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WAYSIDE DERAILMENT INSPECTION REQUIREMENTS STUDY FOR RAILROAD VEHICLE EQUIPMENT

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FINAL REPORT

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16. Abstract

An analysis of the causes of the railroad equipment caused derailments was made. Data reported to the FRA was the primary source of derailment information, however, data from other sources were also available. Individual cause codes were consolidated into groups that had a common characteristic that might be used to detect the presence of the defect. Seven consolidated cause code groupings were identified that accounted for over 80 percent of the cost of equipment caused derailments. Existing wayside inspection systems were evaluated. Developmental wayside inspection systems were identified. A method was developed that assigns a purchase cost number for possible wayside detection schemes that is based on the cost of derailment and effectiveness of the system.

A recommendation is made that FRA set up Wayside Inspection Station(s) as a means of evaluating improvement to present systems and new wayside inspection methods.

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PREFACE

This study has been conducted for the Federal Railway Administration through the Transportation Systems Center (TSC) in Cambridge, Massachusetts. Mr. Raymond Ehrenbeck of TSC has been the technical monitor for the program.

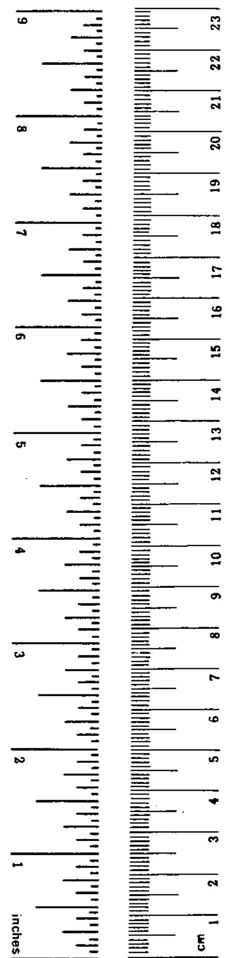
New York State derailment data was made available and explained by Mr. Wallace R. Klefbeck of the New York State Division of Traffic and Safety.

Data from several railroads were made available to us in this study. Acknowledgement of their help is made to Mr. R. F. Tuve of the Southern Railway System, Dr. P. E. Rhine of the Union Pacific and Mr. Dale Harrison of the Santa Fe. Southern Railway data formed the basis of the analysis conducted in Appendix D of this report. Mr. Tuve also was a great help in reviewing a draft of this report and making many suggestions for modifications. Acknowledgement of his help in reviewing this report does not imply that he, or Southern Railway necessarily agrees with the content and the conclusions and recommendations presented in this report.

METRIC CONVERSION FACTORS

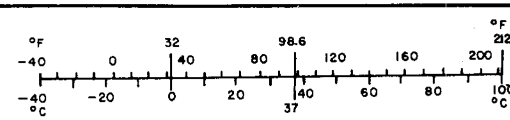
Approximate Conversions to Metric Measures

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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1.0 INTRODUCTION

The objective of this contract work was "to establish the impact and causes of railroad equipment derailments and derailment-related accidents, and to assess existing and possibly new wayside inspection means for preventing or reducing the occurrence of these events". In order to accomplish this objective, three major areas of activity were undertaken: the collection and analysis of accident data, the collection of information about existing or proposed wayside detection schemes and the analysis of the costs and the benefits in reduced derailments that would result from the deployment of new wayside inspection systems.

Accident data was limited to freight car equipment caused derailments. Detection equipment surveyed was therefore narrowed to those devices that could detect and warn of equipment-related defects from a wayside inspection station. The location of the wayside system was not limited and, therefore, could include devices in the yard as well as along the main linetrack. The required spacing of wayside inspection systems is determined by the characteristics of the symptom to be detected and the rate of progression to catastrophic failure once the symptom can be detected. Devices that aid human inspection at periodic intervals are therefore also legitimate candidates for a "Wayside" inspection system.

A major source of accident data is the data collected by the Federal Railroad Administration (FRA) and published yearly in the FRA Accident Bulletin. These data are also available on magnetic tape since 1967 and automatic data processing of these tapes allows the extraction of additional data not published yearly in the accident bulletin. The cause codes used by the FRA prior to 1975 have been used consistently through this report to categorize derailments. Appendix B addresses the changed codes after 1975.

There were approximately 140 individual cause codes describing equipment-related derailments. These individual cause codes were consolidated into groups that had a common characteristic that might be used to detect the presence of a defect. These groups were then analyzed as to their proportional contribution to the number and cost of derailments for several years. Additional analyses were performed on relationships with speed, individual railroads, month of the year and length of train. From this there emerged a list of seven cause code groupings that accounted for over 80 percent of the cost of derailments. These were:

1. Burned Off Journals
2. Dynamics
3. Broken and Cracked Wheels
4. Worn Flange and Loose Wheels
5. Couplers - Pulled Out
6. Truck Bolster and Side Frames
7. Air Brakes and Bad Brakes

Wayside systems are available for burned off journals (plain bearings), and worn flanges, loose wheels and dragging equipment. These systems appear to be cost effective, however, in some cases, high maintenance costs may diminish the margin. Wayside systems are under development to detect cracked wheels, however, evaluation data is incomplete. Present work in the Track Train Dynamics Program can provide useful data that may lead to the development of a dynamics wayside inspection system. Wayside inspection systems do not exist for the other cause groups nor could some type of automatic wayside inspection system be postulated.

A method was then developed that used the hot box detector as an acceptable cost/benefit model and established cost/benefit figures that new systems would have to meet to be acceptable to the railroad industry.

In 1975, bearing failures will be separated as to type of bearing, Plain or Roller. These data coupled with additional data relating to the hot box detector results with roller bearings must be carefully analyzed before a final conclusion may be drawn on the future effectiveness of the hot box detector. Some tentative conclusions are presented in this report.

2.0 SUMMARY

An analysis of the causes of the railroad equipment caused derailments was made. Data reported to the FRA was the primary source of derailment information, however, data from other sources were also available. Individual cause codes were consolidated into groups that had a common characteristic that might be used to detect the presence of the defect. Seven consolidated cause code groupings were identified that accounted for over 80 percent of the cost of equipment caused derailments. Existing wayside inspection systems are evaluated. Developmental wayside inspection systems are identified. A method is developed that assigns a purchase cost number for possible wayside detection schemes that is based on the cost of derailment and effectiveness of the system.

A recommendation is made that FRA set up wayside inspection station(s) as a means of evaluating improvement to present systems and new wayside inspection methods.

3.0 DATA ANALYSIS

3.1 Source of Data

In the initial phase of this program, railroad accident data were obtained from several sources. The major source of data is the Federal Railroad Administration (FRA) computerized data bank that is the basis for the annual publication of the FRA Accident Bulletin. Data is available on magnetic tapes for the years 1967 through 1974. Originally, 1966 was also available; however, this tape has been accidentally erased. The information contained on these tapes and their location in the alphanumeric string is given in Appendix A.

The original data that is the basis of the computerized summary is a FRA Form called the T sheet that is filled out by the railroad and forwarded to the FRA. Up until 1975, the FRA office personnel assigned a cause code to the derailment depending on the individual's interpretation of the written cause of the accident prepared by railroad personnel. While there has been criticism of this procedure, the fact remains that this bank of data is the most complete set of data available. Data from other sources have been used to supplement the FRA data for parts of this report, however, the bulk of the analysis of the numbers and damage to track and equipment is based upon FRA data.

New York State Department of Transportation collects and analyzes railroad accident data for those accidents occurring in New York State. These data were very valuable because the cause of the accident was given in a short descriptive statement and questions regarding these cause statements could be discussed with personnel of the Division of Traffic and Safety.

National Transportation Safety Board reports were reviewed and while limited in number, were valuable since they contain a detailed reconstruction of the events leading to the accident.

Several U.S. railroads were visited and in two cases summary reports prepared by the railroads on accidents occurring on their system were received. Additional data on journal failures were received from one railroad. This type of data was used, along with other statistics, in constructing the experience of a hypothetical railroad used in the evaluation of hotbox detectors.

3.2 Initial Analysis

Figure 1 (solid line) is the number of derailments caused by rail vehicle equipment defects since 1964 as reported in the FRA Accident Bulletin. The data plotted includes locomotive defects and passenger train derailments; however, these numbers are a small proportion of the total. The dashed curve is the least squares straight line fit to the data and shows that in spite of the general decrease from 1969 through 1972, the trend of the data is up. The FRA bulletin breaks the data down into groups of cause codes (see Appendix A). Figure 2 is the top three major equipment groupings of causes by number: wheels and axles (2300), trucks (2200), and couplers (2600)*. Figure 3 plots the top five individual causes. These top causes are journal failure-hot (2319), worn flange (2314), bent or broken bolster (2207), loose wheel (2315), and bent or broken side frames (2201).

It becomes obvious that simply plotting numbers of accidents without assigning dollar consequences of these accidents is unsatisfactory in attempting to establish priorities for existing or future wayside inspection systems. Also, simply looking at single cause codes does not address the possible situation where an inspection system may be capable of detecting more than one individual cause code. For example, systems exist that claim to detect both worn flanges and loose wheels; and, therefore, these two cause codes should be grouped together. Other similar cases exist which is natural since the rationale for establishing the cause codes was to help identify problems that could be reduced by a wide variety of actions.

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* Numbers in parentheses are cause codes. If even hundred numbers are shown such as 2200, this is the whole 2200 series. If other numbers are shown such as 2201, then this refers to one cause code or another grouping of cause codes.

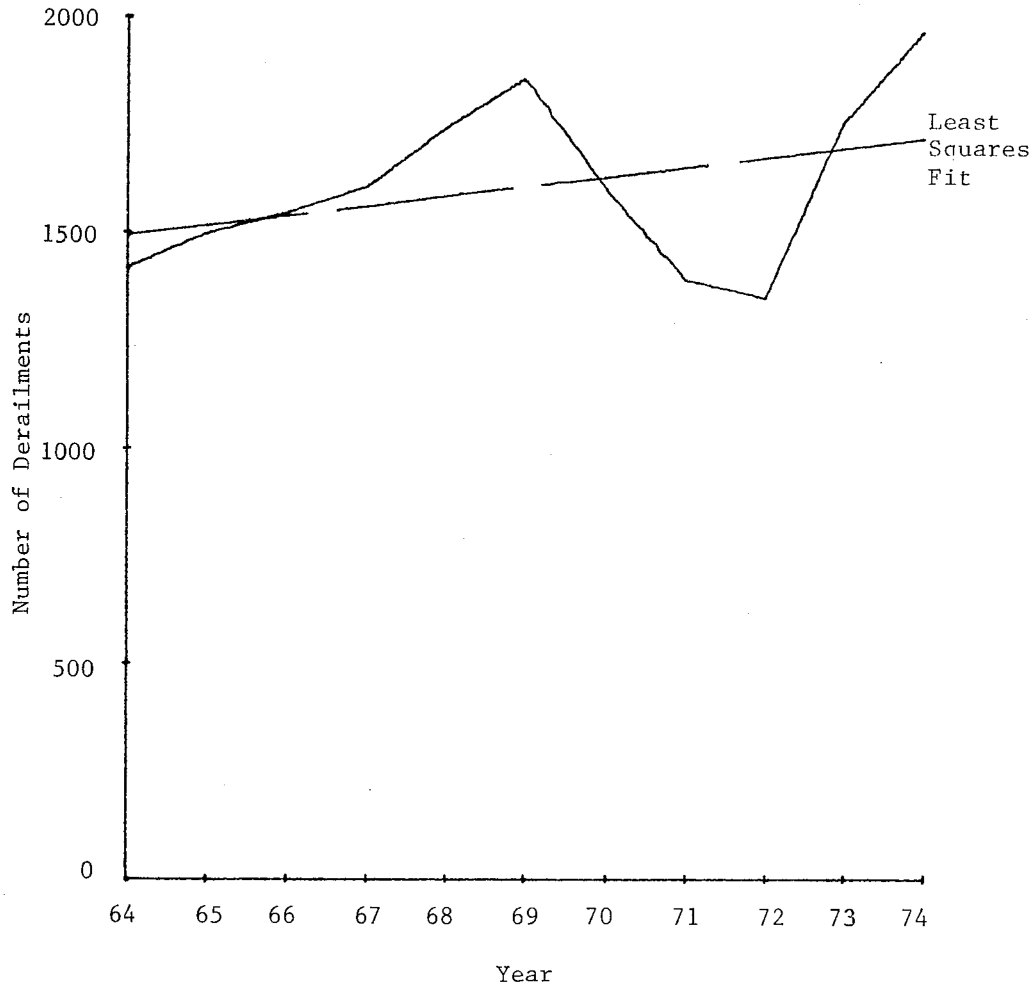


Fig. 1 Number of Equipment Caused Derailments Per Year

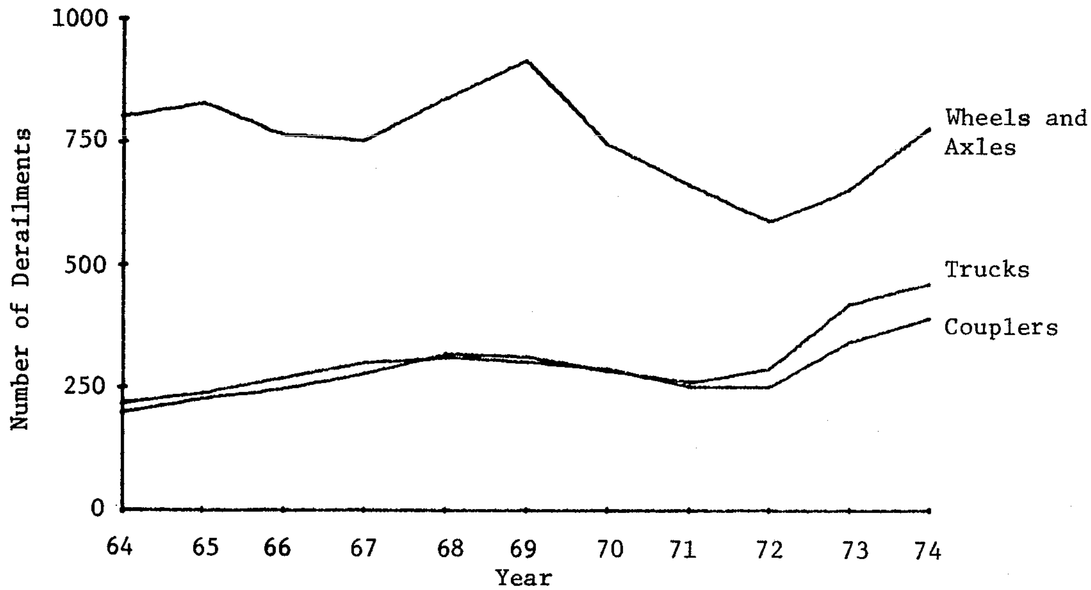


Fig. 2 Top Three Major Equipment Causes of Derailment

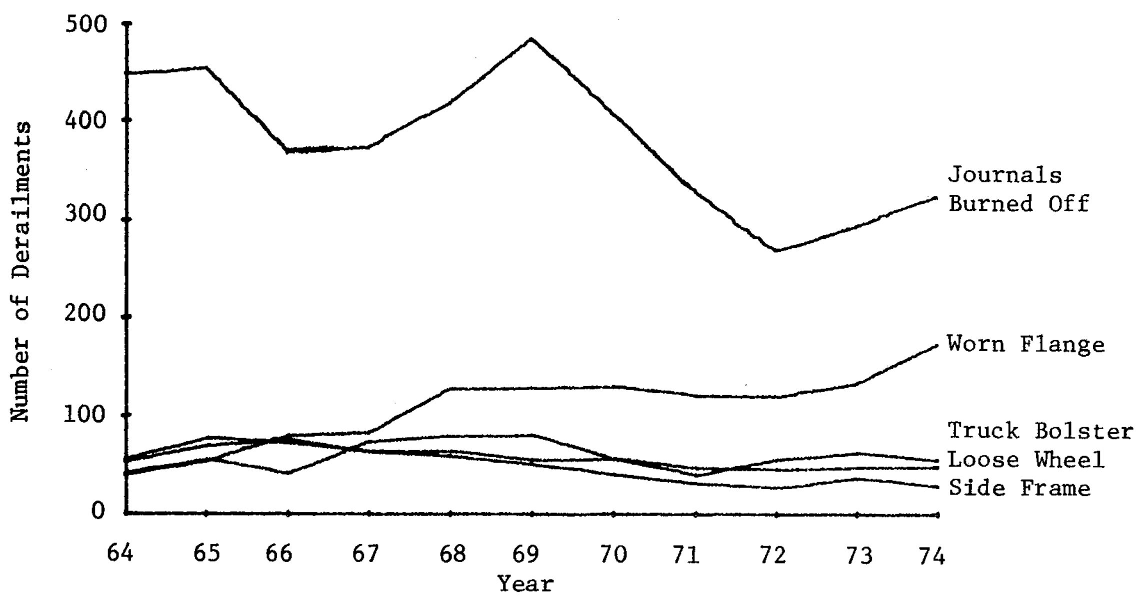


Fig. 3 Top Five Individual Equipment Causes of Derailment

In studying the New York State accident data, where the accident cause is given in a brief descriptive statement, several instances were noted where the cause was listed as a worn flange picking a worn switch point. The FRA equivalent to this cause was located in the 4500 series of cause codes, "Combination of Two or More Causes," as cause code 4501. Other combination causes included "truck stiff and .....", "excessive side bearing clearance and .....", and "slack action and .....". While slack action is not equipment related, it was decided to include the whole 4500 series in the analysis. Also, since cause code 4601 "Rocking or Swaying of Car" can relate both to the dynamic condition of the car and also the track condition, this cause code was also included.

The effect of adding these accidents to the equipment caused accidents is shown in Figure 4. The number increases significantly while the trend is similar.

The top twenty equipment related derailment causes are now shown in Figure 5 as a percentage of the total equipment derailments over the last ten years (1964-1973). Several of the cause codes from the 4500 series as well as 4601 now appear in this listing. The third most important cause appears to be 4588 "Other Combinations of Two or More Causes". This is unfortunate since there is no basis for assigning the cause of these accidents to equipment related reasons unless the original FRA T sheet were analyzed. It appears to be a catchall cause used by the personnel at the FRA that assign the cause code to individual accidents when it is not clear what the cause of the accident was.

Starting in 1975, a new procedure and a new listing of cause codes will be used. In the new procedure, railroad personnel will assign the cause codes rather than FRA office personnel. The new cause codes do not make provisions for any of the combination codes nor for present cause code 4601 "Rocking or Swaying of Cars". However, a secondary cause will be listed if applicable. An attempt was made to investigate the effect of this by assigning 1975 cause codes to the set of 1974 derailments classified under the old cause codes. This was not done by analyzing the T sheets and, therefore, results are only

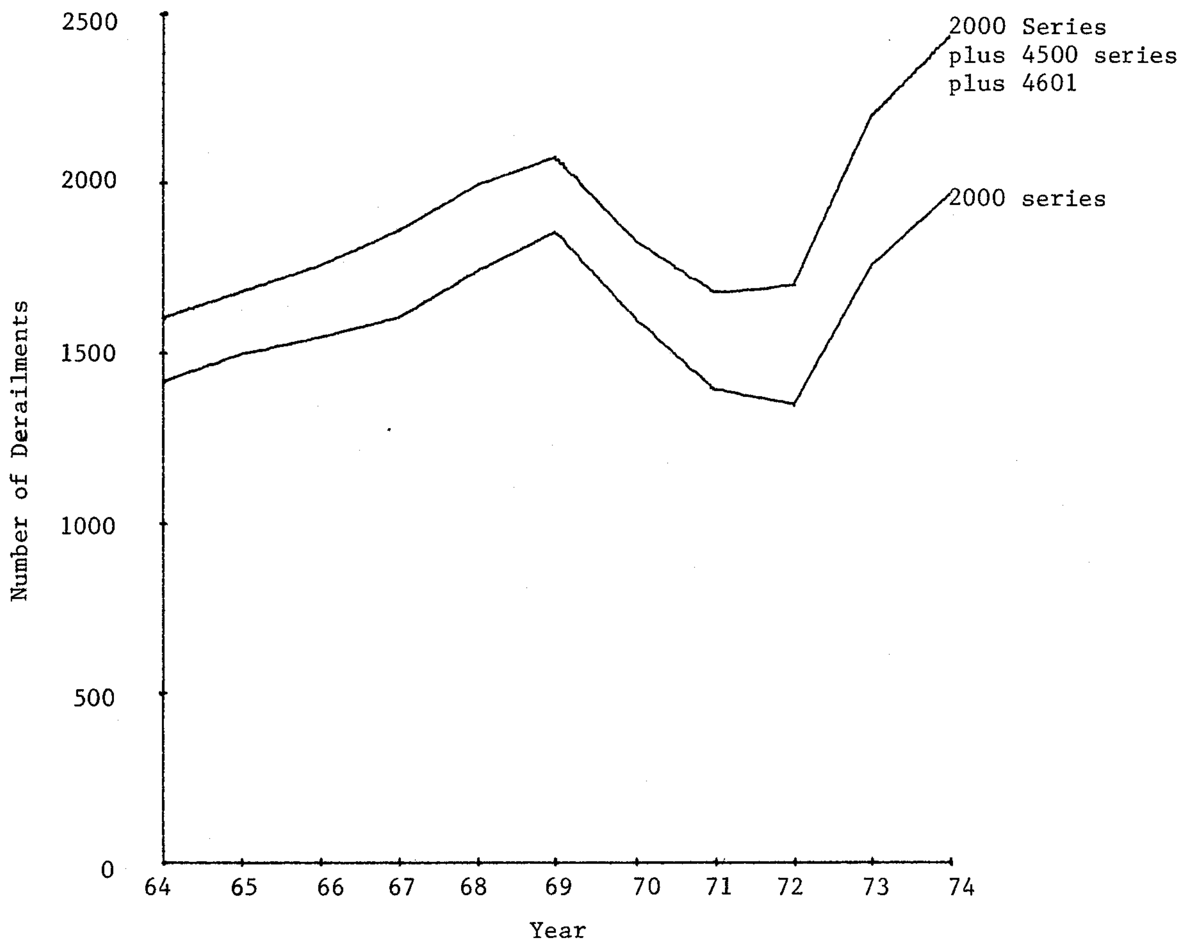


Fig. 4 Comparison of the Equipment Related Derailments (2000 series) with the total Consisting of 2000 and 4500 series and 4601

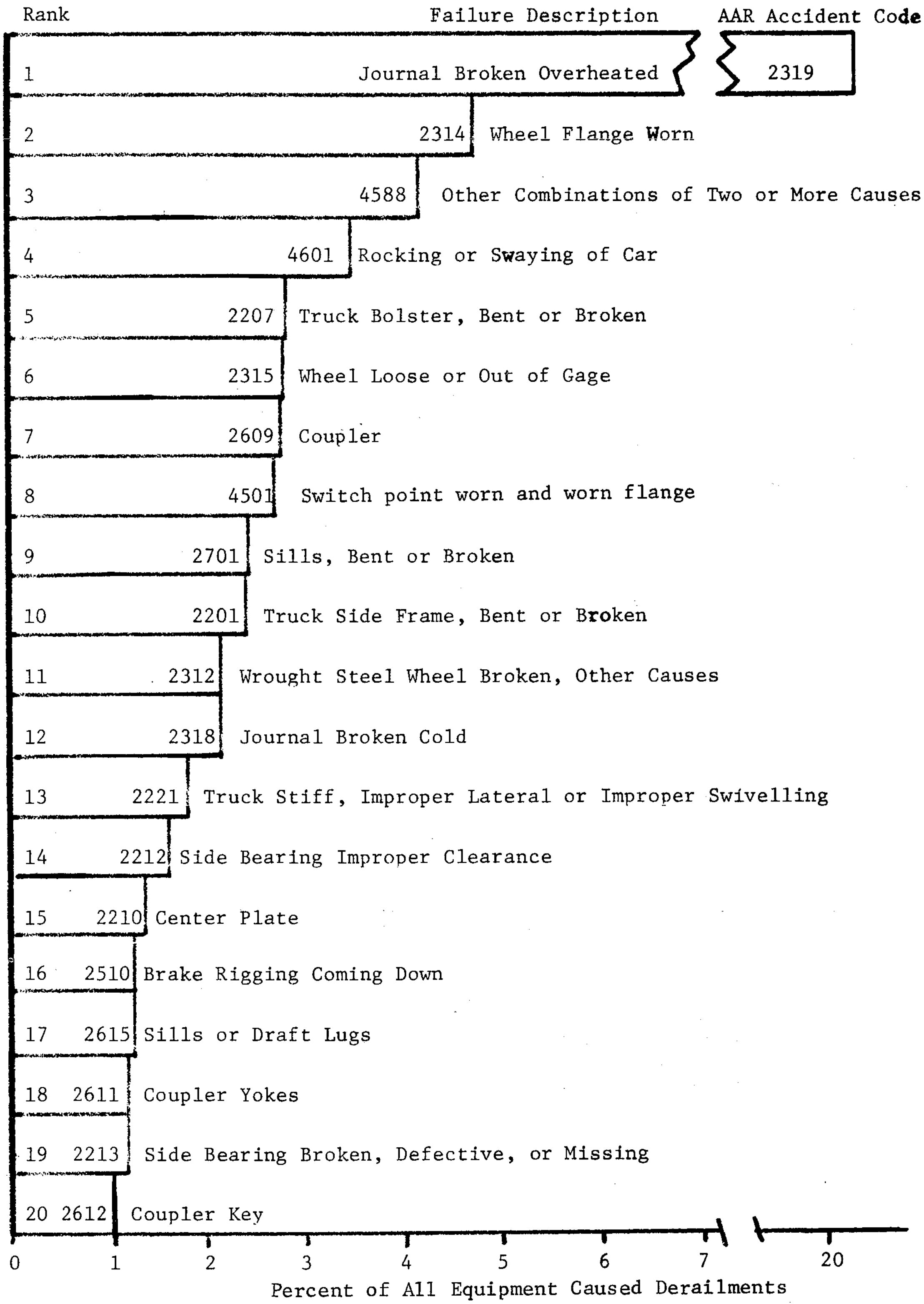


Fig. 5 Rank of Cause Code for Twenty Most Frequent Accident Types; Chart Accounts for 60% of All Equipment Derailments Classified

partially valid. This analysis is given in Appendix B where it is shown that 518 out of 2437 equipment derailments occurring in 1974 would have had to be reclassified if the 1975 rules were in effect. Combination of equipment and rail causes will now have to be assigned to either equipment or rail. Rockoff will also have to be assigned to either a track cause or an equipment cause.

While it appears to be an advantage in being more specific in the assignment of the primary cause, there still are catchall causes allowed in the new rules such as 449 "Cause Code not Listed". Actual variations in the future data versus past data will have to await an analysis of the 1975 results. Some of the new cause codes are clearly advantageous; for example, burned off journals will now be identified as either a plain bearing or a roller bearing.

Because the total number of derailments varies from year to year, each individual cause may be expected to vary. In order to examine the relative seriousness of the various problems, it was decided to plot the data by proportion (i.e., ratio of number assigned to a cause to the total number of derailments for that year). In this manner, yearly fluctuation in number of derailments will be normalized out of the data; and trends can more easily be spotted. Since the proportion by numbers can be misleading in that one cause could be responsible for large numbers of low-cost derailments, plots were also run for proportions by dollar.

Various dollar cutoff points (above the FRA $750 value) were used to determine if some causes were responsible for more costly accidents. The plots with different cutoff values did not give any additional information that could not be deduced from a comparison of the number and dollar proportion as well as the analysis of accidents by speed range. For example, if the proportion of accidents by number was higher than the proportion by damage dollars, then the proportion calculated for higher fixed cutoff dollars would drop slightly.

Figures 6 through 8 show the proportion plots for numbers (top of page) and dollars (bottom of page) for the major cause groupings used by the FRA with a new grouping, 2900, used to include the 4500 series and cause code 4601. Wheels and axles is the clear leader as the cause of accidents and is even more important when viewed as a proportion of the cost of the accidents. The miscellaneous category (4500 and 4601) ranks in the same overall importance as trucks and couplers. The proportion by dollars for couplers drops from the proportion by number indicating that there is a large number of low-cost accidents for this cause. All other major causes are at 5 percent or lower for both number proportion and cost proportion.

In order to investigate the relationship between accident causes and inspection system, the major cause code groupings must be broken down in greater detail.

3.3 Regrouped Cause Codes

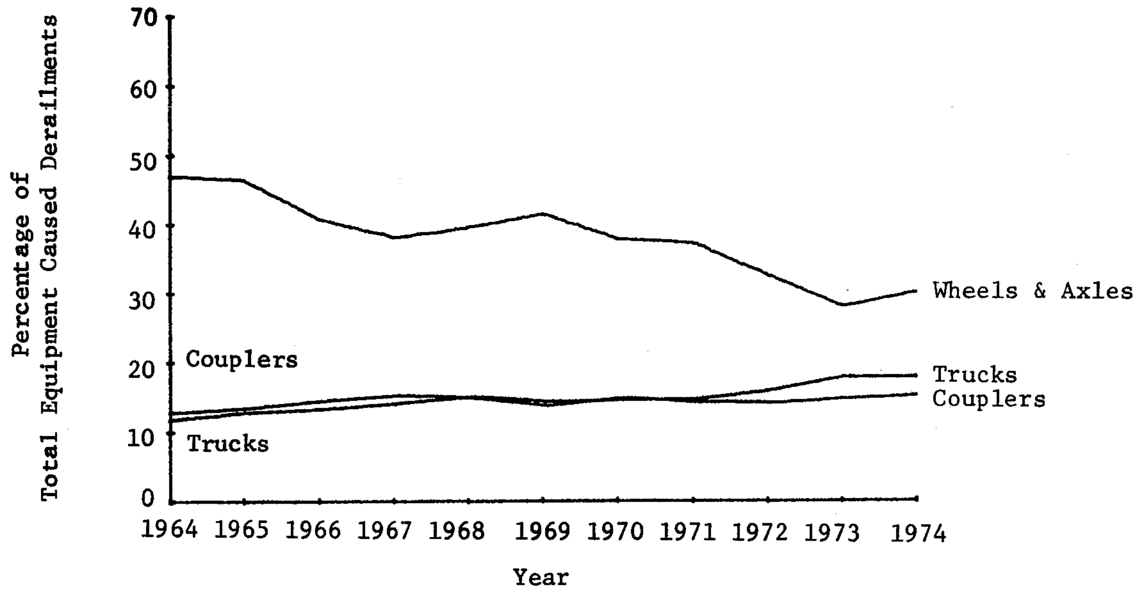
The data stored in the computer was run in many different combinations of cause code groupings. Individual cause codes were also analyzed as to possible inspection systems. Two criteria were established to group the individual cause codes into larger groupings; they were:

1. The grouping had to have some common element to allow detection of an incipient malfunction.
2. The proportions of accidents caused by the group had to be significant.

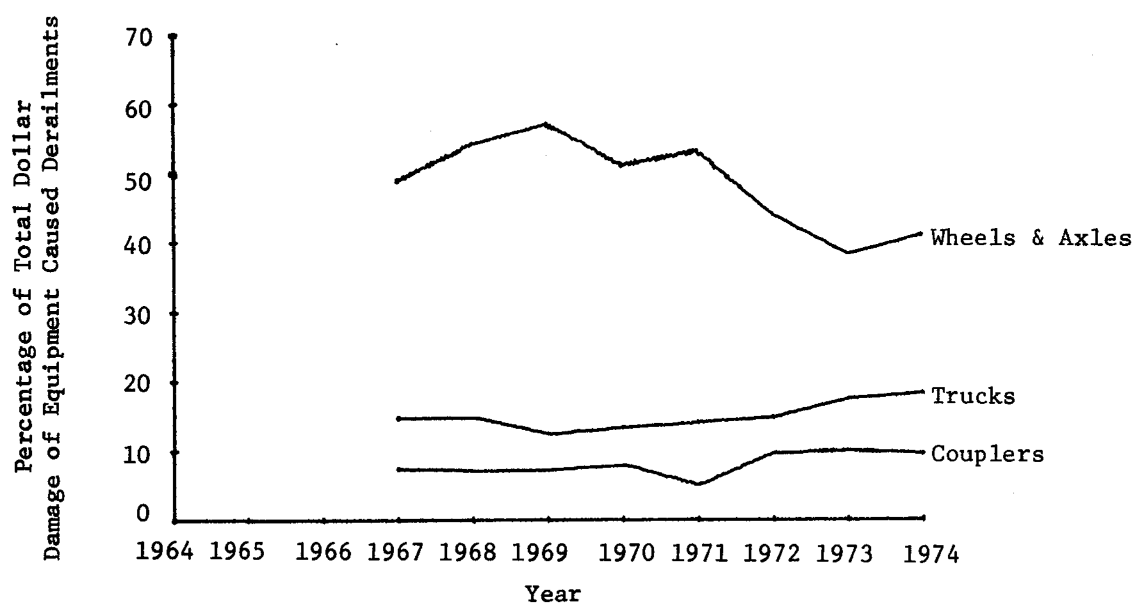
New groupings and the rationale for these groupings are discussed below.

Cause	Cause Codes Included*
1. Journal bearings	2318 & 2319
2. Worn flange & loose wheel	2314 & 2315; 4501 thru 4505
3. Wheels	2301 thru 2313
4. Truck bolster & side frame bent or broken	2201 & 2207
5. Couplers - pulled out	2609 thru 2618
6. Air brakes & bad brakes	All 2400 series; 2501, 2504, 2507, 2510
7. Dynamics	2208 thru 2221; 2701 & 2702; 4506 thru 4513; 4601

* See Appendix A for definitions.

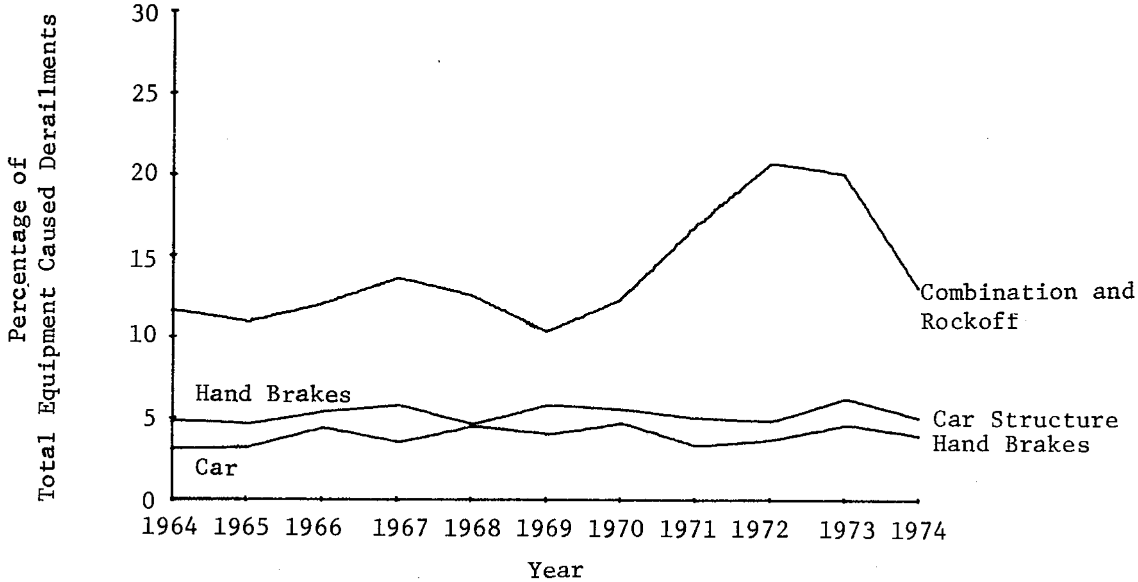


(a) Percentage by Number

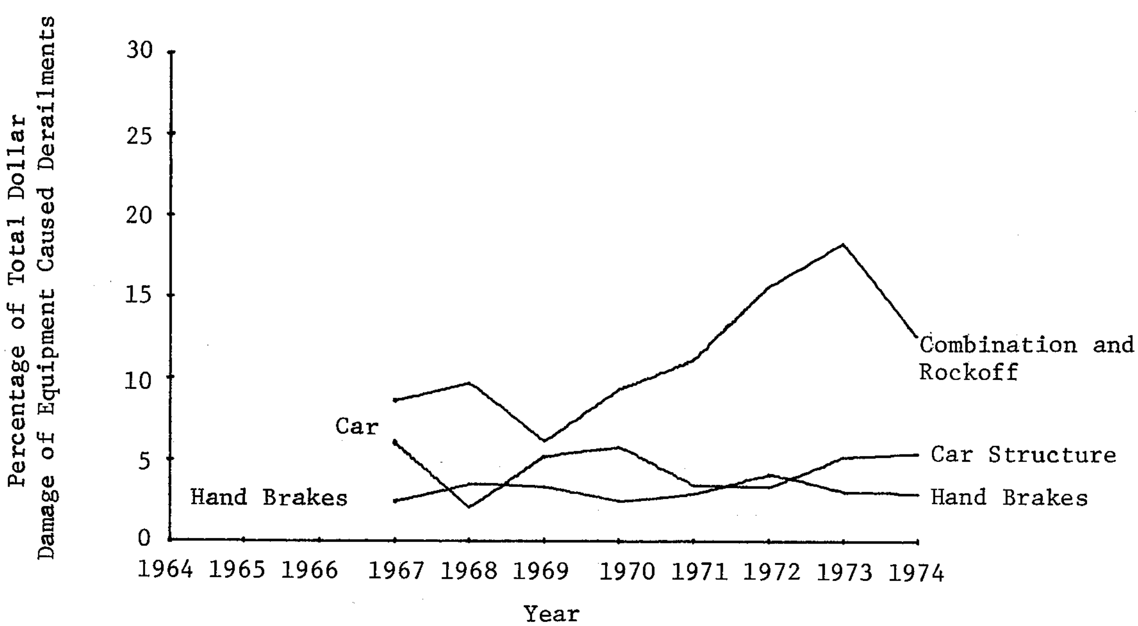


(b) Percentage by Dollar Damage

Fig. 6 Percentage of Total Equipment Caused Derailments Due to Wheels and Axles, Trucks, Couplers

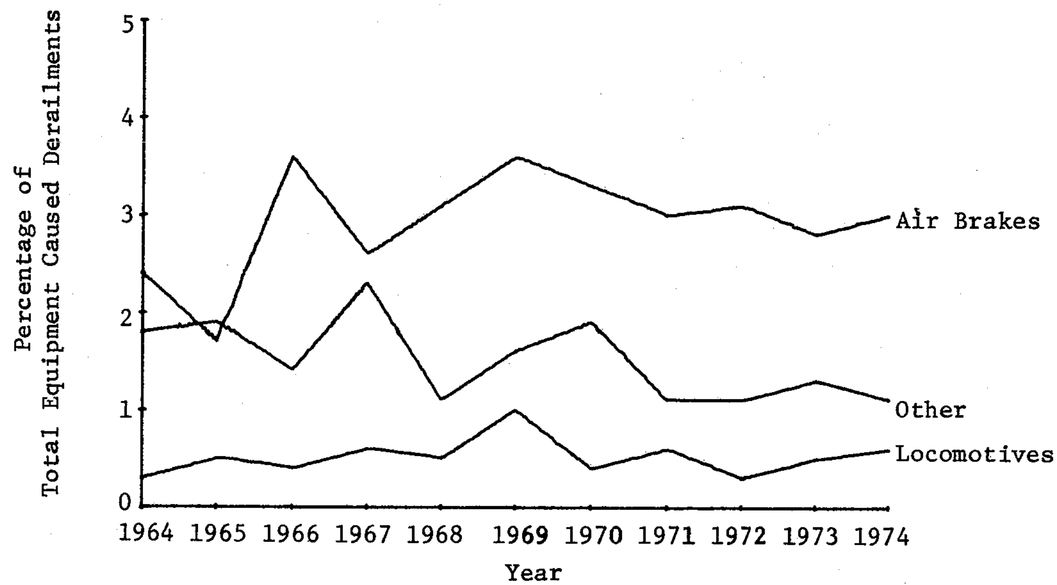


(a) Percentage by Number

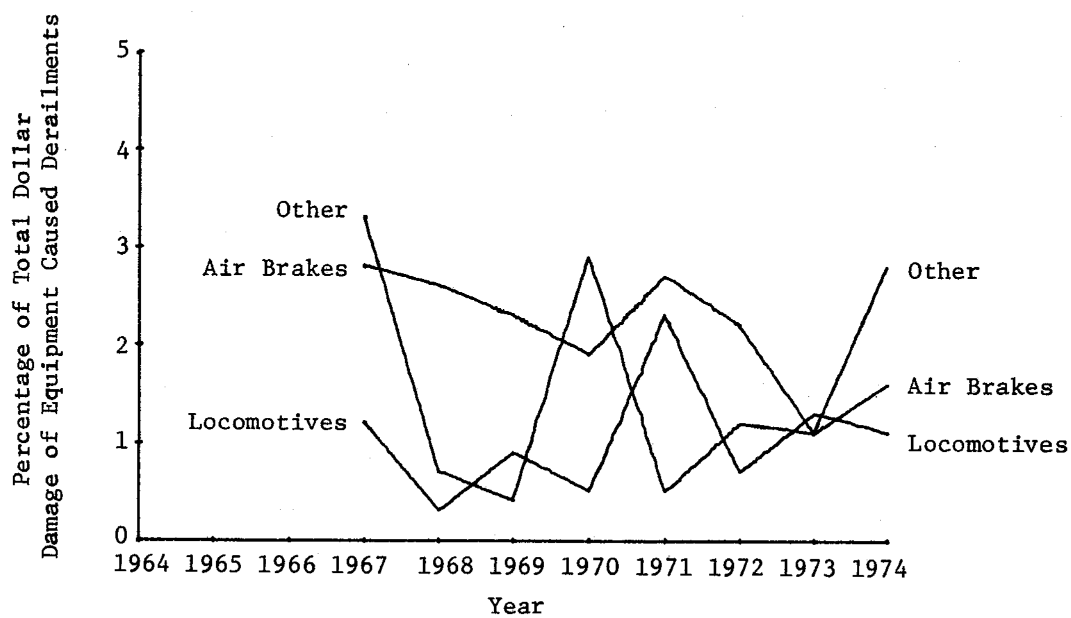


(b) Percentage by Dollar Damage

Fig. 7 Percentage of Total Equipment Caused Derailments Due to Combinations and Rockoff Hand Brakes and Car Structure



(a) Percentage by Number



(b) Percentage by Dollar Damage

Fig. 8 Percentage of Total Equipment Caused Derailments Due to Other Parts, Air Brakes and Locomotives

Two causes were listed for the journal bearing, 2318, journal broken cold and 2319, journal broken overheated. The inclusion of 2318 in this cause is because it is felt that at least a portion of these bearings had been previously overheated and would thus have lent themselves to detection by a hotbox detector. The flange category includes both worn and loose wheels and also the combination causes 4501 through 4505. Somewhat arbitrarily, the categories of wheel-flange broken were not included in this category but were included under the crack and fracture defects listed under wheel.

The wheel category includes all broken or defective wheels including cast iron--even though for the past few years there have been no cast iron wheels in service.

The truck bolster and the side frame are grouped together because they are truck structural members and can cause an accident either by deformation or by fracture.

Couplers-pulled out are separated from the balance of coupler problems since they are a much higher cost proportion than the balance of the category; and also a plot of the couplers not out versus speed indicated a great majority occurred below 10 mph or probably in the yard (see Appendix C).

The air brakes and bad brakes cause codes were grouped since they affect the braking ability of the car.

The dynamics category was assembled to analyze those defects which affect the ability of the car to operate in the railroad environment without dynamic problems leading to derailment. The elements of the car that are included are snubber device, center plate/pin, side bearings, springs, truck stiff, car sills/body bolster--the combination causes involving side bearings and truck stiff and, finally, the car rockoff category. Bent truck bolsters and side frames could possibly have been added except that the cause codes do not allow the separation of a bent from a fractured condition of these components. While the makeup of this category may be controversial, the data analysis indicates that this grouping merits consideration.

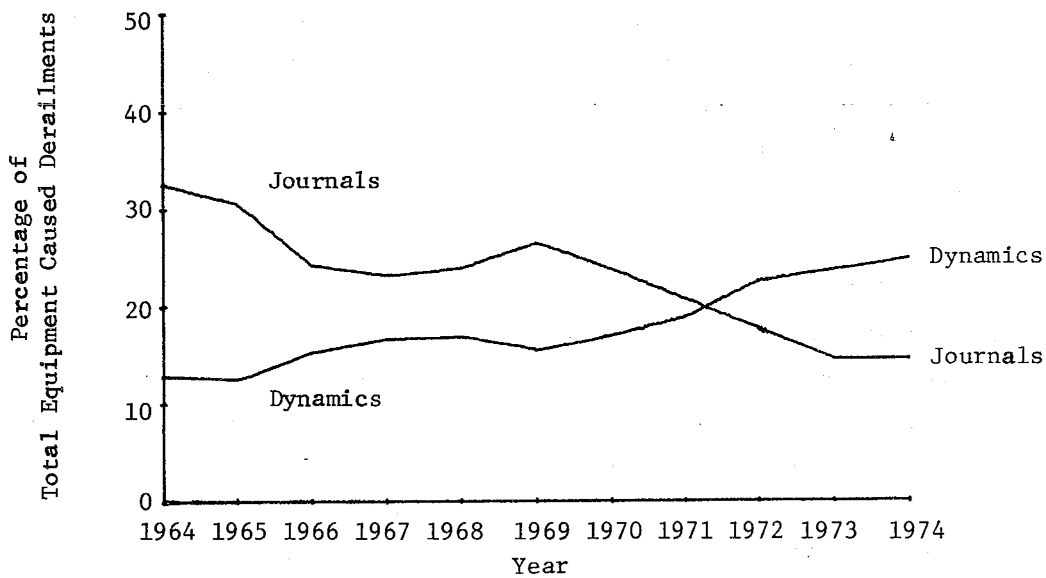
3.4 Analysis Results

A series of plots showing the proportion of the total equipment (including 4500 and 4601) caused derailments that may be attributed to each of the cause code groupings selected. The proportions based on numbers are plotted for the years 1964 through 1974 and are shown at the top of each page. The proportions based on dollar damage are plotted for the years 1967 through 1974 and are shown at the bottom of each page. Backup data is given in Appendix C.

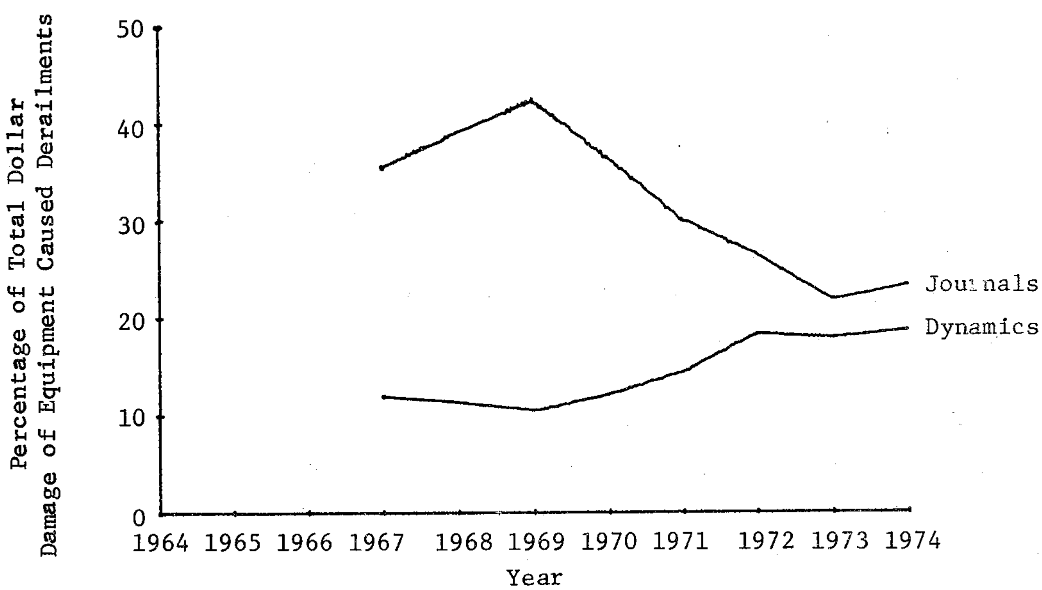
Figures 9a and 9b compare the top two cause groupings for the past 11 and 8 years, respectively. They are journal bearing failures and the assembled dynamics category. The proportions by number show that since 1971, dynamics has become the major cause. The proportion by dollars, however, shows that journal bearing failures are still more costly and, in fact, increased in 1974 while the number proportion leveled off. Analysis of the distribution of the accidents by speed show the reason for this. The dynamics category peaks in the 10 to 20 mph speed range largely due to the influence of rockoff while the journal-caused derailments peaked in the 30 to 60 mph speed range. Speed plots are given in Appendix C along with tabulated data showing the average cost per derailment versus speed range.

Figure 10 compares the proportion of derailments caused by worn flanges and loose wheels to broken or cracked wheels. The proportion plot shows that the flange causes more derailments, however, the broken wheels account for a larger proportion of the costs associated with derailments.

Figure 11 plots the data for the couplers out, air and bad brakes, and bent or broken truck bolster and side frame.

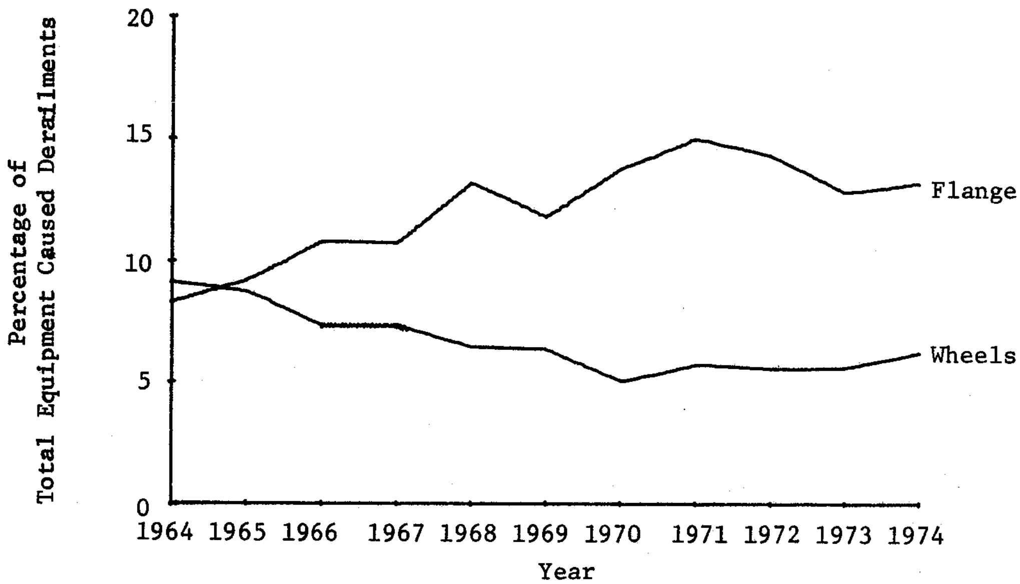


a) Percentage by Number

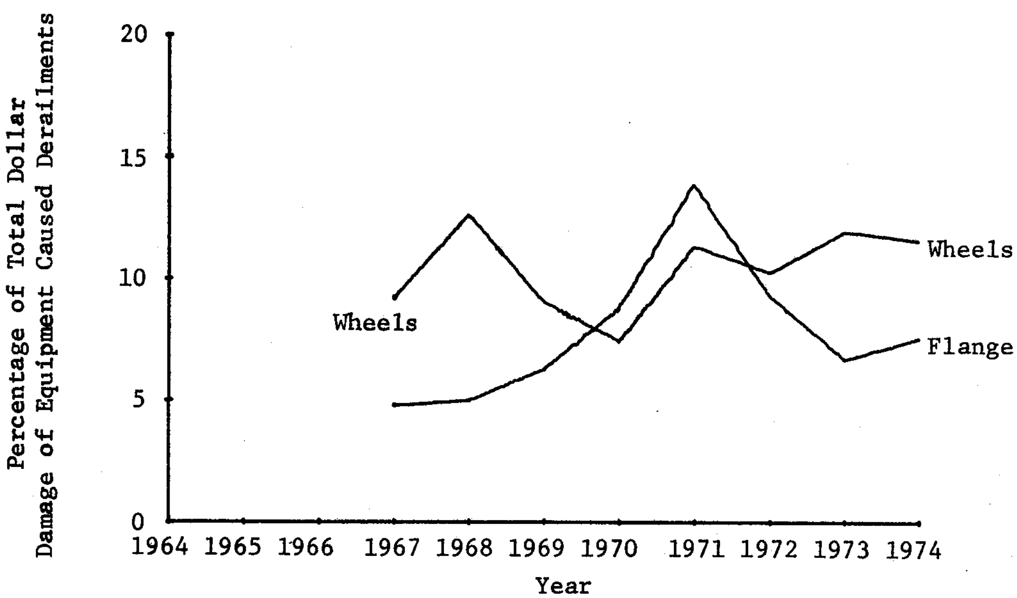


b) Percentage by Dollar Damage

Fig. 9 Derailments Due to Journals and Dynamics

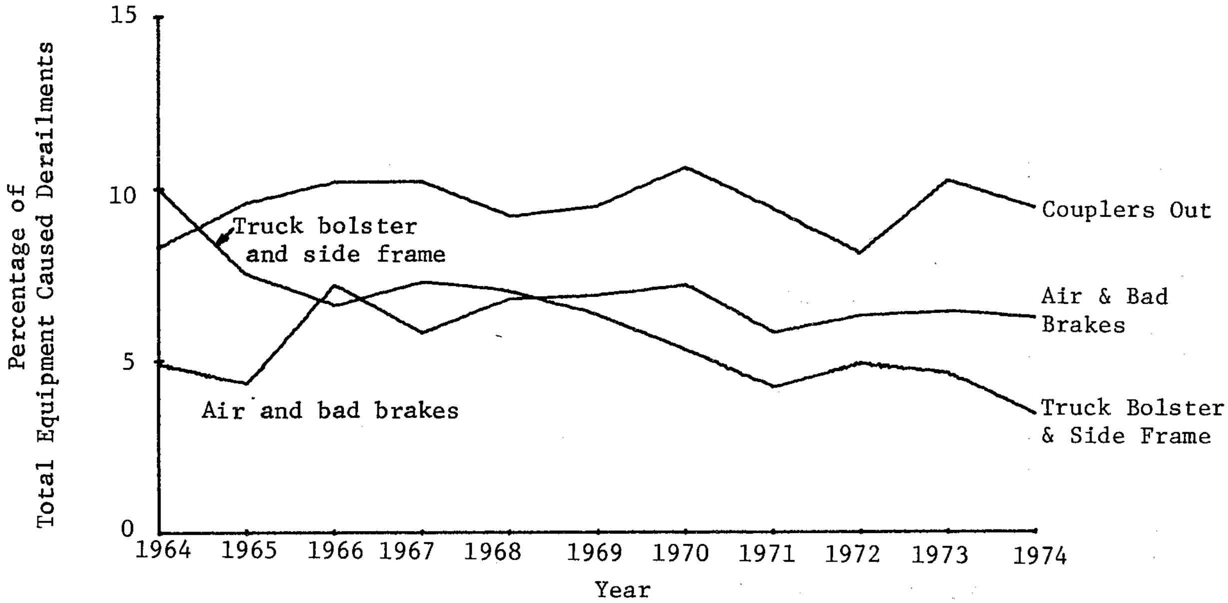


a) Percentage by Number

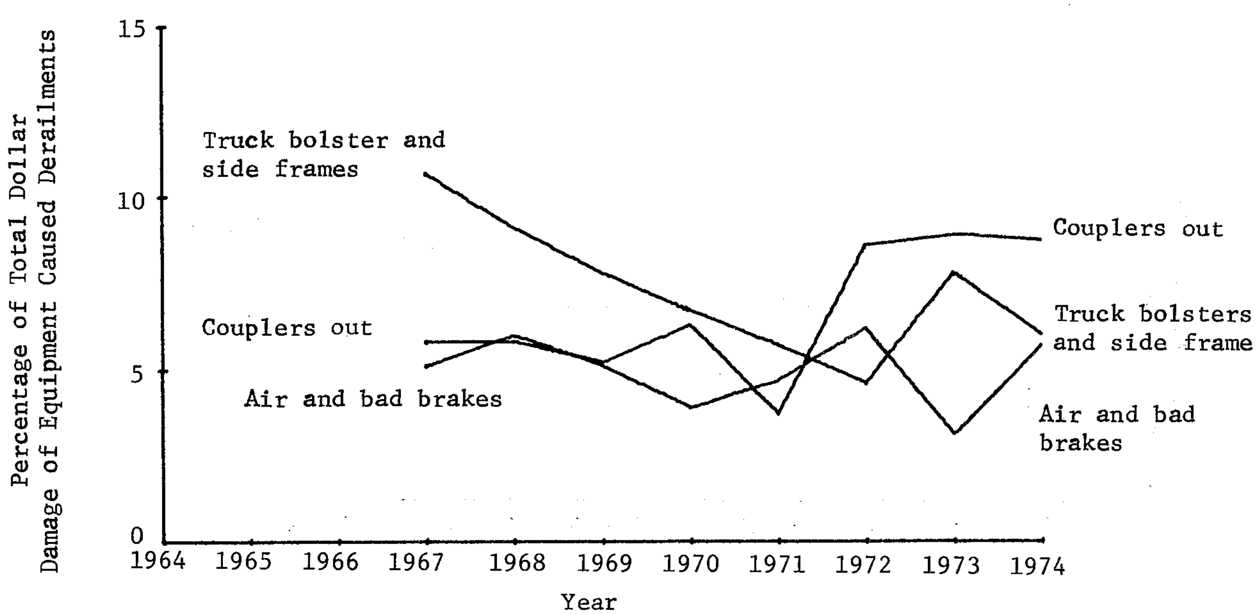


b) Percentage by Dollar Damage

Fig. 10 Derailments Due to Broken Wheels and to Worn Flange and Loose Wheels



a) Percentage by Number



b) Percentage by Dollar Damage

Fig. 11 Proportion of Equipment Caused Derailments Due to Couplers Out, Air and Bad Brakes and Truck Bolster Side Frame

Additional data, including track and human factor-caused accidents, can be found in a recently completed AAR report (1).

3.5 Discussion of Dynamics Category

The somewhat arbitrarily assembled dynamics category ranks as one or two in importance depending on whether the proportions are by number or dollar damage. It is important, therefore, to analyze the relative contributions of causes that make up the dynamics category.

Figures 12a and 12b are two pie charts showing the makeup of the dynamics category for 1967 and 1974. The percentages are calculated on the number of derailments basis with 100 percent being the complete dynamics category for the year. The total derailments due to dynamics for 1967 and 1974 are 295 and 596, respectively. The combination causes of "side bearings stiff and ......" and "truck stiff and ....." are minor contributions to the overall category. Rockoff accounted for 28 percent (83 derailments) in 1967 and 22 percent (134 derailments) in 1974. The side bearing cause contributed 14 percent (41 derailments) in 1967 and grew to 30 percent (177 derailments) in 1974. Sills and body bolsters bent or broken decreased from 25 percent (73 derailments) to 12 percent (70 derailments) in 1974.

Figure 13 shows the trend of the four major contributors to the dynamic category. Again as in Figure 12, the percentages are the percentage of the total dynamic category and not total equipment caused derailments.

Of course, the dynamics category is valid only if some inspection technique is available or can be developed to detect each of the defect types that make up the dynamics category. If 1974 is taken as an example and if a given technique could not detect center plate/pin and car sill and body bolster problems, then the number of derailments in the dynamics category would decrease by 181 derailments and Figure 9 (which showed dynamics accounting for 25 percent of the total derailments) would have to be reduced

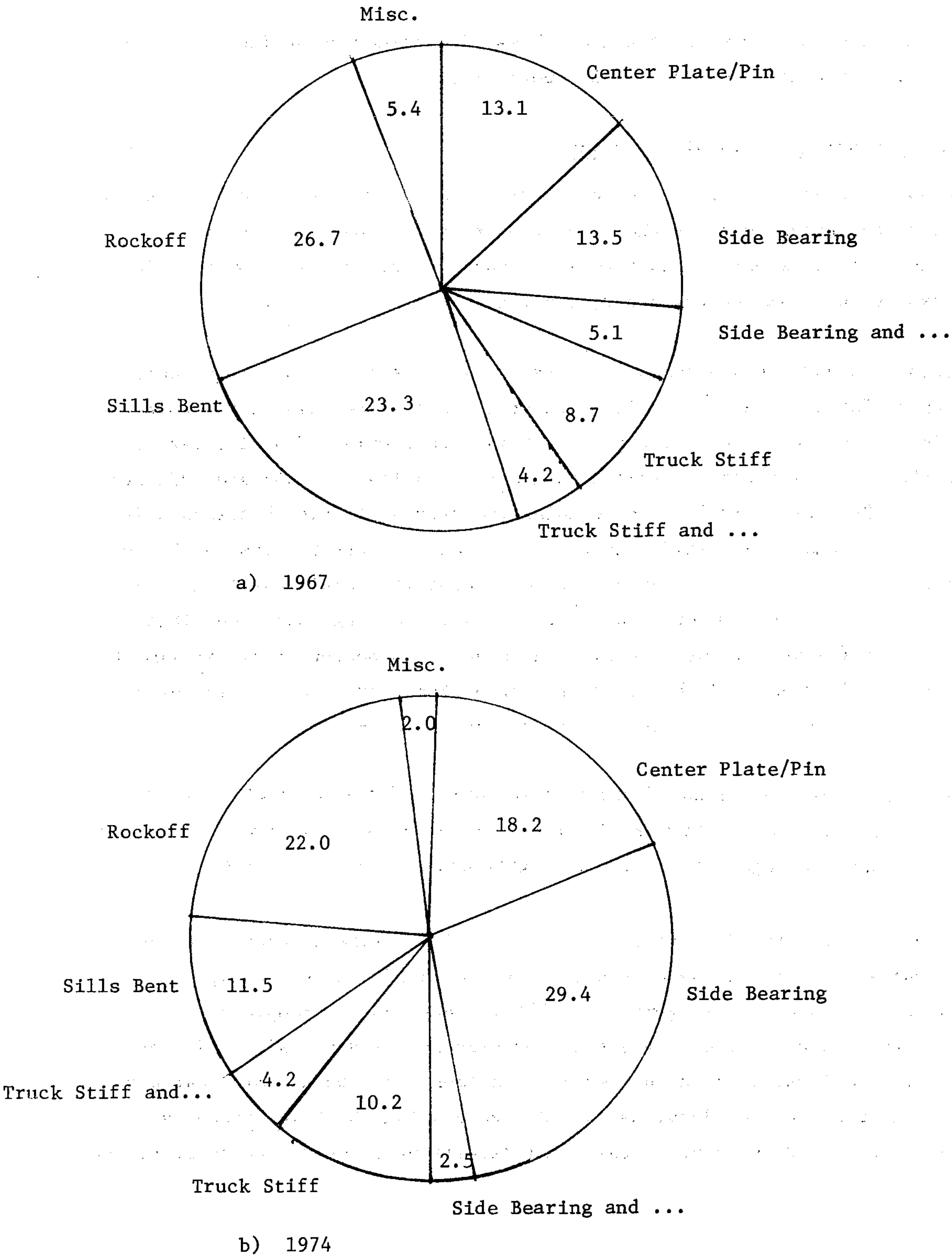


Fig. 12 Makeup of Dynamics Category for Years 1967 and 1974

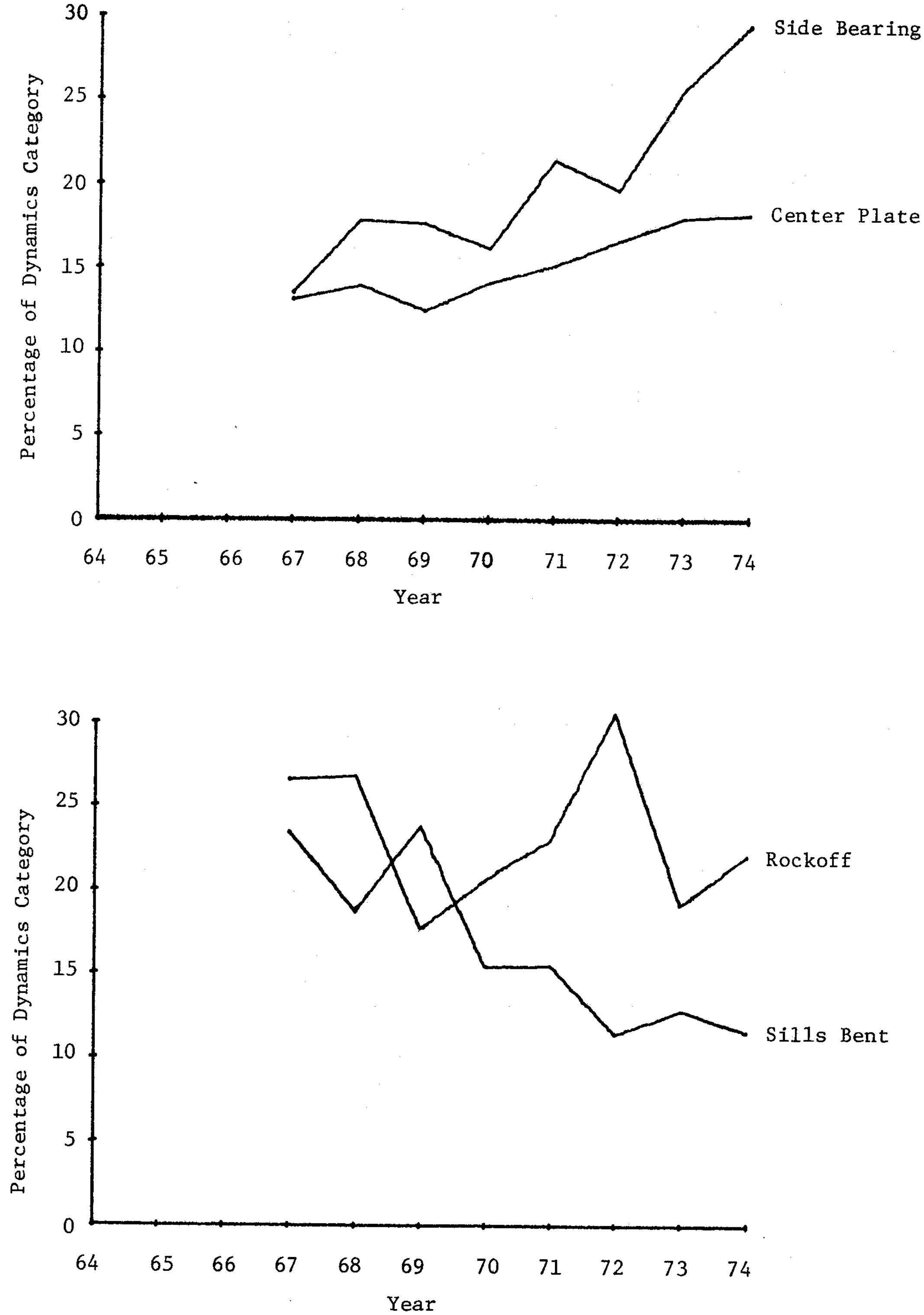


Fig. 13 Trend of Major Contributors to the Dynamics Category

to 17.5 percent of the derailments. This would still rank as the number one cause of derailments for 1974 on a number basis. Of course, if some dynamic inspection of a car could be developed, it could conceivably also address the problem of worn flanges and loose wheels. In this case, an additional 323 derailments would be grouped in the category to raise the percentage from 25 percent to 38.2 percent.

As will be discussed in a later section of this report, there does not exist any commercially available inspection system that can detect the presence of car defects that lead to dynamic-caused derailments. Therefore, the exact makeup of the overall category cannot be exactly defined. The purpose of the grouping is to call attention to a somewhat logical grouping of derailment causes which in total is a very significant proportion of equipment-caused derailments and whose trend is increasing.

3.6 Other Factors Affecting Equipment Caused Derailment

Several other factors that possibly could influence equipment caused derailment were investigated. In the case of possible factors such as time of the year and length of the train, the FRA data could be used directly to investigate the affect these factors had on derailments. In other cases, data was limited and no firm conclusions could be drawn.

Time of Year

Appendix C of this report contains plots of derailments versus month of the year. These data show that overall equipment caused derailments are slightly greater in the winter months than in the summer. It was suspected that this slight increase would be due to an increase in derailments due to wheel fracture or coupler fracture. In both cases, the colder weather would be expected to decrease the critical crack size. For wheel fracture, frozen ground could also apply higher shock loads to the wheels.

This suspicion was not verified by the data when analyzed with regard to the cause code groupings established.

Length of Train

Plots of the relationship between the derailment cause by the seven categories established are also shown in Appendix C. Here some correlation was obtained.

One would expect that as the train length increases, coupler failure related derailment would become more important. This was the case. Derailments due to the category "Air and Bad Brakes" also increased as the length of the train increased.

The "Dynamics" category showed a definite decrease as the length of the train increased. Rockoff was separated from the balance of the dynamics category to determine if this one cause would account for the decrease. Rockoff did indeed decrease with increasing train length, however, so did the balance of the dynamic category.

One could, of course, further divide the analysis to individual cause codes; however, this was not done since attempting to split up the data into small segments reduces the statistical validity of the analysis.

Car Capacity and Car Type

These kinds of data are not available on the FRA tapes. One significant factor was apparent in the failed journal data furnished by one railroad. That is, that in almost every case of a failed journal, the car was loaded. This was true for both the plain bearing and the roller bearing, although limited data were available for the roller bearing.

Conversations with railroad personnel indicated that unloaded, long cars such as automobile carriers are more susceptible to rockoff than other types of cars. No numerical data was available that could be analyzed to verify this relationship.

4.0 WAYSIDE INSPECTION SYSTEMS

A literature search was conducted to identify wayside inspection systems that were either in use by railroads or were being proposed for use as wayside devices. In addition, railroad, Association of American Railroads (AAR), and Department of Transportation (DOT) personnel were contacted to identify additional systems and to obtain an indication of the relative merits of wayside systems.

The wayside systems that have been identified are divided into those that are in actual use by railroads and those that are under development or have had a very limited use to date by railroads. Included with the latter is a tabulation of some nondestructive testing techniques that could have application to the detection of derailment causing defects. References are cited for the existing and developmental wayside systems where information in greater detail may be found since the description in this report was purposely brief.

In the previous section, a dynamics category was assembled out of a group of related cause codes. This category was shown to be a significant contributor to equipment caused derailments. No wayside inspection system was identified that addressed the overall group or even some of the individual cause codes that made up the group. An overview of the problems which should be considered, if a system to detect car defects in this category were to be developed, is included.

4.1 Description of Existing Wayside Detection Systems

4.1.1 Hotbox Detectors. The major cause of derailments over the past ten years is the overheated journal bearing. As a result of this, the first fully electronic wayside system deployed for prevention of derailments was the hotbox detector.

The first detectors became commercially available in the mid fifties. At the present time, there are five manufacturers of these devices in the

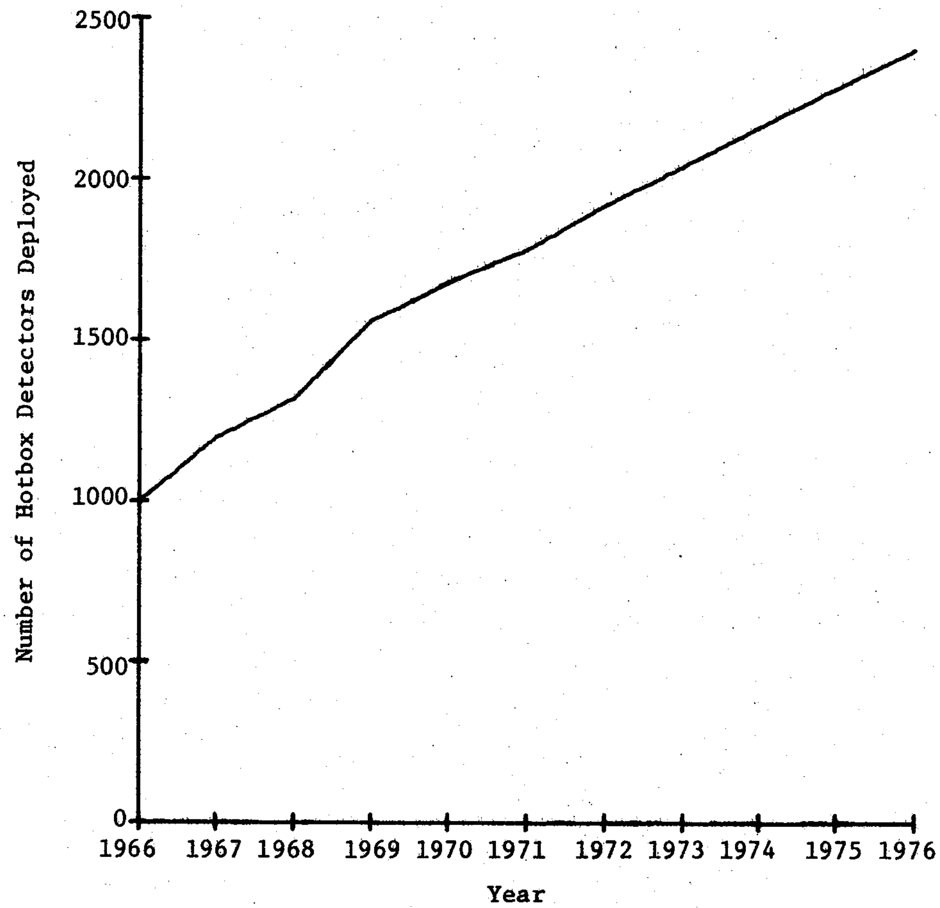


Fig. 14 Cumulative Number of Hotboxes Deployed Versus Year

United States. The exact number of units in service is not known, but it is near 2,400. Figure 13 shows the deployment history of these detectors for the past ten years throughout the U.S.. Detector use and spacing varies widely; some railroads have spacing as small as 30 miles, whereas others have an average over 500 miles. System average for all railroads is near 85 miles for mainline track.

Initially, the hotbox detector was concerned only with the detection of overheated plain journal bearings. With the introduction of the roller bearing, the detection scheme has been complicated. Roller bearings introduce two variations into the detectable signal:

1. The external surfaces (outer race or cup) of normal roller bearings run hotter than outside surface of the plain journal (lube box surface).
2. When roller bearings replace plain bearings, they are sometimes physically placed inside the original journal bearing housing.

The resulting signals from all detectors are at the present time read and analyzed by track personnel. Although the analysis of the signal traces from a detection system is a complex one, some automatic evaluators are available as commercial units (2).

The details of hotbox detection have been reviewed extensively in the past (3,4,5,6). All hotbox detectors are designed to indicate which bearings of passing railcars are operating at an above than normal rise over ambient temperature. The emitted infrared energy coming from the outside of the bearing is used to determine which bearings are running "hot". All detectors available today measure the absolute temperature of the target surface viewed; however, the output signal is proportional to the difference between the viewed surface (bearing) and some reference surface. The reference surface is normally a part of the hotbox structure and is intended to be a measure of the local ambient temperature. Bearings or wheel hubs which are running at a temperature high relative to ambient, will produce a large signal.

Measures of the relative temperatures of two bearings help to reduce one of the major causes of error in determining the apparent temperature rise of the passing bearing. Other sources of error do exist and can degrade the effectiveness of the hotbox sensor; they include:

1. Surface character of bearing housing (dirt, grease)
2. Hot brake or rigging components
3. Local weather conditions (wind,sun, snow etc.)
4. Improper maintenance (alignment, calibration, cleaning)
5. Time response of the detector
6. Human error

Since roller bearings run at higher temperatures than journal bearings there is some difficulty in the interpretation of the hotbox signals. The task of separating "hot" journals and the "hot" rolling element bearings is usually performed by the chart interpreter. He can often separate the normally large signals from roller bearings since these bearings are not mixed with friction bearings on any one railcar. A system has recently been proposed which would electronically compensate for the unusually high output signal of roller bearings. The usual detector "pip" output signal gain is controlled separately over three temperature ranges--from 0 to 90^{o}F, 90 to 175^{o}F, and above 175^{o}F. Since roller bearings in normal operation run much hotter than friction bearings, there is then an automatic gain control on the output signal (7).

Even with several possibilities of error, the hotbox detector is effective in reducing bearing operation failures which can lead ultimately to a derailment. Several bits of information lead to this conclusion. In the past ten years, the derailment occurrence due to hot journals has declined. Although the issue is clouded from the introduction of the roller bearing, some of the reduction is undoubtedly the result of an increased use of hotbox detectors. A plot of the number of derailment accidents caused by hot journal bearings for eleven railroads plotted against relative system track length in 1973 is shown in Figure 15. The dashed best line fit to the data is what might be

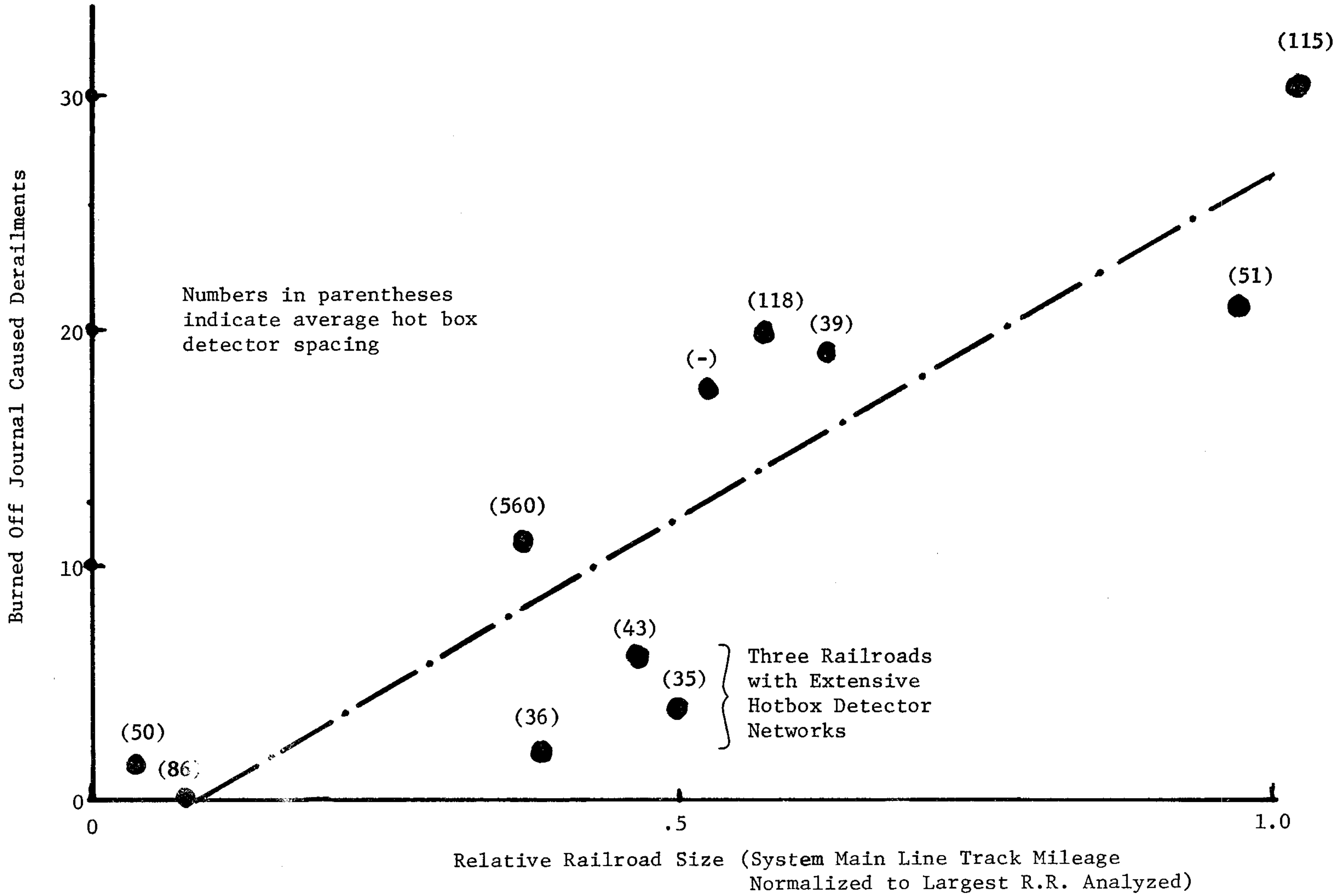


Fig. 15 Burned Off Journal Derailments for 1973 Versus Relative Rail System Size

expected for companies with different sized rail systems. It should be noted that three companies with extensive hotbox detection networks (spacing in parentheses) have fewer accidents of this type than might be expected.

An extensive discussion of the hotbox detector as a prime wayside detection system and its relative effectiveness for a hypothetical railroad is presented in Section 4.1.

4.1.2 Overheated Wheel Detectors. Wheel defects have been extensively covered in an AAR publication (8). Wheel related failures rank second, sixth, and eleventh as the most frequent causes of accidents for the past ten years (see Figure 5).

One wayside system aimed at reducing the overheated wheel problem is now on the market. Its purpose is to detect overheated wheels caused by stuck brakes. The system is basically an off-track mounted remote scanner of the infrared sensing type. It is intended to interface directly with the hotbox detection network.

The orientation of the scanner with respect to the track provides capability for sequentially scanning all wheels on both sides of the track from a single location. The wheels are checked between the top of the rail and the bottom of the brake shoe. The system is designed for calibration through the standard hotbox function generator.

The impact this sensor has had on reducing wheel failures cannot be established at the present time since it has just recently been introduced in the marketplace.

4.1.3 Broken Flange and Loose Wheel Detectors. There have been approximately 100 loose wheel and broken flange detectors placed in service in the United States. The actual number in use is less than 100 since the maintenance requirements of this type of system is high and occasionally they are not replaced if broken. Basic units consist of a row of electro-mechanical fingers mounted along the inside of the rail. As the train passes over the test track section, a spring-loaded set of fingers are depressed by the wheel flange. These units are always installed in switch yards where train speeds are very low.

As the wheels pass by the sensors, an electronic switch is activated. A normal wheel will depress the fingers sequentially. A properly aligned wheel with no defects will depress the fingers through an insulated sleeve and no signal will be generated. A broken wheel flange will, on the other hand, allow the sensing fingers to contact the wheel which generates a signal output. Loose wheel, excessive flange wear, or a wheel that is out of gage will also result in an alarm signal.

This type of device has been marketed for over twenty-three years and is a proven wheel defect detection scheme. As with any mechanical system, it requires proper maintenance for continuous high-quality operation.

4.1.4 Dragging Equipment Sensors. Three basic types of dragging equipment detectors are used throughout the United States. Two designs consist of a swinging gate mounted across the rail track. When the gate is struck, the hinged device activates an electronic alarm. A third detection scheme uses the impact detected through an integral accelerometer. This unit has no moving parts.

All three systems are bidirectional and have self-restoring mounts. The swinging units have adjustable activating torques so that false alarms caused by winds do not occur. The detector's gate height is normally adjustable and can be replaced if damaged by dragging equipment. Rugged construction is the main advantage of the accelerometer type of system.

All components are contained in a compact compartment which fits between the average rail ties. Optional features include electric heaters for operation in severe winter environments.

One available swinging unit contains an optical light beam and sensor (9).

This device is able to detect certain dragging equipment which the conventional models miss. This device scans across the top head of the rail and monitors for defective brake shoe or brake rigging that may not hit the swinging gate. The light beam is normally broken by the passing wheel; however, the component senses the approaching wheel and registers only defective rigging in front or behind the wheel.

4.1.5 High and Wide Clearance and Shifted Load Detectors. Sensors for high and wide load detection have been in operation for more than twenty years. Since each railroad has its own particular requirements, they are often developed and installed by the company. The units in use today are generally of the photo-optic nature.

The electric eye detector is quite inexpensive (10) as a wayside detector--the total cost of some installations being as low as $500. This is one or two orders of magnitude cheaper than some systems installed today. The protection provided against hitting low bridges is well worth the installation costs for this wayside device.

The operation usually requires one or more light beams with photo-cell receivers. Passing high or wide equipment causes one or more of the light paths to be interrupted, resulting in an alarm. The interruption normally causes a sonic or flashing light to be triggered at the operator's desk. Some systems have fail-safe alarms to be set off if a loss of power or defect in the photo-optic system occurs.

4.2 Developmental Failure Detection Systems

There are several areas of development which show promise as potential wayside detection systems. The following paragraphs will review the salient features of some of these.

4.2.1 Ultrasonic Wheel Defect Sensors. A wide number of wheel defects can be detected with the aid of the pulse-echo type ultrasonic system. Among those listed are:

1. Cracks in treads.
2. Peened over surface cracks not apparent in visual inspection.

The system is planned for deployment where train speeds of 1 to 20 mph are typical.

Pulses of surface wave sonic energy are introduced to the wheel as it passes over the transducer which is mounted directly in the track. The sonic pulse is transmitted around the wheel. Cracks or other discontinuities in the wheel result in echos being reflected back to the sending transducer.

Electronic logic built into the system is used to analyze the time of transit and return of the generated pulses. The amplitude number and frequency of the return signals is used to fix the position of the wheel crack if one is present. This system can be used to find cracks as small as 0.5 inches long by 0.05 inches deep. Two alarm modes are generated by the device; a crack presence indication or a "calamity alarm" if the crack is unusually large and extends completely through the rim.

Good coupling between the output pulse transducer and the wheel is needed for proper operation. A water and ethylene glycol spray is applied to the wheel as it passes over the sensor.

Most installations using the pulse-echo detection scheme include:

1. An electronic control system
2. Paper tape recorder
3. Four ultrasonic transducers
4. Special rail sections with heaters
5. A spray system and reservoir tanks
6. Signal lights and alarm horns

The most frequently heard comment by those railroad personnel who have evaluated the device or those familiar with evaluations has been that the system is too sensitive to very small cracks. While the size detected is in agreement with a study on critical crack sizes (11), most railroads feel that it would not be economical to remove such wheels unless it could also be shown that tensile stress has also built up in the rim.

Evaluation tests are continuing by several railroads and the DOT.

4.2.2 Ultrasonic (Anomalous Propagation). This method of nondestructive testing has been used to measure residual stress levels in railcar wheels (12). The measured quantity is usually the velocity of sound in stressed and unstressed samples of metals. Since the buildup of tensile stress in wheels can lead to failure due to fracture, this method may provide a technique for preventing such failures.

It has been reported (8) that preliminary success with such a system has been shown. If some of the technical difficulties related to required measurements of sonic path length and calibration with base materials can be overcome, this method might be deployed as a practical failure detection system. At least one company at the present time manufactures an ultrasonic system which can measure sonic transit times with the necessary accuracy needed for this technique.

4.2.3 Acoustic Impact or Signatures. The hammer has been used by rail personnel for years to determine the condition of rail wheels. Investigations (12) using automated "wheel bangers" have been initiated. The resulting signature coming from a struck wheel may ultimately lead to a reliable test for wheel integrity.

Initial tests performed to date have shown some success. The sonic spectra from defective wheels have been in some cases separated from signatures of good wheels.

The technique works because cracks will influence the vibration modes of the wheel if caused to vibrate. The spectral content of sound in the 1 to 5 KHz range appears to be sensitive to the presence of cracks in the wheel. If effective, it would appear that this technique or one similar to it could be used to reduce wheel failures.

The greatest difficulty is to categorize all wheel composition, shape and size normal resonances from abnormal resonances with no overlap between abnormal and normal.

4.2.4 Magnetic Anomalies. Two methods of nondestructive detection of magnetic phenomenon on a microscopic scale have been applied to the rail wheel defect problem. They are the Barkhausen effect and the magnetic perturbation method.

The magnetic perturbation technique is presently the basis of a system offered by one manufacturer for detecting wheel failures. The technique consists of a magnetic tape which sweeps past wheels being examined. The sensing tape is continuously being imprinted with an alternating field signal. Any wheel defect which carries with it a residual magnetic field will then alter the tape signal. Reading the tape after it has passed a magnetic anomaly in a wheel can then be used to confirm the integrity of the wheel. This system may be evaluated as an operating failure detection system in the near future.

The Barkhausen effect has been used to assess the stress state of defective wheels. Although the technique is primarily a detection scheme which operates on a microscopic level, Southwest Research Institute has shown in a recent study (13) that signal-to-noise output may allow the technique to be applied to wheel failure analysis. Discontinuities in small magnetic field domains provide a magnetic signal which is sensitive to applied stresses in the wheel. The level of the Barkhausen signal is proportional to the applied stress. The technique, now only in the laboratory stages as a failure detection scheme, has yet to be proven for full-scale field operation.

4.2.5 Alternate Detection Schemes. Table I consists of a list of alternate detection schemes which are not primarily designed for rail applications but have been used in nondestructive testing. The table includes their possible

TABLE I

ALTERNATE DETECTION SCHEMES

Detection Technique		Potential or Past Usefulness to Rail Industry
1.	Television Cameras	Allow multipoint scanning by one person of known trouble spots in railyard or system. Coupled with fast scan and hold electronics, this system would allow "fly by" review of some railcar defects.
2.	Thermal Television Scanners	Provide full thermal map of train cars as they pass by in color output display. Could possibly pinpoint overheated wheels/ bearings or leaking hose couplings.
3.	Dye Penetrants	Used to enhance detection of small visual surface cracks in metal. Usually lab applications. Presently used in some railroad inspection procedures.
4.	Radiography (X-Ray or Neutron)	Detection of subsurface abnormalities in metal structures. Laboratory only.
5.	Acoustic Emission	Metal structure ultrahigh frequency acoustic energy release. For determining abnormal stress points in metals. Stationary components only. Requires cyclic stress application.
6.	Magnetic Particles	Location of surface defects in some metals. In shop use only.
7.	Eddy Current Probes	Displacement/speed pickup sensor. Might be incorporated in electronic limit switching for possible rockoff detector.
8.	Gas Leak Detectors	Primary monitor for structural tank car flaws, but possibly used for improper brake hose connections. Could be aromatic, sonic, or pressure sensitive in design.

(TABLE I)

	Detection Technique	Potential or Past Usefulness to Rail Industry
9.	Capacitance Measurement	Car presence, displacement sensors and continuity check devices.
10.	X-Ray Diffraction	Submicroscopic metal structure analysis. Laboratory only.
11.	Exoelectron Emission	Metal surface crack detection. Laboratory only.
12.	Low Energy Gamma Sensors/ Sources	Wheel/car count and presence detection. Has been used in Japan.

usefulness to the rail industry even though they are not considered as strong detection candidates for any specific rail application.

4.3 Consideration for a Wayside Dynamic Inspection System

The dynamics category has been identified as one which is associated with a large number of freight car derailments. Accordingly, there is a need to detect these dynamic malfunctions before they develop to the derailment stage. A discussion of approaches for such detection by wayside devices is presented in this section. The discussion is an overview--eventually, specific devices or technologies need to be developed. Such development is beyond the scope of the present contract and, accordingly, should be addressed by future work.

Wayside devices designed to detect freight car malfunctions in the dynamics category can, in general, measure several kinds of quantities for the car. The first kind of quantity is geometric in nature. Included are distances and angles. The measurements can be for various car or truck dimensions or for car or truck displacements. The second and third kinds of quantities are velocities and accelerations. The last kind of quantity comprises forces and moments. These forces and moments can be those on the entire car, on a truck, on a wheelset, or on an individual wheel.

With a wayside device, it is generally easier to measure forces and moments acting on a freight car than it is to measure most of the other kinds of quantities. Measurement of the first kind of quantity typically involves first determining the location of some point or points on the car relative to a known reference frame. This can be difficult to accomplish reliably, especially in view of the large variety of freight car configurations which are in common use. Once the position of the point or points has been established, measurements of angles or displacements must be made. These measurements can be more difficult than the original reference point determination. Also, they can be made more difficult because of the motion of the car; and, in some cases, by the need to have mechanical contact between the car and the measuring device.

Measurement of the second and third kind of quantity is generally more difficult than measurement of the first kind. Schemes to measure, say, forward velocity of the car can be rather straightforward. However, it is not at all clear how one might measure, say, vertical velocity or roll angular velocity of a moving freight car by a wayside device. Wayside measurement of the corresponding vertical or roll angular acceleration is even more difficult.

The above considerations suggest that a wayside device for detecting dynamics-related malfunctions in freight cars should measure, primarily, forces and moments. There is another reason why force and moment measurements are preferable to displacement and angular rotation measurements. This reason is that motions of a freight car need not be directly related to its derailment potential. The roll motion of the car can be considered as an example. In Reference (14), it can be seen that one 100-ton hopper car can roll 5 degrees without wheel lift; while another car exhibits wheel lift at 4½ degrees. This difficulty of using roll angle as a derailment indicator is addressed specifically in the discussion of the paper. In contrast, the paper describes a force and moment measurement criterion to indicate reliably the lifting of a wheel.

In addition to the kinds of quantities to be measured, the type of measurements to be made must be considered. For the dynamics category, dynamic or static measurements can be made. The dynamic measurements involve those in which the signal varies appreciably with time. A finite portion of the time-varying signal must be measured. The signal, for example, can be the vertical force of the track on a wheel. The use of the signal can be in the frequency domain, for which FFT (Fast Fourier Transform) or other similar techniques can be employed. The time-varying signal can be produced by unstable motions of the car or by naturally or artificially-produced input forces to the car.

Static measurements involve those in which the time variation of the signal is small. These measurements, consequently, involve only a single "snapshot" of the signal. The signal can be produced by any steady force (centrifugal force, lateral c.g. offset, superelevation, constant buff force, etc.).

It is evident that the static measurements are considerably easier to make than are the dynamic measurements. For example, for a wayside device to measure dynamic forces, forces of the track on the wheels at several instants of time must be measured. During this time, however, the train has moved a certain distance. Consequently, many locations need be provided to obtain the time-varying signal. For the static measurement, a single measurement of force is sufficient.

Another difficulty is associated with the time-varying signal. This difficulty is the association of the signal with dynamic malfunctions of the car. Suppose, for example, that a known input to the car has been provided. Such an input could be produced by a wavy track having known characteristics. The time-varying vertical load of the track on the wheels is measured. From this information it is required to determine whether the car is defective in some sense. The problem is, therefore, one of system identification; i.e., from the known inputs and outputs, what are the characteristics of the dynamic system (the freight car). Even for a linear system, this problem is difficult and not amenable to direct, closed form solution. In addition, the freight car system is nonlinear--thereby compounding the problem considerably.

The above suggests that an initial approach to the wayside detection of dynamics-related freight car malfunctions should involve static measurements of forces and moments. It is recognized that such an approach inherently precludes the possibility of detecting several types of freight car problems. These problems include instabilities, resonances, etc. Nevertheless, the information obtained from static measurements could provide information related to these problems as well as information on other malfunctions in the dynamics category, Consequently, a discussion of the potential of static measurements is given below.

For the purposes of the present discussion of static force measurements, consider the following situation. A freight train is moving at constant speed on an inclined curved track. The radius of curvature is constant (at least for the arc length corresponding to a car length) and is known. For simplicity, there is no track superelevation. The freight car under consideration is passing over an instrumented section of the curved track. The speed of the train is measured. Also measured are the wheelbase* and all six forces and moments of the track on each truck*.

For this situation, six unknowns exist. These unknowns are the magnitude of the buff force at the front of the car, the magnitude of the buff force at the rear of the car, the car mass, and the location of the mass center for the car (three coordinate unknowns). From static equilibrium conditions, six equations exist. Consequently, the six unknowns can be obtained. Specifically, the upward (perpendicular to tracks) force and yaw moment equations yield the car mass and the longitudinal c.g. location. The pitch moment, roll moment, lateral force, and longitudinal force equations then provide the vertical and lateral c.g. locations and the buff forces.

Once the six unknowns have been obtained for the freight car, they can provide diagnostic information. For example, the ratio of the lateral location of the c.g. to the vertical location of the c.g. is related to improper loading, side bearing problems, and truck springing problems. The difference in the buff forces can give an indication of the wheel bearing friction and the drag (if any) of the brakes.

The force and moment measurements at each truck can also provide useful information. The couple on the truck from the tracks along the upward axis must, in steady state, be equal to that of the car on the truck. This latter couple is produced by center plate friction so that the measured couple can be used for a stiff truck diagnosis. The ratio of lateral force to upward force can also be useful. Such a L/V ratio is commonly used to assess the potential of a wheel to derail.

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* The wheelbase can be obtained from the train speed and the time for the rear truck to reach the force measuring station after the front truck has reached the station.

The three forces and three moments of the rail on each truck result from a complex force distribution at each of the four wheels. If the composition of this force distribution can be obtained, more information on the dynamic health of the car can result from the static measurement approach. Such information would relate to wheel wear, truck clearances, etc. A consideration of the forces on an axle reveals how such information might be produced.

When an axle rolls around a curve, it tends to yaw away from the turn and to ride offset towards the outside of the turn. The yawed position results because the inner wheel moves a shorter distance along its rail than does the outer wheel. Consequently, the inner wheel tends to "overrun" the rail while the outer wheel tends to "drag" on the rail. Although wheel taper can reduce this effect, the axle rotates slightly to the outside of the turn. The extent of this yaw is influenced by the ability of the truck to skew. Once yawed, the wheels are no longer pointing in the direction they are moving. The slip angles thereby formed produce lateral forces at the wheels. These lateral forces push the wheelset to the outside of the turn. The result of both effects is that the front and rear outside (of the turn) wheels of the truck may make flange contact with the rail (15). Consequently, for a new wheel the forces of the rail on the wheel could involve, for example, a radially outward force at the wheel tread and a radially inward force at the wheel flange. For a sufficiently worn wheel, only one point of contact occurs (16). The flange and tread forces are, therefore, no longer separate and distinct quantities.

The above discussion indicates that the distribution of the rail/wheel forces is a function of the wear of the wheels and the skew flexibility of the truck. Consequently, information on wheel wear and skew flexibility might be obtainable from measurements of the force distribution at the wheel-rail interface. However, it is apparent that significant measurement and analytical problems are associated with any such technique.

In summary, the following should be considered with respect to any wayside system whose intent is to detect dynamics-related malfunctions in freight cars:

1. It is generally easier and probably more useful to measure the forces of the rails on the car than to measure the motions of the car.
2. It is generally easier to measure static forces than forces which vary with time. The use of static forces precludes the detection of some significant dynamics-related freight car conditions. However, the use of dynamic forces to determine these conditions is, at best, difficult analytically.
3. More information on the condition of the truck and wheels can be obtained if, rather than measuring the six steady state forces and moments on the truck, the steady state force distributions on the individual wheels are measured. Such localized force measurements, however, are considerably more difficult than the measurement of the six resultant forces and moments.

4.4 Summary of Wayside Systems Versus Derailment Cause

The availability of wayside detection systems is summarized in three ways. Table II relates the defect to be detected to whether the system is commercially available or developmental in nature, along with the estimated number of U.S. manufacturers/developers.

Figure 15 assigns wayside system to the listing of the top 20 individual (pre 1975) cause codes that have historically accounted for 60 percent of the derailments over the last ten years.

Table III ranks the most important cause code groupings as developed in Section 2.0 which account for 80 percent of the damage due to equipment-caused derailments, lists the actual damage costs for the last eight years, and summarizes whether there is an available system or one under development. This table shows that there are available systems to detect defects that account for 33 percent of the damage cost. There are systems under development that could possibly detect defects that account for 12 percent of the damage. There does not exist systems to detect 55 percent of the damage.

TABLE II

WAYSIDE SYSTEMS

Defect Description	Detector Type: Commercial	Detector Type: Developmental or Rail Company	Estimated Number of U.S. Manufacturers/Developers
Hot Bearings	Hotbox Detector		5
Wheel Defects	Overheated Wheel		1
	Broken Flange		1
	Loose Wheel		1
	Ultrasonic (Pulse Echo)		1
		Ultrasonic (Anomalous Propagation)	1
		Acoustic Signature	1
		Magnetic Anomaly	1
		Dynamic Load	
Dragging Equipment	Swinging Gages		6
	Photo Optic		
High & Wide Loads	Clearance Sensors (Optical)		2
Car Presence	Highway Crossing Barriers		9
	Inductive Coil Loop		-
	Conductivity		-
		Gamma Ray (Source/Receive)	-
High Water		Buoyant Floats	1
Shifted Load	Mechanical Detection		1
	Light Beam		1
Other	---------	---------	-

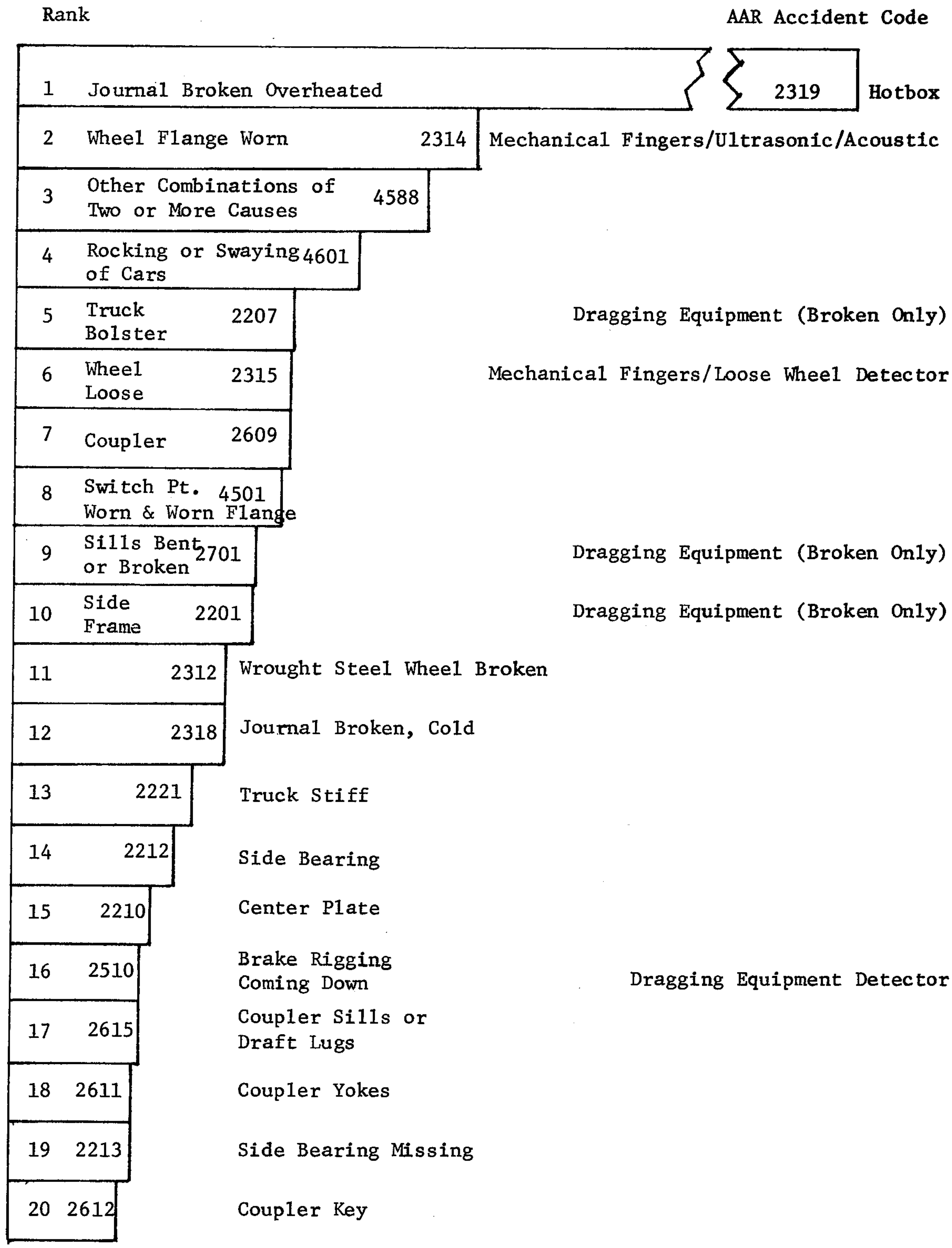

Fig. 16 Wayside Detection Schemes of Twenty Most Frequent Accident Types; Chart Accounts for 60% of All Derailments Classified

TABLE III

SUMMARY OF WAYSIDE INSPECTION SYSTEMS

APPLICABLE TO THE SEVEN MAJOR CAUSE CODE GROUPINGS

Cause	Damage (Millions of Dollars)								Wayside Inspection System
	1967	1968	1969	1970	1971	1972	1973	1974	
1. Journals	13.3	16.1	20.3	13.0	11.1	9.1	9.5	12.5	Hotbox Detector
2. Dynamics	4.4	4.6	5.0	4.3	5.3	6.3	7.8	10.0	None Available
3. Wheels	3.4	5.2	4.3	2.8	4.2	3.5	5.2	6.2	In Track Ultrasonics Wheel Banger Magnetic Anomaly
4. Flange & Loose Wheel	1.8	2.1	3.0	3.3	5.1	3.2	2.9	4.1	Mechanical Fingers Loose Wheel Detector
5. Couplers - Pulled Out	2.2	2.4	2.5	2.5	1.4	3.0	3.9	4.7	None Available
6. Bent & Broken Truck Side Frame & Bolster	4.0	3.7	3.7	2.6	2.1	1.6	3.4	3.2	None Available
7. Air & Bad Brakes	1.9	2.5	2.4	1.5	1.7	2.1	1.4	3.0	Dragging Equipment Detector

5.0 WAYSIDE INSPECTION SYSTEM REQUIREMENTS

Attempting to analyze the cost benefit ratio of any given wayside detector system is extremely difficult. The data shown in this report on the cost of derailments includes only damage to way and equipment and does not include the damage to lading, the cost of clearing the wreck, the cost of delays, or the intangible cost of lost business due to unreliable service. On the benefit side of the ratio, many developmental systems do not have hard facts on the ratio of defects identified to defects missed or the false alarm rates.

A method has been selected, however, that will allow an assessment to be made of the cost benefit requirements of a new system that should be relatively correct when compared to the railroad experience with the hotbox detector. In this section of the report, therefore, the hotbox detector will be analyzed as to its effectivity, cost, and savings accrued. The cost will not address the operation and maintenance cost, but rather original cost. The savings achieved will be on the basis of damage to way and equipment. These results can then be used as a basis for the analysis of other systems.

5.1 Evaluation of Hotbox Detector

The hotbox detector is the most universally applied wayside detection system in use. There is general agreement among railroad personnel contacted that the system is valuable and significantly reduces the occurrence and the cost of derailments due to overheated journals. The hotbox detector is evaluated in detail in this report for three reasons:

1. To verify the value placed on hotbox detectors.
2. To determine a guideline for the cost benefit ratio that is acceptable to the railroads.
3. To extrapolate today's experience and cost benefit ratio into the future when almost all bearings will be roller bearings.

Data for this analysis has been taken from many sources. They include:

1. Hotbox detector manufacturers.
2. Magnetic tape data on FRA reported accidents - 1967-1974.
3. Published FRA Accident Bulletins - 1963-1974.
4. AAR - Yearbook of Railroad Facts.
5. Pocket List of Railroad Officials.
6. Published papers

   and most importantly,

7. Data furnished by several railroads covering journal failures, hotbox set outs, and spacing of hotbox detectors.

The data obtained from the individual railroads are treated confidentially; in many cases lumped together to allow the presentation of the results of analysis of these data without publishing the actual data received.

Definitions of the various terms used in reporting data are stated here to insure uniformity. They are:

Term	Definition
Overheated Journal Derailment (Reported)	A derailment caused by an overheated journal in which the damage to track and equipment exceeded $750 (up to 1975). Does not include cost of clearing the wreck, delay costs, or lading costs.
Journal Failures	Any journal failure, derailment or not, that was not set out prior to failure.
Stopped Trains	A train that is stopped due to a hot-box detector indication of a suspected overheated journal.
Set Outs	A car that is set out after inspection by train crew. Enough evidence is available to indicate an overheated journal or, conversely, lack of enough evidence that the bearing was not damaged.

-Continued-

Term	Definition
Confirmed Setouts	A car that has been set out and a later examination by the mechanical division confirms that the bearing was overheated or damaged.
AAR Reported Set Outs	Generally, the same as confirmed hot-boxes although it is not clear if this is a universal usage in the industry.
Plain Bearing	The older type - oil-lubricated, fluid-film bearing.
Roller Bearing	Predominantly, a double-row, tapered-roller bearing, grease lubricated.
Train Mile	One mile of travel for a freight train.
Car Mile	One mile of travel for a freight car. (Car miles = train miles x # of cars in train).
Gross Tone Mile (GTM)	One mile of travel of a gross ton. (GTM = train mile x train gross weight).

Figure 16 is a plot of the reported derailments due to overheated journals per billion car miles for the years 1964 through 1973. This shows that the industry average dropped from 15.53/billion car miles to 9.37/billion car miles in a ten-year period ending 1973. At least two reasons could be quoted for this decrease: the increased use of hotbox detectors and the decreasing percentage of the population that consists of plain bearings. Figure 17 is a dual plot of the number of hotbox detectors in use in the United States versus year and also the percentage of the total bearing population that consists of plain bearings. This is about as far as one can go based on normally available data. In order to investigate further, data on the way journal failures are split between plain and roller bearings, the costs associated with the journal failures, and the specific relationship between the point of failure, the last hotbox detector, and the spacings utilized by given railroads for hotbox detectors is required. This type of data has been made available to Shaker Research for analysis.

First, it might be well to determine the typical operation of a hotbox

Fig. 17 Derailments Caused by Overheated and Broken (Cold) Journals Per Billion Car Miles Versus Year

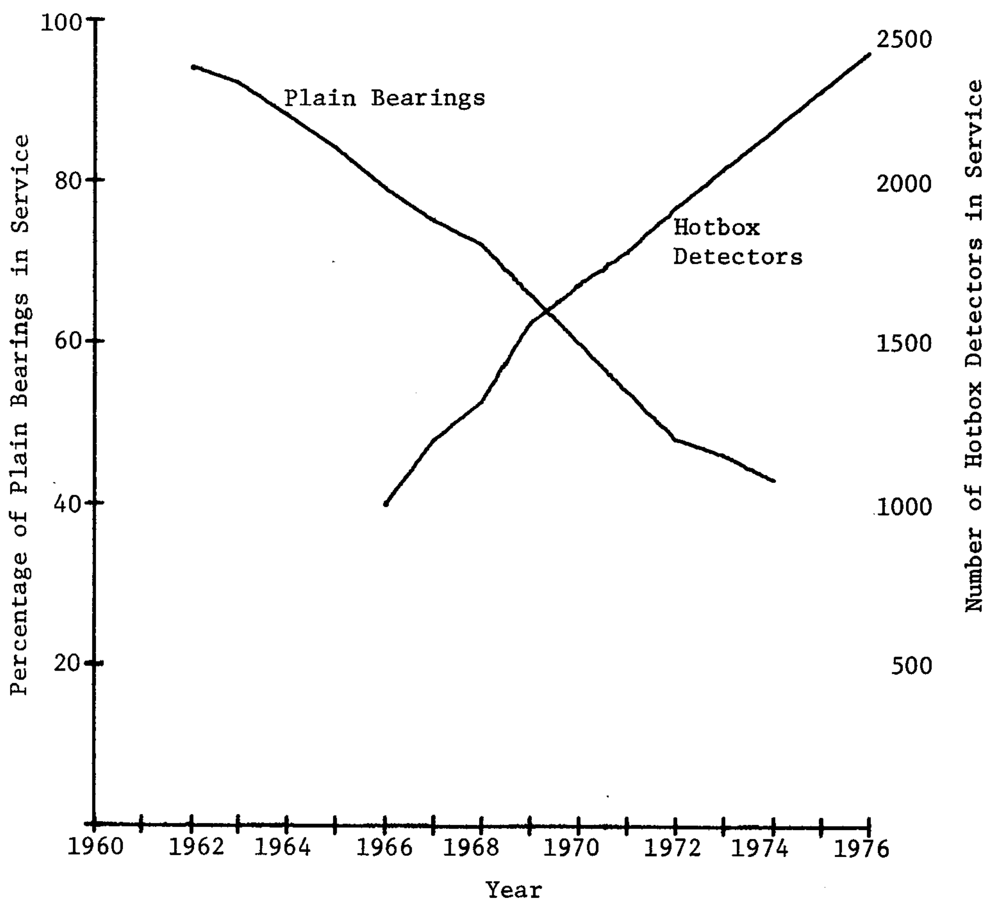

Fig. 18 Plain Bearings and Hotbox Detectors in Service by Year

detector system in the railroad industry. Based on railroads with well-developed hotbox detectors in which main line spacing ranges from 30 miles to 45 miles, the following experience has been gained.

Between 65 and 70 percent of all trains stopped, where the bearing is examined by the crew, the car is set out because there is sufficient doubt about the condition of the bearing. The reason for the 30 to 35 percent false alarm rate is due to several factors. Chief, of course, is the justified approach that it is better to err on the safe side than to chance a derailment. Other factors that contribute include data transmission noise on the system between the hotbox detector and the point at which the strip chart is read. This can cause unwanted spikes or a section of data could be lost in which case the safest action is to stop the train for crew inspection. Finally, normal readings for plain and roller bearings are different as is the decision level for stopping a train. In most cases the strip chart reader can tell the difference between bearing types by comparing a given bearing with others on the same car. In some cases a mistake in identity can result in stopping a roller bearing when it was identified as a high reading plain bearing.

Different railroads have different procedures; some give the train crew the discretion to continue on after inspection if they believe the bearing to be okay. Other railroads allow very little train crew discretion and a warning results in a set out. The procedure selected here will be to allow the train crew to continue the car in service if the hotbox warning does not seem justified.

After a car has been set out by the train crew, personnel of the mechanical division of the railroad go to the set out site. They inspect the bearing and have two options: they may return the car to service if they do not confirm a bearing defect, or they may replace the wheel/axle containing the defective bearing. Approximately 30 percent of the bearings examined are returned to service as acceptable. This large number of bearings returned to service after the crew has inspected the bearing and had enough cause to set it out may seem strange. The primary reason for this number is due to roller bearings. When a train is stopped and a crew inspects the suspect bearing, if it is a plain bearing, the box cover may be lifted and the actual bearing surfaces seen as well as the oil level in the box. It is relatively straight forward to determine if the bearing is good or bad. If the bearing is a roller bearing, on the other hand, only external inspection is possible. Unless the seals have opened and large amounts of grease sprayed out of the bearing, the crew can only go on the fact that it feels hot. The net result of this lack of ability to adequately inspect a roller bearing is that the car will be set out rather than take a chance of putting a defective bearing back into service.

In spite of the large number of defective bearings that are removed from service by the hotbox detector, bearings still fail and cause at best the stopping of the train for maintenance on a main line; or at worst, cause a derailment with the possibility of high damage costs. Of the bearings that fail, three categories may be defined. Those that indicated a high reading at the last hotbox detector and were in the process of being stopped but failed before the car could be set out. Another category are those bearings that passed a hotbox detector and did not indicate a high enough reading to stop the train but subsequently failed. The last category is those bearings that failed but did not pass a hotbox detector. The latter case is more common on branch lines which have relatively few hotbox detector installations. The number of these failures is approximately 2 to 4 percent of the number of confirmed set outs for railroads with well deployed hotbox detector systems. More importantly, of the failed journals, roller bearings account for only about 8 percent of the total.

To summarize the operation of the hotbox detector and to evaluate the results of changing spacing, a hypothetical railroad has been constructed. This railroad has well deployed hotbox detectors spaced approximately 30 miles apart. For this railroad, the hotbox detector is responsible for stopping 1,000 trains per year.

Figure 19 is a flow chart for this hypothetical railroad. Data on the splits between paths have been developed from hard data furnished, although the

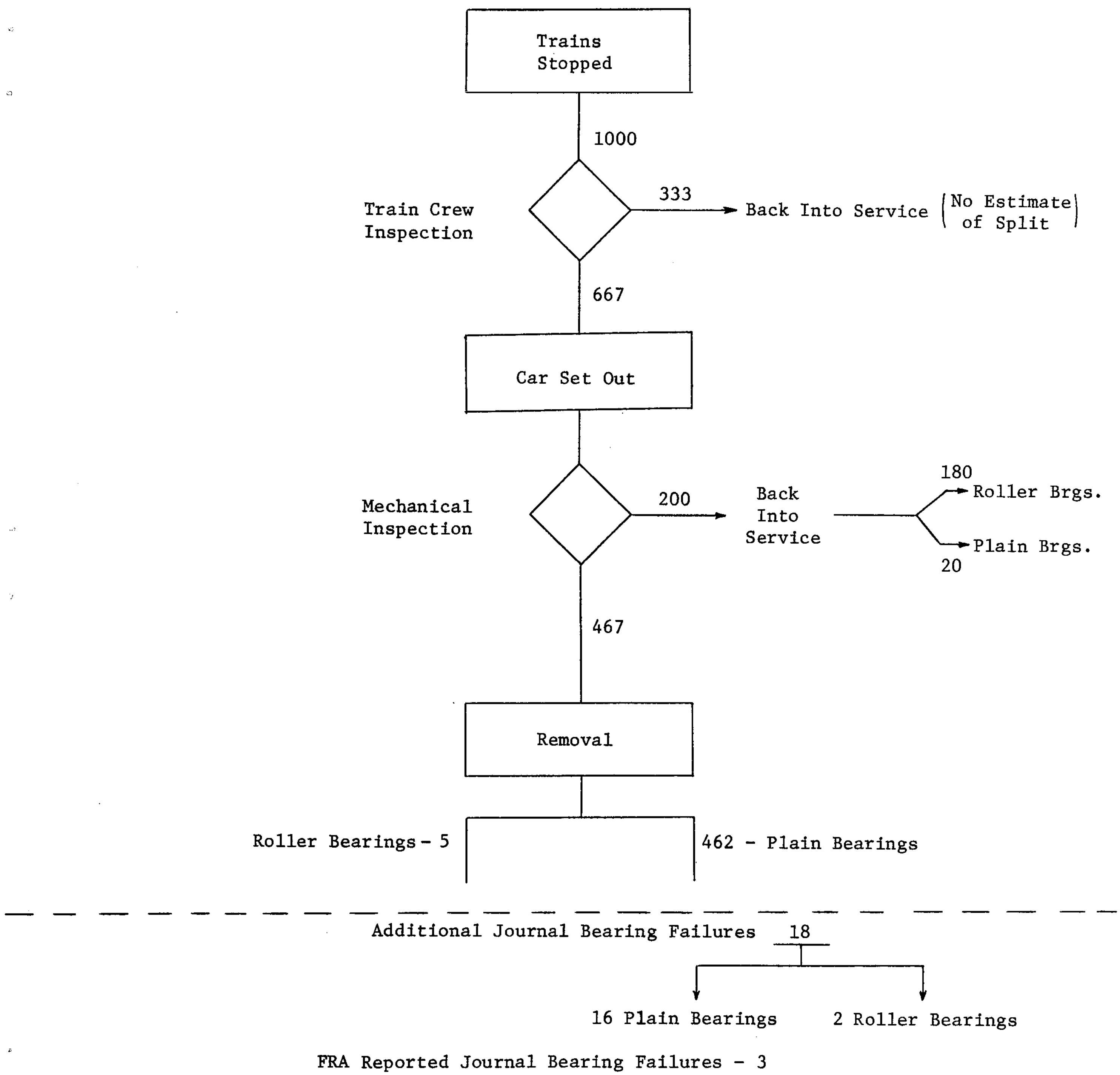

Fig. 19

Flow Chart for Hypothetical Railroad ≈ 30 Mile Spacing sample of railroads is very limited. Data on the relative population of roller and plain bearings for those put back into service and those removed are based on very limited data plus conversations with railroad personnel. The population of plain and roller bearings is based on data from a limited railroad population. The relationship between FRA reported derailments to total journal failures is again based on a very small sample of railroads.

Obviously, errors can be present because of the population of the data base. It still seems advisable to proceed with limited data, however, since it will allow comparison of other wayside inspection system candidates to the hotbox detector. Although the cost of false calls is not calculated, it should be included in the cost of operating the wayside system.

Data available on the location of the journal failures relative to the location of the last hotbox detector and the reading of that detector has been analyzed along with the cost of these failures, including in some cases the cost of clearing but not cost of delay.

For the population of failed journals, 27 percent had passed a hotbox detector and the train was in the process of being stopped; 44 percent had passed a hotbox detector but high readings were not obtained and finally, 29 percent had not passed a hotbox detector. Figure 20 is a bar chart for those bearings that had passed a hotbox detector relating the percentage detected versus mileage from the last detector.

It is easy to misinterpret Figure 20 and conclude that hotbox detector spacings should be 15 miles. If the data is further analyzed and based on earlier example of 1000 train stops shown in Figure 19, the effect of doubling the number of hotbox detectors is put into the proper perspective. A detailed analysis of the data are shown in Appendix D.

For thirty mile spacing, the breakdown of the 18 failed bearings would be; 5 failures in the process of stopping, 8 failures that passed a hotbox detector but were not detected and 5 failures that had not passed a hotbox detector. For fifteen mile spacing, the breakdown of the 18 failed bearings

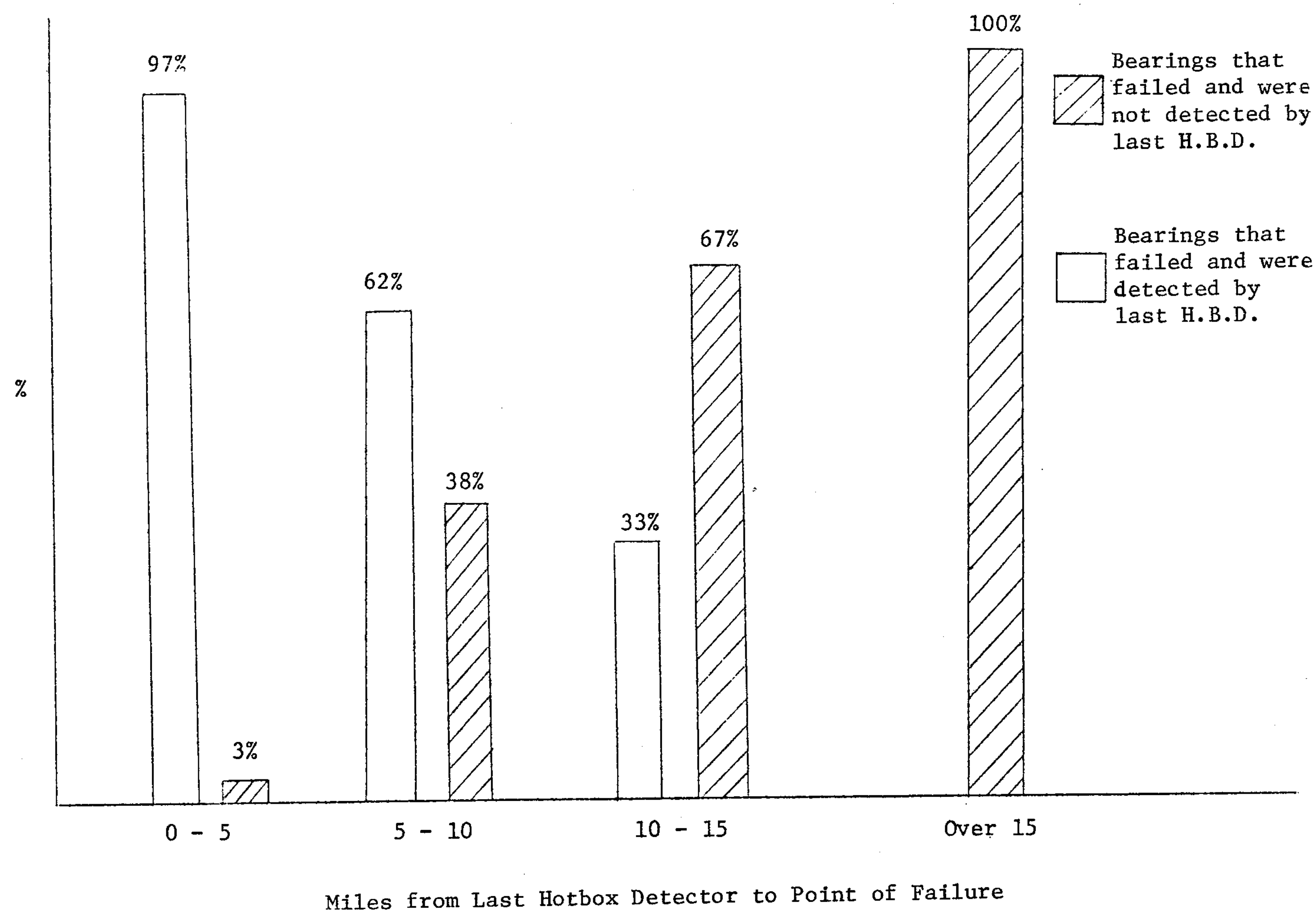

Fig. 20 Relationship between Detected Hot Boxes and Miles from Last Hot Box Detector. Cross-Hatched Bars are Those Not Detected By Last Hot Box Detector.

would be 11 failures in the process of stopping, 2 failures that passed a hotbox detector but were not detected and the same 5 failures that had not passed a hotbox detector. This assumes the worst case that none of the 18 failures occurring for 30 mile spacing would have been successfully setout by the hotbox detector spaced at 15 miles. It also assumes that no new hotbox detectors are placed on branch and low density lines.

Cost of journal failure for those cases where the train crew had been warned and the train was stopping show an approximate cost per failure of about $2,000. The average cost of the failure without warning is $13,000. If the spacing were reduced to 15 miles, the cost of the present hotbox detector deployment would increase by a factor of two.

TABLE IV

COMPARISON OF COST/BENEFIT FOR SPACING OF 15 MILES AND 30 MILES FOR HOTBOX DETECTORS

	Railroad A Hotbox Detector Spacing 30 Miles	Cost for Those That Failed	Railroad B Hotbox Detector Spacing 15 Miles	Cost for Those That Failed
Confirmed Set Outs and Trains in the Process of Stopping	472	$ 10,000	478	$ 22,000
Missed Calls Resulting in Journal Failure	13	$169,000	7	$ 91,000
		$179,000		$113,000
Effectiveness	97.3%		98.5%	

The increased expenditure required to double the number of hotbox detectors in use would only result in a yearly saving to the railroad of $66,000. Clearly then, to attempt to improve the effectiveness of the hotbox detector by reducing spacing to 15 miles is not an economically viable option.

An initial analysis was done comparing the derailments per billion car miles for railroads which have hotbox detector spacing between 30 to 45 miles with the national average calculated earlier. For three railroads with low spacing, the average for 1973 was 3.24 derailments per billion car miles versus the average for all railroads for that year of 9.37 derailments per billion miles.

The hypothetical railroad shown in Figure 18 was based on data from railroads having hotbox detector spacing in the 30 mile range. This would mean that this railroad would have approximately 1.0 billion car miles per year based on a derailment rate of 3/billion car miles. If the railroad had the national average of reported derailments per billion car miles, it would have had 9.37 reportable derailments. If the average of six times the number of reportable derailments equals the total number of journal failures, then the railroad would have experienced 56 journal failures. These failures would cost an average of $13,000 each (assuming that the number failed within 5 miles of a hotbox detector would now be negligible).

A comparision of the cost of failure of the three railroads with hotbox detector spacing of 15, 30, and 85 miles is shown below.

	Spacing	Journal Failures	Failure Cost
Railroad A	30 miles	18	$179,000
Railroad B	15 miles	18*	$ 91,000
Railroad C	85 miles	56	$728,000

The failure cost does not include clearing cost and estimates have been made that this could increase the cost by a factor of 2 to 3. Assuming that a railroad with approximately 1.0 billion car miles would consist of about 7,000 miles of main line, 85 mile spacing would give 82 hotbox detectors and 30 mile spacing would result in 233 hotbox detectors. A typical purchase price for a basic hotbox detector is $15,000. Therefore, the cost of purchasing the additional 151 hotbox detectors would be $2.265 million. Com-

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* Again, as stated earlier, the number of failures were assumed to be the same. The cost saving results because more of the failures occurred after the train was warned and in the process of stopping.

paring railroad A and C, this would result in an annual saving of $549,000 in failed bearing costs. This results in a payback schedule of slightly over four years.

The goal of many railroads is to deploy the hotbox detector at approximately 30 mile intervals on the main line. The economic consideration must, therefore, be acceptable to the railroads in which the investment--exclusive of operating costs--is recovered in four to five years.

Of course, several simplifications have been made in the above analysis. One is that the cost analysis has balanced purchase price of hotbox detectors against derailment caused damage to track and equipment. A tacit assumption has been made that the additional cost associated with installation, maintenance and operation of the hotbox detector would be balanced by the savings due to costs associated with clearing the wreck, damage to loading, delay and the intangible cost of reduced reliability. Data to examine this latter balance was not available.

One additional simplification should be noted. The 30 mile spacing that has been used is an average. Actual spacing is determined by many factors such as traffic density, speed limit, upcoming structures such as tunnels and availability of sidings for car setouts. Taking all these factors into account probably means that a railroad is adequately protected with average spacing between 30 and 40 miles. (See Figure 15.)

Finally, if the case for the hotbox detector is examined in the future, when almost all bearings in the main line service are roller bearings, some tentative conclusions can be made. If all bearings shown in the flow chart in Figure 18 for our hypothetical railroad were roller bearings, then we might expect there would be on the order of 10 bearings removed from service due to hotbox warnings and an additional 4 roller bearings would fail in service on the line. The first thing that is apparent is that either the reject limit or some part of the procedure must be changed since it would be unacceptable to stop 1000 trains to catch 10 in-process failures while missing 4 others.

Although data furnished to Shaker Research Corporation was very limited with regards to roller bearing failures, it could be compared to a statistical analysis of plain bearing failures to see if any changes could be detected. The approach is included in Appendix D. In brief, the analysis fitted available data to a Weibull failure distribution that had been rewritten in terms of hotbox detector spacing. Three variables come out of the analysis:

- α the bearing characteristic life, life for which 62.3% will have failed after temperature has risen to the setout limit
- β Weibull slope
- s detector spacing to insure, with 90% confidence, that all initial failures will be observed

Bearing	α (Upper and Lower 90% Confidence Band)	β (Confidence)	s at $P_r = 0.9$
Plain	32.7 miles (30.4 - 34.9)	3.03 (2.72 - 3.41)	26.2 miles
Roller	36.4 miles (29.5 - 44.9)	1.45 (1.12 - 2.05)	15.7 miles

Admittedly, the confidence levels are wide for the roller bearings due to limited data; however, the results indicate that the spacing of the hotbox detectors for roller bearings would have to be sixty (60) percent that for plain bearings for a ninety (90) percent chance of observing a defective bearing.

Additional data must be gathered to investigate this point, however, the two analysis methods have shown that a basic conflict between two goals may exist. On the one hand, it appears that for an all roller bearing population, hotbox detector spacing should be reduced if the same percentage effectivity is to be maintained; while on the other hand, the number of failed bearings will be reduced to the point where the cost/benefit ratio will not be favorable--especially if the very high false alarm rate continues.

5.2 Cost Analysis - Candidate Wayside Systems

The average number of derailments due to burned off journals for the year 1973 was 9.37 derailments per billion car miles. The average for three railroads that employed spacing of approximately 30 - 40 miles was 3.24 derailments per billion car miles. Assuming that there are 2400 hotbox detectors deployed, the average spacing is 85 miles for main line track in the U.S. These are reportable derailments in which the average cost per derailment over the last eleven years was $32,760. In the preceeding section, a figure of $13,000 was used, however, this was based on the cost of all journal failures reportable (over $750) and not reportable (under $750). Equivalent data (reported and unreported derailments) are not available for the six other derailment causes to be analyzed so, therefore, the comparison in this section will be made on the basis of the average cost of reported derailments.

It is now assumed that if there were no hotboxes deployed, the derailment rate would be approximately 20 derailments per billion car miles. This is based on the present rate for railroads with very large spacing and also the rate for 1958 which was 22.7 per billion car miles. If all railroads were to install hotbox detectors at 30 - 40 mile intervals, the rate of derailments would be reduced to somewhere around 5.0 derailments per billion car miles. For 1973, this would mean the difference between 625 (20 per billion car miles) to 156 (5 per billion car miles). This would, of course, require the installation of 5800* hotbox detectors versus the 2400 now installed.

An acceptable criterion for the cost/benefit ratio of a wayside system can be stated as a payback period of approximately 5 - 6 years.

The payback period is calculated as follows:

Purchase Price, HBD ($15,000 x 5800) = $87 million
Annual Saving (469 derailments x $32,760) = $15.4 million

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* Assumes 204,000 miles of main line track and 35 mile spacing.

Factors not accounted for in this calculation are the added cost of operation and maintenance of the hotbox detector and the added savings if damage to loading, clearing costs, and delay were included.

If it is also assumed that any successful wayside system should achieve the same reduction in derailments, approximately 75 percent of derailments prevented has been assumed for the hotbox detector, then a table may be constructed to determine dollars available for purchasing wayside detection systems for the other six cause groupings identified. This is shown in Table V.

The flange and the brake category must be viewed in a slightly different manner than the other four groups since there are wayside detectors already deployed to pick up some types of defects. Data were not available on the effectiveness of the worn flange, loose wheel, and dragging equipment detectors so the available dollars should be to obtain improved system or greater deployment and/or improvement of existing systems.

The use of the projected five year savings as available dollars for the purchase of wayside systems is only half the story. The required spacing between the wayside systems is the other half. For example, if the dynamic wayside inspection system must be placed at the same intervals as a hotbox detector, then 5800 would be required and the allowable cost for each would be $5,700. If 500 miles spacing would be adequate, then the allowable purchase cost would be $81,030.

5.3 Wayside Inspection Systems Deployment

Deployment requirements of a wayside detection system depend on the type of failure that the system is designed to detect. In the case of the hotbox detector, it has been found that for plain bearings, an approximate 35 mile spacing will catch most of the overheated journals before catastrophic failure. This optimum distance was probably determined from experience with the hotbox detector in service rather than extensive time to failure tests. The overheated plain bearing is a unique type of malfunction in that it gives a short but adequate warning before catastrophic failure.

TABLE V

AVAILABLE DOLLARS FOR WAYSIDE SYSTEMS

Cause	Derailment Reduction *	Average Cost/ Derailment **	Yearly Saving (Millions)	5.5 Year Saving (Millions)
Dynamics	392	$15,340	$6.01	$33.06
Wheel	92	$36,620	$3.38	$18.59
Flange	211	$12,380	$2.61	$14,36
Couplers	168	$14,760	$2.48	$13.64
Bolsters and Side Frames Bent and Brakes	87	$28,320	$2.46	$13.53
Brakes	105	$16,340	$1.72	$ 9.46

* Based on 75% of the 1973 derailments

** Based on an 8-year average

Many of the other freight car defects are entirely different in nature. Some, such as dragging brake equipment, do not have a predictable time to catastrophic failure and in fact may eventually fall off without causing any accident. A worn flange may be detected visually and will cause a derailment primarily as a chance occurrence in combination with some track condition or the presence of a switch. The presence of a critical crack in a wheel or tensile stress in the wheel rim are defects that are awaiting some event such as a large shock load to be converted into a failure and thus a derailment.

With these types of considerations in mind, the deployment of wayside detection systems may be established. The systems considered are those in use, those in development, and those that do not exist. Given the placement of these devices, then a purchase price is assigned each type of wayside detection system with the assumption that the device will be effective in reducing derailments by 75 percent. These numbers and deployment spacing are given in Table VI.

The number of major hump yards was somewhat arbitrarily taken as at an average spacing of 1000 miles for the 204,000 miles of main line track in the U.S.. The allowable cost is, of course, very sensitive to the ability of the system to reduce derailment. If, for example, the system was successful in reducing derailments due to the given cause by only 50 percent, then the allowable cost would have to be reduced by one third.

Not enough data exists to evaluate the hotbox detector for roller bearings. Initial statistical analysis based on very limited failure data indicates that the spacing will have to be smaller for roller bearings for the same level of protection. If this is true, then it may not be cost effective to expand the present system given the smaller number of derailments due to roller bearings. Initial work being performed by Shaker Research Corporation under DOT Contract DOT/TSC- 917 has shown that roller bearings with large (when compared to condemnable defects) defects such as spalling water etch, brinelled, and cracked, can be operated for 5000 miles under full load at 60 mph without a catastrophic failure. Acoustics or vibration have shown

TABLE VI

DEPLOYMENT OF WAYSIDE SYSTEMS

Defect	Detection System(s)	Deployment	Number Required for 204,000 Mile Main Line	Allowable Cost
Burned Off Journals (Plain Bearing)	Hot Box Detection	30 mile Spacing - Main Line Track	5,800	$ 15,000
Burned Off Journals	Hot Box	Not Enough Data Exists on Roller Bearing Failures to Assign Spacing and Effectivity of Hot Box Detector		
Bearing Defect Detector	Vibration	Major Hump Yards	Not Enough Data Exists to Assign Allowable Costs	
Wheels	Some Combination Ultrasonic-in Track Wheel Banger Magnetic Anomolie	Major Hump Yards	204	$ 91,127
Flange and Loose Wheels	Mechanical Fingers	Major Hump Yards	204	$ 15,500
	Loose Wheel Detection	Hot Box Detector	5,800	$ 1,930
Dynamics	Combination of Static and Dynamic Measurements	Major Hump Yards	204	$162,000
Couplers	Unknown	Major Hump Yards	204	$ 66,862
Bolsters and Side Frames	Unknown	Major Hump Yards	204	$ 66,323
Brakes	Brake Parts Coming Down	Hot Box Detectors	5,800	$ 500
	Unknown	Major Hump Yards	204	$ 32,160

some promise of being developed into a wayside system. This type of inspection would allow wide spacing between inspection stations and thus may be a candidate if the hotbox detector cannot be cost effective for roller bearings.

Most railroad personnel interviewed expressed the need for some wheel inspection system. At least three types of systems are under development; however, hard data on their effectivity is not available. It should be noted that a very large number of wheels are now removed by visual inspection of wheels. Two approaches could be considered. The first would be to spend the money to be saved by reducing wheel-caused derailments to increase the effectivity of human inspection by either adding manpower or giving the inspector better tools to aid him in the inspection. The approach at the other extreme would be to spend more than the allowable cost for an automatic wayside inspection system on the basis that it would reduce human inspection costs.

Worn flange detectors and loose wheel detectors are already in service. Therefore, the cost data may already show the effect of an existing system and, therefore, may not be valid. The number as shown justifies the installation of both the mechanical finger flange detector and the widespread deployment of the simple loose wheel detector.

The combination dynamics group has been shown to be an important cause of railroad derailments, however, no detection system is available and in fact an initial analysis made in this report has shown that it will be a difficult system to develop. The allowable cost of $162,000 however, would allow a minicomputer based system to be developed that could process a group of related in track measurements. Also implied by this allowable cost is that the railroads could afford to spend additional money to improve human inspection of the condition of the components that go into the combination dynamics cause.

No wayside systems exist to inspect either the coupler or the truck bolster and side frame. A system to make the required inspection from a wayside location cannot even be conceived so, therefore, it seems probable that any improvement in the derailment rate for these causes will be improved by human inspection or possibly some onboard system to record stress cycles and/or shock amplitudes.

Dragging equipment detectors are already in use so, therefore, the allowable cost in this category is already biased on the low side since the number of derailments due to this cause have already shown the result of system deployment. The $500 allowable purchase cost of the system deployed at the hotbox location does not cover the newer, more sophisticated systems such as the optical system that also scans for dragging equipment on the rail; however, it does cover fence type dragging equipment detectors.

While the priority assigned to the brake inspection system is the lowest of the seven derailment causes listed based on derailment damage, its priority should possibly be higher since the maloperation of freight car brakes can cause wheel damage by overheating and produce excessive buff forces on the coupler.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Equipment-related derailment causes were grouped together based on the possibility of detecting the group of defects by some common wayside inspection system. Seven derailment cause groups were identified which account for over 80 percent of the derailment costs. These groups were:

   Journal bearings
   Dynamics
   Broken and cracked wheels
   Worn flange and loose wheels
   Couplers - pulled out
   Truck bolster and side frame
   Air brakes and bad brakes

2. Failed journals have been a major cause of derailments in the past. However, the trend in both numbers and dollar damage resulting from this cause is down. This is due to two primary causes: the increasing population of roller bearings in service with their low failure rate, and the increasing deployment of hotbox detectors. Additional factors involve the improvements in plain journal bearing lubrication such as the introduction of lubricator pads.

3. The hotbox detector is a cost effective wayside inspection system to warn of potential failures in plain bearings. Based on past experience and the analysis of railroad derailment data an optimum spacing for detectors of 30 miles apart for high density, high speed main line track was determined. Since the speed of a train when it derails is an important factor in the cost of derailment, low speed limit track and low density track would probably not economically support the number of hotbox detectors required for this close spacing.

4. Not enough data was available to evaluate the hotbox detector for roller bearings, however, initial analysis indicates conflicting requirements.

Initial statistical analysis indicates the need for closer spacing for roller bearing failure detection, while the lower failure rate of roller bearings may not result in a cost effective deployment at these closer spacings. Finally, the need exists now to reduce the false alarm ratio and this need will become more urgent as the roller bearing population increases further.

5. The car dynamics group of derailment causes has passed the journal bearing cause as the major cause of derailments and has shown a steadily upward trend in both the number of derailments and the dollar damage caused by these derailments. There does not exist a wayside inspection system for this grouping of causes. Experimental data must be obtained prior to designing such a system.

6. Loose wheel caused derailments are the second most costly freight train derailments attributed to a single cause code. A simple loose or out of gage detector is available, however, wide differences in opinion exist as to its effectivity.

7. Several developmental systems are available to detect other wheel problems, however, not enough data is available to determine their effectivity and, therefore, the benefits that would be obtained by the deployment of these systems.

8. No wayside systems were discovered nor could any be postulated that would inspect for impending fracture of components such as couplers, side frames, and truck bolsters.

9. Although the total number of derailments is slightly greater for winter months, none of the seven derailment cause groups previously identified showed any significant trend with respect to month of the year.

10. The number of derailments caused by couplers and brakes increased with the length of the train. The number of derailments caused by freight car dynamics decreases significantly as the length of the train increases.

11. The conversion to new cause codes for FRA reportable derailments will cause problems in tracking certain types of derailments although in some cases the new codes are more specific; e.g., plain and roller bearing failures will now be separated.

6.2 Recommendations

1. To support Recommendations 2, 3, and 4, an experimental wayside inspection location should be established to evaluate developmental inspection systems and also improvements to existing systems. Two types of tests should be conducted on these systems. A site such as the Pueblo test facility should provide data on a systems capability from closely controlled tests. Systems should also be evaluated in a railroad working environment to determine any degradation in effectivity and also the cost of maintenance of the system when subjected to this environment. Site locations such as yard, yard entrance and main line should be evaluated to determine the proper site for each type of system.

2. The effectivity of the hotbox detector must be established for freight car roller bearings. Three approaches are recommended:

    Additional roller bearing data should be collected that relate bearing failures to the distance from the last hotbox detector on its reading to allow the calculation of failure margin of roller bearings to the same degree of confidence as for plain bearings (see Appendix D).

    Roller bearing failure progression tests should be conducted to experimentally determine failure margin.

    Improvements and modifications to hotbox detectors should be evaluated for their ability to reduce the false alarm rate of present system with regard to roller bearings.

3. Evaluation of developmental wheel inspection systems should continue to establish their effectivity and thus the cost/benefit ratio if such systems were to be deployed.

4. An experimental program should be undertaken, or existing programs such as the Track Train Dynamics Program should be monitored to provide data on track reaction forces versus the dynamic condition of the railcar. These data are necessary if an effective wayside inspection system is to be designed to detect cars that are dangerously defective in their dynamic references.

5. In cases where wayside detection systems are nonexistant or their cost/benefit ratio margined other methods of detecting defective components should be explored. On board detection systems may be applicable to certain failure modes. Also, available and new nondestructive testing techniques should be evaluated for their potential in improving the efficiency of the present human inspection process.

6. Improvements in the design of railcar components prepared in other programs should be constantly reviewed since these improvements would directly impact the cost/benefit ratio of detection systems.

7. FRA data should be analyzed to establish a method of relating pre-1975 to subsequent derailment data.

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APPENDIX A

FRA CAUSE CODE LISTING AND DATA LOCATION ON FRA DIGITAL TAPE

Table AI is the FRA cause codes in use from 1967 through 1974. Table AII shows the location and character length of the data available on the FRA Digital Accident Tape. Table AIII is the explanation of the data format as entered on the accident tape. Only the first 64 characters have been included since the balance of the data available pertain to grade crossing accidents and injuries and deaths.

TABLE AI

FRA ACCIDENT CAUSE CODES

Locomotives Other Than Steam Including Propulsion Equipment of Rail Motorcars

2101 Crankcase and air box explosions.
2102 Internal combustion engines and turbines, other failures of, or defects in.
2103 Generators and motor-generator sets.
2104 Traction motor armature bearing failure.
2105 Traction motors, other failures of or defects in.
2106 Current collection systems.
2107 Electrical control and conversion equipment (including batteries).
2108 Hydraulic, mechanical or other non-electrical power transmission to axles.
2110 Fires from short circuits or grounds in wiring.
2111 Fires from fuel or lubricating oil.
2112 Other fires, not otherwise classified.
2113 Fumes from internal combustion engine or appurtenances.
2188 Other defects on locomotives other than steam.

Trucks

2201 Truck side frame, bent or broken.
2202 Equalizer, bent or broken.
2203 Pedestal tie bar, loose or defective.
2204 Journal box, non-integral type.
2205 Journal bearing assembly, defects, including fires.
2206 Transom, bent or broken.
2207 Truck bolster, bent or broken.
2208 Truck bolster anchor, loose or defective.
2209 Snubbing device in truck bolster guides, locked, broken or otherwise defective.
2210 Center plate.
2211 Center pin, broken or missing.
2212 Side bearing, improper clearance.
2213 Side bearing, broken, defective or missing.
2214 Spring plank, bent or broken.
2215 Swing hanger broken.
2216 Swing hanger pin, broken or missing.
2217 Spring or snubber, missing or defective.
2218 Spring seat or support bar, missing or defective.
2219 Truck safety hanger, loose or defective.
2220 Truck, insufficient weight on any wheel.
2221 Truck, stiff, improper lateral or improper swivelling.
2288 Other truck defects.

Wheels and Axles

2301 Cast-iron wheel, flange broken.
2302 Cast-iron wheel, tread or rim defective.
2303 Cast-iron wheel, broken, overheating.
2304 Cast-iron wheel, broken, other causes.
2305 Cast-steel wheel, flange broken.
2306 Cast-steel wheel, tread or rim defective.
2307 Cast-steel wheel, broken, overheating.
2308 Cast-steel wheel, broken, other causes.
2309 Wrought-steel wheel, flange broken.
2310 Wrought-steel wheel, tread or rim defective.
2311 Wrought-steel wheel, broken, overheating.
2312 Wrought-steel wheel, broken, other causes.
2313 Wheel, other or unknown composition, broken.
2314 Wheel, flange worn.
2315 Wheel, loose or out of gage.
2316 Wheel, tire loose or broken.
2317 Axle, broken between journals.
2318 Journal broken, cold.
2319 Journal broken, overheating.
2387 Other defects in wheels.
2388 Other defects in axles.

TABLE AI (Continued)

Air Brakes and Appurtenances

2401 Air compressor.
2402 Air reservoir, or fittings, safety valve or check valve.
2403 Air brake control valve.
2404 Brake pipe, or fittings, broken or defective.
2405 Air brake hose, broken or burst.
2406 Air brake parts, falling off.
2407 Air brake, sticking.
2408 Air brake, defective, due to snow and ice.
2409 Air brake failure, excessive piston travel.
2410 Triple valves, lazy, dirty, or otherwise defective.
2488 Other air brake defects.

Hand Brakes, Brake Rigging and Appurtenances

2501 Brake beam, broken, disconnected, displaced, etc.
2502 Brake chains or bolts, breaking or giving way.
2503 Brake chains, kinking, twisting, overlapping, or too long.
2504 Brake hanger, broken or disconnected.
2505 Brake rod, broken, defective, or disconnected.
2506 Brake shaft, broken or defective.
2507 Brake shoe, worn, broken, or missing.
2508 Brake wheel, loose or defective.
2509 Pawl or rachet, failure or defect.
2510 Brake rigging coming down, other failure or defect.
2511 No brake on car.
2512 Insufficient braking power, not otherwise provided for.
2588 Other defects in hand brakes, brake rigging and appurtenances.

Couplers, Draft Gear and Related Parts

2601 Coupler, broken, not pulled out.
2602 Coupler, improper height.
2603 Jackknifing of couplers.
2604 Couplers passing in attempting to make coupling.
2605 Knuckle, broken or defective.
2606 Knuckle lock or locklift assembly.
2607 Uncoupling device.
2608 Friction buffer or diaphragm.

Coupler or draft gear pulled out or down, due to failure of:

2609 Coupler.
2610 Coupler rivets or swivel pin.
2611 Coupler yoke.
2612 Coupler key.
2613 Coupler key retainer.
2614 Striking casting or coupler carrier.
2615 Sills or draft lugs.
2616 Draft gear carrier.
2617 Cushion underframe parts.
2618 Other parts causing coupler or draft gear to drop.
2686 Other defects in couplers.
2687 Other defects in draft gear.
2688 Other defects in cushion underframe.

Car Structure

2701 Sills, bent or broken.
2702 Body bolster.
2703 Other underframe parts.
2704 Sides, spreading or buckling beyond equipment clearance line.
2705 Drop end, falling off.
2706 Floor, material falling from or through.
2707 Side door, falling off.
2708 Drop door, open or defective.
2709 Hatch, dome or manhole cover.
2710 Stake pocket or load retainer.
2788 Other defects in car structure.

TABLE AI (Continued)

OTHER PARTS OF EQUIPMENT

2801 Air dump cars, dumping mechanism.
2802 Crane boom on car or tiedowns for.
2803 Snow plow, flanger, ditcher, or spreader defects.
2804 Steam heat connections, dragging or falling off.
2805 Car water tanks.
2806 Axle-driven generator.
2807 Internal combustion powerplant for car electrical auxiliaries or refrigeration.
2887 Other defects in car electrical or mechanical equipment for lighting, heating, cooling, radio, etc. (not propulsion).
2888 Other equipment defects.

COMBINATION OF TWO OR MORE CAUSES

Wheel flange worn and:

4501 Switch point worn.
4502 Switch and adjoining frog too close together.
4503 Improper surface of track.
4504 Tight gage of track.
4505 Improper loading of car.

Truck stiff, close side bearing clearance or improper swivelling and:

4506 Switch point worn.
4507 Improper surface of track.
4508 Tight gage of track.
4509 Improper loading of car.
4510 Wheel flange worn.

Excessive side bearing clearance and:

4511 Improper surface of track.
4512 Improper superelevation of track on curve.
4513 Improper loading of car.

Slack action and:

4514 Improper surface of track.
4515 Tight gage of track.
4516 Improper loading of car.
4517 Heavy impact and weakened condition of car.
4518 High locomotive tractive effort and light cars on sharp curve.
4588 Other combinations of two or more causes.

OTHER ASCERTAINED CAUSES

4601 Rocking or swaying of car.

TABLE AII

DATA LOCATION IN ALPHANUMERIC

Column	Length	Description
1	1	A - (Record Type)
2	1	Class
3	1	District
4-5	2	Road Number
6-8	3	Sheet Number
9	1	Year
10-11	2	Month
12	1	Class of Accident
13	1	Subclass
14-15	2	State
16-22	7	Damages to Equipment
23-29	7	Damages to Track and Roadbed
30-36	7	Total
37	1	Kind of Train
38	1	Second Train Code
39	1	Joint Code
40	1	Train Speed
41-42	2	Number of Train Cars
43	1	Method of Operation
44	1	Kind of Defect
45	1	Explosives
46-49	4	Cause of Accident
50	1	Day of Week
51-52	2	Hour (Light-Dark Code)
53	1	Weather
54	1	Struck by or Ran Into
55	1	Part Train Struck
56	1	Crossing Protection
57	1	Operation Protection
58	1	Unusual Protection
59	1	Visibility
60	1	Illumination
61	1	Auto Speed
62	1	Stalled or Stopped
63	1	Motor Carrier Act
64	1	Defect or Negligence

TABLE AIII

EXPLANATION OF CODES ON BRS ACCIDENT TAPE

1. Class of railroad (position 2).

Class I	0
Class II	1-6

2. District and road number (3-5). Together with class, these form a unique code for each carrier.

3. Sheet number (6-8). Sequence number of T sheets by carrier and by month.

4. Year (9). Last digit only.
   MONTH (10-11)

   Note: The RR code, sheet number, year, and month uniquely identify and accident (and its T sheet).

5. Class and subclass of accident (12-13).

   a. Train accidents

Class :	Collision	1
	Derailment	2
	Other	3
Subclass:	a	1
	b	2
	c	3
	d	4
	e	5
	f	6
	g	7
	h	8
	i	9
	j	0

   See the booklet "Rules Governing the Monthly Reports of Railroad Accidents," pages 6-9, for explanation of subclasses.

   b. Train-service and non-train accidents.

   The first 2 digits of the cause code are entered. (See item 14.)

6. State (14-15). See enclosed list.

7. Damage to equipment (16-22), dollars.

(TABLE AIII)

8. Damage to track and roadbed (23-29), dollars.

9. Total damage (30-36), dollars.

10. Kind of train (37) and second train, if any (38).

Freight	1
Passenger	2
Work	3
Yard	4
Hostler	5
Standing cars or locomotives	6
Runaway cars or locomotives	7
Industrial	8
Unknown	9

11. Joint code (39). A 1 is used to indicate carrier charged with damages; a 1 indicates other carriers involved. If no joint operation, field is blank.

12. Train speed (40).

0-9 mph	0
10-19	1
20-29	2
30-39	3
40-49	4
50-59	5
60-69	6
70-79	7
80-89	8
Over 90 or unknown	9

13. Number of train cars (41-42).

None	88
1-9	77
10-19	01
20-29	02
.	.
.	.
.	.
300-309 (max)	30
Unknown	99

14. Method of operation (43). Coded for collisions only.

Manual	1
Controlled manual	2

-Continued-

(TABLE AIII)

Automatic block	3
Interlocking	4
CTC	5
Cab signal	6
Automatic train control	7
Automatic train stop	8
Train orders	9

15. Kind of defect (44). Coded for train and train-service only.

Defective equipment:	
Locomotive	1
Freight or work	2
Passenger	3
Defective track:	
Main line	6
Branch line	7
Way switching, yard or other	8

16. Explosives (45).

Contains a 1 if hazardous materials were involved in the accident; otherwise, blank.

17. Cause of accident (46-49).

See booklet, "Rules Governing Monthly Reports of Railroad Accidents," pages 22-50.

Note: The following fields, positions 50-64, are coded only for highway grade crossing accidents.

APPENDIX B

COMPARISON OF 1975 CAUSE CODES WITH PREVIOUS CAUSE CODES FOR YEAR 1974

An analysis was made of the 1974 equipment caused derailments in order to see what effect the new cause codes would have on the analysis of derailment data. An attempt was made to assign 1975 cause codes to the 1974 derailments. This was done without inspecting each T sheet but rather on the most likely reclassification. In some cases this was straightforward since the cause codes were identical; for example, "loose wheel." In many other cases a large number of the 1967 codes are now grouped into one code in 1975. While this loss of identity in most cases is not serious, in some it will result in an inability to continue to track some specific defects. This is true of cast steel wheels and wrought steel wheels.

In other cases, such as center plate and pin, the defect has now been grouped under a body problem where previously it was a truck problem. More importantly are those 518 derailments that apparently have no equivalent cause code in 1975. The major example is truck stiff with 62 derailments in 1974. Included also in these 518 derailments are the combination causes and the rock off cause.

On the positive side, it will now be possible to differentiate between plain and roller bearing burnoffs. It is also probably true that many of the old cause codes are no longer applicable.

In 1974 there were 2436 equipment-caused derailments if the combination causes and rock off were added to the equipment-caused derailments listed by the FRA. The disposition of the 420 derailments now classed as combination cause and rock off must be analyzed when 1975 data becomes available.

TABLE BI

COMPARISON OF 1975 CAUSE CODES

WITH PREVIOUS CAUSE CODES FOR YEAR 1974

Pre 1975			1975	
Cause Code	Description	1974 Derailments	Cause Code	Description
2101	Crank case and air box explosions	0	472L	Crank case or air box explosions
2102	Internal combustion engine	0	----	-----------
2103	Generators and motor generator sets	0	----	-----------
2104 2105	Traction motor armature bearing fail. Other traction motor failures	8	471L	Traction motor failure
2106	Current collector systems	0	475L	Current collector systems
2107	Electrical control and conversion	1	476L	Remote control equipment
2108	Hyd., mech. power trans. to axle	0	----	-----------
2110	Fires from short circuits	0	474L	Electrically caused fire
2111	Fire from fuel or lube oil	0	473L	Oil fire
2112	Other fires	0	----	-----------
2113	Fumes from internal combustion engine	0	----	-----------
----	-----------	0	470L	Running gear failure
2188	Other defects	6	479L	Cause code not listed
2201	Truck side frame, bent or broken	28	443	Side frame broken
2202 2203 2204 2205 2206	Equilizer bent or broken Pedestal tire bar Journal bearing nonintegral Journal bearing assembly - inc. fires Transom, bent or broken	7	----	-----------
2207	Truck bolster bent or broken	56	442	Truck bolster broken
2208 2209	Truck bolster anchor Subbing device	1	----	-----------
2210	Center plate	65	423	Center plate broken
2211	Center pin broken or missing	46	425	Center pin broken or missing

TABLE BI (Continued)

Pre 1975			1975	
Cause Code	Description	1974 Derailments	Cause Code	Description
2212	Side bearing clearance	67	440	Side bearing clearance
2213	Side bearing broken or missing	112	441	Side bearing broken or missing
2214	Spring plank			
2215	Swing hanger			
2216	Swing hanger pin			
2217	Spring or snubber	11	----	-----------
2218	Spring seat			
2219	Truck safety hanger			
2220	Insufficient weight on wheel			
2221	Truck stiff	62	----	-----------
2288	Other truck defects	10	449	Cause code not listed
2301-2304	Cast iron wheels	0	----	-----------
2305	Cast steel wheel (CSW) flange broken	10	460	Broken flange
2309	Wrought steel wheel (WSW) flange bkn.			
2306	CSW tread or rim	20	465	Damaged tread or flange thermal/flat
2310	WSW tread or rim			
2307	CSW broken overheated		461	Broken rim
2308	CSW broken other causes	94	462	Broken plate
2311	WSW broken overheated		463	Broken hub
2312	WSW broken other causes			
2314	Flange worn	175	464	Worn flange or tread
2315	Loose wheel	49	466	Loose wheel
2316	Tire loose or broken	3	----	-----------
2313	Wheel, other or unknown broken	47	469	Cause code not listed
2387	Other defects in wheels			
2317	Axle broken between journals	20	450	Axle broken or bent between wheels
2318	Journal broken cold	26	453	Journal fractured - new cold break
			454	Journal fractured - previously overheated

TABLE BI (Continued)

Pre 1975 Cause Code	Pre 1975 Description	1974 Derailments	1975 Cause Code	1975 Description
2319	Journal broken, overheated	323	451 452	Journal (plain) overheated Journal (roller) overheated
2388	Other defects in axles	11	459	Cause code not listed
2401 2402 2406 2407 2408 2409 2410 2501 2504 2507	Air compressor Air reservoir or fittings Air brake parts falling off Air brake sticking Air brake defective - snow, ice Air brake failure - excessive piston travel Triple valve lazy, etc. Brake beam, broken, displaced Brake hanger, broken, disconnected Brake shoe, worn, broken, or missing	46	403	Other brake components damaged, worn, broken, disconnected
2403	Air brake control valve	1	404	Brake valve malfunction
2404	Brake pipe or fittings	10	401 402	Broken brake pipe Obstructed brake pipe
2405	Air brake hose burst or broken	38	400	Air or hyd. hose burst or uncoupled
2502 2503 2505	Brake chains Brake chains kinking Brake rod	10	407	Hand brake linkage
2506 2508 2509	Brake shaft Brake wheel loose Pawl or ratchet	0	406	Hand brake defective
2510	Brake rigging coming down	45	405	Rigging down or dragging
2511 2512 2488 2588	No brake on car Insufficient braking power Other air brake defects Other defects in fluid braker, etc.	19	409	Cause code not listed

TABLE BI (Continued)

Pre 1975 Cause Code	Pre 1975 Description	1974 Derailments	1975 Cause Code	1975 Description
2601	Coupler broken - not out			
2609	Coupler	146	432	Coupler or drawhead broken
2610	Coupler rivits			
2688	Other defects in couplers	6		
2605	Knuckle broken or defective			
2606	Knuckle lock or lock lift	18	430	Knuckle broken or defective
2602	Coupler improper height	36	431	Coupler mismatch high, low
2612	Coupler key			
2613	Coupler key retainer	45	433	Coupler retainerpin/cross key missing
2608	Friction buffer of diaphragm			
2616-	Draft gear carrier	22		
2618	Other draft gear parts		434	Draft gear mechanism
2611	Coupler yoke	25		
2687	Other defects - draft gear	4		
2614	Striking casting or coupler carrier	3	435	Coupler carrier
2603	Jackknifing			
2604	Couplers passing			
2607	Uncoupling device	90	----	-----------
2615	Sills or draft lugs			
2617	Cushion underframe			
2688	Other defects in cushion underframe	0	439	Cause code not listed
2701	Sills, bent or broken	44	421	Center sill
			422	Draft sill
2702	Body bolster	26	420	Body bolster
2703	Other underframe parts			
2704	Sides spreading, etc.			
2705	Drop end falling off			
2706	Floor - material falling through	43	----	-----------
2707	Side door falling off			
2708	Drop door open or defective			
2709	Hatch - dome, etc.			
2710	Stake pocket or hood retainer			

TABLE BI (Continued)

Pre 1975			1975	
Cause Code	Description	1974 Derailments	Cause Code	Description
----	-----------	--	424	Center plate disengaged - off center
2788	Other defects in car structure	10	429	Cause code not listed
2801 ↓ 2888	Other parts of equipment	28	---	-----------
4501	Worn flange and switch pt.	139	---	-----------
4502	Worn flange and switch & freq. too close			
4503	Worn flange improper surface of track			
4504	Worn flange tight gage of track			
4505	Worn flange improper leading of car			
4506	Truck stiff, switch pt. worn			
4507	Truck stiff, improper surface of track			
4508	Truck stiff, tight gage of track			
4509	Truck stiff, improper leading			
4510	Truck stiff, wheel flange surface			
4511	Side brg. clearance & track surface			
4512	Side brg. clearance superelevation			
4513	Side brg. clearance loading of car			
4601	Rocking and swaying of car	134	---	-----------
4588	Other combinations	147	499	General mechanical and electrical

APPENDIX C

BACKUP DATA FOR RAILCAR EQUIPMENT CAUSE DERAILMENT

This appendix presents numerical backup data for the plots shown in this report as well as analysis of derailments by speed range. Table CI relates to Figures 1 through 4. Table CII relates to Figures 6 through 8. Table CIII relates to Figures 9 through 11. Table CIV presents the distribution of derailment costs and dollars by speed range for the years 1967 through 1974. Figures C-1 through C-4 present the distribution of derailment causes by speed range. The percentage plotted is based on all causes adding to 100 percent for each speed range.

Figures C5 through C7 present backup data on derailments versus month of year. Figures C8 through C11 and Table C-V present data on derailments versus number of cars in the train.

TABLE CI

CAUSES OF RAILCAR EQUIPMENT CAUSED DERAILMENTS

			Top Three Major Equip Causes			Top Five Individual Derailment Causes				
			2300	2200	2600	2319	2314	2207	2315	2201
Year	Total Number of Derailments 2000 Series	Total Number of Derailments 2000 & 4500 Series + 4601	Wheels & Axles	Trucks	Couplers	Journal Hot	Worn Flange	Truck Bolster	Loose Wheels	Truck Side Frame
1964	1,418	1,604	802	200	219	449	40	42	57	54
1965	1,499	1,682	830	228	241	454	54	56	77	70
1966	1,550	1,761	763	249	272	369	80	41	72	76
1967	1,611	1,864	753	280	303	374	83	74	63	63
1968	1,748	1,998	839	320	315	420	129	80	64	59
1969	1,864	2,079	916	313	302	486	130	81	55	50
1970	1,604	1,828	745	283	288	409	132	57	57	40
1971	1,394	1,676	662	261	253	328	122	40	47	31
1972	1,350	1,702	587	289	254	267	121	57	45	27
1973	1,760	2,199	652	421	346	294	135	64	48	37
1974	1,973	2,436	778	465	395	323	175	56	49	28
Total - 11 Yrs.	17,771	20,829	8,327	3,309	3,188	4,173	1,201	648	634	535

TABLE CII

MAJOR CATEGORIES OF EQUIPMENT CAUSED DERAILMENTS

Percents shown are only for equipment caused derailments

(Dollars are in Thousands)

Year		2100 Locomotives		2200 Trucks		2300 Wheels & Axles		2400 Air Brakes		2500 Hand Brakes		2600 Couplers		2700 Car Structure		2800 Other Parts		2900 (4500 & 4601) Combina. & Rockoff	
		Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%	Amt.	%
1964	by #	5	.3	200	12.5	802	50.0	38	2.4	49	3.1	219	13.6	77	4.8	29	1.8	186	11.6
	by $	---	---	-----	----	-----	----	----	---	----	---	----	----	----	---	----	---	----	----
1965	by #	8	.5	228	13.6	830	49.3	29	1.7	54	3.2	241	14.3	77	4.6	32	1.9	183	10.9
	by $	---	---	-----	----	-----	----	----	---	----	---	----	----	----	---	----	---	----	----
1966	by #	7	.4	249	14.1	763	43.3	63	3.6	77	4.4	272	15.4	95	5.4	24	1.4	211	12.0
	by $	---	---	-----	----	-----	----	----	---	----	---	----	----	----	---	----	---	----	----
1967	by #	11	.6	280	15.0	753	40.4	48	2.6	66	3.5	303	16.3	108	5.8	42	2.3	253	13.6
	by $	450	1.2	5875	15.7	19505	52.2	1033	2.8	887	2.4	2919	7.8	2244	6.0	1239	3.3	3195	8.6
1968	by #	9	.5	320	16.0	839	42.0	62	3.1	89	4.5	315	15.8	91	4.6	22	1.1	250	12.5
	by $	115	.3	6516	15.8	23800	57.8	1072	2.6	1446	3.5	3094	7.5	829	2.0	291	.7	3981	9.7
1969	by #	21	1.0	313	15.1	916	44.1	75	3.6	83	4.0	302	14.5	121	5.8	33	1.6	215	10.3
	by $	427	.9	6288	13.2	29093	60.9	1093	2.3	1582	3.3	3701	7.7	2501	5.2	183	.4	2902	6.1
1970	by #	7	.4	283	15.5	745	40.8	61	3.3	86	4.7	288	15.8	100	5.5	34	1.9	224	12.2
	by $	187	.5	5119	14.3	19516	54.5	670	1.9	849	2.4	3021	8.4	2085	5.8	1032	2.9	3343	9.3
1971	by #	10	.6	261	15.6	662	39.5	50	3.0	56	3.3	253	15.1	84	5.0	18	1.1	282	16.8
	by $	839	2.3	5571	15.1	21002	56.8	1009	2.7	1079	2.9	1953	5.3	1240	3.4	192	5.2	4106	11.1
1972	by #	5	.3	289	17.0	587	34.5	53	3.1	63	3.7	254	14.9	81	4.8	18	1.1	352	20.7
	by $	246	.7	5499	15.9	16179	46.8	744	2.2	1408	4.1	3547	10.3	1134	3.3	419	1.2	5381	15.6
1973	by #	11	.5	421	19.1	652	29.6	62	2.8	102	4.6	346	15.7	137	6.2	29	1.3	439	20.0
	by $	579	1.3	8085	18.6	17734	40.7	465	1.1	1287	2.9	4680	10.7	2252	5.2	473	1.1	7891	18.3
1974	by #	15	.6	465	19.1	778	31.9	74	3.0	95	3.9	395	16.2	123	5.0	28	1.1	463	19.0
	by $	574	1.1	10569	19.7	23400	43.7	1527	2.8	1544	2.9	5492	10.2	2899	5.4	870	1.6	6726	12.5

TABLE CIII

SEVEN CAUSE GROUPS

Percentage figures are only for equipment caused derailments

(Dollars are in Thousands)

Year		Journals Amt.	Journals %	Dynamics Amt.	Dynamics %	Wheels Broken Amt.	Wheels Broken %	Worn Flange Amt.	Worn Flange %	Couplers - Out Amt.	Couplers - Out %	Bent & Broken Side Frames & Bolsters Amt.	Bent & Broken Side Frames & Bolsters %	Air Brakes & Bad Brakes Amt.	Air Brakes & Bad Brakes %	Total % for Seven Causes
1964	by #	522	32.5	207	12.9	146	9.1	133	8.3	134	8.3	96	10.0	78	4.9	86.0
	by $	-----	----	-----	----	----	----	----	----	----	----	----	----	----	---	----
1965	by #	513	30.5	211	12.5	147	8.7	154	9.2	162	9.6	126	7.5	73	4.3	82.3
	by $	-----	----	-----	----	----	----	----	----	----	----	----	----	----	---	----
1966	by #	427	24.2	269	15.3	129	7.3	190	10.8	180	10.2	117	6.6	126	7.2	81.6
	by $	-----	----	-----	----	----	----	----	----	----	----	----	----	----	---	----
1967	by #	429	23.0	312	16.7	136	7.3	200	10.7	191	10.2	137	7.3	108	5.8	81.0
	by $	13286	35.6	4443	11.9	3430	9.2	1780	4.8	2182	5.8	4014	10.7	1910	5.1	83.2
1968	by #	478	23.9	337	16.9	127	6.4	265	13.3	184	9.2	139	7.0	137	6.8	83.5
	by $	16077	39.1	4624	11.2	5189	12.6	2052	5.0	2375	5.8	3728	9.1	2480	6.0	88.8
1969	by #	551	26.5	323	15.5	131	6.3	245	11.8	198	9.5	131	6.3	144	6.9	82.8
	by $	20258	42.4	4952	10.4	4317	9.0	3026	6.3	2467	5.2	3734	7.8	2447	5.1	86.2
1970	by #	434	23.7	311	17.0	92	5.0	252	13.8	193	10.6	97	5.3	132	7.2	82.6
	by $	13026	36.4	4343	12.1	2807	7.8	3307	9.2	2466	6.3	2626	6.7	1507	3.9	82.4
1971	by #	345	20.6	317	18.9	96	5.7	251	15.0	157	9.4	71	4.2	97	5.8	79.6
	by $	11060	30.0	5325	14.4	4191	11.3	5144	13.9	1381	3.7	2096	5.7	1724	4.7	83.7
1972	by #	298	17.4	385	22.6	94	5.5	243	14.3	138	8.1	84	4.9	108	6.3	79.1
	by $	9138	26.4	6331	18.3	3532	10.2	3207	9.3	2960	8.6	1573	4.6	2138	6.2	83.6
1973	by #	315	14.3	523	23.8	123	5.6	281	12.8	224	10.2	101	4.6	140	6.4	77.7
	by $	9457	21.7	7782	17.9	5183	11.9	2918	6.7	3874	8.9	3389	7.8	1368	3.1	78.0
1974	by #	349	14.3	608	25.0	152	6.2	323	13.2	230	9.4	84	3.4	151	6.2	77.7
	by $	12480	23.3	10031	18.7	6182	11.5	4061	7.6	4664	8.7	3223	6.0	3036	5.7	81.5

TABLE CIV

DISTRIBUTION OF EQUIPMENT CAUSED DERAILMENT NUMBERS
AND COST BY SPEED RANGE

1967

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	434	0.232	1479804	0.039	3409
10 TØ 19	400	0.214	2595441	0.069	6488
20 TØ 29	250	0.134	3572885	0.095	14291
30 TØ 39	227	0.121	6000058	0.160	26431
40 TØ 49	278	0.149	11088851	0.296	39887
50 TØ 59	194	0.104	8329649	0.223	42936
60 TØ 69	60	0.032	3637019	0.097	60616
70 TØ 79	14	0.007	482471	0.012	34462
80 TØ 89	6	0.003	159530	0.004	26588
90 TØ 99	1	0.000	1571	0.000	1571

TØTAL NUMBER = 1864
TØTAL CØST = 37347279

1968

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	542	0.271	1924071	0.046	3549
10 TØ 19	395	0.197	2749254	0.066	6960
20 TØ 29	286	0.143	5110819	0.124	17869
30 TØ 39	233	0.116	7093880	0.172	30445
40 TØ 49	290	0.145	11306802	0.274	38988
50 TØ 59	170	0.085	8200084	0.199	48235
60 TØ 69	68	0.034	4248499	0.103	62477
70 TØ 79	9	0.004	502450	0.012	55827
80 TØ 89	0	0.000	0	0.000	0
90 TØ 99	5	0.002	7615	0.000	1523

TØTAL NUMBER = 1998
TØTAL CØST = 41143474

1969

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	591	0.283	2114411	0.044	3577
10 TØ 19	403	0.193	3516939	0.073	8726
20 TØ 29	286	0.137	5246228	0.109	18343
30 TØ 39	285	0.136	8315824	0.174	29178
40 TØ 49	265	0.127	12298229	0.257	46408
50 TØ 59	171	0.082	10977916	0.229	64198
60 TØ 69	73	0.035	5064821	0.106	69381
70 TØ 79	5	0.002	36302	0.000	7260
80 TØ 89	2	0.000	195050	0.004	97525
90 TØ 99	1	0.000	2749	0.000	2749

TØTAL NUMBER = 2082
TØTAL CØST = 47768469

(TABLE CIV)

1970

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	590	0.324	2362021	0.060	4003
10 TØ 19	346	0.190	3503453	0.089	10125
20 TØ 29	238	0.130	4071867	0.104	17108
30 TØ 39	234	0.128	7007102	0.179	29944
40 TØ 49	251	0.138	10361933	0.266	41282
50 TØ 59	109	0.059	8030484	0.206	73674
60 TØ 69	43	0.023	3567421	0.091	82963
70 TØ 79	5	0.002	42510	0.001	8502
80 TØ 89	1	0.000	1165	0.000	1165
90 TØ 99	1	0.000	1111	0.000	1111
TØTAL NUMBER =	1818				
TØTAL CØST =	38949067				

1971

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	529	0.315	2016410	0.054	3811
10 TØ 19	325	0.193	3311966	0.089	10190
20 TØ 29	274	0.163	5394009	0.145	19686
30 TØ 39	205	0.122	5845944	0.158	28516
40 TØ 49	207	0.123	8438371	0.228	40765
50 TØ 59	101	0.060	7006031	0.189	69366
60 TØ 69	31	0.018	4278179	0.115	138005
70 TØ 79	2	0.001	74968	0.002	37484
80 TØ 89	0	0.000	0	0.000	0
90 TØ 99	2	0.001	624521	0.016	312260
TØTAL NUMBER =	1676				
TØTAL CØST =	36990399				

1972

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	572	0.336	2232093	0.064	3902
10 TØ 19	344	0.202	3770615	0.109	10961
20 TØ 29	252	0.148	4902445	0.141	19454
30 TØ 39	179	0.105	5367755	0.155	29987
40 TØ 49	202	0.118	8991596	0.260	44512
50 TØ 59	104	0.061	5355503	0.154	51495
60 TØ 69	44	0.025	3627382	0.104	82440
70 TØ 79	3	0.001	52163	0.001	17387
80 TØ 89	0	0.000	0	0.000	0
90 TØ 99	2	0.001	256569	0.007	128284
TØTAL NUMBER =	1702				
TØTAL CØST =	34556121				

(TABLE CIV)

1973

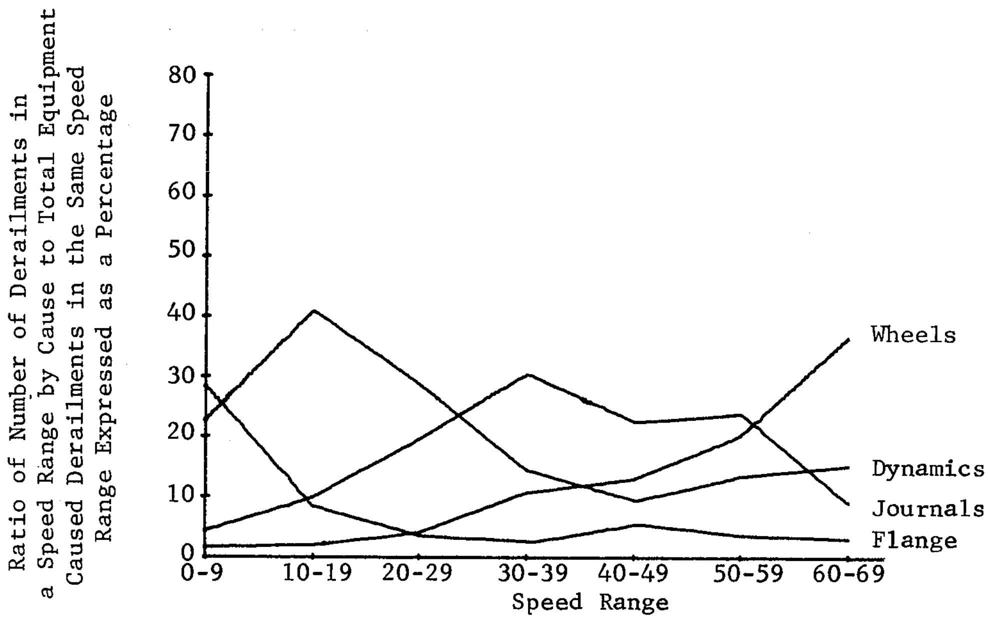
SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	737	0.335	3193706	0.073	4333
10 TØ 19	489	0.222	5612597	0.128	11477
20 TØ 29	322	0.146	6323047	0.145	19636
30 TØ 39	268	0.121	7501637	0.172	27991
40 TØ 49	228	0.103	10256565	0.235	44984
50 TØ 59	113	0.051	7240903	0.166	64078
60 TØ 69	38	0.017	3395374	0.077	89351
70 TØ 79	3	0.001	11898	0.000	3966
80 TØ 89	0	0.000	0	0.000	0
90 TØ 99	0	0.000	0	0.000	0

TØTAL NUMBER = 2198
TØTAL CØST = 43535727

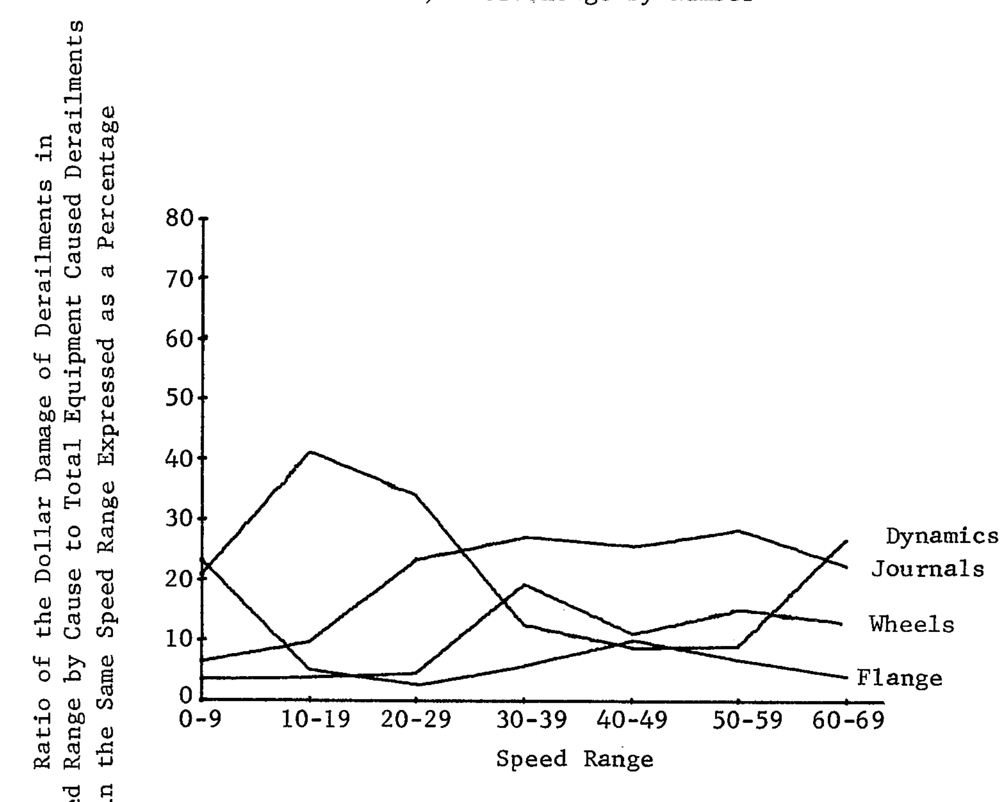
1974

SPEED RANGE	NUMBER	PRØP	CØST	PRØP	AVE CØST
0 TØ 9	823	0.337	3527580	0.065	4286
10 TØ 19	532	0.218	6499773	0.121	12217
20 TØ 29	370	0.151	8155066	0.152	22040
30 TØ 39	276	0.113	8711614	0.162	31563
40 TØ 49	252	0.103	13670876	0.255	54249
50 TØ 59	139	0.057	11331994	0.211	81525
60 TØ 69	32	0.013	1504514	0.028	47016
70 TØ 79	10	0.004	191509	0.003	19150
80 TØ 89	1	0.000	8925	0.000	8925
90 TØ 99	1	0.000	859	0.000	859

TØTAL NUMBER = 2436
TØTAL CØST = 53602710

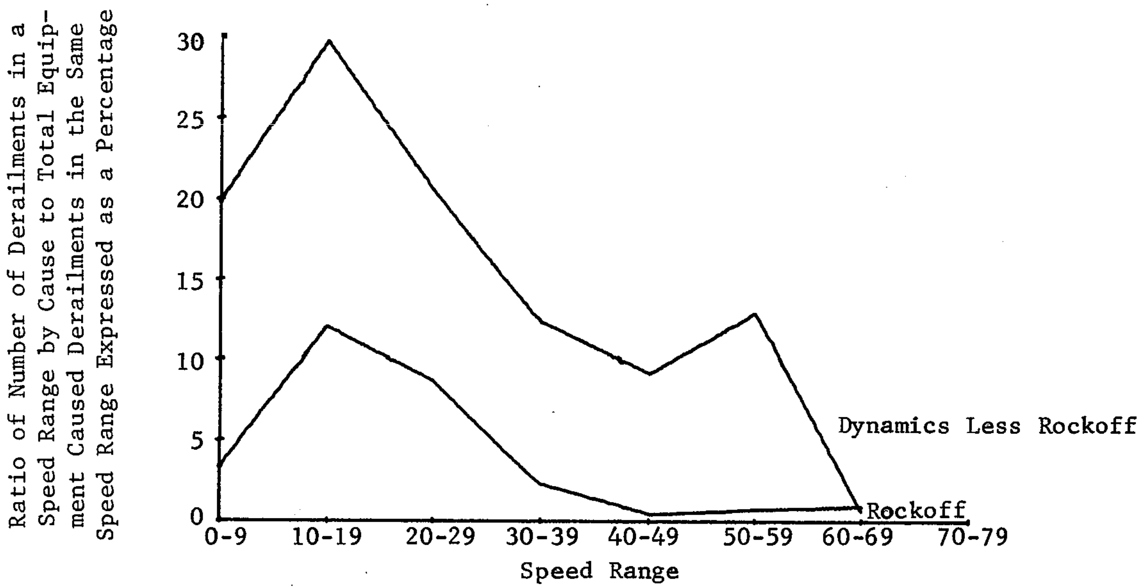


a) Percentage by Number

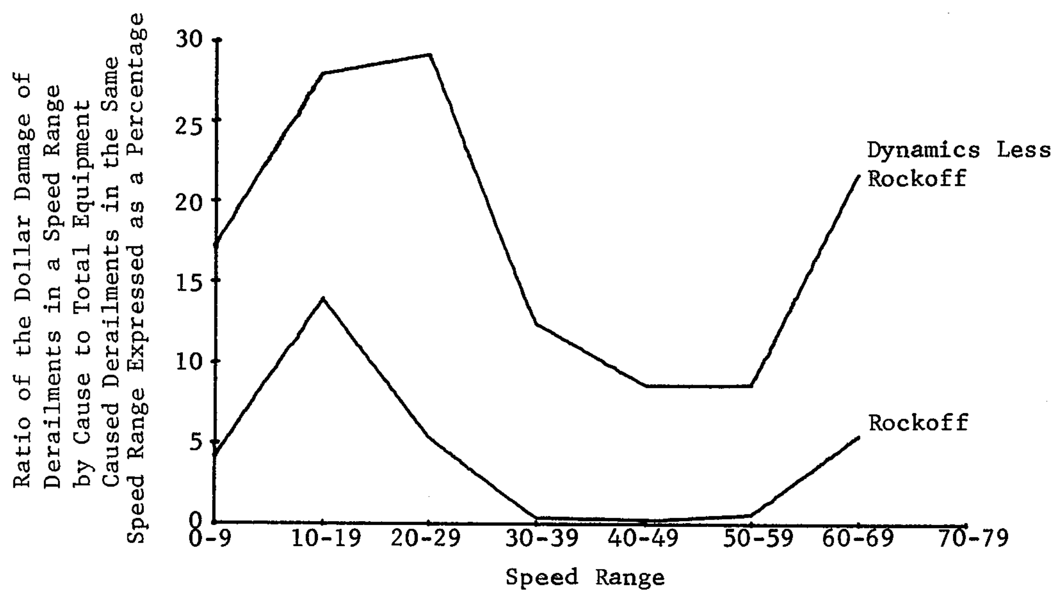


b) Percentage by Dollars Damage

Fig. C-1 Wheels, Journals, Dynamics, and Flange Causes Versus Speed

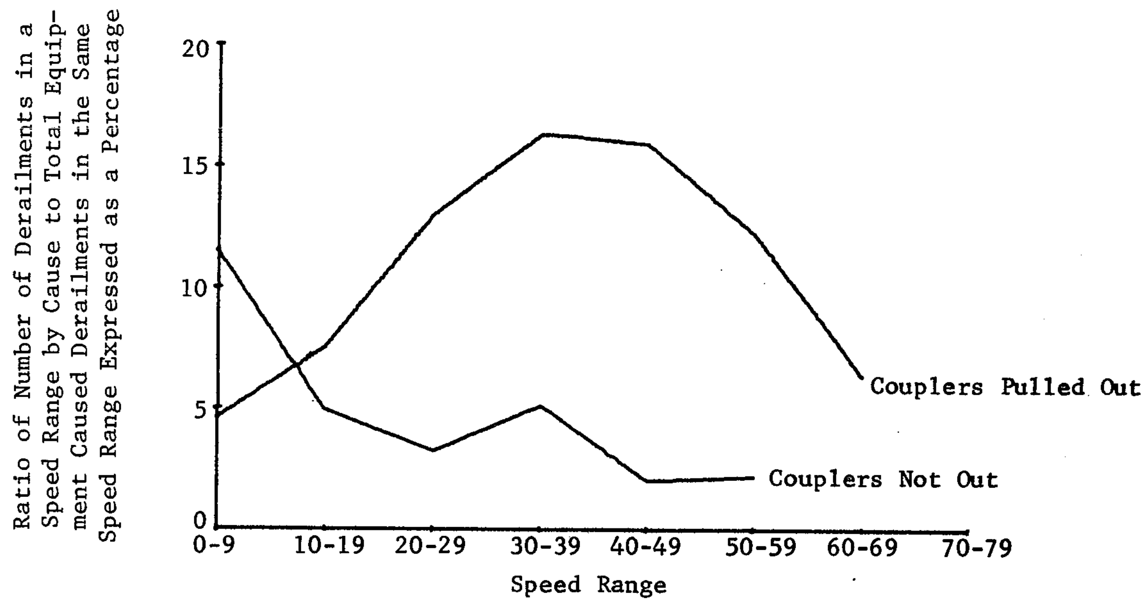


a) Percentage by Number

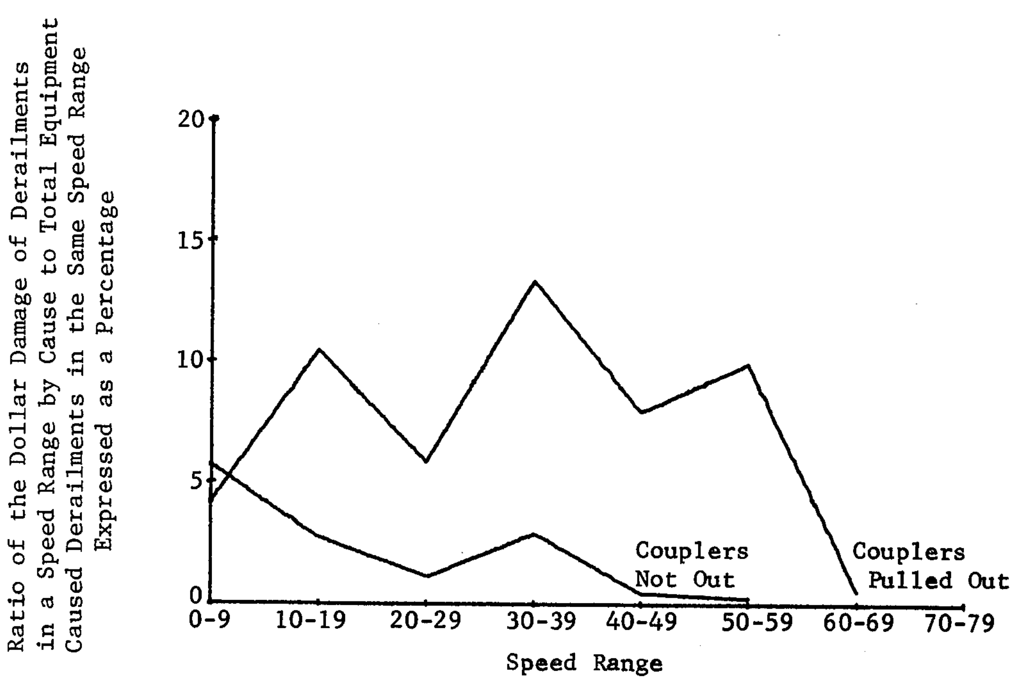


b) Percentage by Dollar Damage

Fig. C-2 Dynamics Less Rockoff and Rockoff Versus Speed

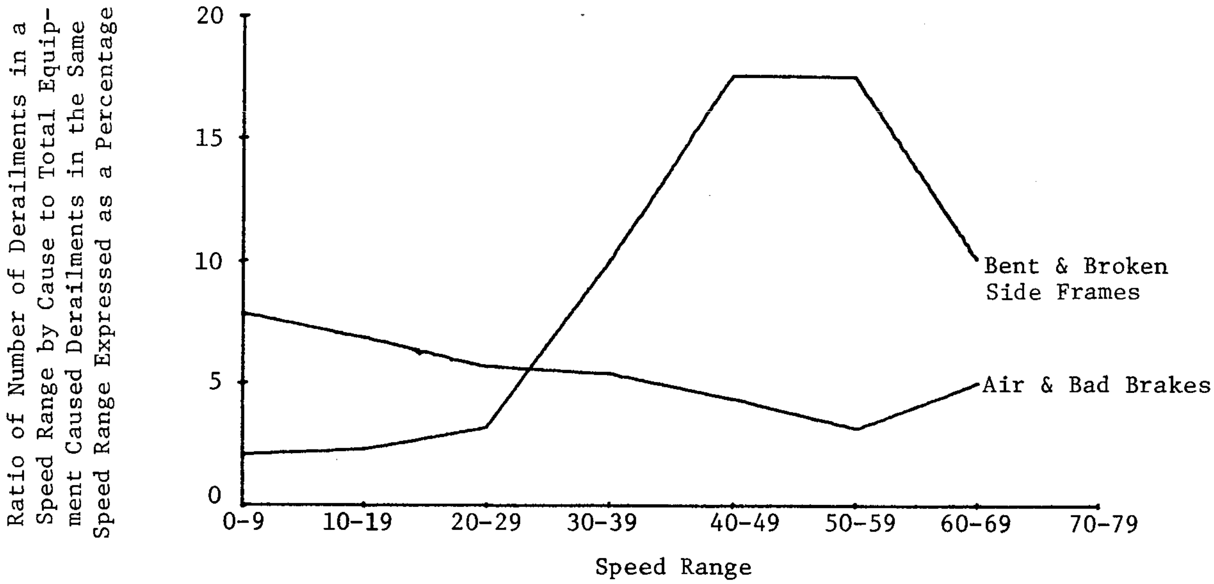


a) Percentage by Number

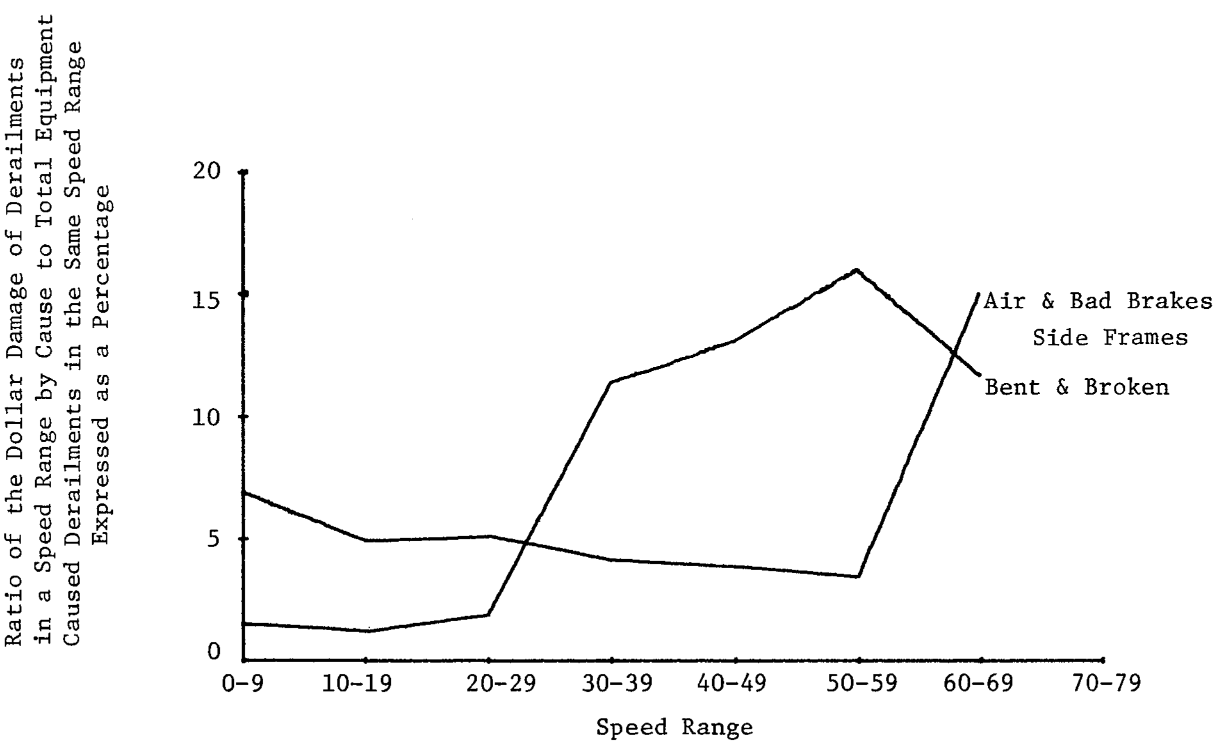


b) Percentage by Dollar Damage

Fig. C-3 Couplers Pulled Out and Couplers Not Out Versus Speed



a) Percentage by Number



b) Percentage by Dollar Damage

Fig. C-4 Air and Bad Brakes and Bent and Broken Side Frames and Truck Bolster Versus Speed

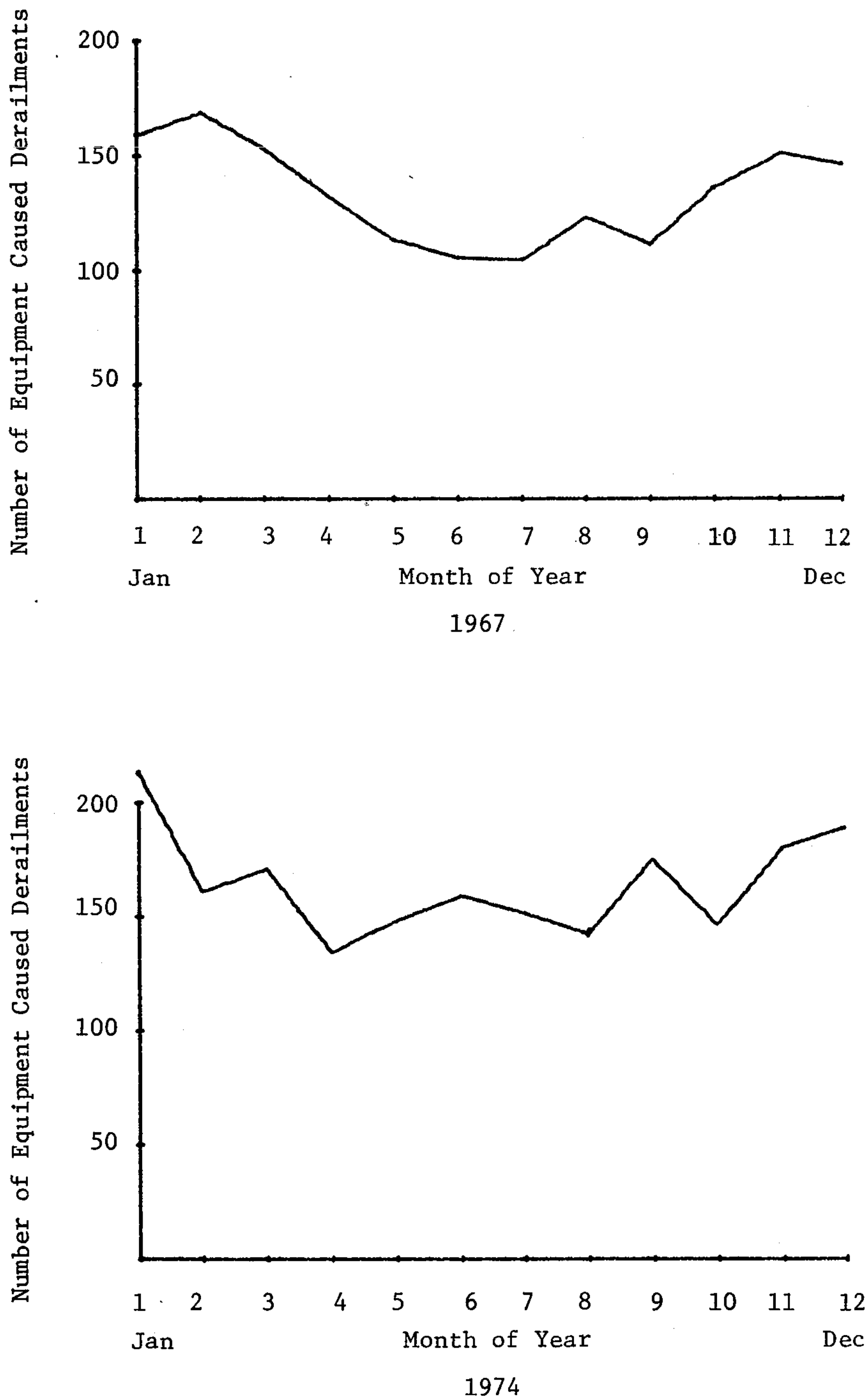
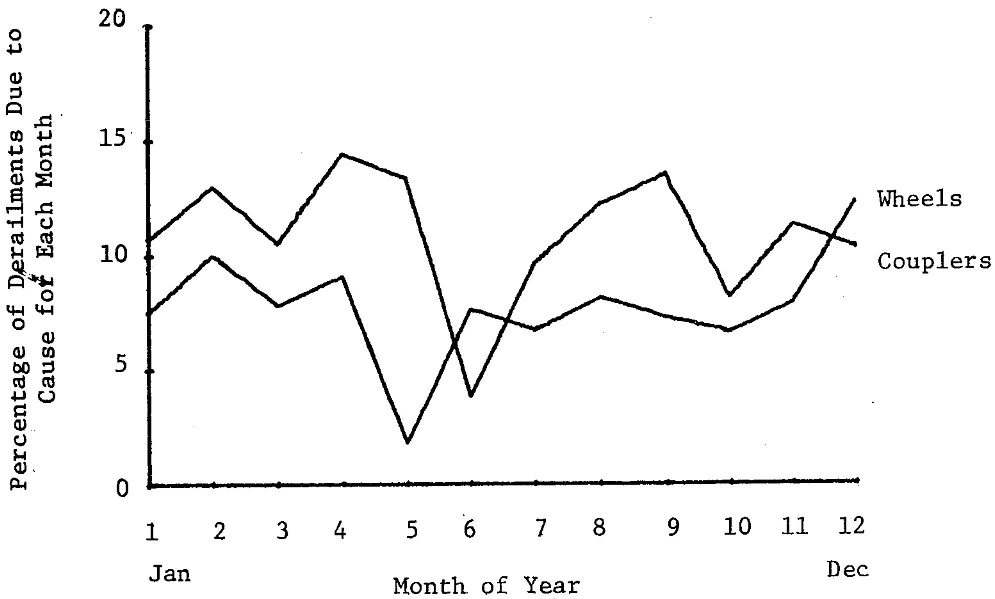
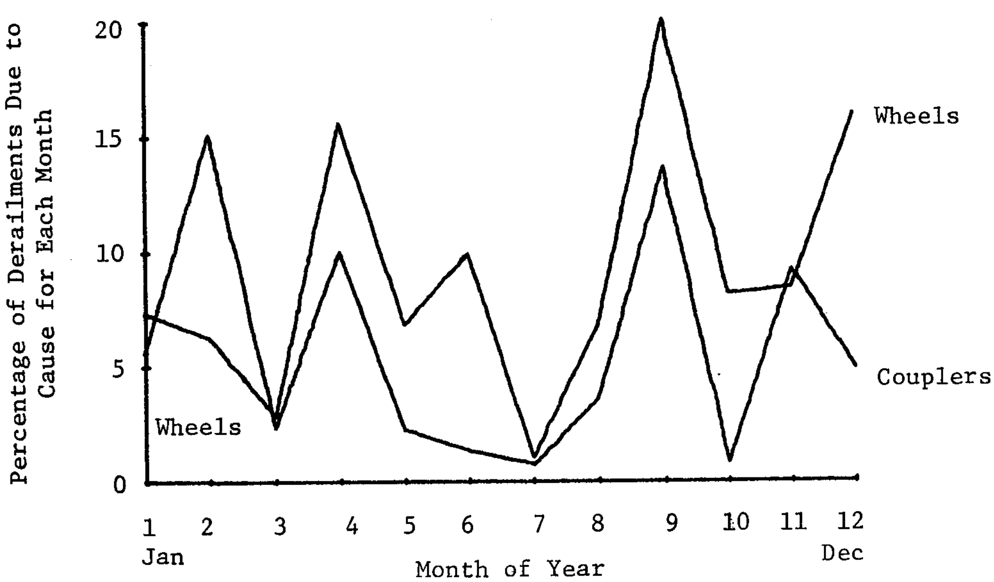


Fig. C-5 Number of Equipment Caused Derailments by Month for Years 1967 and 1974

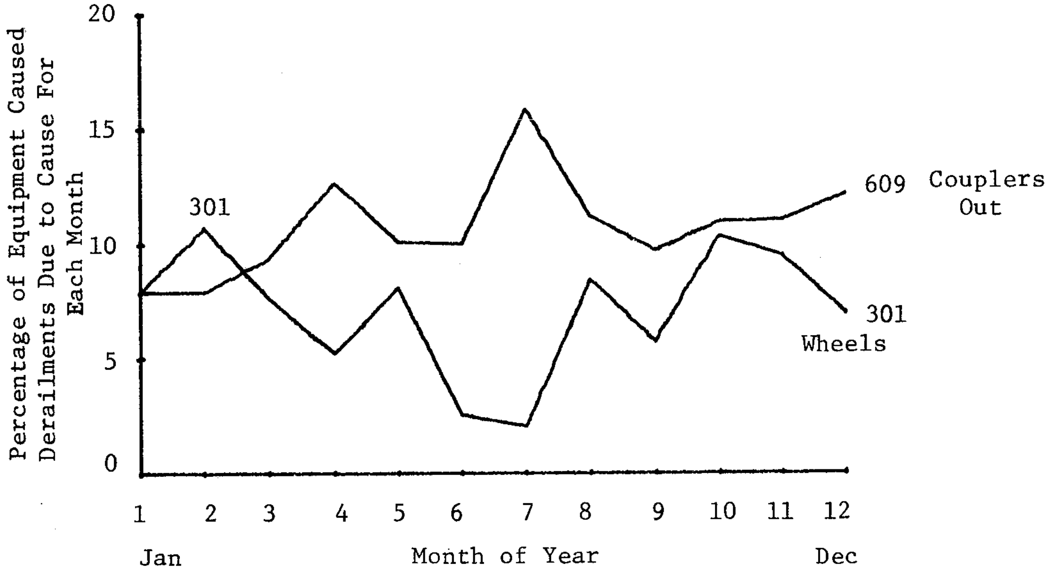


a) By Number

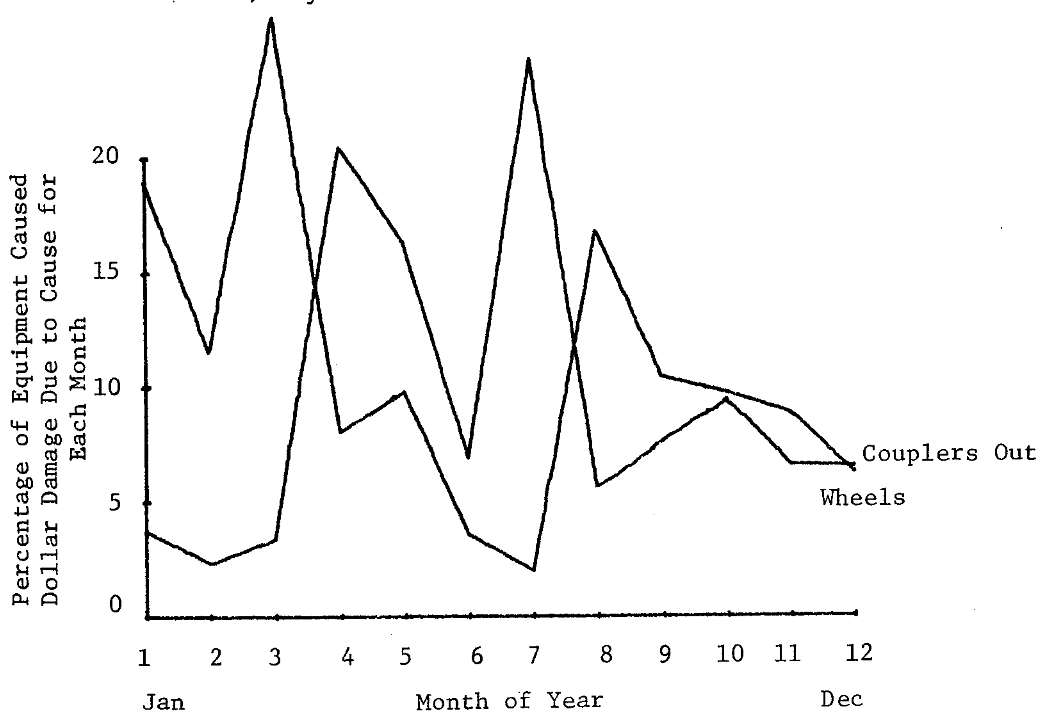


b) By Dollar Damage

Fig. C-6 Proportion of Derailments and Dollar Damage Due to Wheel and Coupler Causes by Month - 1967

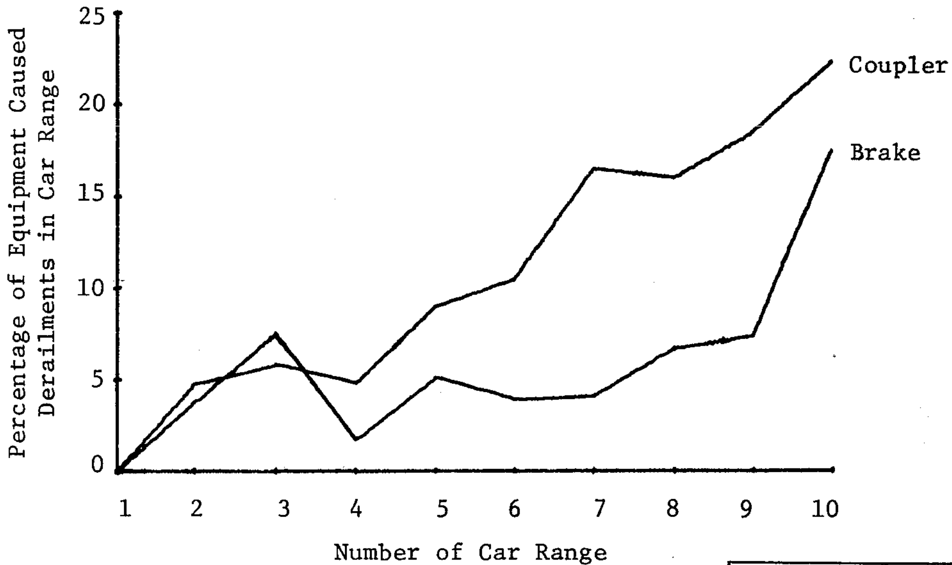


a) by Number



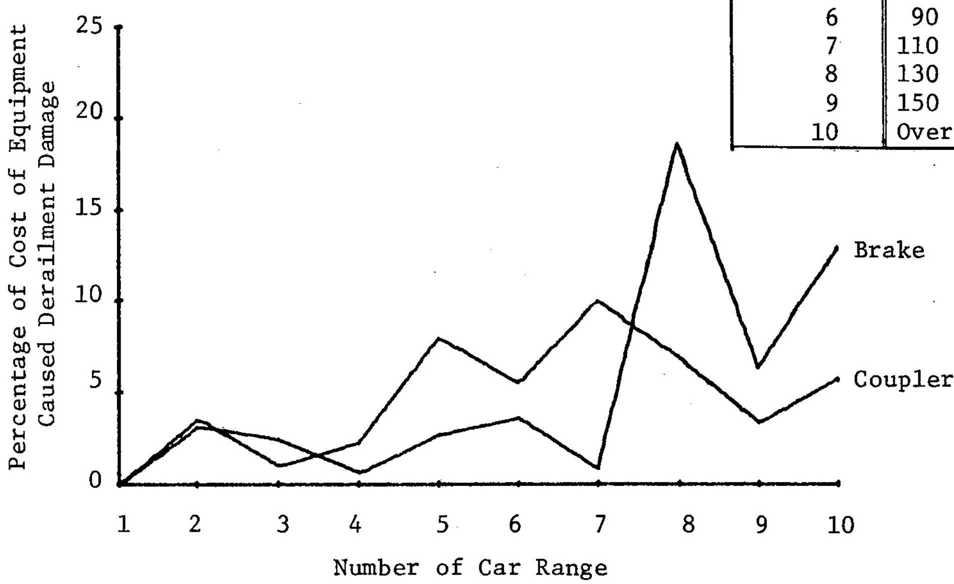
b) By Dollar

Fig. C-7 Proportion of Derailments and Dollar Damage Due to Wheels and Coupler Causes by Month - 1974



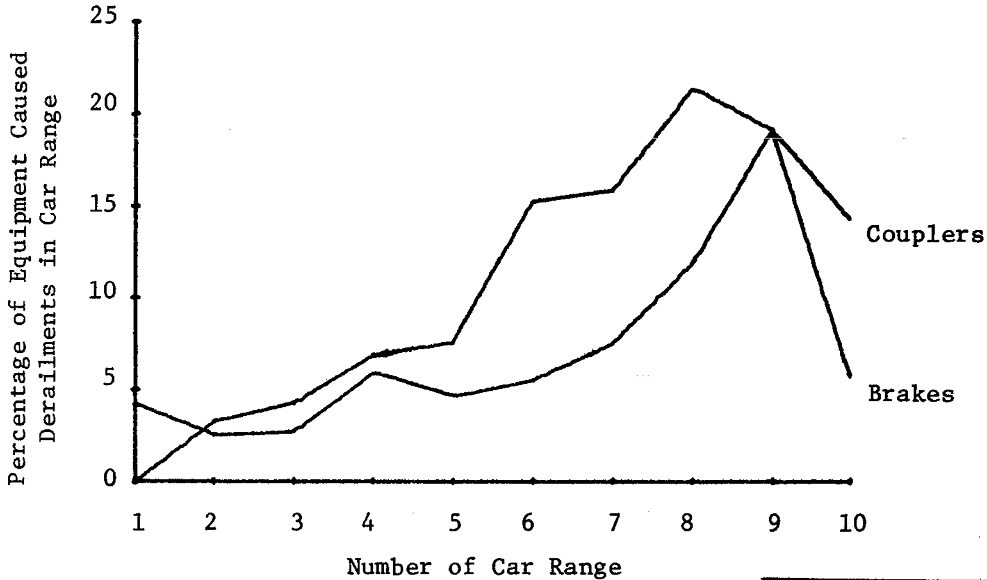
a) By Number

Car Range	# of Cars
1	1 - 9
2	10 - 29
3	30 - 49
4	50 - 69
5	70 - 89
6	90 - 109
7	110 - 129
8	130 - 149
9	150 - 169
10	Over 170



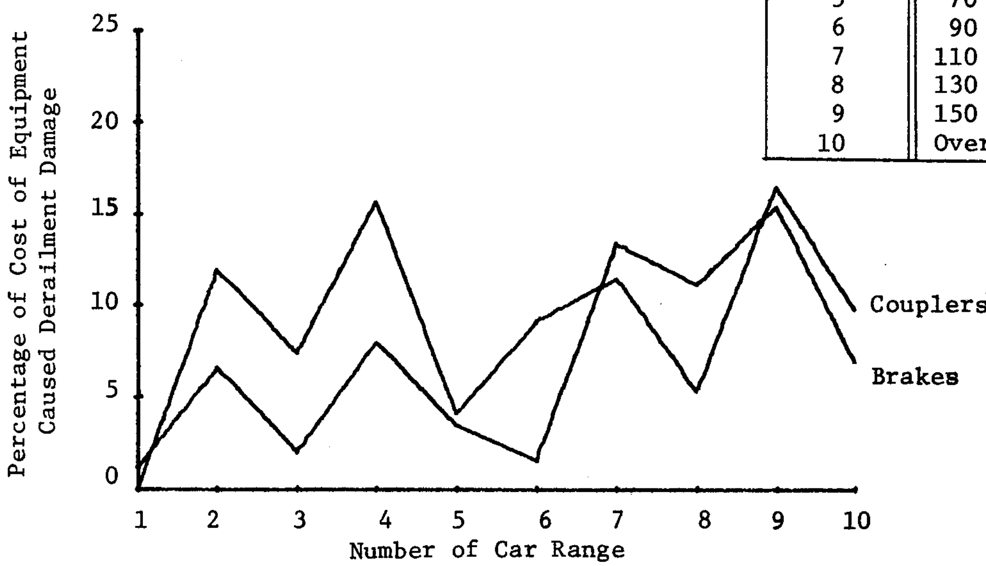
b) By Dollar

Fig. C-8 Proportions Versus Number of Cars for Brake and Coupler Causes - 1967



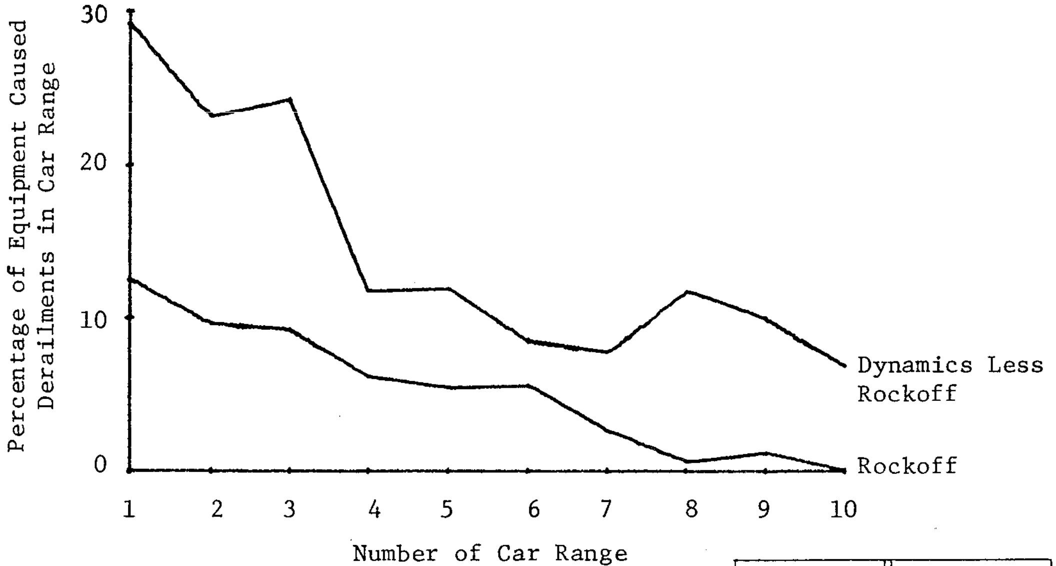
a) By Number

Car Range	# of Cars
1	1 - 9
2	10 - 29
3	30 - 49
4	50 - 69
5	70 - 89
6	90 - 109
7	110 - 129
8	130 - 149
9	150 - 169
10	Over 170



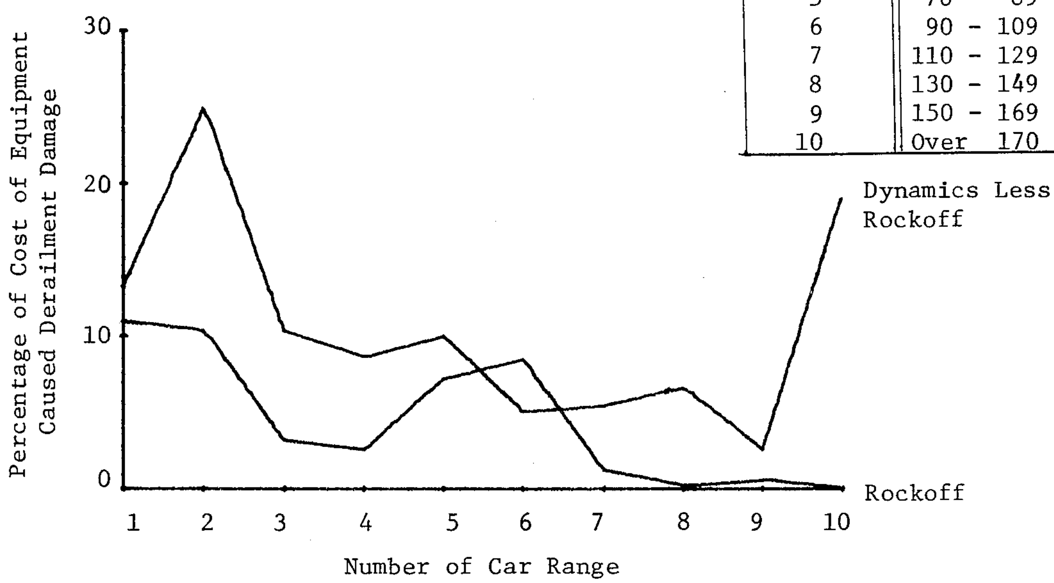
b) By Dollar

Fig. C-9 Proportions Versus Number of Cars for Brake and Coupler Causes - 1974



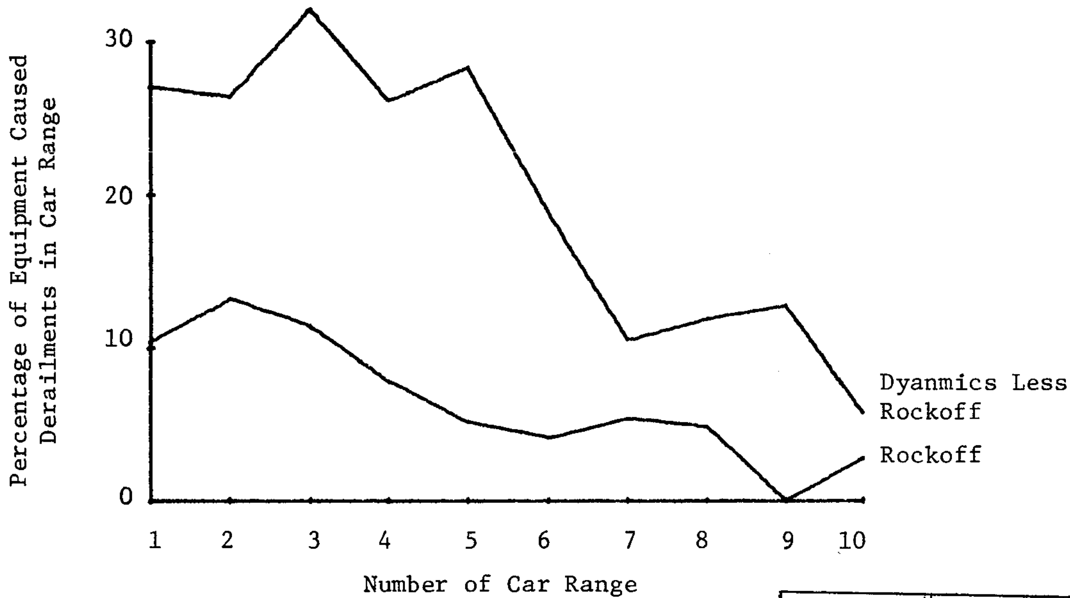
a) By Number

Car Range	# of Cars
1	1 - 9
2	10 - 29
3	30 - 49
4	50 - 69
5	70 - 89
6	90 - 109
7	110 - 129
8	130 - 149
9	150 - 169
10	Over 170



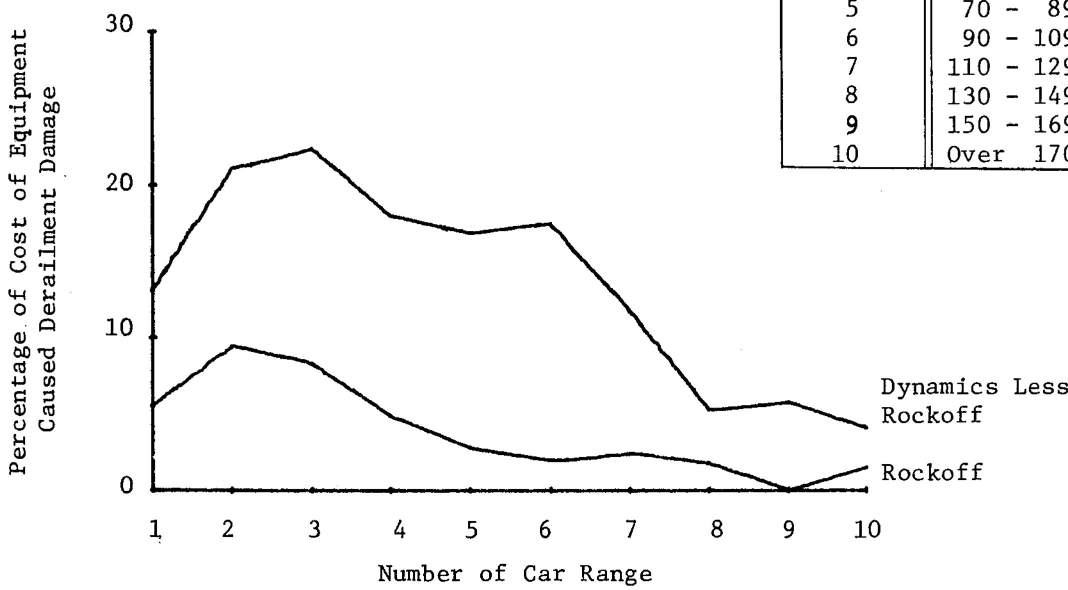
b) By Dollar

Fig. C-10 Proportion Versus Number of Cars for Dynamics Less Rockoff and Rockoff - 1967



a) By Number

Car Range	# of Cars
1	1 - 9
2	10 - 29
3	30 - 49
4	50 - 69
5	70 - 89
6	90 - 109
7	110 - 129
8	130 - 149
9	150 - 169
10	Over 170



b) By Dollar

Fig. C-11 Proportion Versus Number of Cars for Dynamics Less Rockoff and Rockoff - 1974

TABLE CV

NUMBER AND PROPORTION OF DERAILMENT AND
AVERAGE COST BY NUMBER OF CARS IN THE TRAIN

1967

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	24	0.014	116667	0.003	4861
10-29	104	0.064	760592	0.021	7313
30-49	120	0.074	1176176	0.032	9801
50-69	230	0.143	5690072	0.157	24739
70-89	277	0.173	5128572	0.142	18514
90-109	305	0.190	8838284	0.245	28977
110-129	194	0.121	5305305	0.147	27346
130-149	163	0.101	4334708	0.120	26593
150-169	81	0.050	2558735	0.070	31589
ØVER 170	103	0.064	2161811	0.059	20988
TØTAL NUMBER =	1601				
TØTAL CØST =	36070922				

1968

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	27	0.016	92185	0.002	3414
10-29	102	0.061	560828	0.014	5498
30-49	140	0.084	1357561	0.034	9696
50-69	215	0.129	5367796	0.137	24966
70-89	327	0.196	8653799	0.221	26464
90-109	313	0.187	10895028	0.278	34808
110-129	270	0.162	7141686	0.182	26450
130-149	120	0.072	2795488	0.071	23295
150-169	83	0.049	1595412	0.040	19221
ØVER 170	69	0.041	693007	0.017	10043
TØTAL NUMBER =	1666				
TØTAL CØST =	39152790				

1969

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	23	0.013	91763	0.001	3989
10-29	84	0.049	518670	0.011	6174
30-49	139	0.081	2767480	0.059	19909
50-69	236	0.138	6092983	0.131	25817
70-89	333	0.195	9441325	0.204	28352
90-109	370	0.217	12126101	0.262	32773
110-129	237	0.139	5831600	0.126	24605
130-149	146	0.085	4249751	0.091	29107
150-169	77	0.045	4114247	0.089	53431
ØVER 170	60	0.035	975937	0.021	16265
TØTAL NUMBER =	1705				
TØTAL CØST =	46209857				

(TABLE CV)

1970

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	21	0.014	86162	0.002	4102
10-29	96	0.065	941642	0.024	9808
30-49	115	0.078	1453683	0.038	12640
50-69	211	0.143	5185117	0.137	24574
70-89	276	0.187	7986857	0.211	28937
90-109	302	0.204	8952143	0.237	29642
110-129	219	0.148	4677534	0.123	21358
130-149	120	0.081	5267634	0.139	43896
150-169	71	0.048	2180385	0.057	30709
ØVER 170	43	0.029	1027836	0.027	23903
TØTAL NUMBER =	1474				
TØTAL CØST =	37758993				

1971

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	28	0.020	120322	0.003	4297
10-29	88	0.064	622975	0.017	7079
30-49	114	0.083	2061106	0.058	18079
50-69	172	0.125	4462475	0.126	25944
70-89	294	0.214	8324667	0.235	28315
90-109	259	0.188	8278523	0.233	31963
110-129	215	0.156	6860499	0.193	31909
130-149	106	0.077	3257815	0.092	30734
150-169	57	0.041	925627	0.026	16239
ØVER 170	39	0.028	487628	0.013	12503
TØTAL NUMBER =	1372				
TØTAL CØST =	35401637				

1972

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	25	0.018	102279	0.003	4091
10-29	91	0.065	617726	0.019	6788
30-49	164	0.118	2151024	0.066	13116
50-69	207	0.149	4515081	0.139	21811
70-89	275	0.198	8427772	0.261	30646
90-109	281	0.203	5934286	0.183	21118
110-129	162	0.117	5313621	0.164	32800
130-149	98	0.070	3336540	0.103	34046
150-169	49	0.035	854201	0.026	17432
ØVER 170	32	0.023	1013581	0.031	31674
TØTAL NUMBER =	1384				
TØTAL CØST =	32266111				

(TABLE CV)

1973

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	36	0.020	156151	0.003	4337
10-29	139	0.078	1433185	0.034	10310
30-49	176	0.098	3066786	0.074	17424
50-69	291	0.163	8103897	0.195	27848
70-89	347	0.195	8133532	0.196	23439
90-109	386	0.216	10461179	0.252	27101
110-129	193	0.108	4936680	0.119	25578
130-149	117	0.065	2713402	0.065	23191
150-169	44	0.024	793144	0.019	18026
ØVER 170	50	0.028	1634518	0.039	32690

TØTAL NUMBER = 1779
TØTAL CØST = 41432474

1974

NØ. ØF CARS	NUMBER	PRØP	CØST	PRØP	AVE CØST
1-9	48	0.024	298721	0.005	6223
10-29	121	0.061	1446707	0.028	11956
30-49	184	0.094	3321994	0.065	18054
50-69	306	0.156	6941710	0.136	22685
70-89	431	0.220	13394498	0.262	31077
90-109	417	0.213	13411624	0.262	32162
110-129	239	0.122	7236748	0.141	30279
130-149	126	0.064	3560784	0.069	28260
150-169	47	0.024	700647	0.013	14907
ØVER 170	35	0.017	705013	0.013	20143

TØTAL NUMBER = 1954
TØTAL CØST = 51018446

APPENDIX D

DETERMINATION OF FAILURE MARGIN CHARACTERISTICS OF RAILROAD FREIGHT CAR BEARINGS

INTRODUCTION

The Association of American Railroads defines a condemnable defect in a roller bearing as one which would affect the safe operation of a railroad car. It is known from actual practice, however, that bearings with condemnable defects may run for many thousand miles before actual failure occurs. In fact, it is frequently difficult by visual inspection of an assembled bearing, noise level, or hotbox reading to identify a bearing with a condemnable defect.

Once a condemnable defect occurs in a bearing, the severity of the defect will increase with time until it can be detected. For example, its temperature may rise and be sensed by a hotbox detector. This point in time when a defect reaches the stage of detection, we will define as the point of initial failure. The number of additional miles the bearing can travel before catstrophic failure occurs we will term failure margin.

The explicit determination of life-margin and failure-margin is important because it affects the entire concept of railroad roller bearing utilization, inspection, and replacement.

ROLLER BEARING LIFE REGIMES

As illustrated in Figure D-1, the life of a railroad roller bearing can be divided into three parts. The first part which we will call the defect life, is the life measure normally talked about in the industry. The work of Reference 1 shows that this portion of the bearing's life can be described by a Weibull distribution with different Weibull parameters used to describe the various failure modes.

The second portion of the bearing life between the first occurrence of a condemnable defect and its eventual growth to a point where it is detectable, we define as the life margin. Current test work at Shaker Research under Contract DOT/TSC-917 indicates life margins in excess of 5,000 miles for the condemnable defects tested to date.

The last portion or failure margin is the time between the end of useful life and catastrophic failure. This portion of the bearing's life is important because it has the greatest impact on safety of operation.

These three divisions are somewhat arbitrary in that the end of the defect life is defined by the AAR roller bearing manual rules (2) and the end of the life margin by the state of the art of currently used sensors; i.e., the hotbox detector. However, an understanding of these regimes of operation will permit the logical revision of current rework standards and the engineering of better on-board and wayside detection systems.

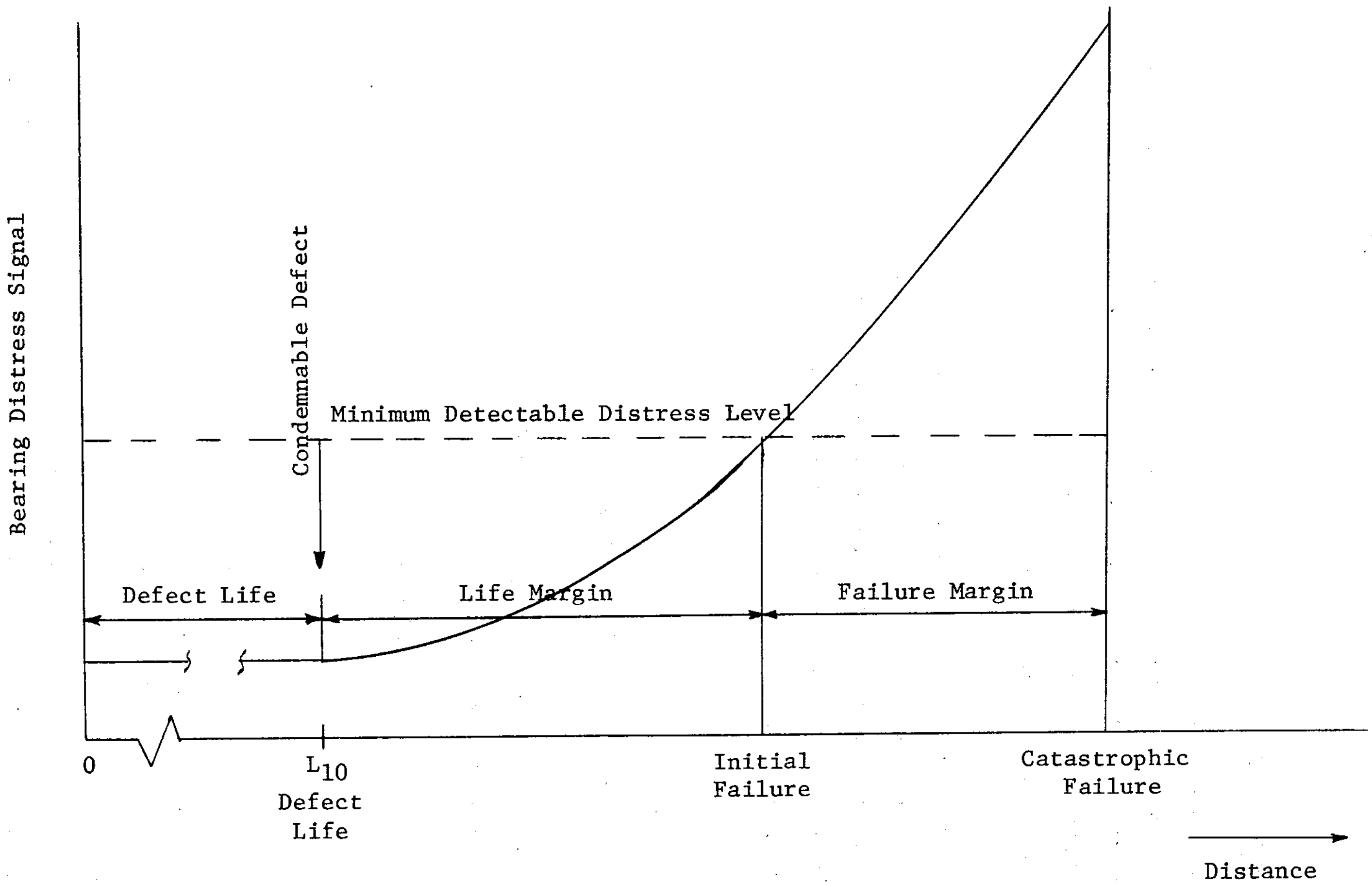


Figure D-1. Roller Bearing Life Regimes

FAILURE MARGIN MODEL

We now direct our attention to developing a model for describing the failure margin of a roller bearing. This problem is important because the life margin dictates the number and location of the detectors used to detect a faulty bearing and directs the engineer to stop the train before the defect can cause a derailment.

Let us consider the section of track illustrated in Figure D-2. We assume that detectors are spaced a distance s apart. If we make the assumption that there is equal probability that an observable defect will occur at any point between detectors, then the probability density function for a defect at distance ξ is

$$f_1(\xi) = \begin{cases} \frac{1}{s} & 0 < \xi < s \\ 0 & \xi < 0 \quad \xi > s \end{cases} \tag{1}$$

Once a defect has occurred at ξ, the probability density function that the bearing will survive until x is

$$f_2(x-\xi) = \frac{\beta(x-\xi)^{\beta-1} e^{-\left(\frac{x-\xi}{\alpha}\right)^{\beta}}}{\alpha^{\beta}} \tag{2}$$

The parameter β describes the shape of the hazard curve. The hazard, $h(x)$, is the instantaneous failure rate; e.g., in a short distance Δ from x to $x + \Delta$, a proportion of $\Delta h(x)$ at the distance can be expected to fail. This is illustrated in Figure D-3 where for $\beta = 1.0$ the hazard is constant and equal to the inverse of the characteristic life. An increasing β implies a greater hazard with distance traveled. As β approaches ∞, most components fail at the characteristic life; and if the detectors are spaced at the characteristic distance, then the probability of observing all defects is one.

The probability density function of a defect before x followed by survival

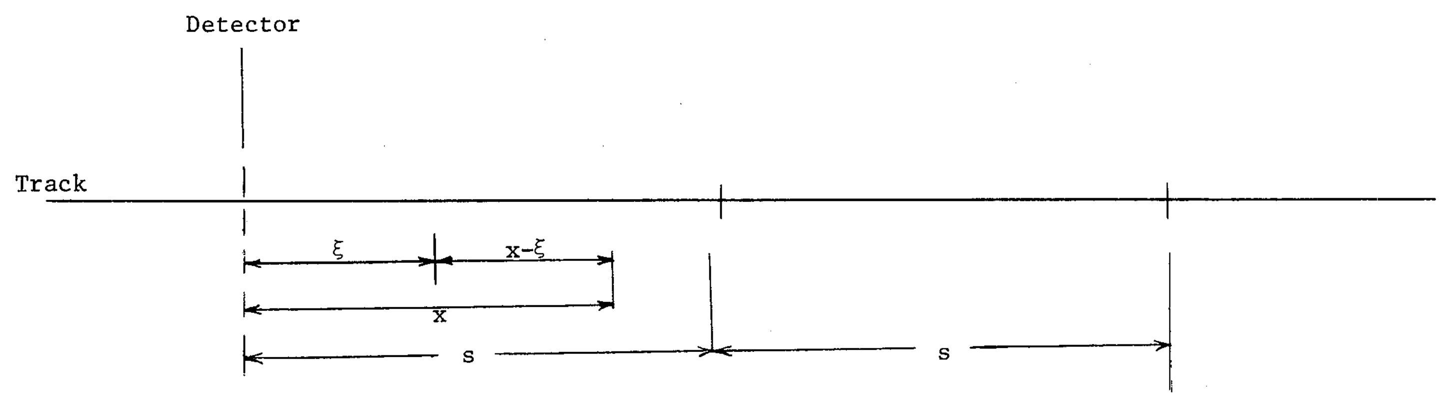


Fig. D-2 Failure Margin Model

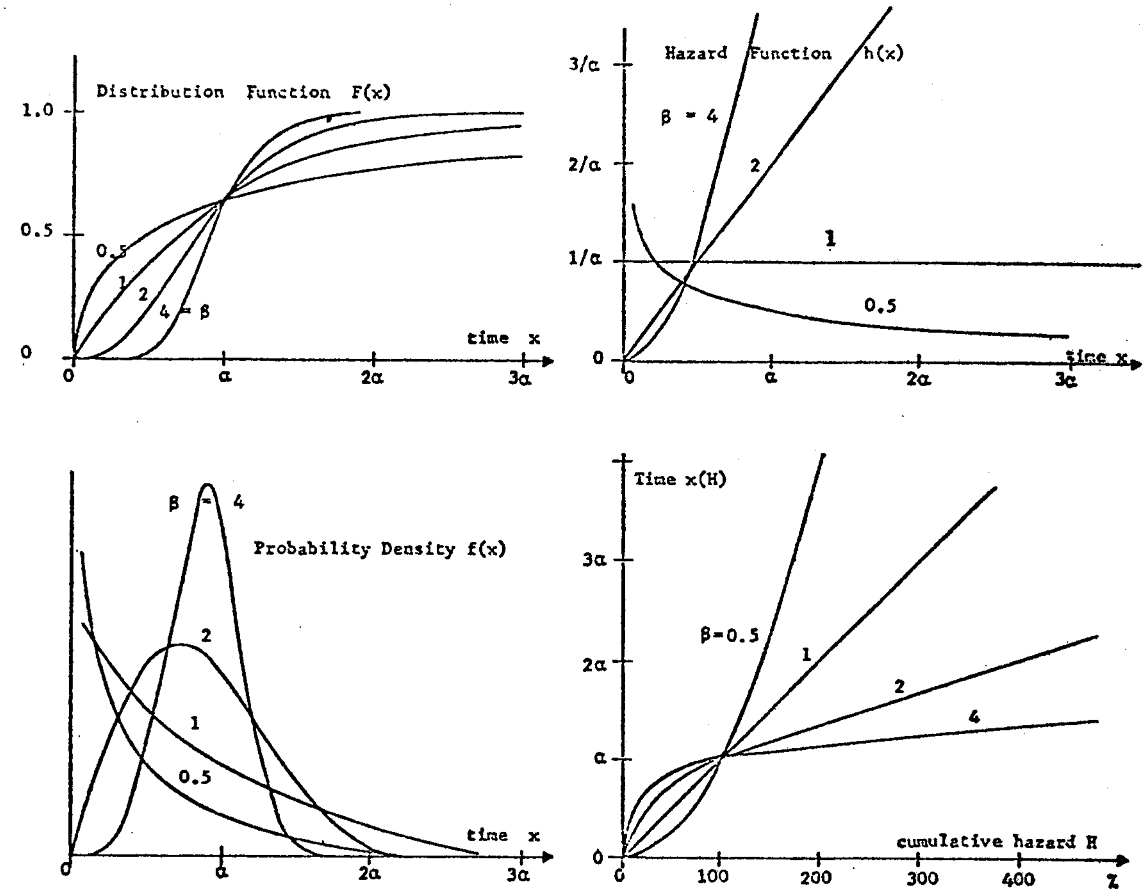


Fig. D-3 Weibull Distributions

until x is the convolution (accumulated product) of Equations (1) and (2).

$$f(x) = \int_0^x f_1(\xi) f_2(x-\xi) d\xi \tag{3}$$

Integrating, we obtain

$$f(x) = \frac{1}{s}\left[1 - e^{-(\frac{x-\xi}{\alpha})^\beta}\right] \tag{4}$$

The fraction of bearings which will fail prior to reaching x is the cumulative probability function or

$$F(x) = \int_0^x f(\xi) d\xi = \int_0^x \frac{1}{s}\left[1 - e^{-(\frac{x-\xi}{\alpha})^\beta}\right] d\xi \tag{5}$$

Integrating, we obtain

$$F(x) = \frac{x}{s} - \int_0^x \frac{1}{s} e^{-(\frac{x-\xi}{\alpha})^\beta} d\xi \tag{6}$$

For the exponential case, β = 1. This expression becomes

$$F(x) = \frac{x}{s} - \frac{1}{(s/\alpha)} \{1 - e^{-x/\alpha}\} \tag{7}$$

The fraction of bearing which will be observed by the hotbox detector is the fraction that will survive until x = s or 1 - F(s)

$$P_{r0} = 1 - F(s) = \int_0^s \frac{1}{s} e^{-(\frac{s-\xi}{\alpha})^\beta} d\xi \tag{8}$$

and for the exponential case (β = 1.0) this is

$$P_{r0} = 1 - F(s) = \frac{1}{s/\alpha} \{1 - e^{-s/\alpha}\} \tag{9}$$

Equation (9) can be expressed simply as

$$P_{r0} = \int_0^s \frac{1}{s} R(s-x)dx \qquad (10)$$

which states simply the probability of the bearing surviving to the hotbox detector is the sum over x of all products of the probability of a defect occurring and the probability of its surviving to the hotbox at $x = s$. For example, in the case $R(s-x) = 1.0$--i.e., 100 percent surety that the bearing will last until the hotbox--P_{r0} is 1.0 as it should be.

Equation (8) is shown plotted in Figure D-4 as a function of s/α for various values of β.

If we know the value of α and β for a given component and failure mode, we can then calculate the detector spacing with a given level of confidence of observing the defect. For this analysis we have assumed that the detector is 100 percent reliable.

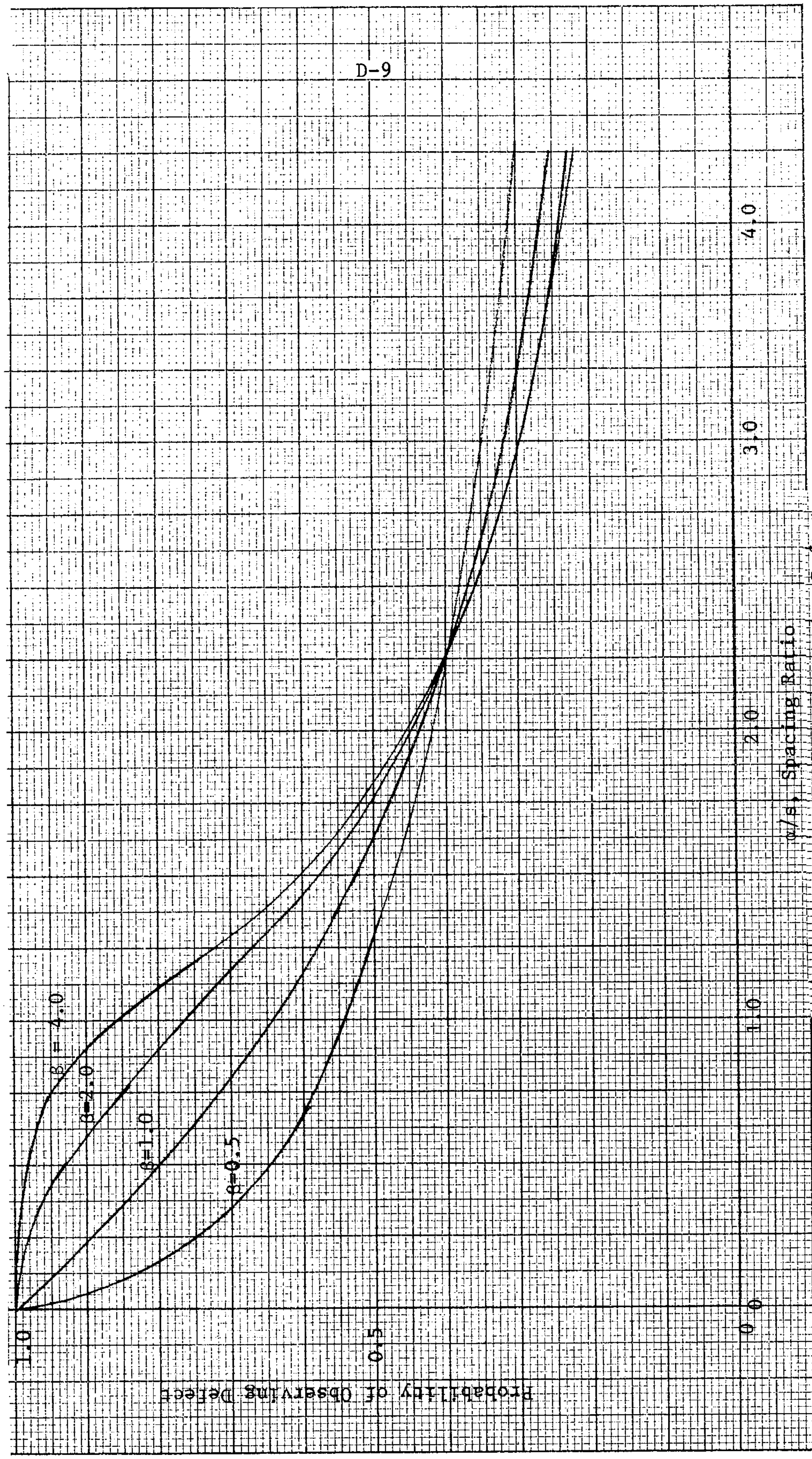


Fig. D-4 Probability of Observing Defect Versus Spacing Ratio

DATA POPULATION

We now wish to determine the values of β and α for describing the life margin once the defect has reached a detectable condition. Table DI summarizes hotbox data from a representative railroad over a seven-year period. The first data line is the total number of confirmed set outs by year. The next two lines give the number of failed plain journals and roller journals respectively. The last line gives the total number of failures where we are considering the set outs as a failure. How we will treat this statistically is described later.

Table DII is a breakdown of the plain journal failures into three categories: (1) those that failed after being detected, (2) those that failed after not being detected, and (3) those that failed without passing a hotbox detector. Because we have no way of analyzing the failures in category 3, we have excluded them from the population.

TABLE DI

DATA POPULATION OF ROLLER AND PLAIN JOURNALS

REPRESENTATIVE SAMPLE

Data Courtesy of Southern Railway System

	1969	1970	1971	1972	1973	1974	1975*
Total Confirmed Set Outs	96.24%	97.88%	97.94%	98.95%	97.37%	97.16%	98.10%
Failed Journals (Plain)	3.50%	2.12%	1.98%	.86%	2.19%	2.58%	1.70%
Failed Journals (Roller)	.26%	0	.08%	.19%	.44%	.26%	.20%
Total	100%	100%	100%	100%	100%	100%	100%

* Estimated

TABLE DII

DATA POPULATION OF PLAIN JOURNAL FAILURES

REPRESENTATIVE SAMPLE

Data Courtesy of Southern Railway System

Year / Category	1969	1970	1971	1972	1973	1974	1975
Detected by H.B.D.* and Train Stopping	11%	28%	25%	22%	35%	33%	41%
Passed H.B.D. But Not Detected	41%	38%	42%	56%	45%	48%	53%
Did Not Pass H.B.D.	48%	34%	33%	22%	20%	19%	6%
Total	100%	100%	100%	100%	100%	100%	100%

* H.B.D. - Hotbox Detector

DATA ANALYSIS

Plotting and analysis of data must take into account the form of the data. Failure data can be complete or incomplete. If failure data contain the failure times of all units in the sample, the data are complete. If failure data consist of failure times of failed units and running times of unfailed units, the data are incomplete and are called censored; and the running times are called censoring times. If the unfailed units all have the same censoring time, which is greater than the failure times, the data are singly censored. If unfailed units have different censoring times, the data are multiply censored.

Complete data result when all units have failed. Singly censored data result in life testing when testing is terminated before all units fail. Multiply censored data result 1) from removal of units from use before failure, 2) from loss or failure of units due to extraneous causes, and 3) from collection of data while units are still operating.

If we assume that the set outs can be considered as removal of units before failure, then our data populations are censored. We will further assume that the censoring times are the distribution of times required to detect a hotbox, signal, perform the decision process, and bring the train to a stop.

Based on a random sample of 49 hotboxes detected in 1975 from a representative railroad, an average stopping distance is between 1.1 and 2.6 miles. Table DIII shows the distribution of the stopping distances for the sample.

There is a substantial amount of empirical evidence (3) that the time required to perform the same task under different environmental conditions is lognormally distributed; that is, the logarithm of time required for completion tends to be normally distributed.

Figure D-5 is a plot of the stopping distances on lognormal probability paper. The fit is reasonably good and in the following analyses we will assume that the stopping distance can be described by the lognormal function.

TABLE DIII

AVERAGE CENSORING TIME

Data Courtesy of Southern Railway System

Distance to Detect Hotbox Signal, Perform Decision Process, and Stop Train (Miles)	Number of Occurrences
< .6	21
.6 - 1.0	5
1.1 - 1.5	3
1.6 - 2.0	5
2.1 - 2.5	4
2.6 - 3.0	2
3.1 - 3.5	0
3.6 - 4.0	4
4.1 - 4.5	1
4.6 - 5.0	1
5.1 - 9.0	
9.1 - 12.0	3
Total	49

Average = 1.85 miles

95% Confidence Limits on Average = 1.1 to 2.6 Miles

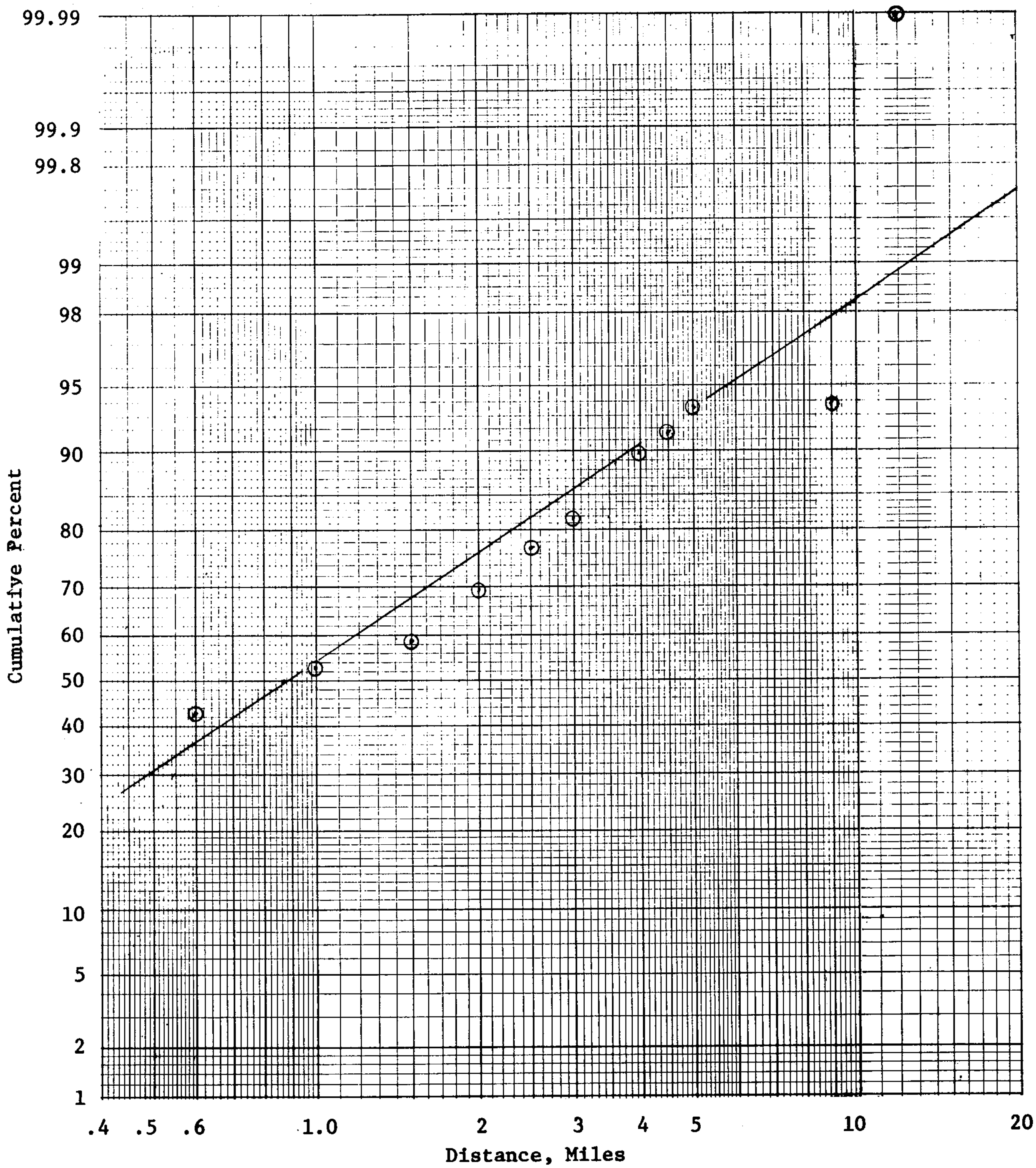


Fig. D-5 Distribution of Times to Detect Hotbox, Signal, Perform Decision Process, and Stop Train

Table DIV presents the number of failures as a function of the distance from the last hotbox detector; i.e., the variable x in Equation (10). We will assume that our hotbox detectors are 100 percent reliable. Thus, if the failure was not detected by the hotbox detector, it was still good at the time the bearing passed the detector. Further, we will assume that the initial failure point (see Figure D-1) was just past the detector location. This assumption will, of course, tend to overestimate the characteristic failure margin. The value of x in Equation (10) is the distance indicated in the first column of Table DIV.

Lastly, we will assume that the initial failure point of those failures which were detected was one half the distance between the previous hotbox detector and the hotbox which detected it. Therefore, the value of x is the distance in column one plus one half the distance between the hotboxes. If the data sheets did not indicate a distance between hotboxes, a value of 30 miles was assumed.

Plain Journal Bearing Analysis

Table DV presents the hazard table for the plain journal failures. The table consists of 101 failure times for the failed bearings and 6757 censoring times for the bearing set outs. The data has been ordered from smallest to largest without regard to whether they are censoring times or failure times. In the list of ordered times, the failures are each marked with an asterisk to distinguish them from the censoring times as discussed earlier. The censoring distances have been distributed in the list according to a lognormal function.

The hazard value, h(x), for a failure time is the inverse of the number K units with a failure or censoring time greater than (or equal to) that failure time. The K value is given in parenthesis next to the unit number. The cumulative hazard, H(x), is the cumulative sum of all failure times preceding and including h(x). Each failure time has been plotted against its corresponding cumulative hazard in Figure D-6. Using linear regression analysis, the equation

TABLE DIV

FRACTION OF FAILURES AS A FUNCTION
OF DISTANCE FROM HOT BOX DETECTOR
REPRESENTATIVE SAMPLE OF PLAIN JOURNALS
Data Courtesy of Southern Railway System

Miles from H.B.D. to Failure	Number of Failures	
	Detected by H.B.D.	Not Detected by H.B.D.
0 - 5	85%	1.5%
5 - 10	12.5%	4.6%
10 - 15	2.5%	3.1%
15 - 20	--	7.7%
> 20	--	83.1%

TABLE DV

PLAIN BEARING HAZARD TABLE

Unit	Distance	h(x)	H(x)
1 (6858)			
↓			
6014 (845)			
6015 (844)	3.6*	1.18E-03	1.18E-03
6016 (843)			
↓			
6421 (438)			
6422 (437)	5.8*	2.29E-03	3.47E-03
6423 (436)			
↓			
6584 (275)			
6585 (274)	8.2*	3.65E-03	7.12E-03
6586 (273)			
↓			
6639 (220)			
6640 (219)	9.7*	4.57E-03	1.17E-02
6641 (218)			
↓			
6654 (205)			
6655 (204)	10.2*	4.90E-03	1.66E-02
6656 (203)			
↓			
6702 (157)			
6703 (156)	13.3*	6.41E-03	2.30E-02
6704 (155)			
6705 (154)			
6706 (153)	13.4*	6.54E-03	2.95E-02
6707 (152)			
↓			
6716 (143)			
6717 (142)	14.3*	7.04E-03	3.66E-02
↓			
6719 (140)	14.4*	7.14E-03	4.37E-02
6720 (139)	14.5*	7.19E-03	5.09E-02
6721 (138)			
6722 (137)			
6723 (136)	14.7*	7.35E-03	5.83E-02
6724 (135)			
6725 (134)			
6726 (133)	15.0*	7.52E-03	6.58E-02

* Denotes failure

(TABLE DV)

Unit	Distance	h(x)	H(x)
6727 (132)	15.1*	7.58E-03	7.34E-02
6728 (131)			
↓			
6730 (130)			
6731 (129)	15.3*	7.75E-03	8.11E-02
6732 (128)			
↓			
6735 (124)			
6736 (123)	15.9*	8.13E-03	8.92E-02
6737 (122)			
6738 (121)	16.1*	8.26E-03	9.75E-02
6739 (120)			
6740 (119)	16.3*	8.40E-03	1.06E-01
6741 (118)			
6742 (117)	16.5*	8.55E-03	1.14E-01
6743 (116)	16.5*	8.62E-03	1.23E-01
6744 (115)			
6745 (114)	16.6*	8.77E-03	1.32E-01
6746 (113)			
6747 (112)	16.7*	8.93E-03	1.41E-01
6748 (111)	16.8*	9.01E-03	1.50E-01
6749 (110)	16.8*	9.09E-03	1.59E-01
6750 (109)	16.8*	9.17E-03	1.68E-01
6751 (108)	16.8*	9.26E-03	1.77E-01
6752 (107)			
6753 (106)	16.9*	9.43E-03	1.87E-01
6754 (105)	16.9*	9.52E-03	1.96E-01
6755 (104)	16.9*	9.62E-03	2.06E-01
6756 (103)			
6757 (102)	17.1*	9.80E-03	2.16E-01
6758 (101)	17.4*	9.90E-03	2.26E-01
6759 (100)			
6760 (99)			
6761 (98)	18.0*	1.02E-02	2.36E-01
6762 (97)			
6763 (96)	18.2*	1.04E-02	2.46E-01
6764 (95)	18.2*	1.05E-02	2.57E-01
6765 (94)			
6766 (93)			
6767 (92)	18.6*	1.09E-02	2.68E-01
6768 (91)			
6769 (90)	18.8*	1.11E-02	2.79E-01

* Denotes failure

(TABLE DV)

Unit	Distance	h(x)	H(x)
6770 (89)	18.9*	1.12E-02	2.90E-01
6771 (88)			
6772 (87)	19.3*	1.15E-02	3.01E-01
6773 (86)	19.4*	1.16E-02	3.13E-01
6774 (85)	19.4*	1.18E-02	3.25E-01
6775 (84)			
6776 (83)			
6777 (82)	19.8*	1.22E-02	3.37E-01
6778 (81)			
6779 (80)	20.6*	1.25E-02	3.50E-01
6780 (79)			
6781 (78)	20.7*	1.28E-02	3.62E-01
6782 (77)			
6783 (76)	20.9*	1.32E-02	3.76E-01
6784 (75)	21.0*	1.33E-02	3.89E-01
6785 (74)			
6786 (73)			
6787 (72)	21.7*	1.39E-02	4.03E-01
6788 (71)	21.7*	1.41E-02	4.17E-01
6789 (70)	22.0*	1.43E-02	4.31E-01
6790 (69)	22.0*	1.45E-02	4.46E-01
6791 (68)	22.0*	1.47E-02	4.60E-01
6792 (67)			
6793 (66)	22.7*	1.52E-02	4.75E-01
6794 (65)			
6795 (64)	22.9*	1.56E-02	4.91E-01
6796 (63)	23.0*	1.59E-02	5.07E-01
6797 (62)			
6798 (61)	23.5*	1.64E-02	5.23E-01
6799 (60)			
6800 (59)	24.1*	1.69E-02	5.40E-01
6801 (58)			
6802 (57)	24.8*	1.75E-02	5.58E-01
6803 (56)	25.3*	1.79E-02	5.76E-01
6804 (55)			
6805 (54)	25.5*	1.85E-02	5.94E-01
6806 (53)	25.5*	1.89E-02	6.13E-01
6807 (52)			
6808 (51)	25.7*	1.96E-02	6.33E-01
6809 (50)	26.2*	2.00E-02	6.52E-01
6810 (49)	26.5*	2.04E-02	6.73E-01
6811 (48)	26.6*	2.08E-02	6.94E-01

* Denotes failure

(TABLE DV)

Unit	Distance	h(x)	H(x)
6812 (47)	26.7*	2.13E-02	7.15E-01
6813 (46)	26.7*	2.17E-02	7.37E-01
6814 (45)	26.9*	2.22E-02	7.59E-01
6815 (44)			
6816 (43)	27.4*	2.33E-02	7.82E-01
6817 (42)	27.4*	2.38E-02	8.06E-01
6818 (41)	27.5*	2.44E-02	8.31E-01
6819 (40)	27.8*	2.50E-02	8.56E-01
6820 (39)			
6821 (38)	28.5*	2.63E-02	8.82E-01
6822 (37)	28.5*	2.70E-02	9.09E-01
6823 (36)	28.6*	2.78E-02	9.37E-01
6824 (35)	28.6*	2.86E-02	9.65E-01
6825 (34)	29.0*	2.94E-02	9.95E-01
6826 (33)	29.0*	3.03E-02	1.03E+00
6827 (32)	29.4*	3.13E-02	1.06E+00
6828 (31)	29.7*	3.23E-02	1.09E+00
6829 (30)	29.8*	3.33E-02	1.12E+00
6830 (29)			
6831 (28)	30.0*	3.57E-02	1.16E+00
6832 (27)	30.6*	3.70E-02	1.19E+00
6833 (26)	31.0*	3.85E-02	1.23E+00
6834 (25)	31.0*	4.00E-02	1.27E+00
6835 (24)			
6836 (23)	32.6*	4.35E-02	1.32E+00
6837 (22)			
6838 (21)	36.1*	4.76E-02	1.36E+00
6839 (20)	36.5*	5.00E-02	1.41E+00
6840 (19)			
6841 (18)	37.4*	5.56E-02	1.47E+00
6842 (17)	38.0*	5.88E-02	1.53E+00
6843 (16)	38.3*	6.25E-02	1.59E+00
6844 (15)	39.2*	6.67E-02	1.66E+00
6845 (14)	39.3*	7.14E-02	1.73E+00
6846 (13)			
6847 (12)	44.0*	8.33E-02	1.81E+00
6848 (11)	44.5*	9.09E-02	1.90E+00
6849 (10)	46.3*	1.00E-01	2.00E+00
6850 (9)			
6851 (8)	51.0*	1.25E-01	2.13E+00
6852 (7)	55.4*	1.43E-01	2.27E+00
6853 (6)	56.0*	1.67E-01	2.44E+00
6854 (5)	66.5*	2.00E-01	2.64E+00
6855 (4)	72.8*	2.50E-01	2.89E+00
6856 (3)	102.8*	3.33E-01	3.22E+00
6857 (2)	122.9*	5.00E-01	3.72E+00
6858 (1)	123.0*	1.00E+00	4.72E+00

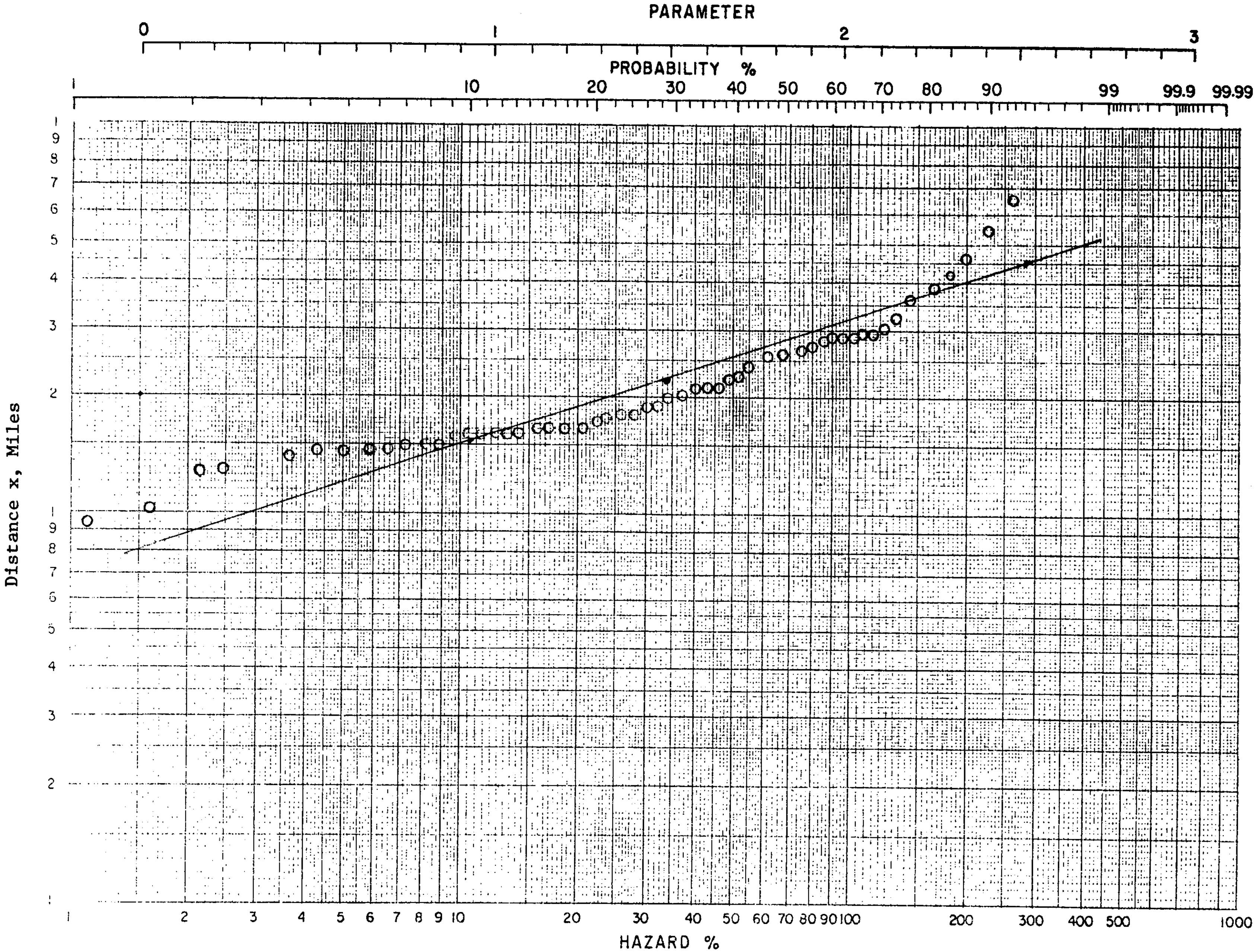


Fig. D-6 Plain Bearing Hazard Plot

$$\log(x) = \frac{1}{\beta} \log H(x) + \log\alpha$$

has been fitted to the data. The following values for β and α were obtained

β = 3.03 (2.72 - 3.41)*

α = 32.7 miles (30.4 - 34.9)*

Roller Journal Analysis

Table DVI presents the number of roller journal failures as a function of distance from the last hotbox detector. Treating this data in the same manner previously described, a hazard table (Table DVII) and plot (Figure D-7) have been prepared. The resulting values of β and α are:

β = 1.45 (1.12 - 2.05)*

α = 36.4 miles (29.5 - 44.9)*

Note that the confidence on this data is very wide. This is due to the smaller sample size and the greater scatter in the data.

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* Upper and lower 90% confidence band.

TABLE DVI

FRACTION OF FAILURES AS A FUNCTION
OF DISTANCE FROM HOT BOX DETECTOR
REPRESENTATIVE SAMPLE OF ROLLER JOURNALS
Data Courtesy of Southern Railway System

Miles from H.B.D. to Failure	Number of Failures	
	Detected by H.B.D.	Not Detected by H.B.D.
0 - 5	67%	12.5%
5 - 10	32%	--
10 - 15	---	--
15 - 20	---	--
> 20	---	87.5%

TABLE DVII

ROLLER BEARING FAILURE HAZARD TABLE

Unit	Distance	h(x)	H(x)
1 (8)			
↓ (↑)			
33 (49)			
34 (48)	.8*	2.08E-02	2.08E-02
↓ (↑)			
70 (12)			
71 (11)	9.1*	0.09E-02	1.11E-01
72 (10)	9.1*	1.00E-01	2.12E-01
73 (9)			
74 (8)	22.4*	1.25E-01	3.37E-01
75 (7)	23.1*	1.43E-01	4.80E-01
76 (6)	25*	1.66E-01	6.46E-01
77 (5)	27*	2.00E-01	8.46E-01
78 (4)	40.3*	2.50E-01	1.10E+00
79 (3)	45*	3.33E-01	1.43E+00
80 (2)	69*	5.00E-01	1.93E+00
81 (1)	72.1*	1.00E+00	2.93E+00

* Denotes failure

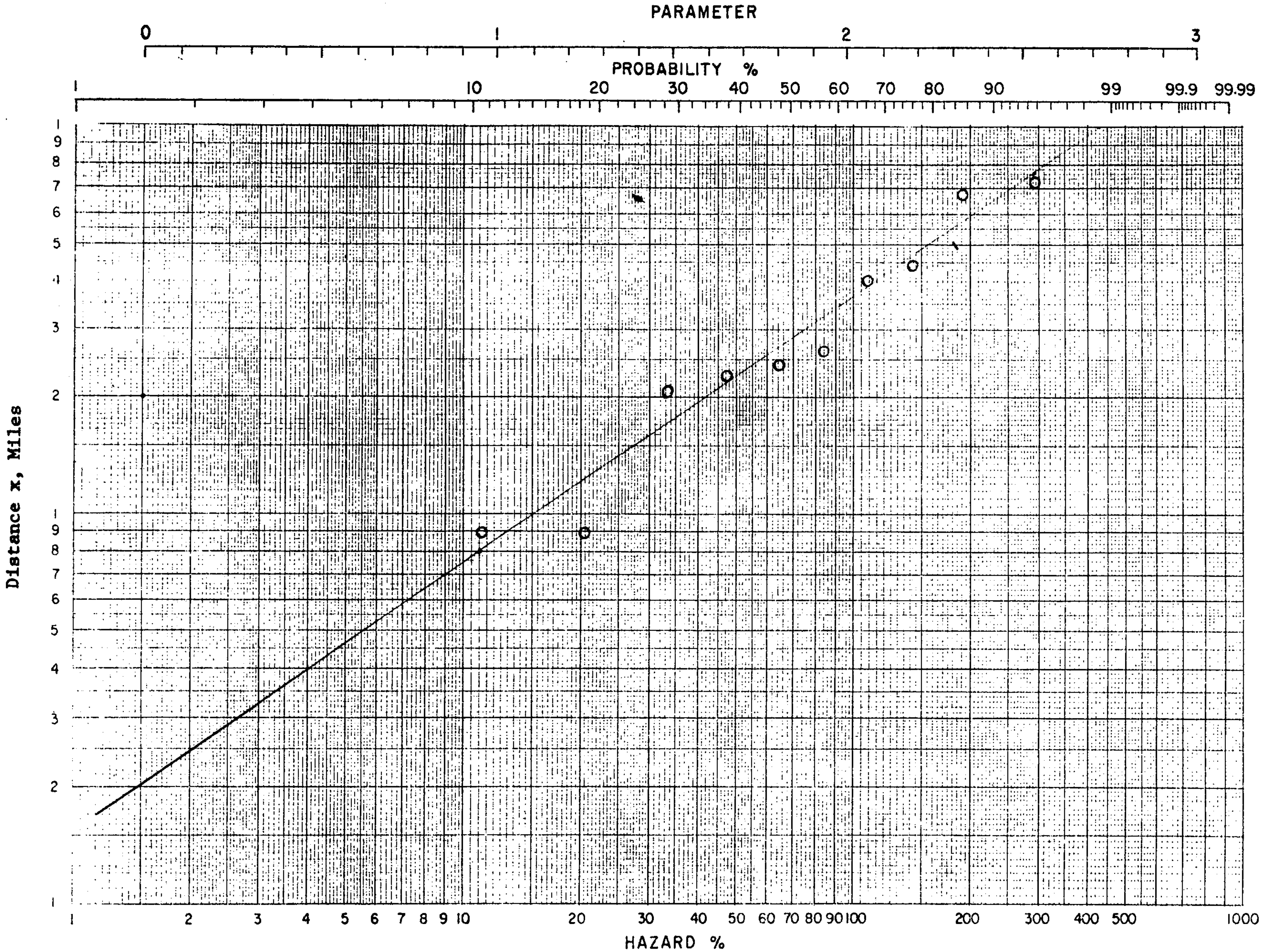

Fig. D-7 Roller Bearing Hazard Plot

DISCUSSION OF RESULTS

Using the techniques of hazard plotting for incomplete data, we have been able to make estimates for the Weibull slope parameter and characteristic failure margin for both plain and roller journals. These are summarized below:

	Bearing Type	
	Plain	Roller
α Characteristic Failure Margin, (Miles)	32.7 (30.4 - 34.9)*	36.4 (29.5 - 44.9)*
β Weibull Slope	3.03 (2.72 - 3.41)*	1.45 (1.12 - 2.05)*

The first thing to note is that our estimate of the Weibull failure margin parameters for the plain journal is much more accurate than our estimates for the roller journal. This is due primarily to the greater quantity and lesser scatter of the plain journal data.

The crucial question is whether the roller characteristic failure margin is greater or less than the failure margin for plain bearings. The data indicates that the plain bearing has a slightly smaller characteristic failure margin; although because of the wide confidence band on the roller bearing estimate, it is not possible to say that there is a significant difference between the roller and plain bearing.

Since β is greater than 1 for both plain journals and roller bearings, the failure rate is going to be an increasing one with distance traveled beyond the detection point. Referring again to Figure D-4 and Equation (8), we can now calculate the probability of observing a defect prior to failure as a function of α/s for both the roller (β = 1.45) and plain (β = 3.03) bearings.

Figure D-8 is a plot of P_{r0}, the probability of observing a defect, versus α/s, the ratio of spacing distance to characteristic life for the two values

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* Upper and lower 90% confidence band.

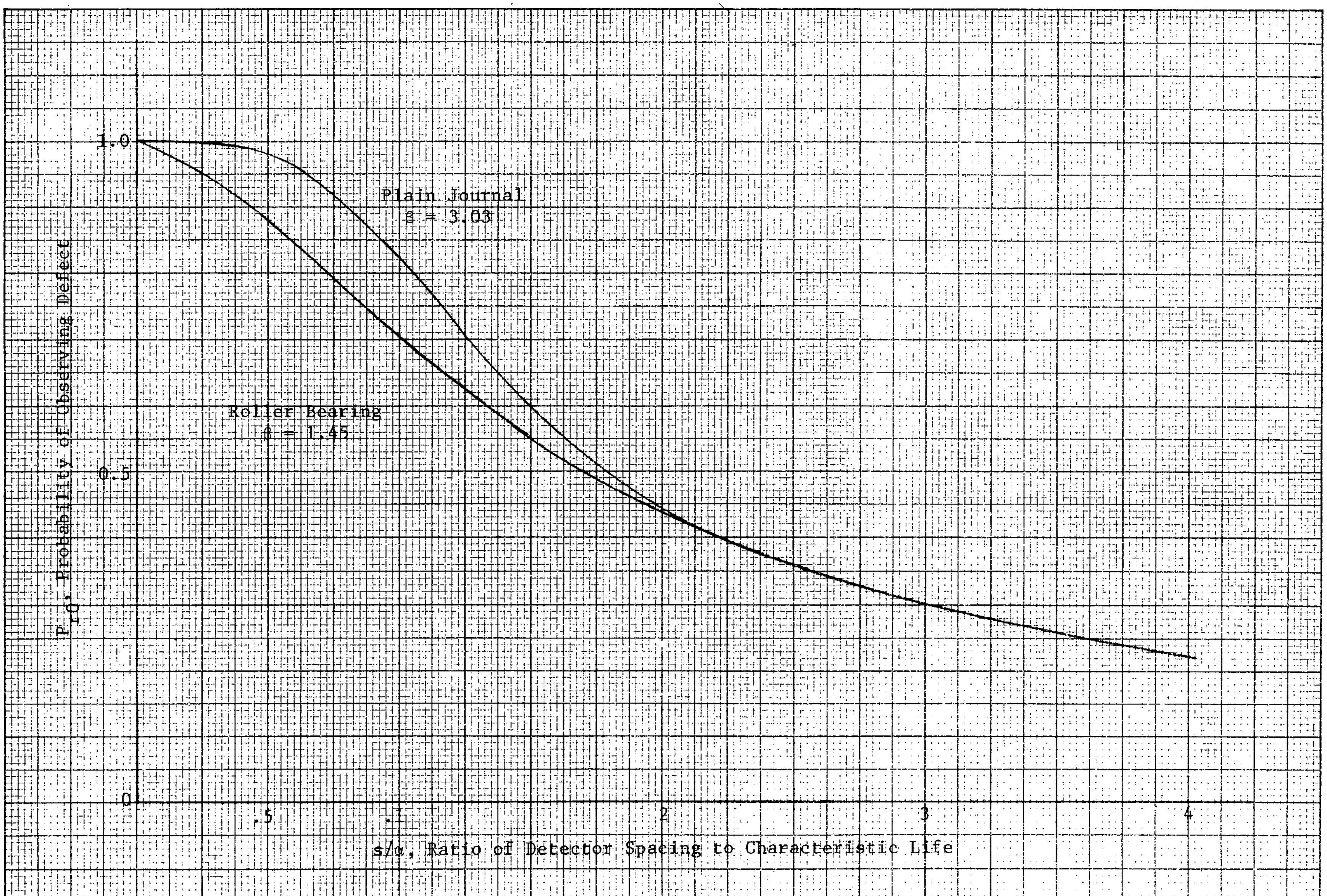

Fig. D-8. Probability of Observing Defect Versus Detector Spacing Ratio of β corresponding to plain journals and roller bearings. This result is most important because it indicates that for the same degree of protection (P_{r0} = .9), the detector spacing for roller bearings must be 54 percent of that used for plain bearings. It should be noted that this difference in required spacing is due primarily to the difference in β.

The reason for this somewhat unusual result is that the higher the value of β (see Figure D-3), the smaller the fraction of bearings that will fail prior to the characteristic life, α. In the limit for $\beta \rightarrow \infty$, all bearings fail at α; and spacing less than α will insure that all defects will be observed.

REFERENCES PER APPENDIX D

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APPENDIX E

REPORT ON INVENTIONS

The objective of the work was to identify sensors that were needed to reduce railcar equipment caused derailments. Although there were no inventions resulting from the reported work several innovations were developed that provided insights into the significance of the derailment data and their associated costs. Additionally a method was developed, that allowed the assignment of target costs for proposed wayside inspection systems.

Specifically, Section Three of the report develops cause code groups and identifies one group, called dynamics, as an important and increasing cause of railroad equipment derailments. The importance of this group is not apparent from an analysis of individual cause code rankings.

Section Five of the report develops allowable cost and deployment data for new wayside inspection systems. This is based on the costs and the results of the hot box detector being acceptable to the railroads for plain bearings. These figures may be used to evaluate the cost/benefit ratio of proposed systems. In addition, these cost numbers may be used to evaluate the effect of improved railcar design.

Two methods were developed to evaluate hot box detector effectivity for roller bearings. One, described in Section Five, constructs the experience of a hypothetical railroad with hot box detectors and extrapolates this experience into the future when the railroad bearing population will be predominately roller type. Appendix D evaluates hot box data from a statistical nature. The two methods arrive at a consistent conclusion.

Finally, Section 4.3 contains a description of the important factors that must be considered in the development of a wayside inspection system for dynamics caused derailments.

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