenance Cost}\\ \text{for Manual S.A.}\end{array}\right] - \left[\begin{array}{l}\text{Purchase and}\\ \text{Maintenance Cost}\\ \text{for Automatic S.A.}\end{array}\right]$$

$$= \left[\frac{BGH}{D} + \frac{GIJ}{F}\right] - \left[\frac{AGH}{C} + \frac{GIJ}{E}\right]$$

$$= \left[\frac{(25)(40{,}000)(4)}{125{,}000} + \frac{(40{,}000)(.25)(30)}{524}\right] - \left[\frac{(64.61)(40{,}000)(4)}{78{,}750} + \frac{(40{,}000)(.25)(30)}{8767}\right]$$

Yearly Cost Saving per Bus = \$440 per bus per year

The variation in cost savings calculated from individual manufacturers' estimates ranged from 0 to \$1100 per bus per year.

FIGURE 10. COST SAVING ANALYSIS INFORMATION

of analysis is, of course, a simplification of the situation at an actual transit agency. However, the method may be useful as a starting point for transit staff to quantify cost savings due to automatic slack adjusters.

For the purpose of this analysis road calls, defect reports, lining life, inventory, rebuild costs and lubrication costs are not considered. A site specific cost saving analysis could utilize these items, if data is available. A list of total life cost items which could be utilized with data from a particular site are listed in Appendix C.

It is recognized that reported savings obtained from manufacturers tend to be optimistic. Therefore, the values received from the three manufacturers were used to bound the upper value of cost savings.

Figures that were used for the cost saving estimate were arrived at by averaging the estimates of the manufacturers. The maximum potential cost saving calculated was approximately $440 per bus, per year. This figure assumes the bus travels 40,000 miles per year and a labor rate of $30.00 per hour, which includes overhead and fringe benefits. The time for combined brake inspection and adjustment is assumed to be 15 minutes. Cost savings in this analysis are the result of reducing the frequency of brake inspections and adjustments. In this analysis savings due to adjustment time alone are not considered because it is assumed that adjustment and inspection are performed simultaneously. Additional cost savings from adjustment time may be possible depending on maintenance and inspection practices. [3]

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[3] SCRTD reports that 15 minutes of adjustment time were eliminated on a 20 minute combined safety inspection.

Utilizing the information in Figure 10, a transit agency would have to reduce its inspections by 14 inspections per bus per year before it could begin to realize any cost savings from automatic slack adjusters (to make up for the larger initial purchase price of automatic slack adjusters as compared to manual slack adjusters).

Inspections have been reported to be reduced at 36% of the transit agencies contacted. The average number of inspections reduced per year (as reported by those agencies who were able to quantify the reduction) was about 29 inspections per bus per year. (Naturally, the reduction in inspections is highly site specific since it depends on how often brakes are inspected to begin with.) From our analysis this would imply an average cost saving of about $116 per bus per year. Yet, only three agencies who reported reduced inspections also reported a definite cost savings. Most are unsure about whether they had been able to realize any cost saving.

One transit agency which had reduced inspections reported no cost saving to date. The lack of cost saving was a result of policy rather than due to the equipment itself. They expected to realize a cost saving in the future, if they could reduce their inspection frequency to a point where work could be consolidated or the time saved on brake inspections would be able to be used productively elsewhere. This brings up a point which needs to be considered along with any cost saving analysis - that is, any calculated cost saving can only be realized to the degree that it is compatible with staffing and maintenance procedures at a particular agency.

The lower bound for cost saving would be no cost saving at all or even an expense due to the higher initial cost. At some transit agencies where automatic slack adjusters were removed from the fleet, maintenance cost was not the primary factor in their removal. In these cases, as problems and costs increased, safety and operational considerations took precedence and cost was of lesser importance.

6. Conclusions and Recommendations

Automatic slack adjusters are currently used on approximately 15% of U.S. transit buses in a variety of locations in the United States. Another 25% of the fleet are GMC-RTS buses with wedge brakes which are self-adjusting. Therefore, 60% of the U.S. transit bus fleet could still use automatic slack adjusters.

Current designs of automatic slack adjusters do not appear to be experiencing the degree of problems associated with the earlier designs of automatic slack adjusters, although some problems are reported. Currrent problems do not appear to be correlated to a particular design or geographical location and more than half the agencies contacted reported few or no problems.

Advantages of automatic slack adjusters reported are reduced road calls, reduced inspections and increased safety. Of the eleven agencies that were able to analyze the costs associated with automatic slack adjusters two-thirds reported cost savings. An outer bound estimate of cost savings from manufacturers' information was calculated to be $440 per bus per year. The lack of cost savings reported by three agencies was not directly caused by the equipment itself, but by policies at the transit agencies. It was not always practical to reduce inspections on mixed fleets. Time saved by reduced inspections was not always able to be translated directly into reduced labor costs. Some agencies continue to use automatic slack adjusters despite a lack of cost saving because they feel that safety is increased.

The safety implications of automatic slack adjusters on transit buses may be a topic for further investigation. Another topic which may be of interest for future work would be the effect of automatic slack adjusters on brake lining, road calls and defect reports. Preliminary background work for that study might include an investigation of the factors which determine brake reline frequency and an investigation of the relationship between brake inspection frequency, brake related road calls and brake defect reports.

APPENDIX A

COMPANY PROFILES

Company Profile - Rockwell

Rockwell Heavy Vehicles Components Operations
2135 West Maple Road
Troy, MI 48084

Location of manufacturing plant:	Rockwell Ashtabula Brake Plant Ashtabula, OH
Employees:	400
Plant size:	390,000 sq. ft.
Plant product line:	heavy vehicle brakes, brake components automatic slack adjusters

Parent Corporation: Rockwell International is a multi-industry company with operations in the following businesses: Aerospace, Electrical, Automotive, and General Industries. The automotive section develops, manufactures and markets components principally for heavy duty trucks and special purpose vehicles as well as light trucks and passenger cars. Their total sales for 1983 were $7 billion and their total number of employees is 100,000.

Based on information from Rockwell; Directory of Corporate Affiliations, National Register Publishing Co., Wilmette, Il, 1984, p. 801; Thomas Register of American Manufacturers, Vol. 12, Thomas Publishing Co., N.Y., N.Y., 1984, p. 1666; Standard and Poor's Register, Vol. 1, McGraw Hill, N.Y., N.Y., p. 2145.

Company Profile - SAB

SAB Automotive Co., Inc.
2925 North 7 Highway
P.O. Box 790
Blue Springs, Missouri 64015

Location of manufacturing	plant:	Blue Springs, Missouri
	plant size:	37,400 sq. ft.
	plant product line:	automatic slack adjusters, automatic drain valves, twin dryers

Parent corporation: The main manufacturing company and head office for SAB are located in Sweden. The company was recently acquired by The Incentive Group (a Swedish company). Incentive employs 11,200 people and has annual sales of $680 million.

Based on information from SAB literature.

Company Profile - Bendix

Bendix Heavy Vehicle Systems Division
901 Cleveland St.
Elyria, OH 44036

Location of manufacturing plant:	Frankfort, KY	
	employees:	500
	plant size:	225,000 sq. ft.

Parent corporation: Bendix Heavy Vehicle Systems Division has branches at seven locations which manufacture air brakes, compressors, valves, valve clutches, cruise control systems, reservoir hoses, tubing, fittings, foundation brakes, brake actuators, heavy-duty brake block and anti-lock braking systems, fan clutches, air dryers, slack adjusters and air disc brakes. Bendix Corporation is a member of the Allied Corporation. Total sales for 1983 for the Allied Corporation are $6 billion and their total number of employees is 50,000.

Based on information from Bendix; Directory of Corporate Affiliations, National Register Publishing Co., Wilmett, Il, 1984, p. 29; Thomas Register of American Manufacturers, Vol. 2, Thomas Publishing Co., N.Y., N.Y., 1984, p. 253.

APPENDIX B

USE OF AUTOMATIC SLACK ADJUSTERS BY TRANSIT AGENCIES

The following data was obtained from reports of manufacturers' sales and verified where possible in phone conversations with transit agencies.

Transit Agency	# Buses	Year ASA	Type ASA	Type Bus	Source
Arizona					
Phoenix	20	1977-78	SAB OEM	MAN	MAN
Phoenix	67	1983	Rockwell OEM	FLX	FLX
Phoenix	3		SAB	'74 FLX	Agency
Phoenix	15	1984	SAB	MAN	Agency
Alabama					
Birmingham	38	1981	Borg & Beck OEM	FLX	FLX
Arkansas					
Little Rock	10	1983	Rockwell OEM	FLX	FLX
California					
Culver City	10	1983	SAB (? B&B) OEM	Gillig	Gillig
Fresno	12	1981	Borg & Beck OEM	FLX	FLX
Los Angeles	30	1977-78	SAB OEM	MAN	MAN
Monterey	11	1979	Borg & Beck OEM	FLX	FLX
Monterey-Salinas	21	1981	Borg & Beck OEM	FLX	FLX
Oakland	30	1977-78	SAB OEM	MAN	Agency
Orange County	266		SAB	FLX	Agency
Orange County	105		SAB	Gillig	Agency
Oxnard	15	1982	Rockwell OEM	FLX	FLX
Riverside	4	1983	SAB (? B&B) OEM	Gillig	Gillig
Sacramento	23	1982	SAB (? B&B) OEM	Gillig	Gillig
San Diego	8	1984	Rockwell	FLX	Agency
San Diego	34	1981	Borg & Beck OEM	FLX	FLX
San Diego	30	1982	Rockwell OEM	FLX	FLX
San Francisco	25	1980	Borg & Beck OEM	FLX	FLX
San Francisco, MUNI	180	on order	SAB OEM	Flyer	Flyer
San Jose	15	1983	SAB OEM	MAN	MAN
San Raphael	10	1977-78	SAB OEM	MAN	MAN
Santa Clara (test)	219	1981	Rockwell OEM	FLX	FLX
Santa Clara	15		SAB	'83 MAN	Agency
Santa Clara	15		SAB	'83 Crown	Agency
Santa Cruz	23	1979	Borg & Beck OEM	FLX	FLX
Santa Monica	15	1979	Borg & Beck OEM	FLX	FLX
Santa Monica	32	1980	Borg & Beck OEM	FLX	FLX
Santa Monica	15	1981	Borg & Beck OEM	FLX	FLX
Santa Rosa	9	1983	Rockwell OEM	FLX	FLX
Sonoma County	12	1981	Borg & Beck OEM	FLX	FLX
SCRTD	260	1983	SAB retrofit	1978-79 AM Gen.	Agency
SCRTD	(415)	1984	SAB OEM(Delivery)	Neoplan	Agency
Simi Valley	4	1982	? OEM	Gillig	Gillig
Colorado					
Denver	89	1983	SAB OEM	MAN	MAN
Denver	90+	1982-83	SAB retrofit		Agency

Transit Agency	# Buses	Year ASA	Type ASA	Type Bus	Source
D.C.					
Washington	43	1977-78	SAB OEM	MAN	MAN
Washington	33	1983	SAB OEM	MAN	MAN
Washington	170	1982-83	SAB retrofit	62-66 GMC	Agency
(WMATA)	76	1983	SAB OEM	Neoplan	Neoplan
Georgia					
(MARTA)	50	1981	Borg & Beck OEM	Neoplan	Neoplan
(MARTA)	134	1978	Borg & Beck OEM	FLX	FLX
Columbus	10	1983	Rockwell OEM	FLX	FLX
Florida					
Bloom County	17	1982	Rockwell OEM	FLX	FLX
Broward County	57	1981	Borg & Beck OEM	FLX	FLX
Jacksonville	63	1982	Rockwell OEM	FLX	FLX
Miami	100	1982-83	SAB retrofit	76 AMG	Muncie
Orlando	18	1982	Rockwell OEM	FLX	FLX
Orlando	9	1983	Rockwell OEM	FLX	FLX
Tampa	40	1982	Rockwell OEM	FLX	FLX
Tampa	30	1983	Rockwell OEM	FLX	FLX
Tampa	15	1983	Rockwell OEM	FLX	FLX
Volusia	25	1983	Rockwell OEM	FLX	FLX
W. Palm Beach	8	1982	Rockwell OEM	FLX	FLX
W. Palm Beach	10	1984	Rockwell OEM	FLX	FLX
Illinois					
Chicago, CTA	20	1977-78	SAB OEM	MAN	MAN
Chicago, CTA	125	1982	SAB OEM	MAN	MAN/CTA
Chicago, CTA	200	1983-84	SAB OEM	Flyer	Flyer/CTA
Chicago, CTA	363	on order	SAB OEM	Flyer	Flyer
Rockford	24	1982	SAB OEM	Neoplan	Neoplan
Decatur	19	1979	Borg & Beck OEM	FLX	FLX
Champaign	5	1980	Borg & Beck OEM	FLX	FLX
Champaign	20	1980	Borg & Beck OEM	FLX	FLX
Hawaii					
Honolulu	74	1980	Borg & Beck OEM	FLX	FLX
Indiana					
Indianapolis	21	1984	SAB OEM	MAN	MAN
Ft. Wayne	23	1983	Rockwell OEM	FLX	FLX
Iowa					
Sioux City	7	1982	Rockwell OEM	FLX	FLX

Transit Agency	# Buses	Year ASA	Type ASA	Type Bus	Source
Kansas					
Wichita	16	1983	Rockwell OEM	FLX	FLX
Kentucky					
Louisville	53	1980	Borg & Beck OEM	FLX	FLX
Massachusetts					
Springfield	21	1982	Rockwell OEM	FLX	FLX
Maryland					
Baltimore	81	1982	Rockwell OEM	FLX	FLX
Baltimore	80	1983	Rockwell OEM	FLX	FLX
Michigan					
Ann Arbor	7	1980	Borg & Beck OEM	FLX	FLX
Ann Arbor	5	1982	Rockwell OEM	FLX	FLX
Detroit (testing)	?	1982-83	SAB retrofit	?	Muncie
Grand Rapids	15	1980	Borg & Beck OEM	FLX	FLX
Saginaw	16	1981	Borg & Beck OEM	FLX	FLX
Sheboygan	4	1983	Rockwell OEM	FLX	FLX
Minnesota					
St. Paul	20	1977-78	SAB OEM	MAN	MAN
St. Paul	62	1983	SAB OEM	MAN	MAN
Missouri					
Kansas City	62	1980	Borg & Beck OEM	FLX	FLX
Nebraska					
Lincoln	13	1980	Borg & Beck OEM	FLX	FLX
North Carolina					
Charlotte	42	1982	Rockwell OEM	FLX	FLX
Raleigh	6	1980	Borg & Beck OEM	FLX	FLX
Roanoke	13	1979	Borg & Beck OEM	FLX	FLX
North Dakota					
Fargo	8	1979	Borg & Beck OEM	FLX	FLX
Nevada					
Las Vegas	12	1982	Rockwell OEM	FLX	FLX
New York					
Nassau	125	1981	Borg & Beck OEM	FLX	FLX
Nassau	34	1984	SAB OEM	FLX	Agency
Suffolk County	31	1982	? OEM	Gillig	Gillig
Syracuse Central	25	1981	Borg & Beck OEM	Flyer	Flyer
Yonkers	61	1983-84	SAB OEM	MAN	MAN

Transit Agency	# Buses	Year ASA	Type ASA	Type Bus	Source
Ohio					
Canton	10	1981	Borg & Beck OEM	FLX	FLX
Cincinnati	87	1981	Borg & Beck OEM	FLX	FLX
Cincinnati	124	1982-83	SAB retrofit	'77 AMG	Agency
Cleveland	77	1984	Rockwell OEM	FLX	FLX
Columbus	99	1982	SAB	FLX	Agency
Columbus	85	1983	Rockwell OEM	FLX	FLX
Columbus	100	1982-83	SAB retrofit	'75 GMC	Agency
Ohio State Univ.	5	1981	Borg & Beck OEM	FLX	FLX
Toledo	29	1982	Rockwell OEM	FLX	FLX
Pennsylvania					
Cambria Johnstown	8	1981	Borg & Beck OEM	FLX	FLX
Johnstown	12	1983	SAB OEM	Neoplan	Neoplan
Pittsburgh	20	1977-78	SAB OEM	MAN	MAN
Pittsburgh	30	1983	SAB OEM	MAN	MAN
Reading	4	1982	Rockwell OEM	Neoplan	Neoplan
Scranton	8	1983	SAB OEM	Neoplan	Neoplan
SEPTA	150	1982	SAB OEM	Neoplan	Neoplan
Tennessee					
Knoxville	40	1982	Borg & Beck OEM	FLX	FLX
Memphis	10	1983	SAB OEM	MAN	MAN
Nashville	15	1983	SAB OEM	MAN	MAN
Texas					
Dallas	152		SAB Retrofit	'66 GMC	Agency
Dallas	100		SAB retrofit	72-74 GMC	Agency
Dallas	69		SAB	FLX	Agency
Dallas	85		SAB	FLX	Agency
Houston	97	1980	Borg & Beck OEM	FLX	Agency
Washington					
Seattle	353	1977-82	SAB OEM	MAN	Agency
Spokane	20	1983	Rockwell OEM	FLX	FLX
Tacoma	33	1980	Borg & Beck OEM	FLX	FLX
Tecumsah	?	1982-83	SAB retrofit	?	Muncie
Wisconsin					
Green Bay	5	1983	SAB OEM	Neoplan	Neoplan
Madison	15	1983	Rockwell OEM	FLX	FLX
Milwaukee (testing)	?	1982-83	SAB retrofit	?	Muncie
Virginia					
Norfolk	72	1979	SAB OEM	FLX	Agency
Norfolk	47	1982-83	SAB retrofit	FLX	Agency
Vermont					
Burlington	9	1981	Borg & Beck OEM	FLX	FLX

APPENDIX C

TOTAL LIFE COST DATA ELEMENTS

(for automatic brake slack adjusters and for manual slack adjusters)

Brake Inspection Data	Inspection frequency or dates Length of time for brake inspection
Brake Reline Data	Length of time for brake reline Reline frequency or dates Reline parts cost replacement linings - reconditioned drums
Brake Adjustment Data	Length of time for brake adjustment Brake adjustment frequency or dates
Slack Adjuster Overhaul Data	Removal and Replacement times (SA) Rebuild or Overhaul time (SA) Rebuild or Overhaul frequency (SA) Replacement of SA with new unit, frequency
Slack Adjuster Lubrication Data (other than regularly scheduled vehicle lubrication)	Slack adjuster lubrication frequency Time for SA lubrication
Additional Data	Frequency of Brake-related defect reports Dates or frequency of Brake-related road calls Spares Inventory (#'s) # Fleet Vehicles with auto. SA # Fleet Vehicles with manual SA Retrofit time for installation SA # of Vehicles retrofitted Purchase price OEM SA Purchase price retrofit SA

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