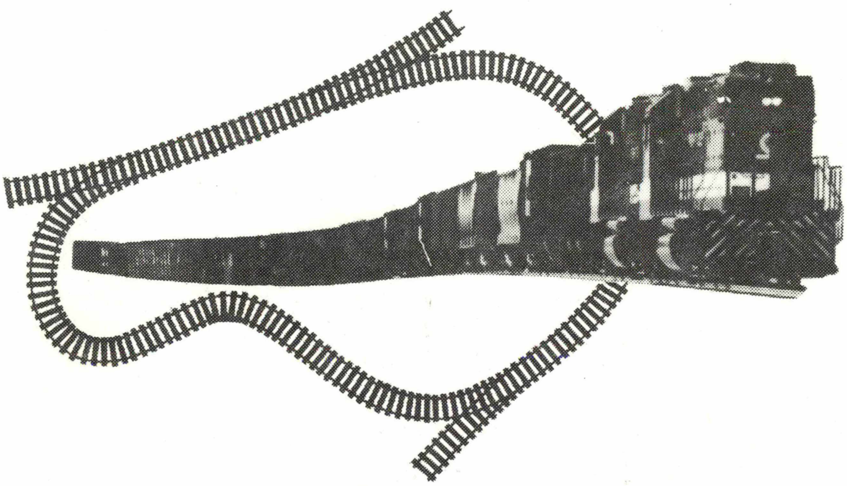
Report No. FRA/ORD-79/56

ISSUES AND DIMENSIONS OF FREIGHT CAR SIZE: A COMPENDIUM



October 1980

U.S. DEPARTMENT OF TRANSPORTATION
Federal Railroad Administration
Office of Research and Development
Washington, D.C. 20590

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Front Cover: An illustration of the Facility for Accelerated Service Testing (FAST) at DOT's Transportation Test Center in Pueblo, Colorado. This joint government and industry research project provides valuable insight into the behavior of both track and rolling stock.

Back Cover: The Rail Dynamics Laboratory (RDL) at DOT's Transportation Test Center provides controlled dynamic wheelset inputs for investigations of the dynamic behavior of rolling stock. This photograph shows a flat car with two attached highway trailers undergoing a test on the Roll Dynamics Unit (RDU) within the RDL.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-79/56		

4. Title and Subtitle	5. Report Date
ISSUES AND DIMENSIONS OF FREIGHT CAR SIZE: A COMPENDIUM	October 1980
	6. Performing Organization Code
7. Author(s) P.R. Nayak, D.W. Palmer	8. Performing Organization Report No. ADL-80589-11
9. Performing Organization Name and Address Arthur D. Little, Inc. 20 Acorn Park Cambridge, MA 02140	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-FR-74261
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Rail Safety Research Washington, D.C. 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

This report augments the results of a study mandated by Public Law 95-574.

16. Abstract

An investigation is made into the effects of the size, weight, and length of freight cars on the safety and efficiency of U.S. rail transportation. A review is made of the historical and present population and usage of the U.S. freight car fleet. Distinct trends toward the purchase of larger, heavier cars and the subsequent effect on the fleet are shown.

Several data bases are used in a novel fashion to provide actual derailment rates for the fleet by car-miles and ton-miles as functions of various parameters, including car type, nominal weight capacity, and length. A key finding is that, historically, the use of 100-ton capacity freight cars, in itself, has not been detrimental to the safety of U.S. rail transportation.

An overview of current analyses of the causes of derailments is given, with special considerations to tank car accidents and grade-crossing accidents. Based on these analyses, technical measures for improvement are outlined.

In culmination, a series of options available to the government and industry is given, with consideration to technical, regulatory, and economic impacts.

17. Key Words	18. Distribution Statement
Freight cars, vehicle design, derailment, hopper car, tank car, economics, safety, high-capacity car, high axle load	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		299	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The following is extracted from Section 10 of Public Law 95-574, dated November 2, 1978:

Section 10. (a) The Secretary of Transportation shall conduct a study and evaluation concerning the safety and efficiency of rail transportation. Such study and evaluation shall include —

(1) A determination of the relationship of the size, weight, and length of railroad cars (other than those contained in unit trains) to the safety and efficiency of rail transportation; and

(2) a determination of the effect of the exclusive ownership and control of rights-of-way by individual railroads on the safety and efficiency of rail transportation, considering, among other things, whether or not such rights-of-way might be better employed under new structures of ownership or other conditions for joint usage.

(b) Within one year after the date of enactment of this Act, the Secretary of Transportation shall complete the portion of the study described in subsection (a)(1) of this section.

(c) Within two years after the date of enactment of this Act, the Secretary of Transportation shall complete the portion of the study described in subsection (a)(2) of this section and submit a report to the Congress setting forth the results of such study, together with recommendations for such legislative or other action as the Secretary deems appropriate.

As a result of this mandate, a study was conducted. The italics designate the portion of the mandated study that this report addresses.

METRIC CONVERSION FACTORS

...roximate Conversions to Metric Measures

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

...or other exact conversions and more detailed tables, see NBS Misc. Publ. 286, ...sures, Price $2.25, SD Catalog No. C13.10:286.

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m^2
km^2
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kg
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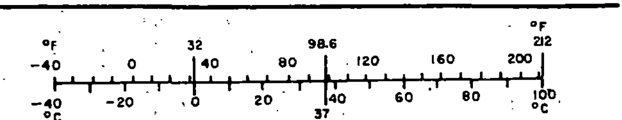
m^3
m^3

°C

Approximate Conversions from Metric Measures

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



ACKNOWLEDGMENT

The following groups contributed to this report through compilation of data, analysis of data, review of plans or reports, or suggestions for study improvements. The support of all who contributed is greatly appreciated.

Arthur D. Little, Inc.

Association of American Railroads:
Economics and Finance Department
Operations and Maintenance Department
Research and Test Department

Atchison, Topeka & Santa Fe Railway

Ballistic Research Laboratory

Battelle Columbus Laboratories

Cranston Research Inc.

Dynamic Sciences

Dynamic Science Inc.

Dynatrend, Inc.

Federal Railroad Administration:
Office of Policy and Program Development
Office of Research and Development
Office of Safety
Office of the Chief Counsel

Illinois Institute of Technology

IIT Research Institute

Interstate Commerce Commission

National Transportation Safety Board

A. Stucki Co.

Systems Technology Laboratory, Inc.

Transportation Research Board

Transportation Systems Center

United Transportation Union

U.S. Department of Transportation,
Office of the Secretary of Transportation,
Office of Programs and Evaluation

U.S.S.R. Technical Information Exchange

In addition, we would like to thank the brake manufacturers, the major tank car owners, and member railroads of the Association of American Railroads for their contributions.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

6-3 Structure of a Hazardous Materials Railroad Incident 6-4
6-4 Hypothetical Accident Site — Englewood Yard 6-6

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

EXECUTIVE SUMMARY

1.1 ABSTRACT

This study presents a review and evaluation of the relationships between the safety and efficiency of rail transportation and the size of railroad freight cars. The study concludes that most larger cars can be operated safely over well-maintained track, but that large-capacity cars tend to exert greater forces on the track structure than do smaller cars. Many railroads have not made appropriate adjustments in maintenance-of-way expenditures to compensate for this increased wear. In addition, cars of certain designs have proved unusually susceptible to derailment because of peculiar dynamic characteristics. These factors have contributed materially to the overall increase in derailments over the current decade. However, factors related to car size cannot be said to have been responsible for a significant number of additional train accident fatalities, especially when countervailing safety considerations are taken into account.

The study did not produce a precise conclusion as to whether the financially troubled railroad industry has realized a net benefit from the introduction of larger freight cars. Available information points to the conclusion that profitable railroads have realized net benefits generated by lower transportation costs, while some poorer railroads may have been adversely affected as a result of their inability to make necessary investments in maintenance of way.

Looking to the future, the study predicts a significant challenge for the railroad industry and the government. Unless major changes are made in government regulatory policies and the railroads take advantage of resulting opportunities in the marketplace, deferred maintenance of track will become an even more critical problem in the 1980's. At the same time, an increasing portion of the freight car fleet will be made up of larger cars, and hazardous materials traffic is expected to double. The possibility of additional catastrophic accidents could be heightened considerably, unless the network marginal track is improved or unless severe operating restrictions are imposed.

As to the specific issues of freight car performance, the study found three areas in need of interim attention.

1. The high center-of-gravity covered hopper cars and some long flat cars have a higher accident-causal rate than other cars in the fleet. Accordingly, the Federal Railroad Administration (FRA) will accelerate related ongoing activities and convene an appropriate forum to further identify the magnitude of the problem and explore opportunities for improvement to these types of cars. The FRA will bring together representatives of the Association of American Railroads, the Railway Progress Institute, and the Railway Labor Executives' Association to facilitate a comprehensive examination of corrective actions, such as modifications to car designs, car dynamic behavior controls, train makeup procedures, train-handling methods, routing decisions, maintenance practices, and operating routines. Since the derailing tendencies of cars on

tracks of different quality, as measured by the six FRA track classifications, cannot be determined from existing data bases, this group will concentrate on determining the nature of countermeasures which may be required to effectively improve safety by evaluating the consequences of running the questionable cars over specific combinations of real-world track and operating conditions.

2. The need to establish and maintain a more meaningful data base was clearly evident during the study. A data collection and analysis system should be established to responsively trace meaningful real-time trends.

3. There is the need to continue the development and validation of research tools so that quantitative predictions of effects and interactions can be made and used to guide the formulation of performance requirements. It is necessary to look at a freight car both in terms of its own response characteristics and the way it affects train action as a whole. A discussion of railroad cars out of the context of train makeup and operation is at best a difficult task. While extreme care was taken during this study not to misuse the individual car data in arriving at conclusions as to what actions, if any, are needed for improvement, it was evident that better research tools are required. The FRA, in conjunction with the industry, has been developing the requisite tools. Some are already in operation. Until these tools are validated, decisions should be made with caution. Examples of major tools that will permit meaningful study of car action in varying train consists under different operational scenarios include the following:

   - *The Facility for Accelerated Service Testing (FAST)* — to evaluate the effects of car axle load on track and car maintenance and to determine the economical safe life of track and roadbed structural components.
   - *The Rail Dynamics Laboratory (RDL)* — to determine the dynamic behavior characteristics of various car types and control devices.
   - *The Stability Assessment Facility for Equipment (SAFE)* — to assess the ability of car designs to interact acceptably with track variations.
   - *The Locomotive Research and Train Handling Evaluator (LRTHE)* — to evaluate operating procedures and control devices to ensure that car performance in longer trains is as good as that in shorter trains.
   - *The Track Train Dynamics Program (TTD)* — to uncover ways that cars in the present fleet can be designed to be more forgiving of track irregularities.

The study identifies possible options to further improve the performance of heavier railroad cars. Long-term options would include government actions to improve the economic condition of railroads, establishment of incentives to shorten the implementation period for improvements, and encouragement for the development of performance criteria for new cars. Other options, which are not as clear-cut or supported by an adequate data base, are left for further consideration, refinement, and development of a position as to what government or industry actions are warranted. These options include utilization of information from operating employees, review of present standards and specifications pertaining to car size, and review of operational requirements for cars carrying hazardous materials.

1.2 INTRODUCTION

The objective of this study was to determine the relationships between freight car size, weight, and length and railroad safety and efficiency. In recent years, most new freight cars can be classed as large cars because of their long length (e.g., 90-foot-long trailer on flat cars [TOFC] or container on flat cars [COFC]), their large load-carrying capacity (e.g., 100 tons), or their large cubic capacity (e.g., 33,000-gallon tank cars). The trend to larger and heavier cars has coincided with an increase in train derailments (approximately 4% per year over the last 9 years) and with an increase in accidents involving cars carrying hazardous materials. The scope of the study included a review of the options available for making railroad transportation safer and of the problems of assigning responsibilities to carry out these options.

The investigation was complicated by the fact that parameters other than simple descriptions of car length, weight, and load capacity had to be considered; for example, dynamic stability. Also, the various aspects of safety had to be evaluated, such as employee injuries, train derailments, grade-crossing accidents, and the potential of catastrophes involving hazardous materials. The determination of options to improve safety had to consider the fact that freight cars are freely interchanged among more than 40 major North American railroads and numerous smaller ones with different operating environments, facilities, track conditions, operating procedures, and economic constraints.

The findings of the investigation were derived from the following major information sources:

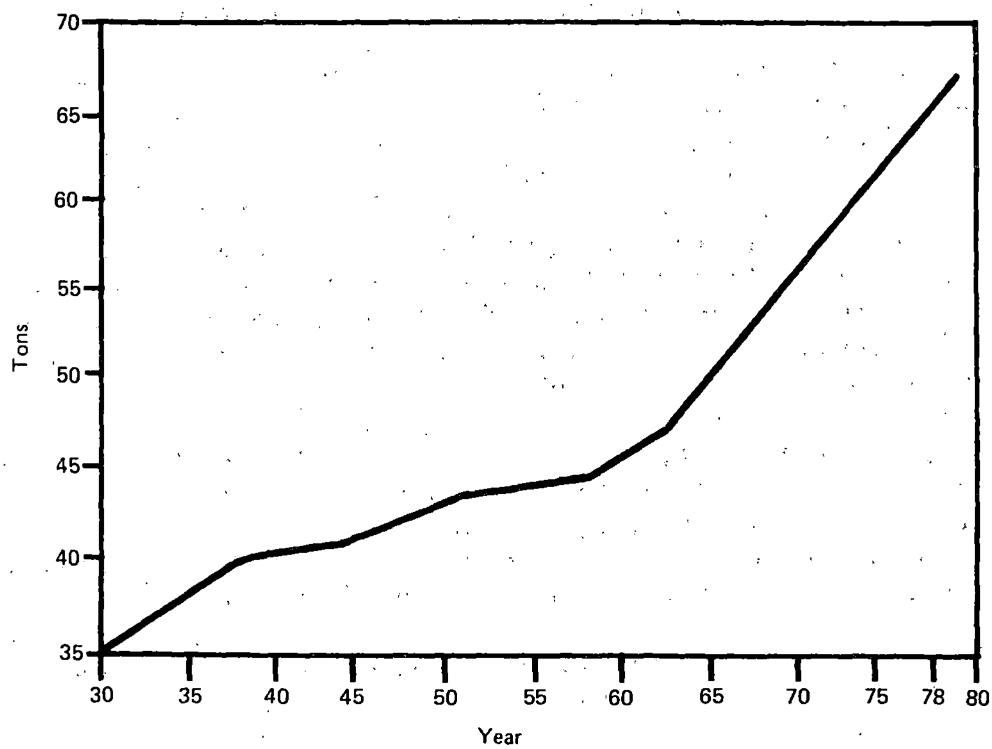
- The historically collected statistical data and trends pertaining to safety and efficiency. The Federal Railroad Administration's (FRA) Rail Accident and Incident Statistics, the Association of American Railroads' (AAR) Universal Machine Language Equipment Register (UMLER file), the FRA 1% Waybill Sampling, and several Interstate Commerce Commission (ICC) information sources were cross-analyzed by individual car characteristics to establish trends such as derailments per car-mile traveled and derailments per ton-mile hauled.
- Prior research and technical tests, data, and findings.
- Surveys, questionnaires, and interviews of directly involved management of railroads, the supply industry, and responsible government representatives.
- An extensive questionnaire survey, conducted by the United Transportation Union (UTU). This survey provided an important contribution to the study. Over 900 operating railroad employees who routinely work with freight cars for many carriers at locations throughout the country took part in this survey. Their tabulated responses have a remarkably good correlation with the other data sources of the study and form a valuable base of first-hand experience for evaluation.*

*A more detailed reporting of the responses, as well as other data upon which this report is based, can be found in "Issues and Dimensions of Freight Car Size: A Compendium," FRA/ORD-79/56.

It is necessary to emphasize, however, that these sources do not contain the full amount of information necessary to vigorously address the determination of the effects on safety and efficiency of size, weight, and length of rail cars. The FRA accident data base is the most comprehensive transportation safety data base in existence, but meaningful references to types of cars have been included only since 1975. Moreover, exposure data, which relate the number of train-miles run and the freight tons hauled to the number of accidents, are incomplete. The annual one-percent waybill sampling maintained by the FRA is currently the best means to predict fleet utilization (or exposure) figures, but extrapolations based on it are subject to normal statistical error. Also, although ongoing research, such as the Facility for Accelerated Service Testing (FAST) experiment at the FRA's Transportation Test Center, is aimed at determining the maintenance and operating differences caused by various levels of axle loads, specific conclusions are not yet available. For these reasons, surveys, questionnaires, and interview results were used to supplement statistical data. Each source was important, and each was used to cross-check the others.

1.3 HISTORY

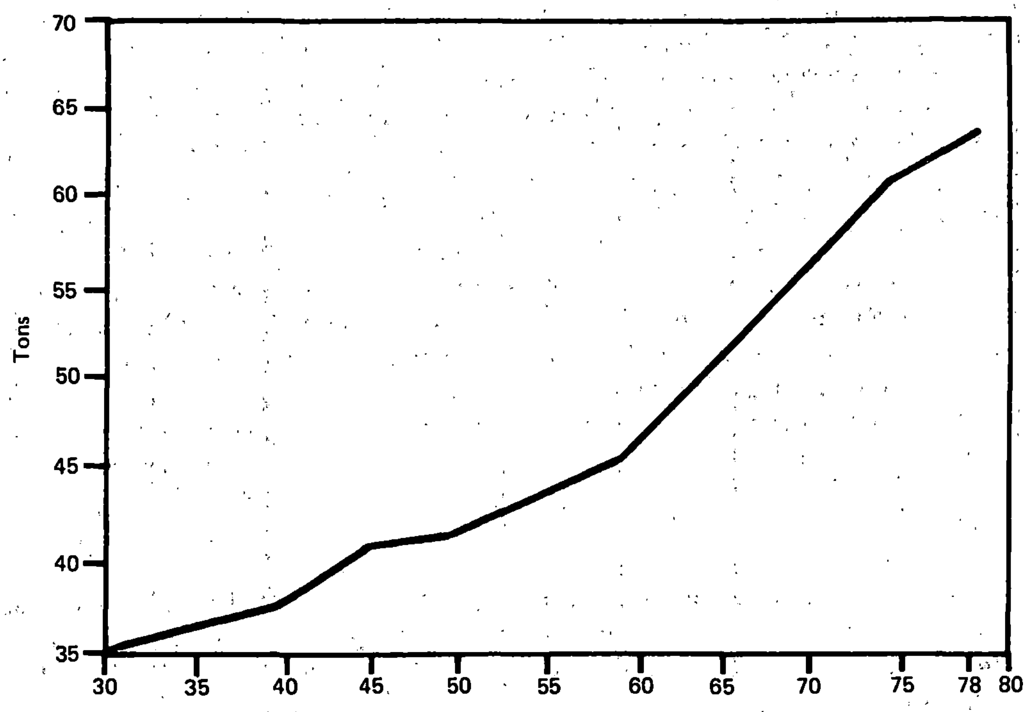
Both the capacity to haul heavier loads and the weight of the loads being hauled in a freight car are increasing (Figures 1-1 and 1-2). This growth is attributable to the introduction of progressively larger freight cars. At present, more than 30% of the freight cars can carry 100-ton loads.



Note: Average for 1978 from Car Service Division, AAR

Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 1-1 AVERAGE FREIGHT CAR CAPACITY TREND



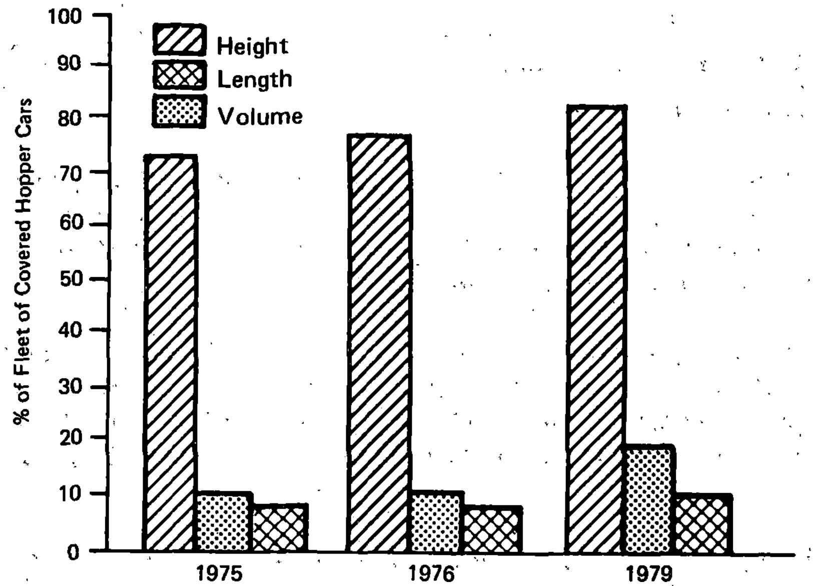
Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 1-2 AVERAGE FREIGHT CARLOAD TREND

Originally, cars carried about ten tons of cargo. By the turn of the century, new cars that could carry 40 or 50 tons of cargo had been developed and were in use. The 70-ton cars were introduced a few years later. By 1950, cars that could carry 100 tons were in service. Relatively few problems were encountered in the transition from 50- to 70-ton cars. The introduction of 100-ton cars required more attention to design details and operating procedures, as did the attempt to go to 125-ton cars. The results of tests and operational experience led to a voluntary decision some years ago to restrict normal interchange movements to cars of 100-ton capacity or less. Operating under different conditions and constraints, international railroads generally have limited static axle loads to 20-25% less than North American practices.

The increase in freight car size has led to the present fleet which is characterized by the fact that some of the largest cars now being used by the railroads are more than 90 feet long, some are more than 16 feet high, and some have more than 5,000 cubic feet capacity. Figure 1-3 shows how the outside length, extreme height, and cubic capacity of covered hopper cars have grown. Figure 1-4 contains similar data for tank cars.

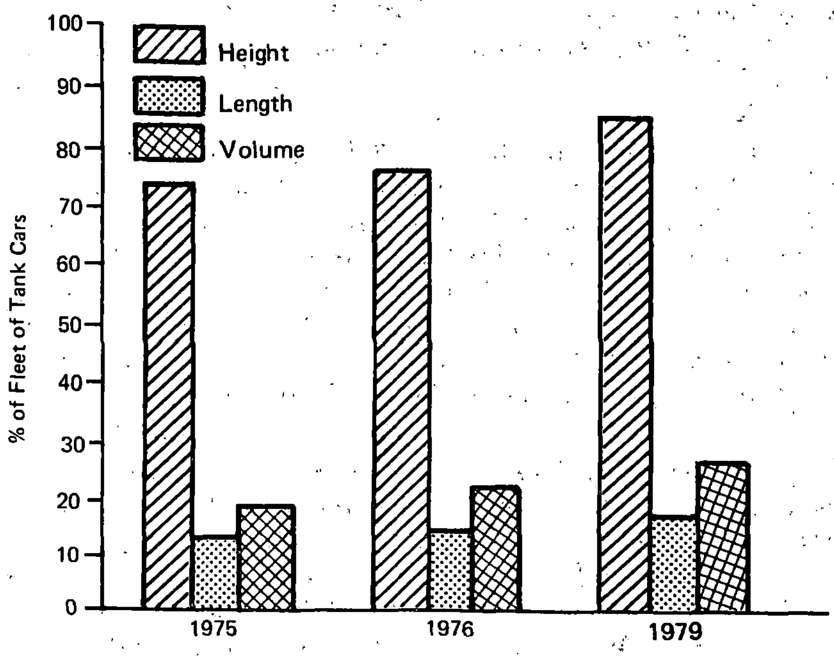
There are numerous combinations of the size, weight, and length of cars for each particular type of car, such as hopper, gondola, box, tank, and flat. This study places primary emphasis on the load-carrying capacity of the cars and groups them into three categories — 100, 70, and 50 tons — since these are the common designations used by the industry. Different lengths and heights, as well as other characteristics, and their combinations were analyzed in this context. It should be noted that the average load carried in a 100-ton car is currently about 83 tons versus 43 tons for a 70-ton capacity car and 31 tons for a 50-ton capacity car.



Height = % with extreme height ≥ 14 ft.
Length = % with outside length ≥ 70 ft.
Volume = % with volume ≥ 5000 ft^3

Source: AAR UMLER Files

FIGURE 1-3 COVERED HOPPER CAR GROWTH



Height = % with extreme height ≥ 14 ft.
Length = % with outside length ≥ 70 ft.
Volume = % with capacity ≥ 22,000 gallons

Source: AAR UMLER Files

FIGURE 1-4 TANK CAR GROWTH

1.4 IS THERE A SAFETY PROBLEM?

1.4.1 The Safety Record

A comprehensive review of the railroad safety record must examine different categories of accidents, including injuries to employees working in yards, train derailments, accidents with hazardous materials cars, injuries to trespassers, and grade-crossing accidents. Measures of safety include injuries, fatalities, and property damage.

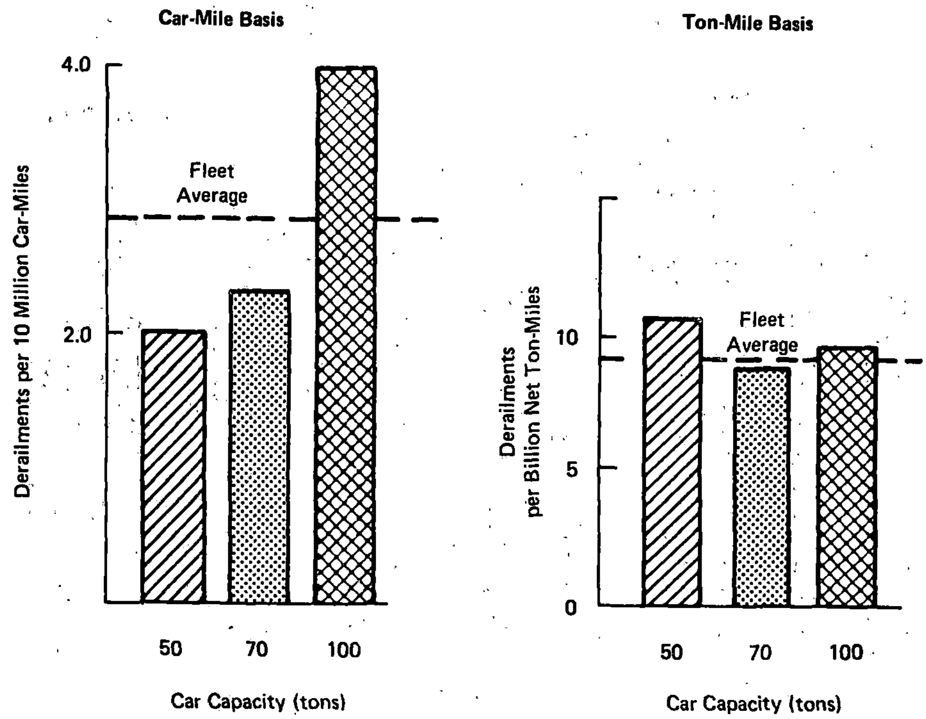
With respect to injuries to employees working in yards, aggregate industry statistics and the UTU railroad worker survey indicate that larger freight cars per se are not more dangerous to personnel working around them (e.g., yard switchmen). However, the safety risk is higher with certain types of cars (e.g., flat cars) and certain designs and locations of components (e.g., handbrakes).

Grade-crossing accident data show no evidence that the size, weight, and length of railroad cars passing through a crossing have any direct influence on the probability or severity of an accident at that crossing for a particular train. Nevertheless, since accident frequency is a function of train frequency, policies that increase the number of trains, such as lowering the maximum allowable load-carrying capacity of a freight car, would lead to a small, but perceptible, increase in the frequency of grade-crossing accidents.

Train derailment is the aspect of railroad safety that is most likely to be influenced by car size, weight, and length parameters. A review of the derailment record shows that a substantial portion of train accidents occurs at low speeds, but these accidents account for only a small percentage of total derailment casualties and costs. In 1978, of over 8,000 derailments, less than 25%, regardless of the reported cause, occurred at speeds greater than 10 miles per hour.

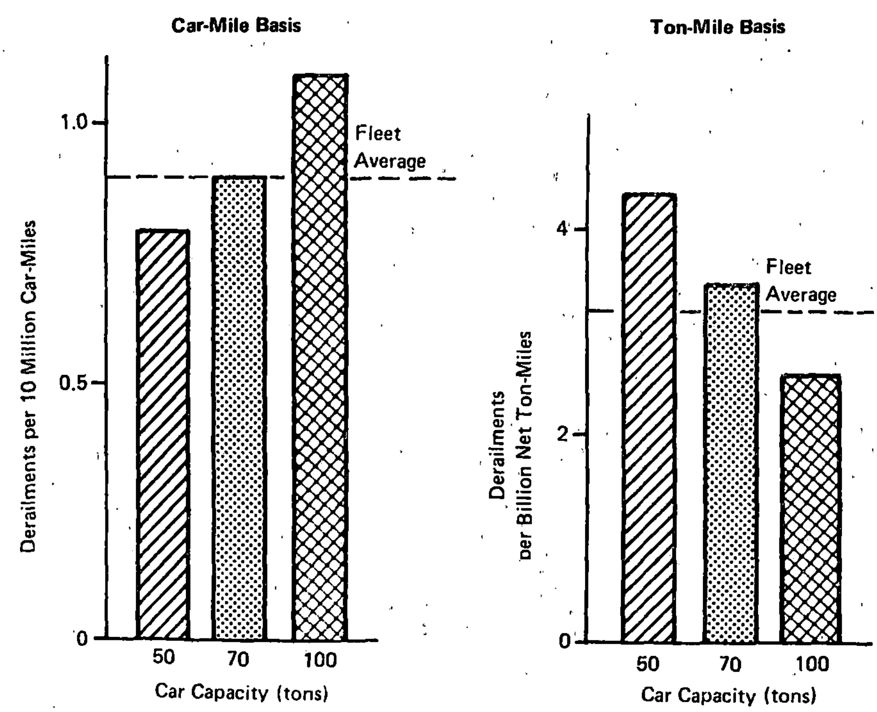
It is necessary to enhance and interpret raw data on the number of derailments to obtain meaningful safety comparisons by car capacity or car type. This analysis must rely on the designated causing car or the first car derailed as reported to the FRA and does not account for other cars that may have been a "contributing" cause. Figure 1-5 presents a concise safety status of the three major load capacity groupings of freight cars. Illustrated is the comparative derailment history of 50-, 70-, and 100-ton cars for the period 1975-1978 based on two of the most appropriate measures, car-miles and ton-miles. Figure 1-6 shows similar comparisons for each of the years 1975 through 1977.

Many approaches can be used to interpret past results and predict likely future consequences. However, these different approaches will produce different views of the problem, and definite pitfalls must be avoided when relying on data groupings collected from dissimilar railroads. For example, Figure 1-7 contains statistics which show that the 50-ton cars have the best safety record when related to either the actual number of accidents, the number of loadings, or the car-miles; the 70-ton cars have the best safety record when related to tons originated and ton-miles. Each of these computations uses identical accident data.



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

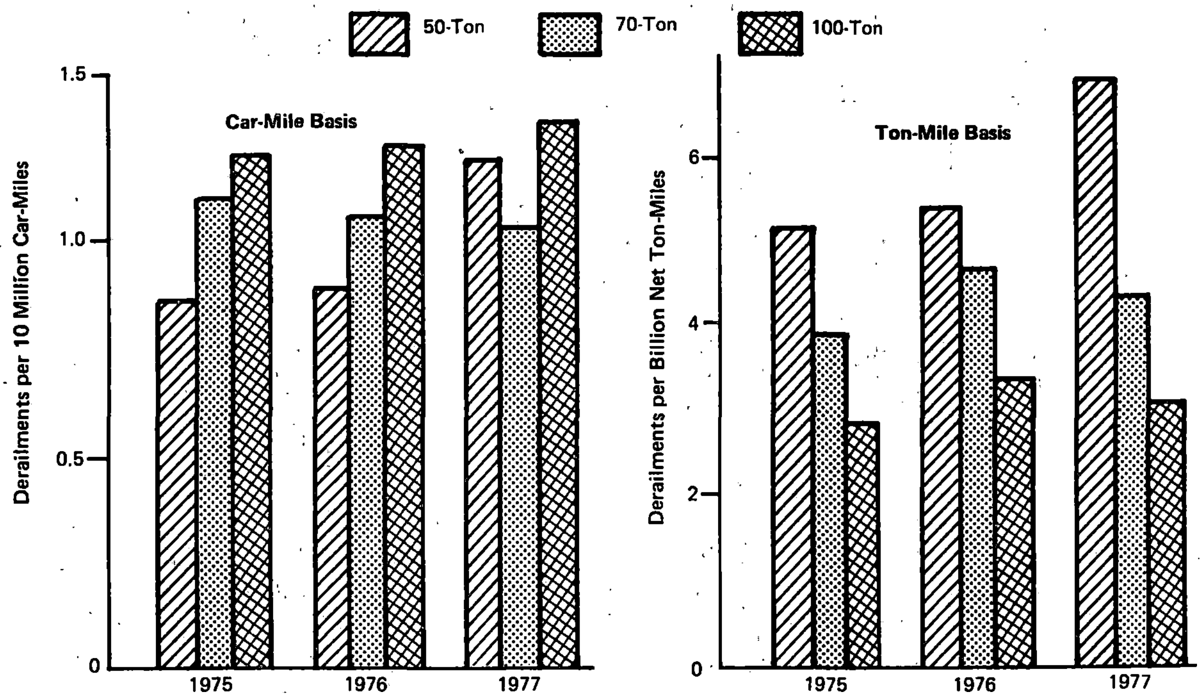
(a) All Speeds



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

(b) Speed Greater Than 10 MPH

FIGURE 1-5 DERAILMENT FREQUENCIES FOR CARS OF VARIOUS TONNAGE CAPACITIES, 1975–1978



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 1-6 RELATIVE ACCIDENT HISTORY ON CAR-MILE AND TON-MILE BASIS (Speed Greater Than 10 MPH)

	Car Capacity		
Basis	**50 ton**	**70 ton**	**100 ton**
Total Number of Accidents	[1]	2	3
Accidents per Car in Fleet	2	[1]	3
Accidents per Car Loading	[1]	2	3
Accidents per Ton Originated	3	2	[1]
Accidents per Car-Mile	[1]	2	3
Accidents per Ton-Mile	2	3	[1]

[ ] Indicates best safety record

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 1-7 RELATIVE SAFETY RANKINGS (Accident Speed Greater Than 10 MPH)

During this study, a special effort was devoted to ascertaining the best statistical basis for comparison. Over 10 different bases were examined. Finally, car-miles and ton-miles were selected as the most valid indicators for use in comparing cars of different capabilities. "Car-miles" is the best descriptor to assess safety on a "per trip" basis, and "ton-miles" is more appropriate to a description of the relative safety of moving a given amount of tonnage. Using car-miles, the 100-ton car shows the poorest safety ranking. Paradoxically, on a ton-mile basis, the 100-ton cars are indicated as having the best safety statistics. Both of these statements can be consistent and believable. Responses from the UTU survey of over 900 working railroad employees support this conclusion. From a switchman's viewpoint, the risk per trip could be greater as he observes obvious "bad actor" large cars in the train. From a total system safety perspective, the overall risk might be lower with large cars because fewer trips are needed to transport the required tonnage.

Both the UTU survey and the industry management survey identified the loaded covered hopper car, which has a high center of gravity, as the car type most likely to derail. The aggregate rail safety statistics clearly show the same result. The industry has long recognized this problem, conducted tests, and initiated changes to correct the problem. However, implementation of corrective improvements is proceeding at a slow pace.

Table 1-1 provides additional insights into the derailment tendencies of the four types of cars with poor records, based on either the aggregate rail industry statistics or the UTU survey. It confirms recent FRA testing results that empty vehicles such as the long flat cars can apply as large lateral loads during side-to-side oscillations (known as "hunting") on the track structure as locomotives with very heavy axle loads.

The most important measure of safety in any field of endeavor is the total loss of life attributable to the variable under consideration. During the period 1975-1978, the average number of fatalities per year that could conceivably be attributed to the size, weight, and length of cars was less than 5. On an annual basis, the number of fatalities ranged from 1 to 9 for the last 4 years. The average number of fatalities per year amounts to less than 1% of all fatalities connected with railroad operations. Table 1-2 shows how these estimates of fatalities were derived.

However, it can also be said that some fatalities are avoided by the use of larger capacity cars. As noted in the following discussion of efficiency, the use of larger capacity cars reduces the exposure of employees to hazards associated with switching (fewer cars to switch) and reduces the frequency of rail/highway grade-crossing accidents (fewer trains). Since fatalities from rail/highway grade-crossing accidents average approximately 1,000 each year, it is obvious that any significant increase in the number of trains operated could produce human consequences as serious as the 5 fatalities per year that may be related to car size, weight, or length (absent increased protection at affected crossings). Also, larger cars and fewer trains mean less chance of collision between trains and less hazard to railroad employees and others who may be on the railroad right of way.

With total fatalities as the yardstick, then, it does not appear that the trend to larger cars has resulted in a new diminution of operational safety. However, the occurrence of one or more accidents involving the exposure of a large number of people to explosive or toxic harzardous materials could radically alter this assessment. Over the last 3 years, approximately 160 tank cars have released hazardous materials as a result of train accidents. With a few notable exceptions, the consequences of most of these accidents have been minor. However, the destructive accidents that have occurred provide ample support for a standard rule of caution in the transportation of these materials.

TABLE 1-1

DERAILMENT TENDENCIES OF "WORST" CAR TYPES

Car Type	Aggregate Industry Statistics		United Transportation Union Survey			Associated Car Characteristics	Industry Action/ Recognition
	Car-Miles	Ton-Miles	Overall	Loaded	Empty		
Covered Hopper	Highest	High	High	Highest	Medium	High center of gravity (98 inches) when loaded.	Dynamic control problem, under study for some years, has led to additional snubbing requirements.
General Flat	High	High	High*	High*	High	Many are more than 80 feet long.	Historical curving problems, especially when empty.
Auto Flat	Medium	Highest	High	High	High	Long lengths. High center of gravity when loaded.	Curving problems. Tendency for dynamic interactions with adjacent cars.
Tank	Medium**	Medium**	Highest***	High***	Medium**	Jumbo's have center of gravity above 84 inches. Hazardous material commodities carried make derailment particularly costly.	Early dynamic structural problems. Special studies over past 10 years. culminating in petition resulting in HM–144 regulations.

*TOFC (Trailer on Flat Cars) Only.
**All Tank Cars.
***Jumbo Tanks Only.

TABLE 1-2

TRAIN DERAILMENT FATALITY ANALYSIS BY YEAR

	1975	1976	1977	1978	4-Yr. Total	Average/ Yr.
Total Fatalities from all Derailments*	2	15	8	41	66	16.5
Less Passenger Train Derailments	—	1	—	6	7	1.75
Less Vandalism	—	—	—	8	8	2.0
Less Locomotive - Caused	1	3	3	1	8	2.0
Less Track Washout, Slide, etc.	—	—	—	2	2	0.5
Identified Human Factors	—	—	—	16	16	4.0
Miscellaneous Causes Not Related to Size, Weight, or Length of Rail Cars	—	2	2	3	7	1.75
Remaining Fatalities	1	9	3	5	18	4.5

*From FRA Accident Bulletin.

Source: FRA Study of Accident Data.

1.4.2 Car Performance and Track Conditions

Statistics indicate that railroads, in the aggregate, have greatly increased investments to improve track and equipment, even though recent FRA analysis shows that much more needs to be done. During the last decade, the tons of rail and number of cross ties laid have approximately doubled. The present rate for the industry as a whole, however, is still only what it was in the middle 1950's, even though ton-miles have increased by 25%; and certain railroads continue to incur sizeable amounts of "deferred" maintenance.

While aggregate industry statistics can assist in measuring past performance, they contain a mixture of variables. Case studies can isolate these variables and provide valuable supplemental data. In this instance, the record shows that specific railroads are able to profitably operate larger cars while maintaining, comparatively, a good safety record. These railroads attribute their success to additional investments in track inspection and maintenance. The data in Table 1-3 quantify the reported maintenance performed from 1955 through 1978 by one railroad that operates a substantial number of larger cars and that has a derailment rate approximately equal to the industry average.

On the basis of accident statistics that specify the number of derailments per million train-miles caused by track or equipment, there is a wide disparity in the abilities of individual railroads to safety transport cars. Table 1-4 shows that the ratio of the derailment rates among railroads can vary by more than 10 to 1. Most of the differences in derailment rates among railroads can be attributed to variations in track conditions.

As further discussed below, 100-ton cars and certain other cars tend to produce greater stresses on track structure than do smaller cars. The accumulated rail fatigue, tie cutting, and other degradation of the track structure generated by larger cars will eventually increase the overall derailment rate for all rail equipment unless adequate programs of restoration and upgrading are implemented. The railroads that have successfully adjusted to heavier axle loading and dynamic stability problems have done so by transforming jointed rail into continuous welded rail, by investing in heavier rail sections for mainline operations, and by giving increased emphasis to roadbed stabilization. These measures promote the reduction of derailment rates, although cars with dynamic stability problems will tend to derail more frequently than other cars.

TABLE 1-3

TRACK MAINTENANCE RECORD OF A SELECTED RAILROAD

Time Frame	Tie Replacements per Year	Rail Replacement in Tons per Year
1955-59	38,800	3,900
1960-64	45,100	3,400
1965-69	68,800	5,700
1970-74	70,520	6,460
1975-78	74,150*	6,075*

*Based on 4-year average

Source: AAR Railroad Industry Survey

TABLE 1-4

COMPARISON OF DERAILMENT RATES AMONG VARIOUS U.S. RAILROADS

Railroad	Track & Equipment Derailment Rate (per million train-miles)	Ratio Relative to Railroad "A"
A	2.1	1.0
B	3.3	1.6
C	6.0	2.8
↓	↓	↓
X	16.7	8.0
Y	23.7	11.3
Z	31.7	15.1

Source: Accident/Incident Bulletin No. 146, 1977, Federal Railroad Administration Office of Safety, August 1978.

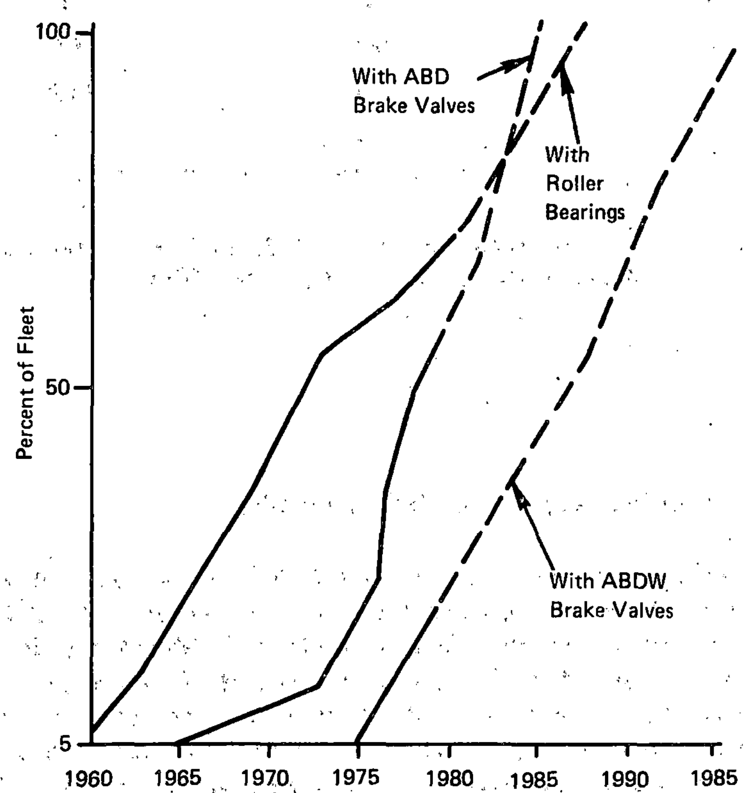
1.4.3 Countermeasure Development and Implementation

When the 100-ton cars were introduced into service, the types of dynamic performance, structural strength, and fatigue life problems experienced were similar to those periodically encountered by the automobile and aircraft industries in introducing new systems. Some early mistakes were difficult to discover and correct in a short period of time; for example, the manufacture of cars with 39-foot truck centers that matched the rail lengths and contributed to "rock-and-roll' instabilities. Where major safety problems visibly surfaced, however, government and industry efforts accelerated the installation of corrective improvements in both new and existing rail vehicles. Examples of such efforts are the retrofit of jumbo tank cars mandated under DOT Regulation HM-144* and actions taken with respect to 6-axle locomotives. Normally, a long period of time is consumed in introducing and equipping the railroad car fleet with a product improvement. Figure 1-8 shows estimates of the amount of time required to incorporate typical design fixes and improvements. When safety is of prime concern, much shorter implementation times have been specified. For example, the modifications required under HM-144 are to be completed in 3 years, with major portions of the program having been completed in the first 2 years.

*See Title 49 of the Code of Federal Regulations, Parts 173 and 179. HM-144 requires improved protection of certain hazardous materials tank cars.

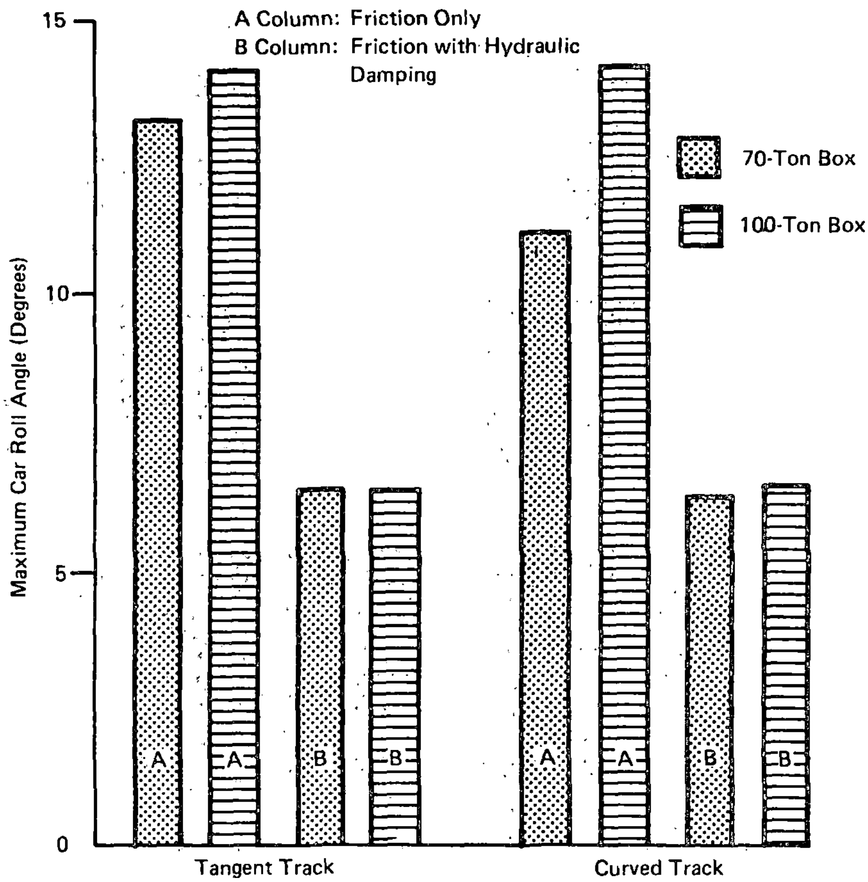
The industry continues to become more technically knowledgeable and is steadily developing capacities to detect problems, evaluate potential solutions, and initiate countermeasures. Figures 1-9, 1-10, and 1-11 are examples of the degree to which countermeasures applied to cars can be effective in controlling car dynamics over relatively severe track conditions. Figure 1-12 contains examples to illustrate how the industry is implementing car-located dynamic control devices to realize the potential improvement levels depicted in Figures 1-9, 1-10, and 1-11.

A recent special study to understand more fully the covered hopper problem revealed that the performance of manufacturing designs should be looked at more closely. A certain combination of parameters such as length and center of gravity height may be unique to cars built during a limited period. Figure 1-13 indicates that covered hopper cars manufactured in the early 1960's currently have a much higher rate of derailment than those built in either preceding or succeeding years.



Source: AAR 4% Annual Projections for Roller Bearing Data Beyond 1979; Shaker Research for Roller Bearing Data Up to 1979; Manufacturers for Brake Valve Data

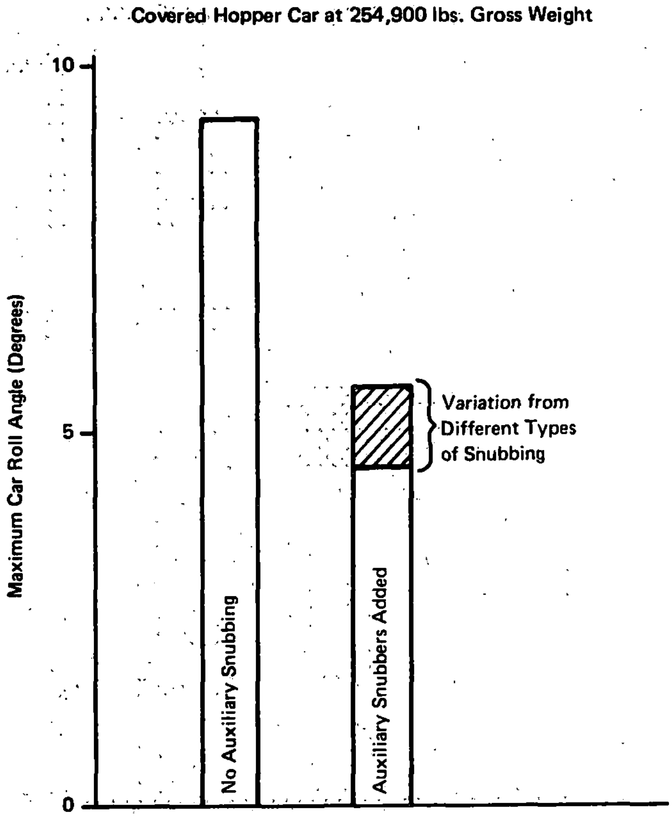
FIGURE 1-8 RATE OF INTRODUCTION OF CAR IMPROVEMENTS



Source: An individual Carrier's Study.

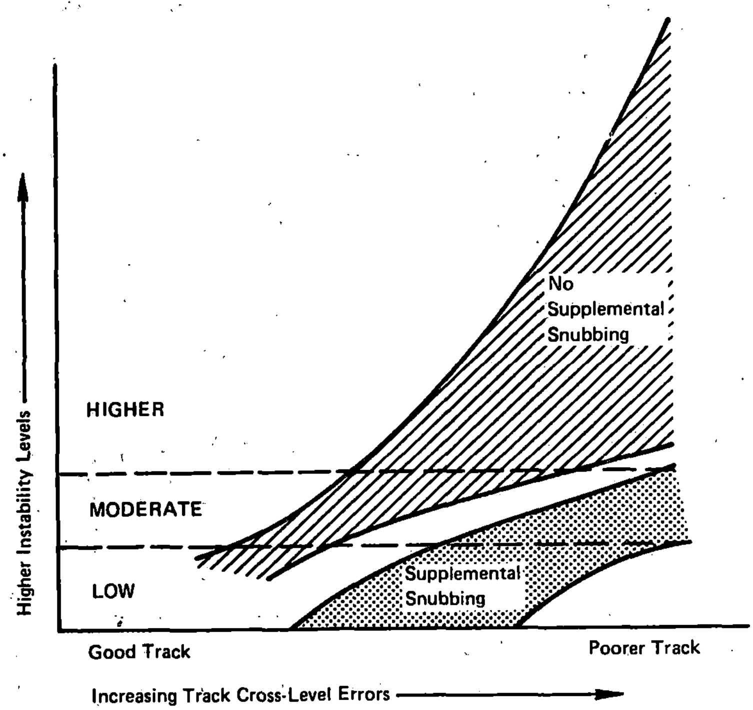
FIGURE 1-9 IMPROVEMENT FROM ADDITION OF HYDRAULIC DAMPING (1-Inch Surface Variations, ½ Stagger, 39-Ft. Rail, 13–19 MPH)

Numerous tests and technical analyses have disclosed that there is no simple relationship between the size, weight, and length of a rail car and the wheel-rail interface forces which are generated. The forces are complex and depend on variables such as train speed; the way the train is made up (i.e., the location of loaded and empty cars); the way the engineer handles the train; the dynamic control devices used; and especially, the local track conditions over which the train operates. The analytical tools predict that under certain conditions, lighter or shorter cars are a greater derailment threat. However, in general, these same analytical models predict that larger cars have a demonstrated tendency to exert greater forces against adjacent cars and against the rail and cause its more rapid deterioration.



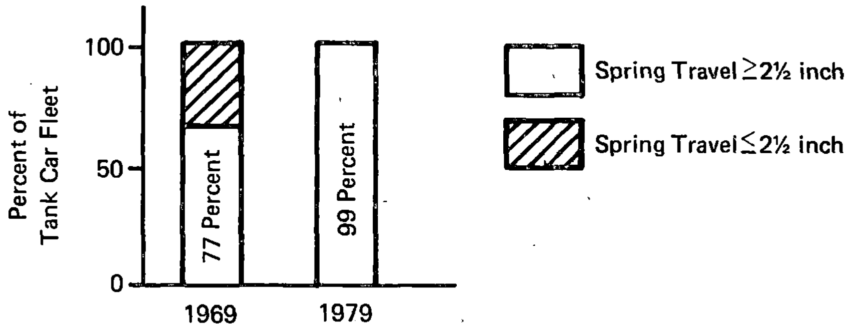
Source: An Individual Carrier's Study.

FIGURE 1-10 IMPROVEMENT POSSIBLE WITH ADDITION OF SNUBBERS (3/4-Inch Cross-Level Variations, ½ Stagger, 39-Ft. Rail, 12–20 MPH)



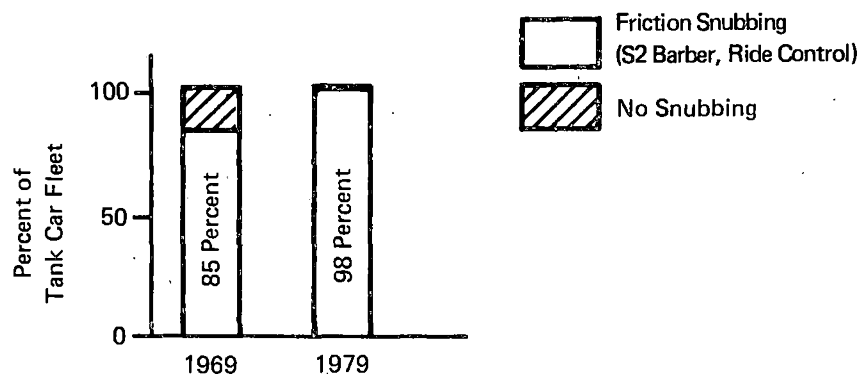
Source: An Individual Carrier's Study.

FIGURE 1-11 RANGE OF EXPERIMENTAL RESULTS FOR 100-TON OPEN HOPPER CAR



Note: Today, only about 1% of tank cars, about ½ percent of coal hoppers, and a few other cars have D2 (less than 2½ inch travel) springs. The remaining D2 springs are primarily on 40- or 50-ton cars.

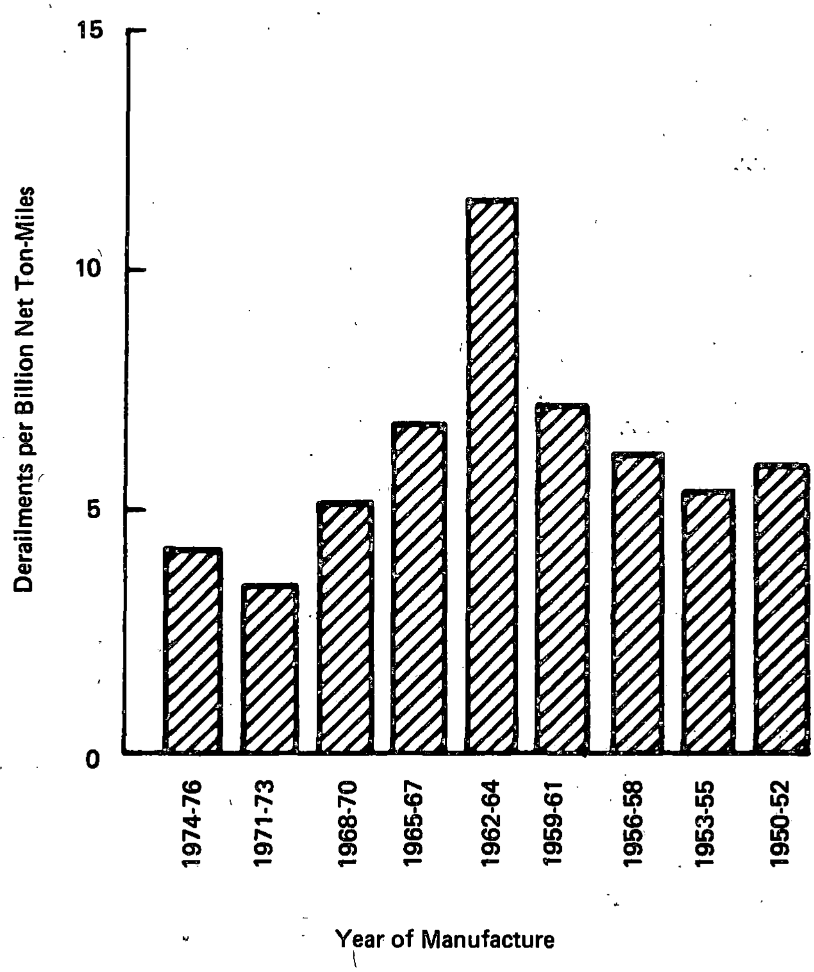
(a) Implementation Record: Improved Spring Travel on Tank Cars (based on a survey of approximately 75% of the tank car fleet)



(b) Implementation Record: Improved Snubbing on Tank Cars (based on a survey of approximately 75% of the tank car fleet)

Source: AAR Survey of Tank Car Owners.

FIGURE 1-12 EXAMPLES OF INDUSTRY COUNTERMEASURE IMPLEMENTATION



Note: FRA Safety Data from Years 1975-1977.

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample.

FIGURE 1-13 VARIATION IN CURRENT DERAILMENT RISK WITH YEAR OF MANUFACTURE FOR COVERED HOPPER CARS

Since the early 1970's, the research and development office of the FRA has used a considerable portion of its budgeted funds in conducting analyses, making field tests, evaluating improvements, and demonstrating countermeasures for controlling rail vehicle dynamics. The performance of heavy 6-axle locomotives over a variety of track conditions, the behavior of jumbo tank cars during impacts, and the mechanism of locomotive-to-caboose collisions were explored in the context of the size, weight, length, structure, and configuration of cars. In addition, with major support from the FRA, the railroad industry has been very active in determining ways to control the dynamics and mitigate the adverse wheel loads of freight cars. The activities in Track Train Dynamics (TTD), the Facility for Accelerated Service Testing (FAST), the Rail Dynamics Laboratory (RDL), the Truck Design Optimization Program (TDOP), and other facilities and special studies are producing valuable data. Validated improvements and upgrades are scheduled and introduced as part of routine car maintenance.

1.4.4 Safety Regulation

The FRA has responded to the increased frequency of derailments in a variety of ways. Enforcement of the present Track Safety Standards emphasized the remediation of problems on major hazardous materials routes. Violation sanctions, speed reduction orders, and emergency orders have been employed to bring about repairs, improvements, or appropriate reductions in train speeds.

As previously noted, the tank car retrofit order in HM-144 was in response to the more frequent derailments involving certain tank cars carrying compressed gas. The Department will also propose the application of improved safety systems to additional portions of the tank car fleet in the near future.

Several options are discussed below which may lead to further regulatory action directed at discrete problems that cannot be resolved within a reasonable time through voluntary action. However, in light of already existing AAR restrictions on cars in the interchange fleet, currently there is not sufficient justification for broad government mandates directly limiting the size, weight, or length of freight cars.

Ultimately, the need for immediate attention, whether or not spurred by the government is based on how the future threats to the public are assessed. If track deterioration continues to persist on important track segments in the National Rail Distribution Network, the answer as to whether a more serious safety problem is developing is obviously, yes. Continually degrading track has increasingly less tolerance to heavier and larger cars, and it is extremely unlikely that improvements made to freight cars or in operations can be a dominant offsetting factor under these conditions.

1.5 IS THERE AN EFFICIENCY PROBLEM?

Some observers question whether the trend toward freight cars of larger capacity has produced a net economic benefit to the railroad industry. Citing major increases in maintenance-of-way costs and deferred maintenance, they argue that the national system of standard gage track was not designed to support current axle loadings. Other analysts point to the significant savings in transportation expenses made possible by increased per-car capacity and the role of those savings in more competitive rates for bulk products. These advantages are said to have been crucial to the survival, or profitability, of some railroads.

The limited time period of this study and the unavailability of basic cost data prevented the Department from reaching a definitive conclusion as to whether the railroad industry as a whole has benefited from larger cars. It does appear likely, however, that the marginal value of larger cars, like their safety record, depends on the vitality of the operating railroad — in particular, on how well the railroad maintains its track system. Operation of larger cars on deteriorating track will hasten the accumulation of deferred maintenance and necessitate speed and other restrictions, thereby eroding the quality of rail service and driving traffic to other railroads or competing modes of transportation. Healthy, well-managed railroads are able to make compensating investments in maintenance of way and evidently realize overall savings from the use of larger cars.

The efficiency of freight cars of various sizes is best measured by the total cost of transporting a ton of cargo on a per-mile basis. This parameter is obviously a function of carload weight capacity because a low capacity means that more cars will be required at greater expense and a large car capacity increases the likelihood of higher track maintenance and repair expenses. The problem is in determining the optimum carload capacity that would provide minimum total transportation cost. Some insight and guidance can be obtained by reviewing the factors associated with car size — both the factors tending to raise costs and the factors tending to reduce costs. An evaluation of the efficiency of railroad usage of cars by size, weight, and length must be derived primarily from past experience. The transition to heavier carloads clearly has produced some negative factors that, from a financial perspective, have increased certain costs; but because of the lack of a suitable accounting system that reflects the total cost of interchange service, it is difficult to even roughly isolate the aggregate railroad industry effects caused by the introduction and use of 100-ton car service. Costs have risen in the following areas:

- *Track Maintenance* — The heavier service cars definitely tend to increase maintenance frequencies and costs. In addition to investments to stabilize the roadbed, heavier rail and head-hardened rail are being procured in higher quantities to combat rail wear.
- *Car Maintenance* — The heavier loads in the cars, the larger lateral forces that they exert in curves, and elevated coupling masses cause wear and increase maintenance costs for certain components; i.e., wheels, couplers, centerplates, brake shoes, etc.
- *Increased Derailment Costs* — If certain portions of track are degraded faster and reach marginal states, the larger cars with higher loadings will mean a higher frequency of derailments. Also, these heavier cars have more momentum and thus tend to incur more damage when involved in accidents. The costs of derailments, including societal costs, are a major expenditure that has been steadily increasing. Table 1-5 shows the calculated total for 1977.
- *Testing and Upgrade Expenditures* — Over the last decade, the rail industry has incurred considerable costs in determining solutions and fixes to the problems that occurred upon introduction of the 100-ton cars. Some of the costs, as in the case of the regulated tank car retrofit, are not borne by the railroads alone. Shippers, as car owners, many times bear a large part of the costs and, inevitably, pass them on to the public.
- *Miscellaneous Expenses* — Increases in inspection, training, and third-party liability insurance costs are examples of these expenses.

On the other hand, benefits that have accrued from the use of larger cars include the following:

- *Lower Direct Transportation Costs* — The direct costs associated with train movements to transport certain bulk commodities have been significantly reduced. This reduction has enabled the railroads to maintain or improve their share of the market and to better their cash flow positions while keeping rates competitive.

TABLE 1-5

ESTIMATED COSTS OF DERAILMENTS FOR 1977

1. Property Loss

(a) Reported Track Damage (D_T) = \$ 44.3 Million

(b) Reported Equipment Damage (D_E) = \$148.7 Million

(c) Estimated Total Property Loss (including 3d-Party Loss, Wreck Clearing, Lading Transfer, and Non-Reportable Accidents) $= 1.66 \times D_E + 1.28 \times D_T$ = \$303.6 Million

2. Loss of Life

(a) Number of Fatalities = 8

(b) Estimated Loss to Society per Fatality = \$300,000

(c) Estimated Total Loss Resulting from Fatalities = \$ 2.4 Million

3. Loss Resulting from Injuries

(a) Days of Work Lost Resulting from Injuries = 3,340

(b) Estimated Loss to Society per Workday Lost = \$130

(c) Estimated Total Loss Resulting from Injuries = \$ 0.4 Million

4. TOTAL LOSS = \$306.4 Million

Source: Arthur D. Little, Inc., Estimates

- *Reduced Fuel Costs* — With fewer car trips to transport the required tonnage, fuel savings are realized.
- *Reduced Operating Costs* — Fewer cars need to be loaded, switched, inspected, and accounted for, reducing operating costs.
- *Reduced Car Replacement Costs* — A 100-ton car costs less than two 50-ton cars.
- *Ability To Transport Increased Volumes* — Since a 100-ton car is not twice as long as a 50-ton car, an equivalent increase in the capacity of yards and sidings is realized. This has allowed the railroads to avoid additional investments in plant and property that would have been necessary to transport increased volumes.

- *Costs Associated With Less Exposure of Railroad Workers* — With fewer cars needed to transport the same tonnage, there is a reduction in the required number of high-risk yard tasks (e.g., riding cars, coupling air, getting on or off cars, etc.).
- *Costs Associated With Less Exposure of Motorists at Grade Crossings* — With fewer cars required to move the same tonnage, there are fewer car passages per grade crossing — and less chance for an accident.
- *Miscellaneous Cost Savings* — Car loading and unloading costs tend to decrease since fewer "set ups" are required. The consumer shares in some of the resultant cost savings.

Some of the expected direct railroad impacts of varying car size that might occur can be quantified by using actual 1978 railroad operating data. Table 1-6 contains estimates of the effects of hypothetically reducing the maximum carload by 15% (i.e., to 85 tons instead of 100 tons) during this one year. Freight car and track maintenance considerations are not listed because of the lack of agreement on allocations of such costs to a single year. In addition, the estimates do not include allowances for changes in practices of rolling stock and locomotive power utilization that probably would occur in the real situation, but that are difficult to predict.

TABLE 1-6

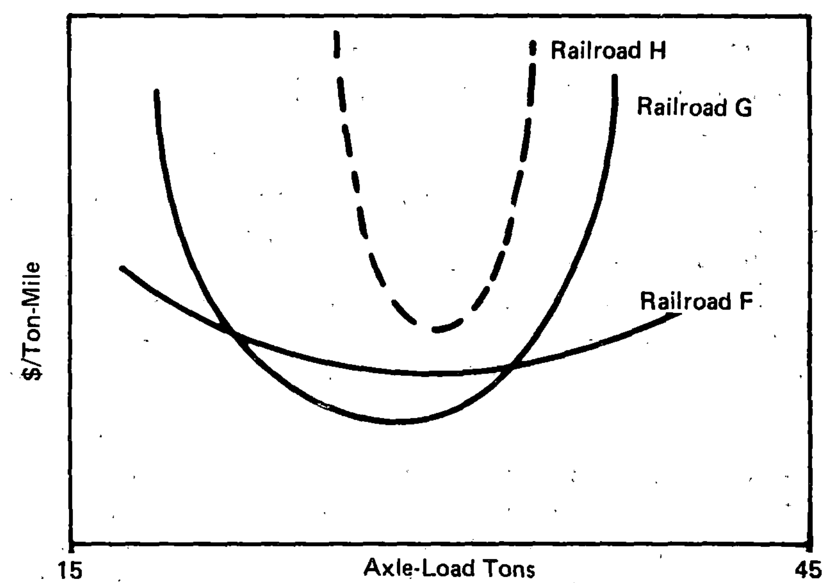
ADVERSE INDUSTRY IMPACTS FROM A 15% REDUCTION IN THE MAXIMUM PERMISSIBLE LOADING IN 100-TON CARS

Item	Estimated Adverse Effect
Car Loadings	1.8 Million Additional Loadings
Car Trips	2.9 Million Additional Trips
Trains	46,000 Additional Trains
Freight Cars	83,300 Additional Cars
Locomotives	465 Additional Locomotives
Train-Miles	7.3 Million Additional Train-Miles
Car-Miles	1.5 Billion Additional Car-Miles
Fuel	113 Million Additional Gallons
Train Accidents	540 Additional Accidents
Fatalities Resulting from Train Accidents/ Incidents and Grade-Crossing Accidents	32 Additional Fatalities

Source: Arthur D. Little, Inc., Estimates

On the other hand, responding to a question in the industry management survey, one railroad calculated that a 15% increase in car capacity would result in a 13% increase in total variable costs per net ton-mile for bulk commodities and a corresponding 8% increase for merchandise commodities. Individual railroads that haul bulk commodities consistently contend that usage of the 100-ton car has resulted in a net favorable benefit for them, but most agree that they are now approaching or are just beyond the "break-even" point in car size. The consensus in the railroad industry based on past experience is that the balance of pros and cons is favorable. Regardless of the 100-ton car's benefit to the industry, however, it certainly would cost the industry considerable amounts in the short run to reverse the trend toward these cars.

Will the 100-ton car continue to be as valuable to the industry in the future? When all of the costs and savings enumerated above are combined to produce a total cost per ton-mile figure, it is clear that these costs will decrease as axle loadings become heavier up to a point. Beyond this point, the cost components will outweigh the savings components and total cost will increase with heavier axle loadings. The difficulty in determining an "optimal" car weight or axle load in this fashion is that costs and savings vary from railroad to railroad; e.g., a railroad with a softer roadbed will have a steeper rise in the maintenance-of-way expense curve as axle loads are increased than another railroad with a stiffer roadbed. Some railroads estimate increased maintenance-of-way costs of up to 40% with 100-ton car usage. However, under controlled conditions, analysis and small-scale laboratory test data show more exaggerated results; i.e., wear expectations for curves are nearly doubled under a 100-ton car simulation compared to that of a 70-ton car simulation. Figure 1-14 is an example of the variations that the total costs per ton-mile might assume for different carrier conditions.



Source: American Railway Engineering Association Bulletin 673.

FIGURE 1-14 VARIATIONS OF TOTAL COSTS PER TON-MILE

This inability to define future conditions in cost terms (including those associated with the quality of track on interchange railroads) causes uncertainties as to how the location of the low cost point in Figure 1-14 will shift in respect to axle loading. For the aggregate railroad industry, any evaluation of future efficiency will ultimately depend on the extent to which derailments are forecast to increase as a result of usage of 100-ton cars over degrading track segments. The costs of an increasing frequency of derailments or erosion of service through operating restrictions can rapidly offset any savings. Furthermore, the importance given to future injury or damage to the public and the likelihood that vital traffic might be seriously interrupted determine the outcome of a cost/benefit analysis.

1.6 THE FUTURE

Even though economic considerations and third-party liability implications pressure the industry to ensure safety consciousness, separate studies show that there is increased wear of track and increased wheel-rail forces when axle loads are heavier, cars are longer, and center of gravity dimensions are higher. Therefore, the ability of the industry to implement countermeasures more rapidly than in the past may be crucial. Projections into the future must consider existing overall trends such as the following:

- Each successive year, there are larger percentages of heavier, longer, and higher center of gravity cars in the fleet.
- There is an increasing rate of derailments, especially those attributed to track problems.
- Because of poor earnings and a low rate of return on investment, certain railroads are finding it increasingly difficult to meet their track maintenance requirements.
- The number of long, heavier trains is increasing.
- Hazardous materials rail movements are likely to double in the next ten years.

These trends have been going on for many years, and although most railroads (and the industry as a whole for the most part) have been able to meet vital freight demands without serious safety or efficiency problems, certain track segments have become or are becoming "weak links" in the total network. The continuing interchange of longer, heavier cars into these links can only increase the deterioration rate. The demand for passage of increased volumes of hazardous materials over these weak links will increase the probability of tank car derailments.

Are there actions in process (or any that could be implemented) which will head off adverse predictions for the future? At a cost of over $200 million to the industry, the HM-144 mandated retrofit of compressed gas tank cars to minimize the consequences of accidents involving flammable compressed gases will alleviate a large portion of the total hazardous materials problem, but not all of it. Train speeds have been reduced in accordance with track conditions, and train-handling and train makeup revisions have been made, but the trends of increased derailments from track deterioration persist. This deterioration of track can eventually overwhelm any improvement that is installed on cars.

The advisability of actions and the determination of who should take the lead can only be ascertained through additional in-depth trade-off delineations and cost/benefit analyses. In some areas, there is a need for additional basic cause-effect data before effective cost/benefit analyses. In some areas, there is a need for additional basic cause-effect data before effective cost/benefit studies can be conducted. Several ongoing FRA/Industry cooperative research and development projects as FAST and in TDOP are aimed at obtaining such data to support engineering specifications of performance requirements together with proof-testing procedures. Steps concerned with the general health of the industry or of specific groups of carriers probably require additional government initiatives. (Some are already in process.) There are certain options that the railroad industry itself has the power to voluntarily exercise — once it is convinced of the future advantages.

1.7 OPTIONS

In light of the study findings, is there anything that should be done to improve the safety and efficiency of rail transport as influenced by the size, weight, and length of freight cars? If so, by whom, in what time frame, at what cost, and with what benefits? Answers to these types of questions must consider the following:

- Specific cars of certain design characteristics, as opposed to larger cars as a group, are found to have derailment frequencies higher than their exposure warrants.
- While derailment costs are relatively high, few fatalities over the past five years, if any, can be attributed solely to the size of cars.
- If the rail network is reduced by mergers and consolidations, the traffic volume per mile of mainline track will increase. A fleet composed of lower capacity cars, with the attendant increase in train densities, would present increased operational traffic control demands that might strain existing signaling systems and increase safety risks.
- The greatest threat from larger cars lies in the future when such cars might accelerate track wear on segments of the network where the track owner is not in a financial position to perform appropriate maintenance. This could set in motion the downward spiral of lower speeds, poorer service, loss of traffic, and decreased revenues on additional rail properties.
- The diversion of traffic to other routes and modes to avoid "weak-link" track would be costly, would probably not be as safe, and might not even be feasible in many cases.
- Increased shipment of hazardous materials by rail in the future has the potential for dramatically expanding the consequences of derailments.
- A rigorous determination of costs versus benefits of stipulated actions is hindered by the usual hazards involved in anticipating the magnitudes of future problems (which is the controlling factor in this case) and the degree to which current countermeasures by the government or industry will be effective.
- A number of government and industry initiatives in various stages of implementation are aimed at safer hazardous materials transport, the creation of freight car and track specifications to enhance safety, and the guaranteeing of the viability of important rail connecting links in the national rail network.

There is not sufficient information to integrate the above considerations into a defensible government/industry mandate for action. The available evidence indicates that certain longer range efforts are advisable and that some short-term actions may assist in bridging the gap until the longer range solutions can become effective. The options listed here are meant as a starting point for joint government/industry/labor examination of those beneficial actions that can reasonably be accomplished within:

- Realistic time frames;
- Funding limitations;
- The realm of other ongoing improvement or regulatory actions; and
- The scope of feasible actions by the government or, on a voluntary basis, by the rail industry.

1.7.1 Long-Term Options

Dealing with the problems of heavier cars seems to involve efforts that will, optimistically, take at least 10 years to institute and become effective. These long-term major options are the following:

1. Legislation and government/industry actions to ensure the health of essential hazardous-materials-carrying railroads so that even the crucial marginal ones will have track that can resist heavier loads. Deregulation and federal assistance are examples of supporting efforts now under way. The second study mandated by Public Law 95-574 addresses the roadbed problem and may result in additional answers.

Cars with more than 70-ton capacity or which impose higher dynamic loads will tend to push the dominant cause of track failure from "wear" to "fatigue" (i.e., crack growth). Both occur over a relatively long period of time, but fatigue poses a more serious threat to safety since the result is a sudden failure. Heavier rail sections, better and more frequent inspection, or increased maintenance are necessary to avoid a deterioration in safety. Because of long-standing financial conditions, however, some railroads are not in a position to meet the near-term demands for increased expenditures generated by the greater usage of 100-ton car service; to survive, these railroads have had to use 100-ton cars with their associated larger physical dimensions and increased payload per car.

The rail transport network depends upon several financially marginal railroads to deliver vital goods to various geographical locations. It would be in the long-term best interest of these railroads to be able to invest in better track. Therefore, any actions to assist the rail carriers in restoring those rail links to a healthy condition for 100-ton car service (which the more prosperous ones have found appropriate and profitable) would contribute to the safety and efficiency of rail service.

2. Development and establishment of incentives for railroads to shorten the implementation period for improvements. The latest innovation to improve freight car curve negotiation (i.e., the self-steering truck) will, after lengthy trials, if proved beneficial, take an extended period to be installed on a significant portion of the fleet.

Analytical tools indicate and testing confirms that cars with certain dimensional, structural, and suspension characteristics are more prone to derail (than an average car) when traveling over marginal track. While this fact may be well recognized in the industry, the derailment risk for these cars is still low from a "probability" viewpoint. The rate at which improvement or "upgrades" are applied to cars (or track) is dependent upon many factors which the industry handles by trading off economic, customer service, and safety (including liability) considerations. Car (or track) owners make decisions based on their particular set of circumstances, and seldom are these decisions a result of predetermined national fleet policies. (Specially mandated rules and regulations with schedules [e.g., HM-144] are the exceptions.)

The reasons for this situation are numerous and complex. Rail carriers have a large investment in the over 1.7 million cars in the total fleet. Most of these cars are routinely interchanged among many railroads with diverse interests and financial conditions. For the most part, a freight car can be off the property of the owner (often, the shipper) or not under the owner's control a large percentage of the time. Thus, the owner may realize only a small portion of the benefits of upgrades for which it must pay. Compensation by "leasing" railroads, along with the criteria for replacement of worn-out components, often does not provide a sufficient return to the owner to stimulate "upgrading."

Any revision in car components, track, operating practices, and inspection methods, in order to be interchanged to the system of railroads, must be compatible with the existing parts of the system; i.e., it takes tremendous efforts to radically change certain car interfaces such as the coupler. Spare parts must be available, details of operation and construction circulated, procedures agreed upon, and administrative machinery instituted so that proper handling and repairs can be made at any of several hundred repair locations. Also, the availability of materials, workload of manufacturing facilities, seasonal factors, and individual financial considerations can inhibit retrofits for extended periods of time.

The established mechanism for routinely detecting problems, coordinating studies, and resolving safety issues among railroad carriers resides with designated AAR committees. The AAR derives its responsibilities from its member railroads because of their need for uniformity and compatibility in the passage of individually owned railroad cars from one railroad to another, via "interchange." As a part of its duties, the AAR regularly enacts and enforces interchange rules that impinge on the size, weight, and length of freight cars (e.g., limits on maximum weight on rail, center of gravity height, and car length are self-imposed). The historical record reflects the degree to which the process has succeeded. It should be pointed out, however, that the AAR has little influence on the track maintenance expenditures of railroad carriers. Accordingly, there is some question as to whether such a mechanism will be able to respond satisfactorily to any future crises on carriers where track deterioration is occurring beyond safe limits. Of critical importance is the creation of a competitive, innovative climate that will give the railroad industry the incentive to identify important improvements and accelerate upgrades on a more uniform and consistent basis among the rail carriers and car owners. Significant regulatory reforms should create such a climate, along with the financial capability to support the implementation of such improvements.

In particular, some way should be found to make it attractive to owners to invest in improvements to cars that will be interchanged to other railroads. Presently, railroads are more prone to invest in such improvements on unit trains that remain under their control. For example, assume that self-steering trucks have the potential of reducing lateral forces on curves by as much as 60% and that in addition to a lower probability of derailment in curves on track of marginal quality, overall curve wear will be reduced by 90%. However, the estimated additional cost per car is in excess of $3,000. If the car spends a large percentage of the time on track other than the owner's, how can the stockholders be convinced to diminish immediate earnings to equip their large (i.e., perhaps 10,000) car fleet when other railroads will accrue most of the long-term benefits?

3. *Development, establishment, and use of performance criteria for the introduction of new cars, which in essence would dictate the kinds of track and the conditions under which the new car can run safely without undue wear or deterioration of components.*

Based upon extensive work in Track Train Dynamics (TTD), other dynamic tests, and output from available analytical tools, arbitrary limits on the size, weight, and length of cars should be avoided. The real proof as to the safety and efficiency of a moving freight car is in its dynamic performance or how it interacts with the track. Certain "bad actor" cars can be converted to better-than-average performers by the installation of, for example, a better suspension system, an improved snubbing device, or a new type truck. Certain innovations now being tested (e.g., self-steering trucks) promise to make freight cars far more forgiving of track deficiencies. Such innovative effort should be encouraged. A performance standard indicating the minimum level of car performance over a range of severe track conditions should be established, and all new cars and certain types of existing cars should conform.

1.7.2 Interim Options

While longer range solutions are being implemented, it is debatable which particular interim "stop gap" measures (i.e., within the next ten years) are advisable or can be justified. Regulatory initiatives by DOT such as the recent FRA Notice of Proposed Rulemaking on the Track Standards and other ongoing rulemaking activities are aimed at creating performance requirements to alleviate safety problems associated with freight cars of many varieties traveling over track of various configurations and attributes. Nonetheless, this study strongly suggests four major interim activities that should be purused jointly by government, industry, and labor. These activities are directed toward concerns associated with the following:

- *"Bad Actor" Cars* — Organize a special task force made up of representatives from railroads, the supply industry, rail labor, and the FRA to investigate the feasibility and to quantify the advantages of instituting corrective measures that will counter the below-average safety record of high center-of-gravity covered hopper cars and long flat cars.
- *Real-Time Safety and Efficiency Comparisons* — Encourage and take steps to set up a real-time data collection and analysis system that will detect abnormalities in safety records as they occur.

- *Research Aimed at Establishing Performance Requirements and Evaluating Conformance* — Accelerate ongoing government and industry efforts to lay the technical groundwork for performance standards.
- *Other Concerns or Options* — Consider, in terms of relative value and contribution, the improvements in the areas of concern that are identified below.

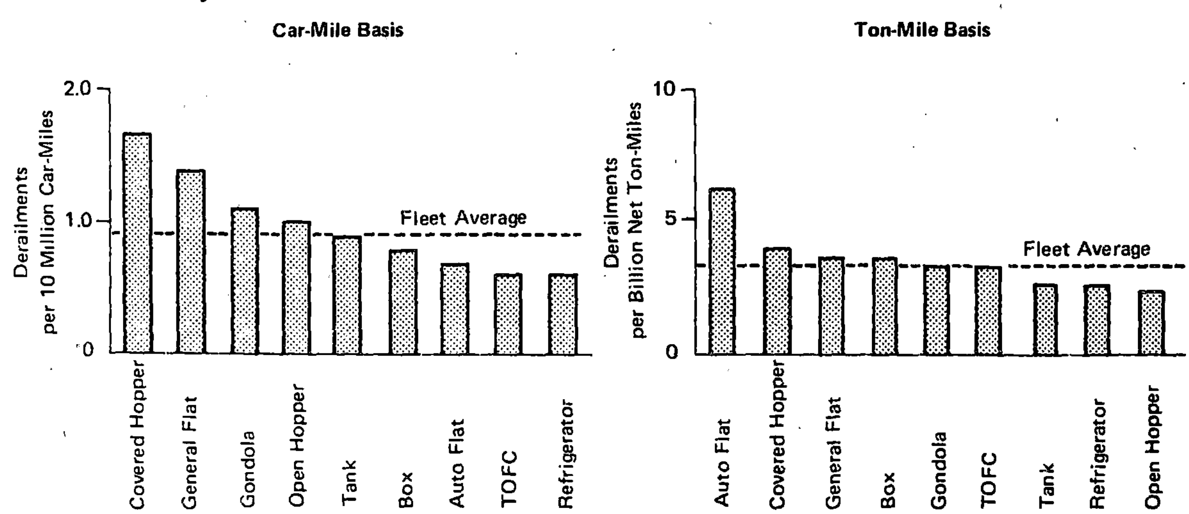
Bad Actor Cars

The relatively higher derailment rates of certain types of cars (e.g., long flat cars and higher center-of-gravity covered hopper cars) were identified in this study. Figure 1-15 is an example of how derailment statistics can be quantified to depict comparisons of different types of cars. Further breakdowns can reveal the disparate derailment record of any particular design within each larger grouping. A special task force of the concerned parties would provide a proper forum for determining what corrective actions may be warranted for identified bad actor cars in the existing fleet.

Real-Time Safety and Efficiency Comparisons

This investigation was handicapped (as were previous studies) by the paucity of information in the various data bases currently being maintained. The safety statistics and the mileage, tonnage, and age figures were received from the FRA, the ICC, and the National Transportation Safety Board. Facts on the size of the car fleet, retrofit rates, research results, industry practices, etc., were secured from the AAR, the UTU, and separate shippers, suppliers, railroads, and government/industry study groups. An inordinate amount of time had to be spent in determining the best sources, extracting the information and matching up the time periods of coverage with other information.

Appropriate data should be routinely collected so that comparisons based on current derailments per car-mile and per ton-mile can be maintained in some detail (e.g., by car type and size). The behavior of such trends could provide a forewarning of potential problems and allow timely remedial actions.



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 1-15 DERAILMENT FREQUENCIES OF VARIOUS TYPES OF CARS

Research Aimed at Establishing Performance Requirements and Evaluating Conformance

Research initiatives and activities have spurred much of the increasing technical awareness and knowledge of the railroad industry. Analytical tools and testing facilities developed in recent years have much advanced the understanding of car and train dynamics. The basis for the eventual specifications of performance requirements is being generated in the related government/industry efforts. When requirements can be stated in terms of minimum performance and the performance can be measured, arbitrary limits based solely on past experience can be abolished. The Track Train Dynamics Program (TTD), the Rail Dynamics Laboratory (RDL), AAR's Track Structure Laboratory, the Locomotive Research and Train Handling Evaluator (LRTHE), and the proposed Stability Assessment Facility for Equipment (SAFE) are existing efforts toward this end.

Encouragement should be given to government/industry research and test facility activities to assist in timely accomplishment of both short- and long-range countermeasures and in the establishment of performance requirements.

Other Concerns and Options

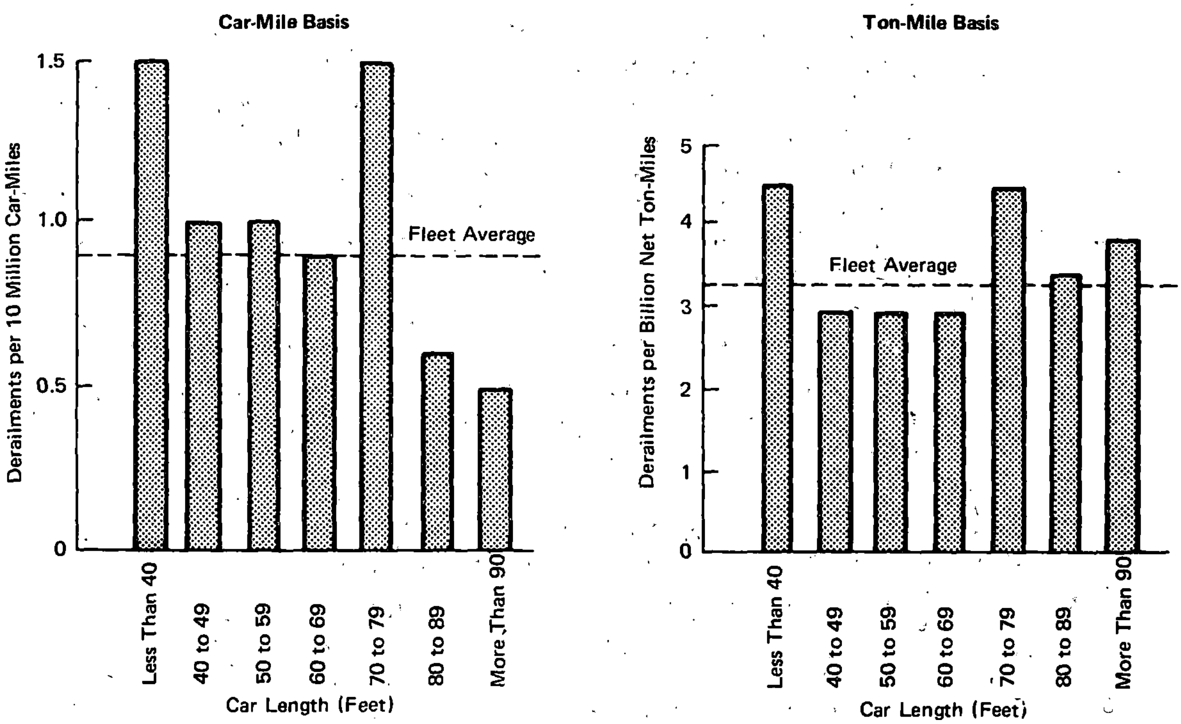
There is an opportunity for a variety of actions to improve car dynamic behavior and to reduce the likelihood of derailments. While it is premature to prescribe a comprehensive program at this time, it is possible to outline potentially fruitful options for investigation. The following list of options contains examples prompted by the findings of this study. These options must be subjected to further evaluation as to their effectiveness, benefits, penalties, and costs.

Establish a mechanism that will continually utilize inputs from operating employees to determine what interim and long-range actions might be most effective.

The information obtained in this study from over 900 railroad operating personnel is a good starting point toward gaining a better understanding of and resolving inconsistencies in the less-than-complete reporting system and resulting statistics which now exist. Management receives inputs from employees as a routine part of daily business. Most of these interactions are at the local level. Insights can be gained from requesting and collecting structured information as perceived by those closest to the operations. This information can then be aggregated and analyzed to produce industry-wide trends. The Rail Safety Research Board, composed of various government, industry, and labor members, was an effort in this direction.

Review existing controls that limit the size of cars, and examine new approaches for achieving satisfactory performance of cars. Consider:

- The poorer record of certain cars shorter than 40 feet or longer than 70 feet (Figure 1-16). Several groups of evidence from this investigation suggest that the long cars and very short cars tend to present a somewhat higher risk, especially during curving and when coupled to certain other cars with non-complementary "overhangs."



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 1-16 DERAILMENT FREQUENCIES FOR VARIOUS CAR LENGTHS

- The effect of heavier axle loads in the unrestricted interchange of cars. Theoretical analyses and actual tests agree that a 32-ton axle load is approaching the wheel-rail contact strain limit for new wheels and new rail. The railroads that have successfully operated 100-ton (or heavier) cars have justified and made considerable investments in track, equipment, operations, and inspection betterments. Considering the projected interchange environment, the railroads, on their own, have imposed a 263,000-pound 4 axle car weight-on-rail limit for normal interchange movements. In lieu of eventual performance specifications, there is no justification for relaxation of restrictions on cars used in interchange service.
- The implications of large-volume hazardous materials cars (i.e., those larger than 34,500 gallons). In the event of puncture during derailment and subsequent rocketing of the tank, the range of potential casualties to the surrounding public becomes larger as the capacity increases. There is no justification for relaxing the present 34,500-gallon restriction that limits the expected maximum rocketing range.

Review existing operational requirements and performance standards, and examine new approaches for minimizing the frequency of hazardous materials release incidents. Consider:

- Reducing the magnitude and frequency of occurrence of excessive dynamic axle loads — especially on cars with centers of gravity greater than 84 inches high — by installation of improved suspensions. Priority should be given to hazardous materials cars and high mileage cars with high centers of gravity.

Cars with high (90 inches or more) or relatively high (over 84 inches) centers of gravity are more sensitive to conditions in track which excite "rock-and-roll" behavior in cars. Many of the cars which transport hazardous materials (e.g., tank cars) have higher torsional stiffness which increases tendencies toward wheel lift when track warp irregularities are encountered. Some of the existing "snubbing" systems on freight cars are meant to dampen car oscillations through frictional resistance, but become erratic or are much less effective when worn. High mileage and hazardous-materials-carrying tank cars pose the greatest exposure risk and should receive corrective upgrades (i.e., hydraulic snubbing or other control units) on a priority basis over other cars.

- Taking steps to ensure that hazardous-materials-carrying tank cars are outfitted with selected improvements such as self-steering trucks or better suspension systems at a priority rate — at least compared to other cars. Although the derailment of other cars can cause the involvement of hazardous-materials-carrying cars, the relatively higher severity of derailment consequences for hazardous materials cars may justify special precautions.
- Minimizing the likelihood of hazardous materials cars being involved in derailments through careful placement in the consist. Over marginal track, hazardous materials cars which immediately follow other cars with higher risks of derailment virtually assume the higher risk of the car ahead. Some restriction might be warranted on the minimum proximity of a hazardous-materials-carrying tank car in a train to loaded 100-ton covered hopper cars or to some flat cars that are not equipped with improved snubbing devices. However, revising train makeup practices can be a costly step. This suggestion is aimed at uncovering more practical train makeup practices that might lower the probability of involvement of hazardous materials cars in derailments.
- Formalizing guidelines, similar to those already in use by several railroads, to reduce the severity of derailments involving tank cars carrying hazardous materials. Lower classes of track generally have less ability to resist increased wheel-rail forces. Reducing the maximum authorized speed of trains that contain a number of such tank cars and that travel over track with a lower FRA classification is an obvious action which tends to reduce both the lateral track forces on curves and the magnitude of the consequences of derailment.
- Identifying ways to minimize the extent to which train action and variations in train-handling can increase the derailment risk of tank cars carrying hazardous materials. In lieu of performance specifications, interim restrictions on allowable train consists and the methods employed in handling tank cars may be necessary when the movement of hazardous materials cars over track of classification 3 and below is involved. Some relaxation of any resulting more stringent restrictions might be in order in individual cases, as, for example, where the controlling locomotive has an effective feature for maintaining brake pipe pressure; the carrier has demonstrated the adequacy of the braking systems on its trains and its operating instructions; and the carrier has reasonably proved that compliance with published safety requirements is regularly achieved. Train-handling variations can influence the level of in-train and lateral track forces to a large degree. Longer trains and undulating terrain are more of a challenge. The engineer and crew may need special training or indoctrination in the safe operation of certain trains carrying hazardous ma-

terials over undulating terrain. Train control systems (e.g., better operating brakes or the use of remote control locomotive units) can make longer trains as safe as many shorter trains. Transport of hazardous materials warrants better performing trains.

Investigate means for speeding up implementation of car designs that are more tolerant of track irregularities. Consider:

- Devising an approach to ensure faster implementation of important improvements on all cars identified as less stable. Accelerated retrofit schedules should be promoted. Priorities for installation of known and recognized effective improvements are usually set by the AAR through interchange requirements. Incentives and other rewards to owners that accelerate upgrades have been studied in the past. Some of the less complicated schemes might be applied on an accelerated priority basis to one or two identified improvements.
- Renewing dedication to responsible development of performance guidelines that can be applied on a case-by-case basis to size limitations on cars and trains (i.e., avoid arbitrary across-the-board limits). Wherever possible, even interim steps should be described in terms of the minimum performance required. This allows maximum flexibility and ingenuity in accomplishment and will not "lock in" today's technology in the future.

1.8 CONCLUSIONS

Problems have occurred as a result of increases in size of freight cars. Overall, the rate of derailments is increasing as is the percentage of track-caused derailments, but on an exposure basis, the larger cars are not substantially worse than other cars. It is evident that certain identifiable *types* of cars that have dimensional extremes in length and height pose a relatively higher derailment threat (i.e., inability to operate over existing trackage with as good safety records as other cars) unless dynamic control improvements are made. The rail industry is becoming technically more competent and more willing to take actions to solve such specific problems. Fleetwide implementation, either through introduction of better design in new cars or retrofit of existing ones, however, is still a long process.

From a current perspective, and in an aggregate sense, it is the industry's strong contention that the growth to 100-ton load service has resulted in net economic benefits to the majority of railroads and shippers without the incurrence of safety problems that result in significant fatalities. This study did not find convincing evidence to the contrary. There are disturbing indicators, however, that the future picture might not look as good. The need to *interchange* cars from one railroad to another to reach important city and rural population centers is the major reason. While the larger 100-ton cars can successfully be run at reasonable speeds on rail properties which invest in and maintain track at a level commensurate with the increased loading on rail, these same cars can cause more rapid deterioration (and ultimate failure) of lesser trackage.

It is true that enforcement of the present FRA Track Standards, which require reductions in train speed according to specified classifications of track quality, tends to maintain tolerable levels of wheel-rail forces and, in the event of a derailment, is a favorable factor in limiting consequences. It is well recognized, though, that since individual types of cars exhibit a wide variance in dynamic performance, the standards should ideally either differentiate between cars or be based on the "worst case" car. In spite of several extensive studies, the implications of such an approach in standards are not yet fully understood. Without car improvements, an additional slowing of rail traffic will certainly result, and without standards revisions of this kind, poorer performing cars will continue to represent a higher derailment risk. While individual car improvements can reduce wheel-rail forces, it does not appear that the rate of dynamic control improvements in the car fleet can offset the rate of track deterioration on some railroad properties. Therefore, as projected annual tonnage increases, at any given speed range, there is an increased likelihood of derailment. Concurrently, there is a higher probability of hazardous materials cargo involvement on rail properties that receive a larger proportion of 100-ton cars operating over trackage with a decreasing ability to withstand the loading.

Thus, size, weight, and length of cars are contributing elements to railroad safety, but not the direct problem. The exclusive use of 70-ton cars would only delay the time to failure. Continued emphasis on long-term and lasting measures for ensuring adequate trackage in the vital links of the national rail network is needed to prevent an "epidemic" situation in the future. Arbitrary limits (which do not consider improved performance) on maximum car or train sizes which require additional mechanical and operating investments may serve to accentuate the problem by further reducing the financial ability of the railroads to perform necessary maintenance and upgrading. Interim actions can help and may be necessary in order to buy time for the longer range solutions to be implemented. However, justification of the attendant costs is complicated by the inability to isolate causes to the size of cars alone.

In the longer range, it appears that the trend is toward a more streamlined and efficient U.S. rail network that will annually carry increasing amounts of freight tonnage. The result will be less trackage and much higher freight densities over the remaining track. Pressures to use a greater portion of the inherent efficiency of rail transport, resulting from the need to conserve energy, could further elevate future amounts of traffic per mile of track. Under these conditions, the existing larger capacity cars (even without the technological breakthrough needed to go beyond 32-ton axle loads) support the required increases in overall transportation capability. Positive actions to decrease the derailment probability of the 100-ton capacity cars operating over the future network would enhance the efficiency by which the future transportation needs of the nation can be met.

2. INVESTIGATIVE PROCEDURES

2.1 INTRODUCTION

This study relies on three complementary investigative procedures to determine the influence of the size, weight, and length of railroad cars on safety and efficiency. These three procedures are:

- Surveys of railroad management and employees;
- Statistical analyses of historical accident data; and
- Engineering analyses obtained from previous research and test programs.

These procedures are briefly discussed below.

2.2 SURVEYS

The results of three surveys of railroad industry personnel were used in this study to gain a qualitative understanding of the effects of car size, weight, and length on railroad safety and efficiency:

- *United Transportation Union (UTU)* — Local switchmen around the country were surveyed for their opinions during August and September 1979. The results provided insights into the problems of car handling in yards, consist makeup, and consist handling.
- *Association of American Railroads (AAR)* — Railroad management was surveyed in August and September 1979, with special emphasis on the effects of changes in freight car capacities as well as on steps taken by the industry to accommodate these changes.
- *Track Train Dynamics (TTD)* — During the development of the TTD program, the railroad industry management was surveyed on many issues. Some of the questions and responses are directly relevant to this project.

2.3 STATISTICAL DATA

Much of the statistical characterizations of freight car populations, derailments, car mileage, and ton-mileage were taken from three data source files. These files are discussed below.

2.3.1 Universal Machine Language Equipment Register (UMLER)

This data file, which is updated four times per year, contains information about each freight car registered for interchange service. The following items from this file were used for this study:

- Car owner's initials;
- Serial number;
- AAR car type code;
- Outside length;
- Nominal weight capacity;
- Volume capacity.

2.3.2 Railroad Accident/Incident Reporting System (RAIRS)

This data file, maintained by the FRA, contains an entry for each accident or incident reported, including the following information:

- Car owner's initials and serial number of the causing car;
- Accident type (derailment, collision, grade crossing);
- Cause code;
- Speed.

When RAIRS is used in conjunction with UMLER, it is possible to identify each accident with a specific car type, size, weight, and length.

2.3.3 Waybill Sample

The FRA maintains a file of a 1% sample of all ICC railroad freight shipment waybills. Each entry includes the following information:

- Car owner's initials and serial number;
- Number of tons shipped;
- Distance shipped.

When used in conjunction with UMLER, this file allows an estimate of the number of car-miles and the number of ton-miles accumulated by each specific car type, size, weight, and length.

2.4 RESEARCH AND TESTING

An exhaustive review was made of the extensive literature devoted to providing an understanding of the mechanisms that lead to accidents. Appendix A lists references pertinent to this study. An analysis of this information provided insights into both the causes of accidents and their cures.

2.5 DATA ANALYSIS PROCEDURES

In the analysis of accident frequencies for this study, several important exceptions were made, and certain problems were encountered. These exceptions and the means used for resolving the problems are discussed below.

2.5.1 Choice of Accident Records

All accidents that occurred at 10 mph or less were eliminated from the analysis. The justification for this exception is detailed in Chapters 4 and 5. Briefly, the only significant impact of the large numbers of low-speed accidents, primarily in yards and on poor-quality branchline track, is a direct monetary loss to the railroads; there is virtually no influence on safety. Inclusion of these low-speed accidents would only confuse the safety picture, making it difficult to identify the causes of those accidents which endanger railroad employees or the public and its property.

In addition, a judgment was made, on the basis of a thorough examination of the FRA accident reporting system, that several large classes of accidents had no direct relation to car size, weight, and length. Examples of these classes are:

- Collisions, which result primarily from human error ("human factors");
- Grade-crossing accidents, which result largely from the circumvention by motorists of the protection systems at grade crossings.

Specifically, the following "Cause Codes" were included in the analysis, since it was felt that accidents attributed to the associated causes could possibly be influenced by the size, weight, and length of cars.

Cause Code Numbers	Associated Cause
101 – 109	Roadbed Defects
110 – 113	Wide Gage
114 – 115	Track Alignment
116	Track Profile
117 – 118	Superelevation
119 – 120	Cross-Level
129	Miscellaneous Track Geometry
130 – 149	Rail and Joint Bar
160 – 179	Frogs, Switches, and Track Appliances
180 – 189	Other Way Structure
200 – 209	Signal and Communication
400 – 410	Brakes
411 – 419	Trailer or Container on Flat Car
420 – 429	Body
430 – 439	Coupler and Draft System
440 – 449	Truck Components
450 – 459	Axles and Bearings
460 – 469	Wheels
470 – 479	Locomotives
480 – 489	Doors
499	General Mechanical and Electrical
500 – 509	Use of Brakes

2.5.2 Car Type Identification

Each accident was associated with either the car that caused it, or the first car along the train that was derailed or damaged. Every accident record is meant to include one or the other of these two pieces of information. In situations in which the causing car is also the first one along the train to derail, the two car positions are identical.

This approach to associating a car type with each accident is the best one available. It does suffer from the possibility that the first derailing car may be innocent as, for example, when some car derails because of poor track and manages to derail a car in front of it.

2.5.3 Waybill Elimination

All waybills were included in the analysis except those which contained bad data, defined as follows:

- Trip length less than or equal to 10 miles;
- Trip length greater than 5,000 miles;
- Weight of freight less than 5 tons per carload; and
- Weight of freight such that the car carrying it would be overloaded by more than 20 percent.

2.5.4 Data Quality Control

Several accident records were excluded because of data problems, including the following:

- Speed of accident not recorded;
- Causing car or first derailing car not identified by car owner's initials and serial number; and
- Cause code not listed.

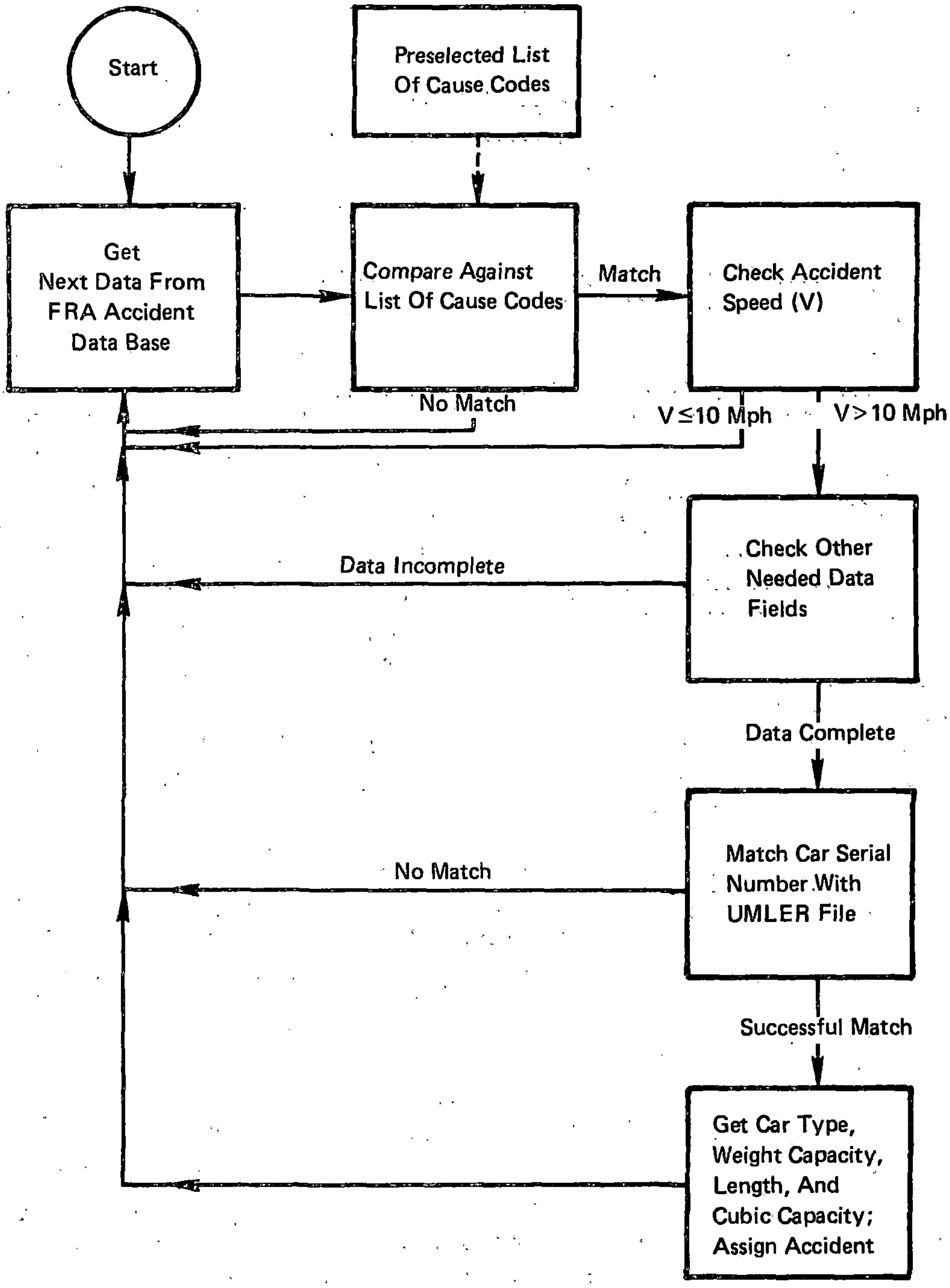
Several waybill records were eliminated because of data problems, including specifically, the absence of the matching car owner's initials and serial number in the UMLER file.

2.5.5 Overall Procedures

The overall procedure for obtaining accident statistics by car type, size, weight, and length is shown in Figure 2-1. The overall procedure for obtaining "exposure" data such as car-miles and ton-miles by car type, size, weight, and length is shown in Figure 2-2.

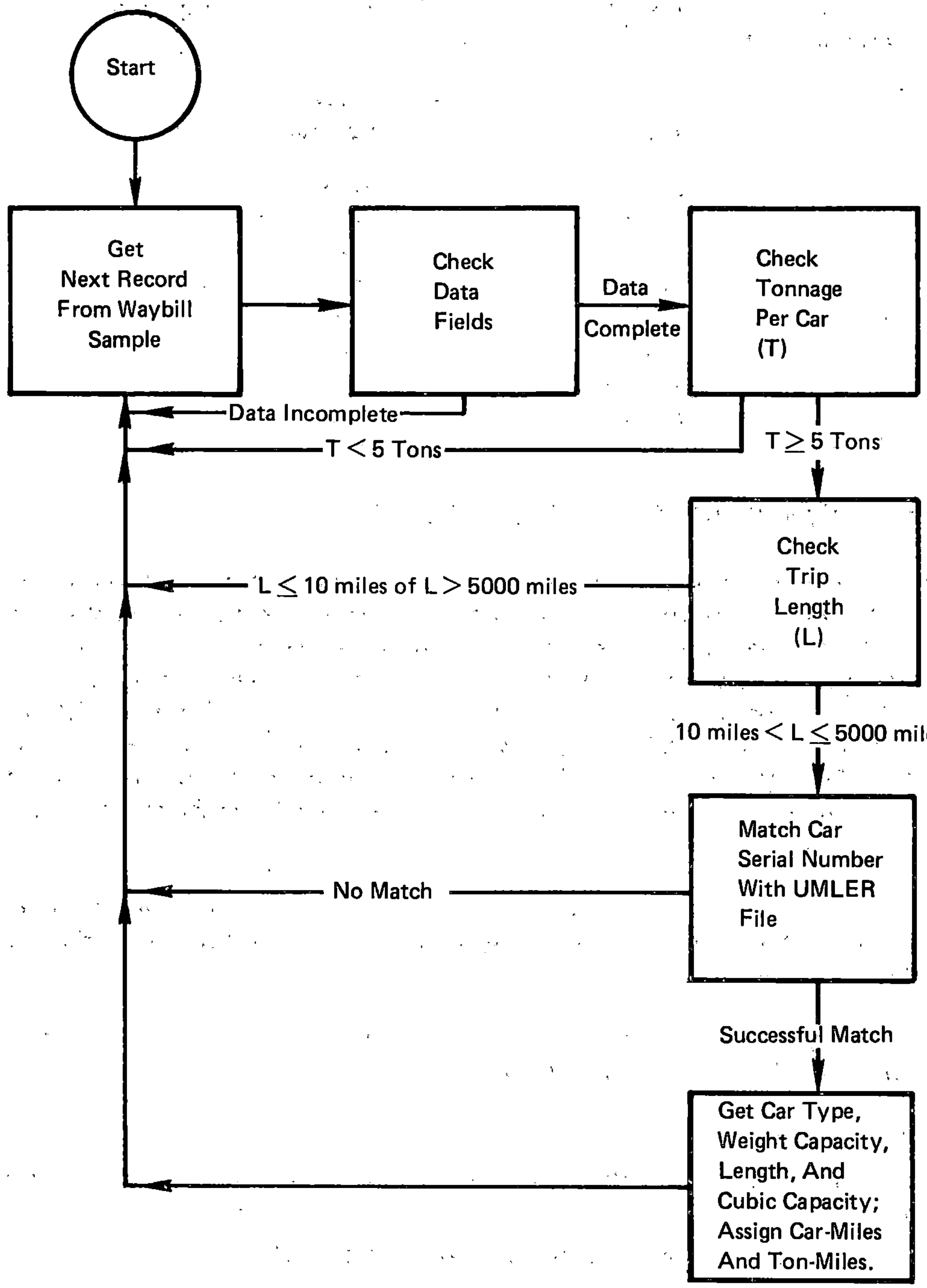
2.5.6 Car-Mile Estimate Modification

The car-mile estimates obtained by matching the waybill data with the UMLER file were modified to account for empty car-miles. Since many of the accidents occur when the car is empty, it is appropriate to add empty car-miles to loaded car-miles in determining the "exposure" or level of use which led to a given number of accidents. The modification was



Source: Arthur D. Little, Inc.

FIGURE 2-1 PROCEDURE FOR ANALYZING ACCIDENT STATISTICS ACCORDING TO CAR CHARACTERISTICS



Source: Arthur D. Little, Inc.

FIGURE 2-2 PROCEDURE FOR ANALYZING EXPOSURE STATISTICS ACCORDING TO CAR CHARACTERISTICS

based on an estimate obtained by the ICC* of the ratio of empty-to-loaded car-miles. These estimates are as follows:

Car Type	Empty Car-Miles/ Loaded Car-Miles
Box	0.67
General Flat	0.88
Auto Rack	1.00
TOFC/COFC	0.47
Gondola	0.85
Covered Hopper	1.01
Open Hopper	0.90
Refrigerator	0.70
Tank	1.10

2.6 COMPARISON OF ACCIDENT STATISTICS

The procedures used in developing accident statistics strongly determine whether statistics developed in one study are comparable to those from another. In the present instance, several accident records were not included in the analyses because of the reasons cited above. In addition, a problem was noted with the car-mile and ton-mile estimates based on the 1% waybill sample. After the estimation of the 100% level of car-miles, the number was considerably less than the car-mile estimate provided annually by the *AAR Yearbook of Railroad Facts.* For 1977, for example, the AAR source quotes an estimated 28.7 billion car-miles. The number obtained from the waybills, on the other hand, is about 16 billion car-miles.

Thus, the accident *frequencies* stated in this report will be *lower* than those in other studies because of the elimination of several accidents, and *higher* because of the underestimation of car-miles and ton-miles.

It is speculated that the reasons for the discrepancy between the waybill-based exposure data and the AAR estimates are the following:

- The 1% sample is in fact less than 1%.
- Several waybills were eliminated because they could not be matched with UMLER.
- Several waybills were eliminated because of data problems.
- The technique used in estimating the waybill mileage often underestimates the true trip length.

At present, however, this remains speculation. No attempt was made to correct the accident frequency statistics in this study to account for these potential sources of error. The implication is that the absolute values of accident frequencies are not likely to be particularly accurate; however, comparisons among car types, nominal weight capacity ranges, etc., are justified.

*ICC Bureau of Accounts, "Ratios of Empty to Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through and All Trains Combined," 1972.

3. FREIGHT CAR FLEET CHARACTERISTICS

3.1 ABSTRACT

The approximately 1,666,000 freight cars in the U.S. fleet travel a total of almost 29 billion miles in a year. Their average load-carrying capacity is 78 tons, and the average load is 63 tons. The miles traveled and tons carried in a year can vary substantially from one type of car to another, "car type" referring to such designations as box car, gondola, or covered hopper. Generally, specific commodities or groups of commodities can be associated with each of the major car types.

Box cars and covered hoppers account for almost 50 percent of the fleet. However, the share of box cars has been dropping steadily over the years, while those of covered hoppers, open hoppers, and tank cars have been gradually increasing. Concomitantly, there has been a continuous trend to larger and heavier cars. The average load-carrying capacity of cars in the fleet has increased from a value of 60 tons in 1965 to 78 tons at present.

Currently, most freight cars fall into one of three nominal categories of load capacity: 50 tons, 70 tons, and 100 tons. Approximately 25%, 43%, and 32% of the fleet fall into these three categories respectively. This division by weight capacity also varies significantly by car type: 6.8% of all box cars have a capacity of 100 tons, compared with 76.7% of all covered hoppers.

Car lengths range from a low of about 20 feet to a high of over 90 feet, the high end of the range being occupied primarily by flat cars.

The internal volume, or cubic capacity, of present-day cars varies from as low as 1000 cubic feet to over 10,000 cubic feet. Some cars, such as flats, have no definable cubic capacity.

The extreme heights of cars vary from as little as 3 feet for flats to as much as 17-1/2 feet for some box cars.

3.2 INTRODUCTION

This chapter investigates the freight car population both historically and, with more detail, the present population. Characteristics by car type (i.e., box car, flat car, gondola, etc.) and by car size, weight, and length are emphasized. Tank cars are discussed in terms of volume capacity with some description of historical technical developments. The data presented indicate a trend toward a fleet of larger and heavier freight cars.

Also presented are operational descriptions of the fleet which show the trends toward increased productivity of railroad freight transportation.

3.3 CURRENT CAR POPULATIONS

The U.S. rail vehicle fleet can be categorized into three groups: locomotives, freight cars, and passenger cars. Table 3-1 shows the approximate number in and yearly mileages traveled by each of these groups. Freight car usage is dominant over the other two groups, and freight car revenues are the mainstay of the industry.

TABLE 3-1

U.S. RAIL VEHICLE FLEET – 1977*

	Population (thousands)	Revenue (billions)	Vehicle Miles (billions)
Locomotives	28.1	Not Applicable	1.60
Freight Cars	1666.5	$18.9	28.70
Passenger Cars	5.5	$ 0.6	0.07

*Includes Class I Railroads and the National Railroad Passenger Corporation (AMTRAK)

Source: Association of American Railroads

There are several distinctions in design within the fleet of freight cars, primarily based upon the transportation requirements of various commodities (Table 3-2). The difference in the car types is primarily the construction of the car bodies. Thus, the freight cars are substantially different in terms of size, weight, and length depending on the specific commodities to be carried. For instance, flat cars carrying highway trailers are long. Similarly, covered hopper cars designated to carry light density farm products like grain are as high as allowable and therefore tend to have a high center of gravity. Appendix B illustrates the basic design for each of the types of freight cars used in this study.

The overall design of the freight car trucks does not depend on the type of freight car to which they are attached. The main difference among the trucks is their maximum gross weight capacity. The three major truck types are 50-ton, 70-ton, and 100-ton, respectively, representing the approximate payload (i.e., nominal weight capacity) which can be carried in the freight car. The truck gross weight capacity is based on the design of the bearings, axles, wheels, centerplate, and other components, which varies from one truck type to another. Table 3-3 shows certain AAR design specifications for components of 50-, 70-, and 100-ton freight car trucks as well as the maximum gross weight on rail for 50-, 70-, and 100-ton freight cars. One of the specifications on Table 3-3, Axle Designation, implies several dimensional values, which are shown in Figure 3-1.

The freight car fleet can be broadly described in two ways: by car type and by similar geometrical configurations. The use of car types (i.e., box cars, flat cars, etc.) is the most customary approach and, for purposes of commodity assignment and shipment, the most practical. However, work currently under way by the FRA has looked at the car fleet from

TABLE 3-2

TYPES OF FREIGHT CARS* AND TYPICAL COMMODITIES CARRIED

Box Car	Field Crops, Wood Products, Miscellaneous
Flat Car	Food Products, Wood Products, Highway Trailers, Miscellaneous
Vehicular Flat Car	Transportation Equipment
Gondola	Coal, Non-Metallic Minerals
Covered Hopper	Field Crops, Wood Products
Open Hopper	Coal, Non-Metallic Minerals
Refrigerated Car	Food Products, Field Crops
Stock Car	Livestock
Tank Car	Chemical Products, Petroleum, Oil

*Refer to Appendix B for illustrations of the various freight car types

TABLE 3-3

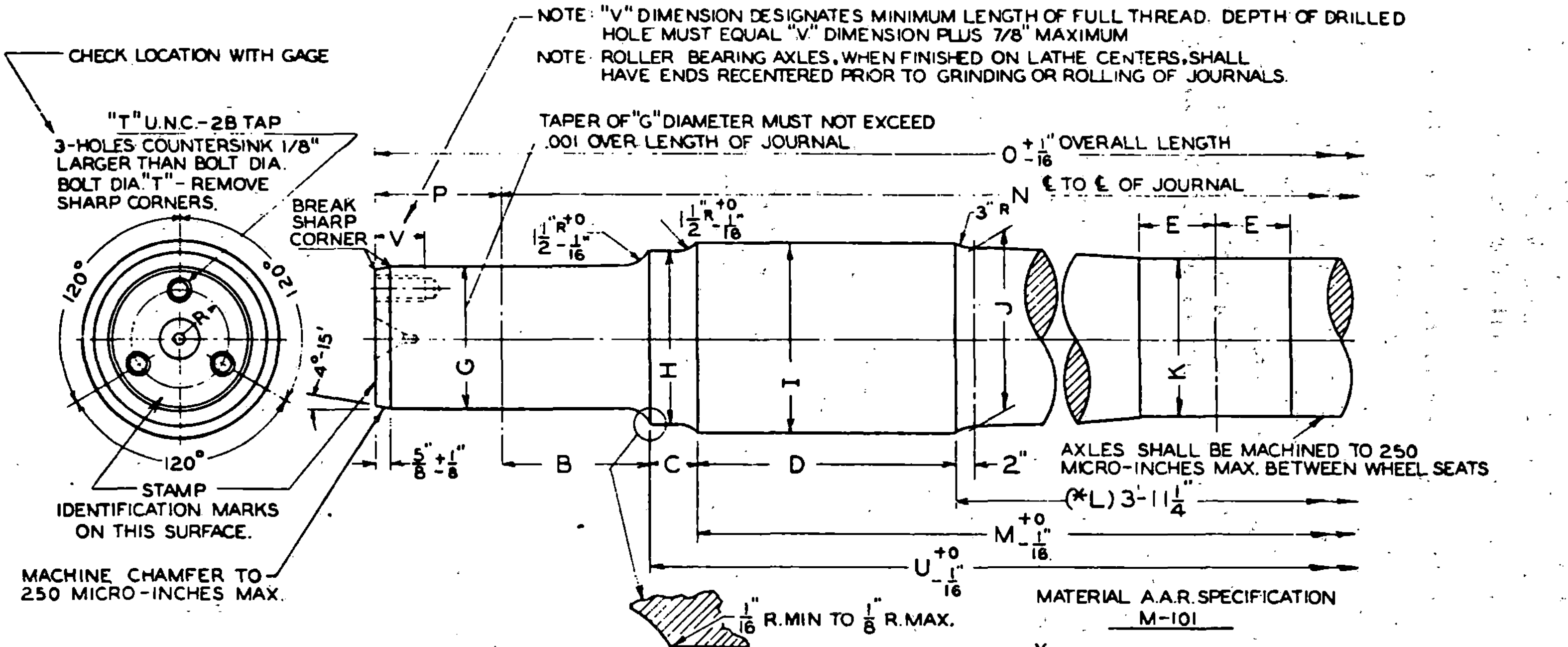
AAR DESIGN SPECIFICATIONS FOR FREIGHT CAR TRUCKS

	50 Ton	70 Ton	100 Ton
Bearing Journal Size (inches)	5-1/2 x 10	6 x 11	6-1/2 x 12
Axle Designation[1]	D	E	F
Wheel Diameter (inches)	28 to 33	28 to 33	30 to 36
Center Plate Diameter (inches)	12	14	16
Maximum Gross Weight on Rail (pounds)[2]	177,000	220,000	263,000[3]

NOTES:

1. See Figure 3-1 for an explanation of roller bearing axle designations.
2. The total weight on rails shown is for 4-wheel trucks, four axles per car. For cars having 6-wheel, 8-wheel, etc., trucks, the total weight on rails is proportional to the number of axles under the car.
3. Cars with a weight on rails greater than 263,000 pounds can only be operated in limited interchange when complying with Railway Line Clearance special statement and under the special requirement for new cars to be approved by the Executive Vice-Chairman of the Mechanical Division.

Source: Specifications for Design, Fabrication, and Construction of Freight Cars, AAR, October 1977



FOR AXLE CENTER SEE SEPARATE PLATE.

ENLARGED SECTION SHOWING OPTIONAL RADIUS WHEN USING CONTOUR GRINDER

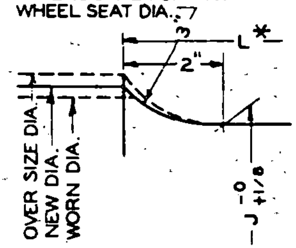
*THE "L" DIMENSION NEED NOT BE CORRECTED FOR LENGTH EACH TIME THE WHEEL SEATS ARE TURNED

CLASSIFICATION OF AXLE	SIZE OF JOURNAL	DIMENSIONS																
		B	C	D	E	G	H	I	J	K	M	N	O	P	R	T	U	V
B	4 1/4" X 8"	4 5/8"	1 5/8"	7 5/8"	1 1/2"	MAX. 4.004 MIN. 4.003	5"	6 5/16"	5 7/16"	4 3/4"	62 1/2"	75"	83"	4"	1 7/32"	3/4"-10	65 3/4"	1 5/8"
C	5" X 9"	5 5/16"	1 7/16"	7 5/8"	1 1/2"	MAX. 4.6915 MIN. 4.6905	5 7/8"	7"	6 3/16"	5 3/8"	62 1/2"	76"	84 7/8"	4 7/16"	1 1/2"	7/8"-9	65 3/8"	1 7/8"
D	5 1/2" X 10"	5 1/2"	1 3/4"	7 5/8"	3"	MAX. 5.1915 MIN. 5.1905	6 3/8"	7 9/16"	6 3/4"	5 7/8"	62 1/2"	77"	86 1/8"	4 9/16"	1 3/4"	7/8"-9	66"	1 7/8"
E	6" X 11"	5 15/16"	1 13/16"	7 5/8"	3"	MAX. 5.6915 MIN. 5.6905	7"	8 1/4"	7 5/16"	6 7/16"	62 1/2"	78"	88"	5"	1 15/16"	1"-8	66 1/8"	2"
F	6 1/2" X 12"	6 7/16"	1 13/16"	7 5/8"	3"	MAX. 6.1915 MIN. 6.1905	7 1/2"	8 3/4"	7 7/8"	7 3/8"	62 1/2"	79"	89 5/8"	5 5/16"	2 1/8"	1 1/8"-7	66 1/8"	2 1/8"
G	7" X 12"	5 15/16"	2 5/16"	7 5/8"	3"	MAX. 7.004 MIN. 7.003	8.002 8.000	9 1/2"	8 9/16"	8"	62 1/2"	79"	89 1/4"	5 1/8"	2 5/16"	1 1/4"-7	67 1/8"	2 1/4"

NOTE: I DIMENSION TOLERANCE IS $^{+0.015}_{-0.015}$

NOTE: REQUIRED FOR PRESS FIT OF ROLLER BEARING BACKING RING WHERE THIS DIAMETER IS TOLERANCED.

ON NEW AXLES MACHINE 3 INCH RADIUS AT SPECIFIED DIMENSION "L" FOR ANY WHEEL SEAT DIA.



ENLARGED VIEW SHOWING CONDITION AT FILLET JOINING BODY PORTION OF AXLE TO INSIDE EDGE OF WHEEL SEAT.

Source: Specifications for Design, Fabrication, and Construction of Freight Cars, AAR, October 1977

FIGURE 3-1 DIMENSIONS OF RAISED WHEEL SEAT ROLLER BEARING AXLES FOR FREIGHT CARS

the second approach; that is, the FRA has described and compared vehicles by specific geometric or dynamic characteristics. For example, cars can be described by their overall lengths or by their nominal weight capacity, independent of the particular car type.

Both approaches are used in this report. The use of car types is more valuable for an intuitive understanding of the fleet, but the application of studies and statistics using geometric descriptors may be more applicable to the investigation of the effects of car size, weight, and length on railroad safety and efficiency. Much of this study used the UMLER data file maintained by the AAR. This file contains entries representing every freight car approved for interchange service. (An abbreviated textual version of the file is known as the Official Railroad Equipment Register.) The following descriptions of the present car fleet are derived from an analysis of the November 1977 version of UMLER and an engineering analysis of certain critical vehicle parameters.[1]

The total fleet includes approximately 1.7 million cars which are divided into nine major car type groups. Table 3-4 shows the number of cars in each group, along with its percentage of the total fleet.

TABLE 3-4

PRESENT FREIGHT CAR POPULATION, 1977

Car Type	Population (thousands)	Percent of Fleet
Box	458.0	27.5
Flat	132.9	8.0
Vehicular Flat	33.1	2.0
Gondola	183.9	11.0
Covered Hopper	227.0	13.6
Open Hopper	355.4	21.3
Refrigerator	94.6	5.7
Stock	4.9	0.3
Tank	177.0	10.6
TOTAL	1666.8	100.0

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

The remainder of this section provides a characterization of the U.S. railroad freight car fleet in terms of its size, weight, and length attributes. Various descriptors of size, weight, and length were investigated, including for size, volumetric capacity, height of loaded center of gravity, and extreme height; for weight, nominal weight capacity and empty weight; for length, overall length, truck center spacing, and inside length. However, based on the needs of this report and the extent of available data sources, the definitions of size, weight, and length are as follows:

- Size describes the vehicle's volumetric capacity in cubic feet, or gallons (tank cars only).
- Weight refers to the vehicle's nominal weight capacity in thousands of pounds (for all equipment types). The nominal weight capacity is the recommended payload capacity based on the strength of the freight car trucks and the empty (or tare) weight of the freight car.
- Length refers to a vehicle's outside (overall) length in feet (for all equipment types).

Two freight car classes were considered in characterizing the fleet: the general service class and the commodity-related class. Cars in the general service class are assigned to haul a wide variety of commodities of differing densities and characteristics. These cars are also used to ship partial loads or drop loads with more than one delivery point. Commodity-related cars are designed to carry a particular commodity such as grain, liquids, or automobiles. These cars are typically fully loaded to their full weight capacity.

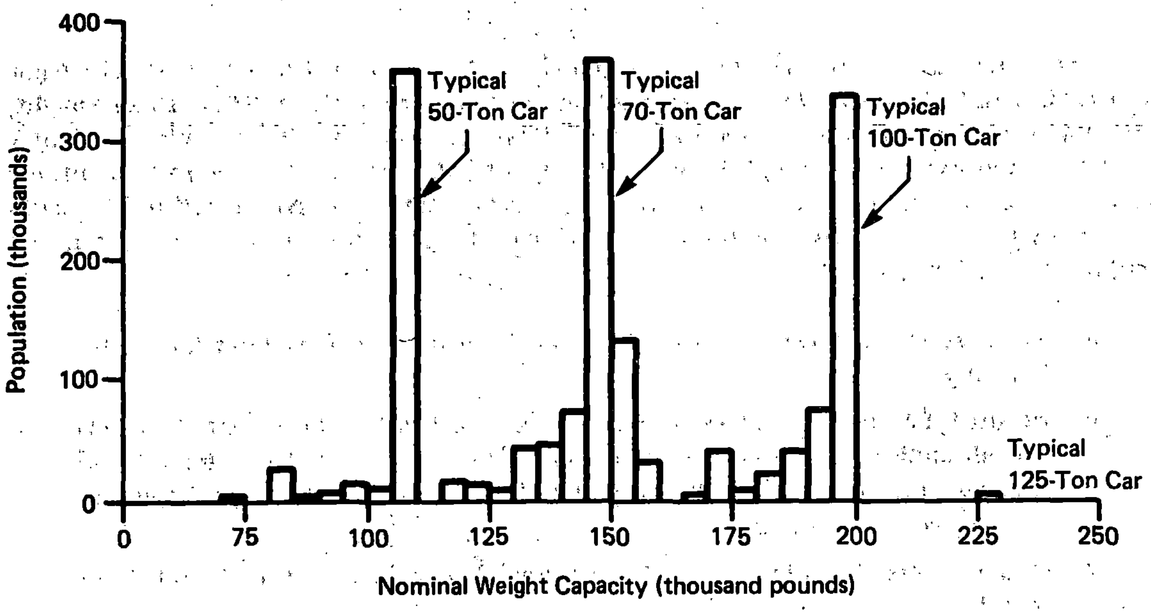
Certain figures and tables will give slightly different numbers for various car type populations since several data sources were employed in this study. The differences are small (less than 5%) and are primarily due to choices in sorting parameters based on the intended use of the data file. The results obtained in this study are not sensitive to these small discrepancies in car populations.

3.3.1 Car Population Distribution by Nominal Weight Capacity

As Figure 3-2 indicates, dominant freight car populations are at about 110,000, 150,000 and 200,000 pounds (or about 55-, 75-, and 100-ton capacity).

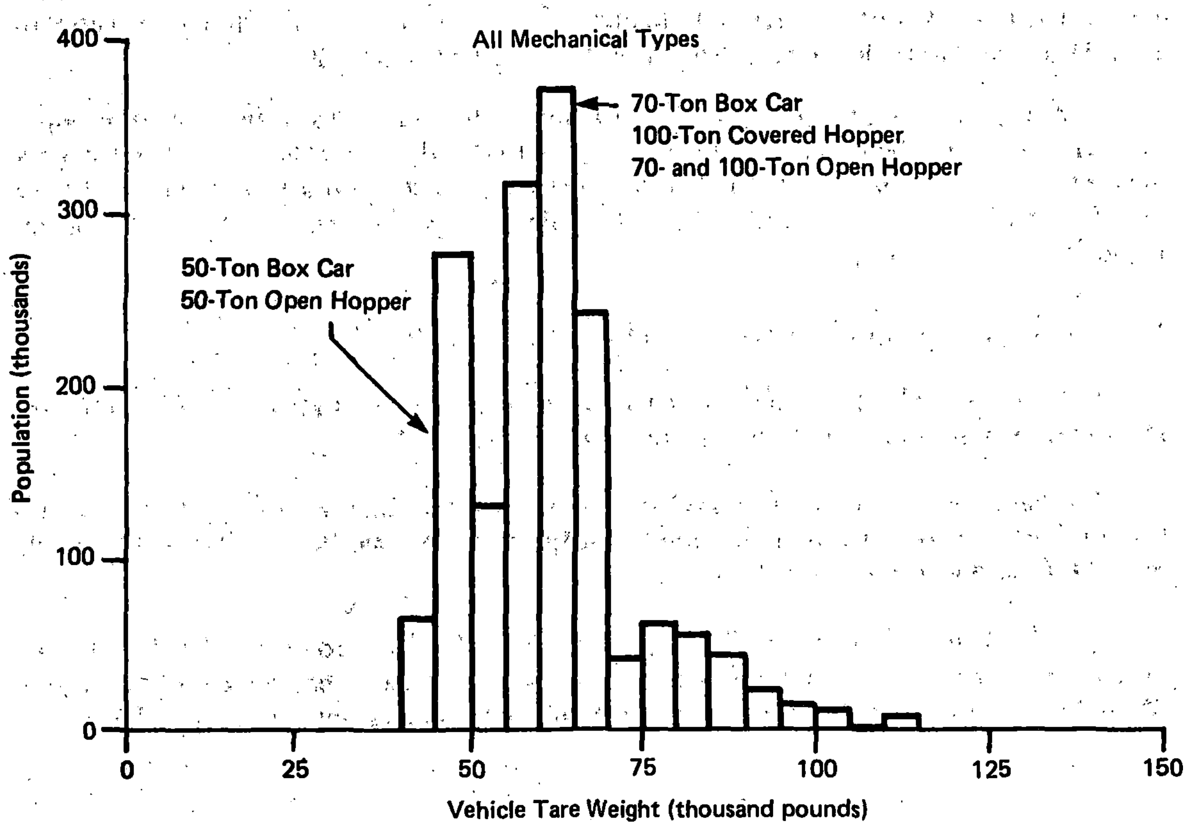
The variation in capacity is somewhat determined by the tare weights (unloaded weight) for the fleet. Figure 3-3 shows that the majority of the cars are in the 50,000- to 70,000-pound (25- to 35-ton) tare weight range.

For simplicity of discussion, the population is divided into groups by "truck capacity" which is inferred from the nominal weight capacity. This division, based on dominant population groupings, along with a corresponding weight descriptor, is shown in Table 3-5.



Source: DOT Transportation System Center Estimates Based on 1977 UMLER

FIGURE 3-2 DISTRIBUTION BY NOMINAL WEIGHT CAPACITY, ALL CAR TYPES



Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-3 DISTRIBUTION BY TARE WEIGHT, ALL CAR TYPES

TABLE 3-5

WEIGHT RANGES

Nominal Weight Capacity (thousand pounds)	Truck Capacity (tons)	Weight Descriptor
70-110	50	Light
110-160	70	Medium
160-200	100	Heavy
225-230	125	Very Heavy

Table 3-6 indicates that approximately 25% of the total fleet is equipped with 50-ton trucks, 43% with 70-ton trucks, and 32% with 100-ton trucks. A small portion of 125-ton trucks, less than 1% of the fleet, is also in service. There has been an increasing number of heavy trucks as described in Section 3.3.

The dominant car types in each of the 50-, 70-, and 100-ton truck capacity ranges are shown in Table 3-7. Within each of the three truck capacity ranges, the percentage of all freight cars in that capacity range included by the dominant car types is listed.

TABLE 3-6

U.S. RAIL FREIGHT VEHICLE FLEET BY MAJOR VEHICLE TYPES AND WEIGHT CAPACITIES, 1977
(Population in Thousands)

Mechanical Type	Truck Capacity				Percent of Fleet
	50 Ton	70 Ton	100 Ton	Total	
Box	233.2	193.5	31.3	458.0	27.5
Flat	32.3	91.9	8.7	132.9	8.0
Vehicular Flat	18.7	14.4	*	33.1	2.0
Gondola	19.6	105.2	59.1	183.9	11.0
Covered Hopper	*	53.0	174.0	227.0	13.6
Open Hopper	34.7	175.7	145.0	355.4	21.3
Refrigerator	12.7	74.5	7.4	94.6	5.7
Stock	4.9	*	*	4.9	0.3
Tank	63.0	12.3	101.7	177.0	10.6
TOTAL	419.1	720.5	527.2	1666.8	
Percent of Fleet	25.2%	43.2%	31.6%		

*Less than 0.05

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

TABLE 3-7

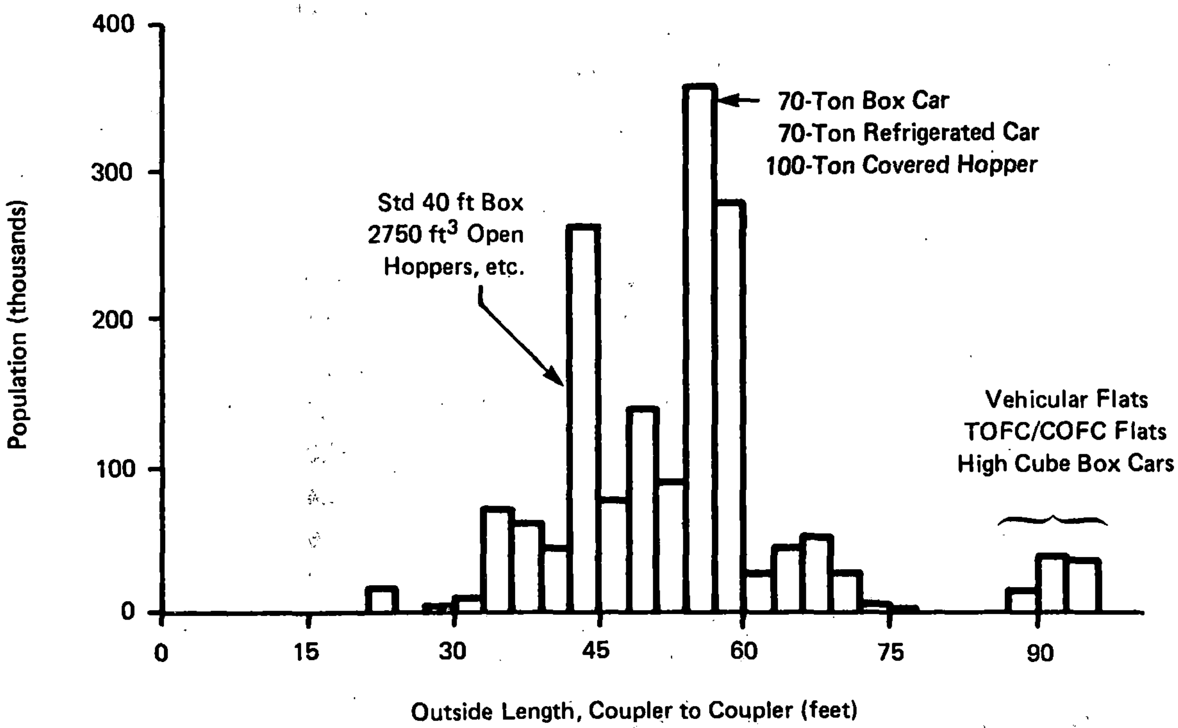
DOMINANT CAR TYPES BY TRUCK CAPACITY

Truck Capacity (tons)	Dominant Car Types	Percent of Truck Capacity Population Included by Dominant Car Types
50	Box, Tank	71
70	Open Hopper, Box, Gondola, Flat	79
100	Covered Hopper, Open Hopper, Tank	80

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

3.3.2 Car Population Distribution by Length

As shown in Figure 3-4, a substantial portion of vehicles have an outside length between 54 and 60 feet. Specific car type designs can often be associated with specific ranges, as indicated in Figure 3-4. For this study, and ease of discussion, overall length was divided into the length categories shown in Table 3-8.



Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-4 DISTRIBUTION BY OUTSIDE LENGTH, ALL CAR TYPES

TABLE 3-8

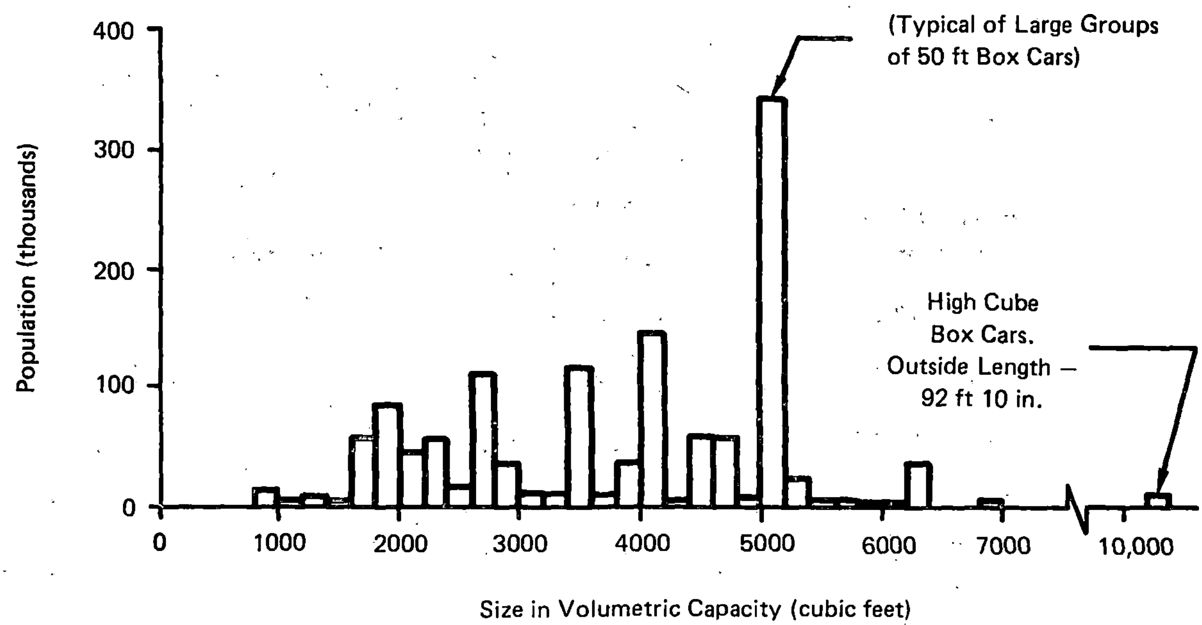
LENGTH RANGES

Overall Length (feet)	Length Descriptors
21-45	Short
45-60	Medium
60-78	Long
78-90	Very Long

Car Population Distribution by Size

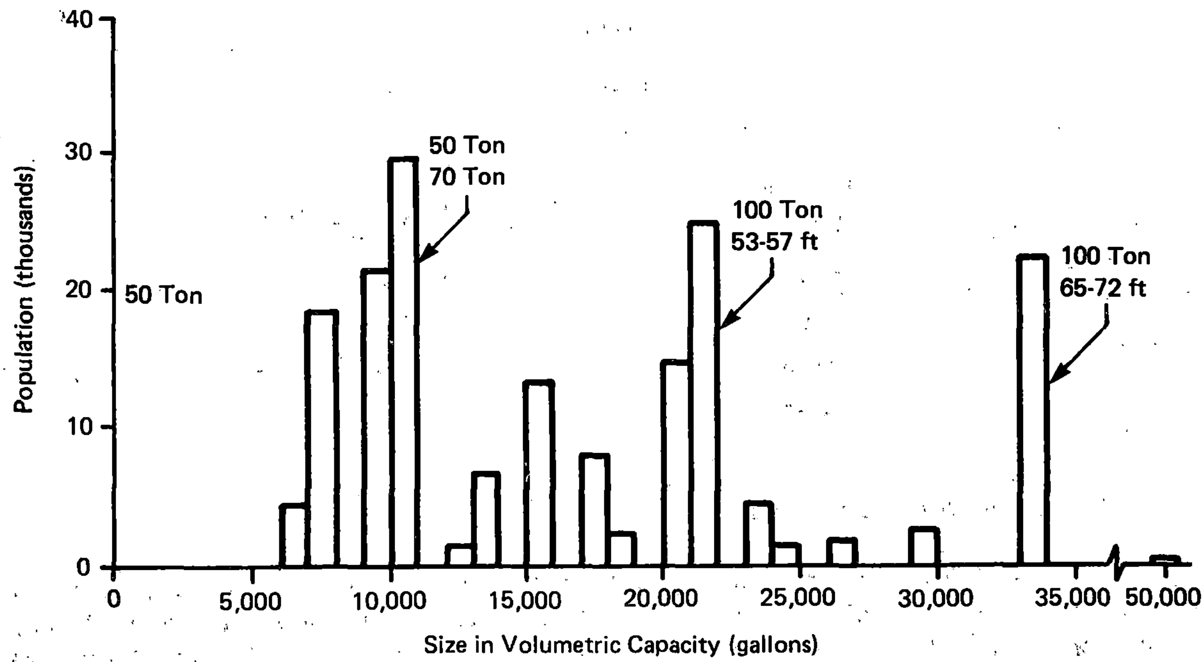
Figures 3-5 and 3-6 contain similar population distribution by size, i.e., volumetric capacity in cubic feet (for all cars except flat and tank cars) and in gallons (for tank cars). In this study, flat cars are characterized only by weight capacity and length descriptors, since volume capacity is meaningless.

Volumetric capacity is divided into ranges as shown in Table 3-9.



Source: DOT Transportation System Center Estimates Based on 1977 UMLER

FIGURE 3-5 DISTRIBUTION BY CAPACITY, INCLUDING BOX, STOCK, REFRIGERATOR, COVERED HOPPER, OPEN HOPPER, AND GONDOLAS



Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-6 DISTRIBUTION BY CAPACITY, TANK CARS ONLY

TABLE 3-9

SIZE RANGES

Volumetric Capacity (cubic feet)*	Gallons**	Size Descriptors
800-3000	6000-16000	Small
3000-5000	16000-25000	Medium
5000-7000	25000-34000	Large
7000-10000	25000-34000	Very Large

* For all cars except flat and tank cars
** For tank cars only

3.3.3 Combinations of Parameters Related to Size, Weight, and Length

Tables 3-10 and 3-11 give the number of vehicles falling into each of the basic configurational groups defined by combinations of physical attributes related to size, weight, and length. Flat cars and vehicular flat cars are grouped separately, as are freight vehicles having extreme configurational features. The largest population (320,040) corresponds to a medium-size, medium-length, high-weight capacity (100-ton) vehicle configuration. This group, which represents approximately 20% of the entire fleet, is composed of car types shown in Table 3-12.

Approximately 92,000 vehicles are in service with an overall length in the 87 to 96 foot range. These vehicles include long high-cube box cars, TOFC/COFC vehicles, and vehicular flat cars.

TABLE 3-10

FLEET POPULATIONS BY GROUPS OF SIZE, WEIGHT, AND LENGTH

All Mechanical Types Except Flats and Vehicular Flats

1. Small Volumetric Capacity (800-3,000 ft^3 or 6,000-16,000 gal)

		Weight Capacity (thousand pounds)		
		70-110 (Lt)	**110.1-160 (Med)**	**160.1-200 (Heavy)**
Overall Length (ft)	21-45 (Short)	87,450	201,940	38,650
	45.1-60 (Med)	16,840	124,790	49,870
	60.1-78 (Long)	0	10,130	0

2. Medium Volumetric Capacity (3,000-5,000 ft^3 or 16,000-25,000 gal)

		Weight Capacity (thousand pounds)		
		70-110 (Lt)	**110.1-160 (Med)**	**160.1-200 (Heavy)**
Overall Length (ft)	21-45 (Short)	134,430	4,420	5,090
	45.1-60 (Med)	16,270	12,750	320,040
	60.1-78 (Long)	0	8,480	2,710

3. Large Volumetric Capacity (5,000-7,000 ft^3 or 25,000-34,000 gal)

		Weight Capacity (thousand pounds)		
		70-110 (Lt)	**110.1-160 (Med)**	**160.1-200 (Heavy)**
Overall Length (ft)	21-45 (Short)	0	0	0
	45.1-60 (Med)	100,520	215,600	26,390
	60.1-78 (Long)	0	40,650	73,320

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

TABLE 3-11

FLEET POPULATIONS, SPECIAL CASES

Flat and Vehicular Flat Cars

		Weight Capacity (thousand pounds)		
		70-110 (Lt)	**110.1-160 (Med)**	**160.1-200 (Heavy)**
Overall Length (ft)	21-45 (Short)	0	0	0
	45.1-60 (Med)	29,400	31,380	0
	60.1-78 (Long)	0	12,700	8,680

Very Large Freight Vehicles (in terms of length, weight capacity, and/or volumetric capacity)

		Typical Vehicles
Weight Capacity (225-230 Kips)	1,900	Open Hopper (125 ton)
Overall Length (87-96 ft)	92,530	Box, Flat and Vehicular Flat
Volumetric Capacity (10,000 ft^3)	8,650	High Cube Box

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

TABLE 3-12

DISTRIBUTION OF CAR TYPES WITHIN THE HEAVY, MEDIUM-LONG, MEDIUM-CAPACITY GROUP

Mechanical Type	Approximate Population	Percent of Mechanical Type
Gondola	12,000	7% of All Gondolas
Covered Hopper	125,000	55% of All Covered Hoppers
Open Hopper	130,000	37% of All Open Hoppers
Tank	53,000	30% of All Tank Cars
TOTAL	320,000	

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

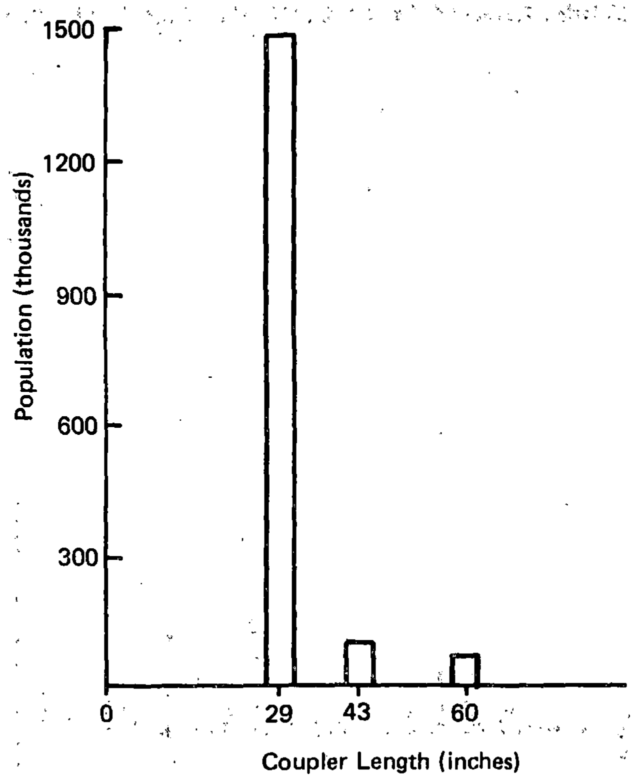
3.3.4 Other Principal Physical Characteristics

For the purpose of investigating dynamic car performance, the car fleet was characterized by certain other geometrical and dynamic properties.

Figure 3-7, which illustrates the distribution of coupler lengths within the fleet, shows that the vast majority of cars are equipped with the standard 29-inch coupler. A few longer couplers are in service on longer vehicles such as flat, vehicular flat, and long cushioned under-frame box cars. Long couplers, however, provide certain difficulties while coupling on curves.

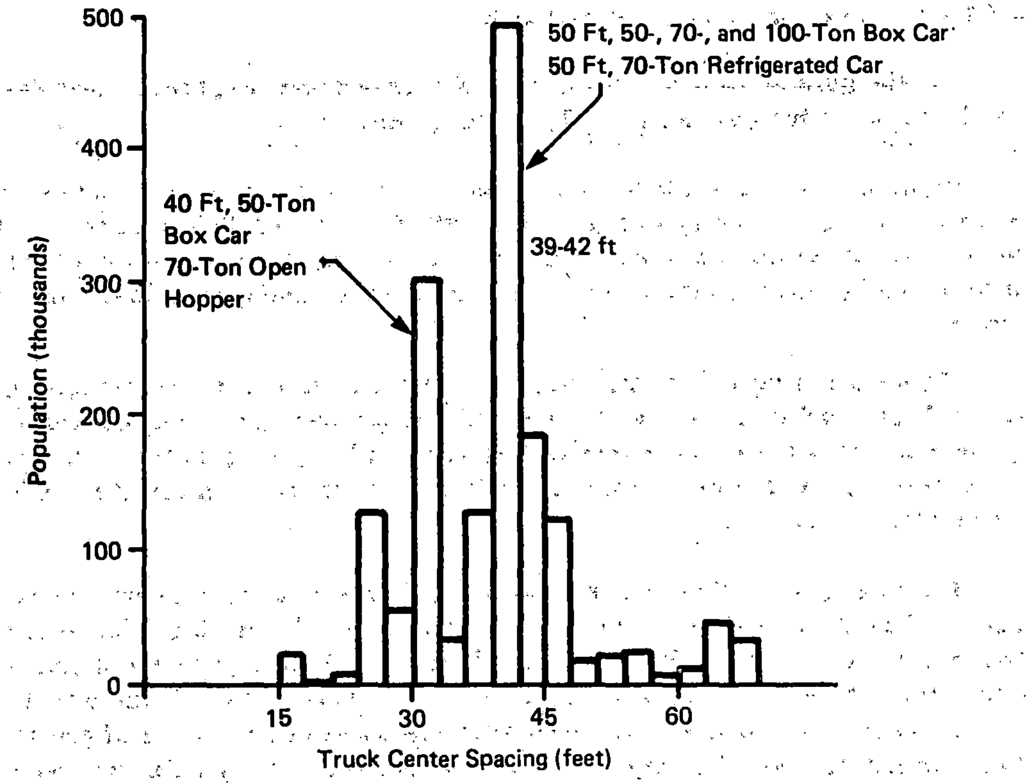
Figure 3-8, which illustrates vehicle population versus truck center spacing, indicates that a large number of vehicles have a truck center spacing between 39 and 42 feet. This group is of particular concern because this truck center spacing is equal or close to the typical 39-foot rail length used in track construction. This factor is important in vehicle dynamic activity (see Chapter 5).

Figure 3-9, which illustrates vehicle populations as a function of extreme height, shows that the largest number of vehicles have an extreme height of 15 to 15.5 feet. This implies that a large percentage of the freight vehicle fleet will have high center of gravity heights in either the loaded or unloaded configuration. This consideration is important in the harmonic roll process associated with the dynamic response of high center of gravity vehicles to track having moderate to large cross-level track geometry irregularities (see Chapter 5).



Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-7 DISTRIBUTION BY COUPLER LENGTH, ALL CAR TYPES



Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-8 DISTRIBUTION BY TRUCK CENTER SPACING, ALL CAR TYPES

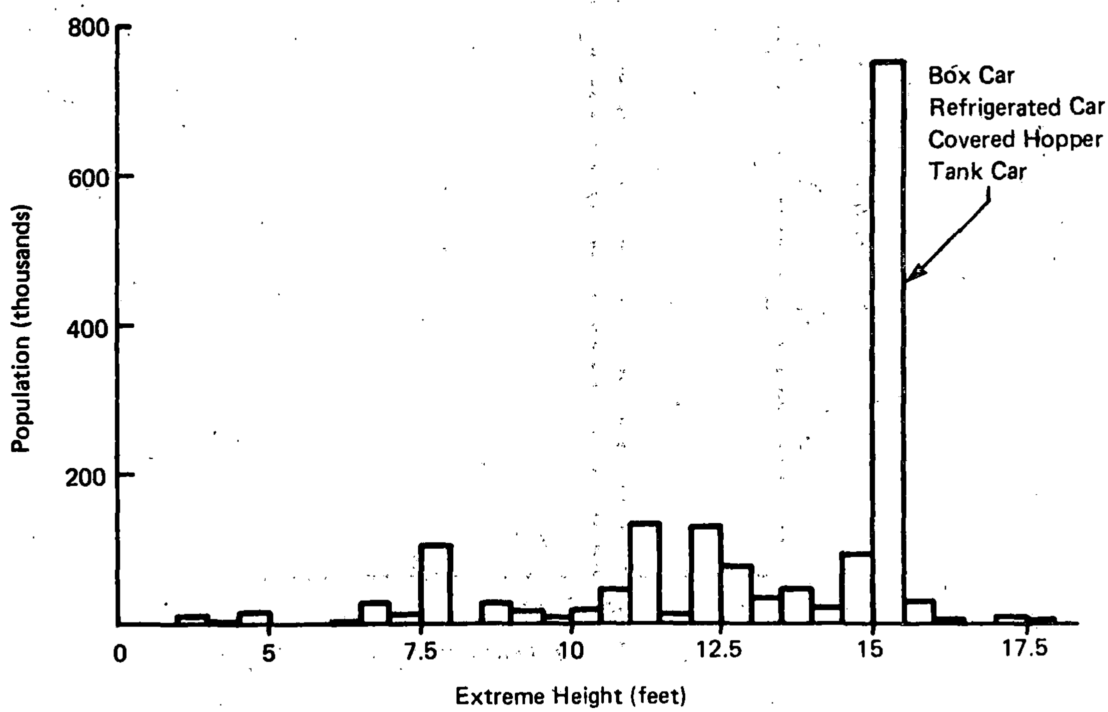


FIGURE 3-9 DISTRIBUTION BY EXTREME HEIGHT, ALL CAR TYPES

Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

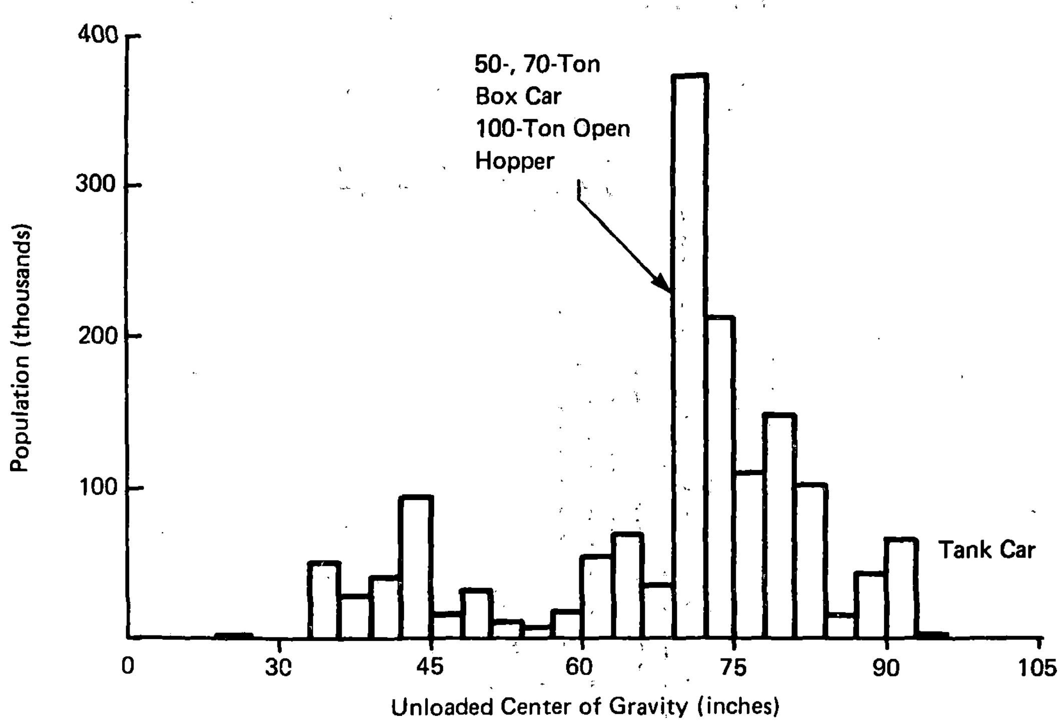
Figures 3-10 through 3-13 illustrate center of gravity, height, axle load distributions, carbody roll inertia, carbody vertical bending frequency for unloaded vehicles. These parameters influence a railcar's vertical, lateral, and harmonic roll response to track geometry and structural irregularities.

3.4 HISTORIC TRENDS IN CAR FLEET POPULATION AND CAPACITY

This section presents the car fleet population and capacity in the perspective of the past several years. Figure 3-14 shows that the number of cars has dropped rather steadily over this period, from a high of about 1.83 million in 1966 to a low of 1.65 million in 1978. Table 3-13, which gives the population by car type from 1973 to 1978, indicates that some car types are decreasing in number, while others are increasing. Specifically, Table 3-14 shows the 1978 population as a percentage of the 1973 population for each car type. The year 1973 was chosen as the base year in this calculation to provide an indication of recent trends in freight car populations.

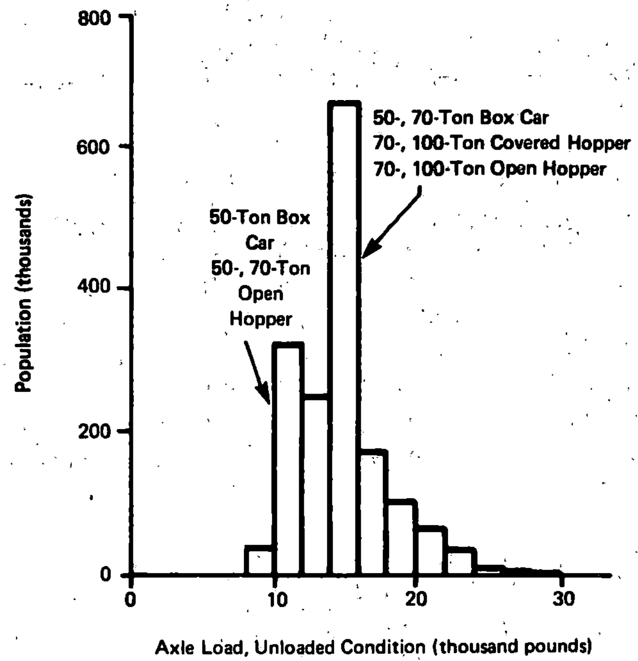
Several factors dictate the car populations. The most important of these are:

- Quantity of commodities shipped; and
- Average capacity of the fleet.



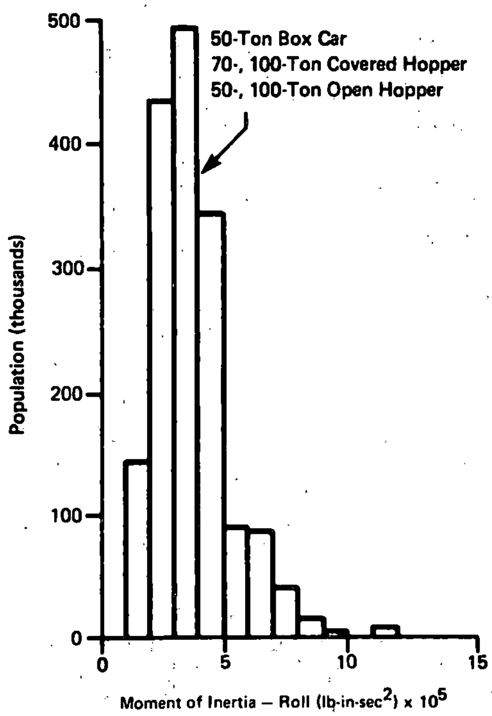
Source: DOT Transportation Systems Center Estimates

FIGURE 3-10 DISTRIBUTION BY CENTER OF GRAVITY HEIGHT IN UNLOADED CONDITION, ALL CAR TYPES



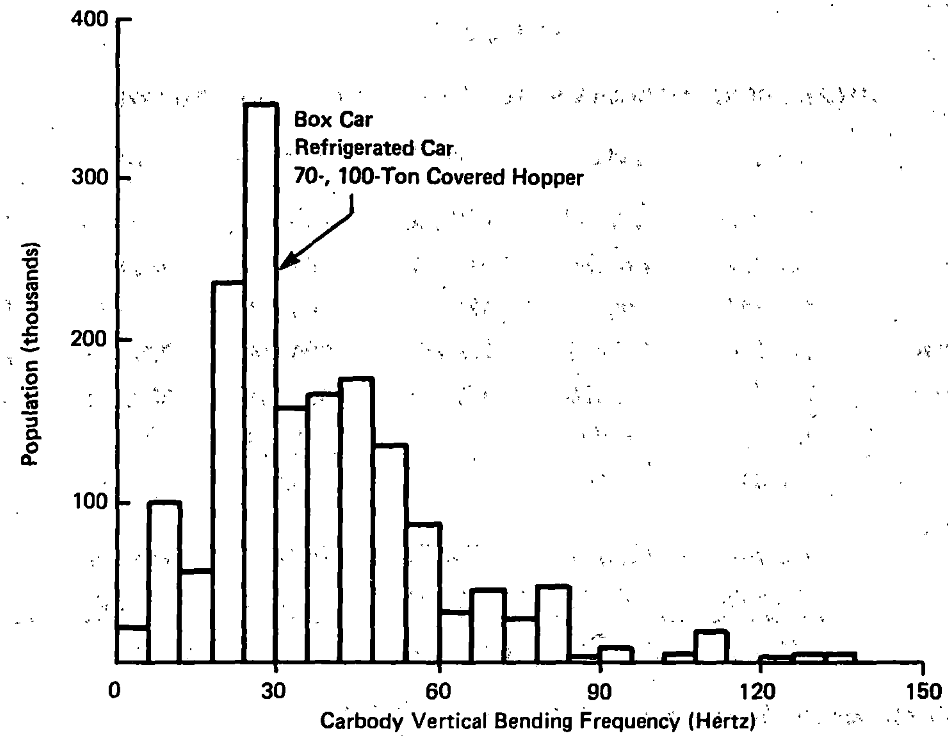
Source: DOT Transportation Systems Center Estimates Based on 1977 UMLER

FIGURE 3-11 DISTRIBUTION BY AXLE LOAD IN UNLOADED CONDITION, ALL CAR TYPES



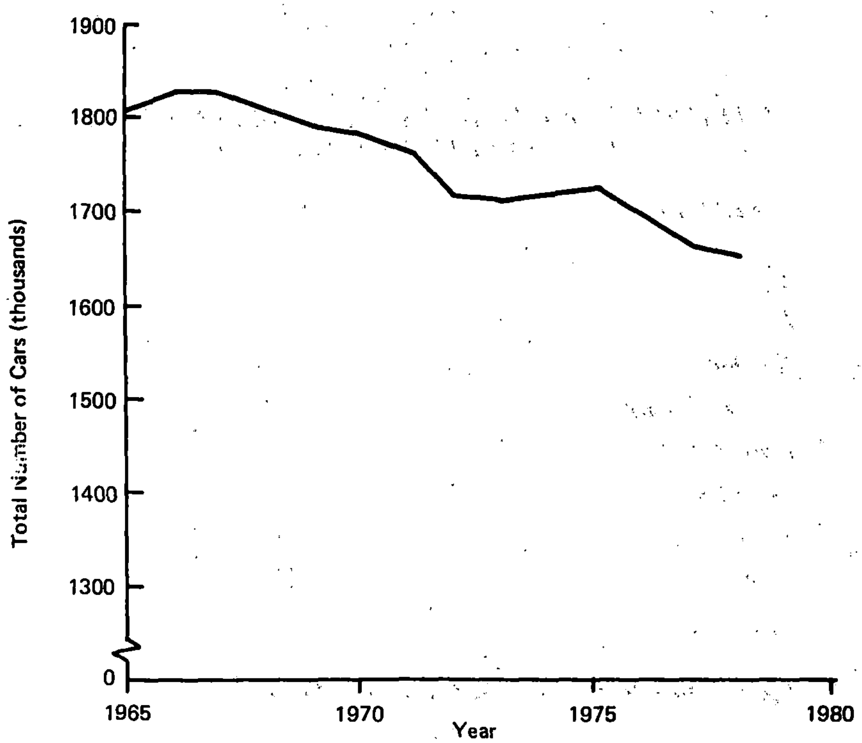
Source: DOT Transportation Systems Center Estimates

FIGURE 3-12 DISTRIBUTION BY ROLL MOMENT OF INERTIA, ALL CAR TYPES, UNLOADED



Source: DOT Transportation Systems Center Estimates

FIGURE 3-13 DISTRIBUTION BY VERTICAL BENDING FREQUENCY, ALL CAR TYPES



Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-14 FREIGHT CAR POPULATION

TABLE 3-13

TOTAL FREIGHT CARS IN SERVICE BY CAR TYPE, 1973 TO 1978

Car Type	1973	1974	1975	1976	1977	1978
Box	511,396	506,197	495,139	473,953	450,779	435,671
Flat	132,222	139,186	141,316	141,781	142,811	146,402
Gondola	187,347	186,720	186,773	185,776	179,475	175,777
Covered Hopper	204,926	219,362	228,265	230,069	235,829	246,087
Open Hopper	365,333	356,626	363,186	365,526	359,168	354,086
Refrigerator	104,721	104,024	100,815	98,017	93,823	87,601
Stock	5,307	4,980	4,423	3,637	2,943	Not Available
Tank	165,309	169,237	170,876	168,018	169,745	174,170
Others	33,558	34,241	32,792	32,250	31,960	32,980
TOTAL	1,710,569	1,720,573	1,723,605	1,699,027	1,666,533	1,652,774

Source: AAR Yearbook of Railroad Facts, 1979

TABLE 3-14

1978 FREIGHT CAR POPULATION AS A PERCENTAGE OF THE 1973 POPULATION

Car Type	Percent
Box	85
Flat	111
Gondola	94
Covered Hopper	120
Open Hopper	97
Refrigerator	84
Stock	42
Tank	105
ALL	97

Source: AAR Yearbook of Railroad Facts, 1979

Table 3-15 indicates that originated tonnage has held rather constant at about 1.44 million tons per year. Similarly, Figure 3-15 shows that the total fleet capacity, in tons, is increasing steadily. In combination with the decreasing number of cars, this fact indicates that the carrying capacity of the average freight car is increasing. Figure 3-15 also gives the capacity of the car fleet owned by Class I railroads only, which is a subset of the total. This capacity, which excludes private owners, shows approximately the same trends. This trend of increasing capacity applies to all car types, as shown in Table 3-16.

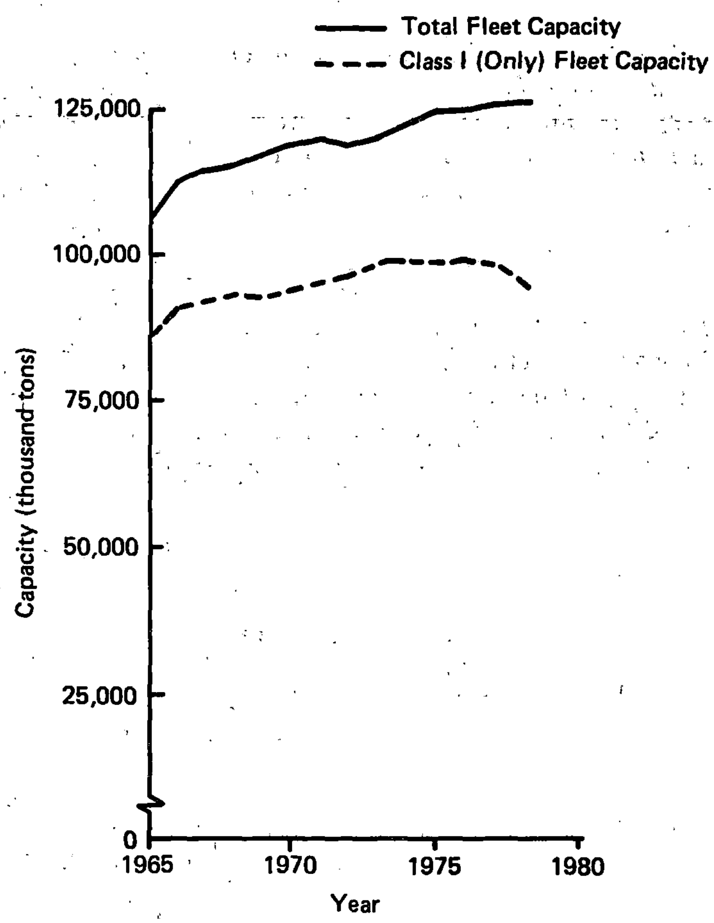
Table 3-17 summarizes this increase in average car capacity (Class I railroads only) giving the 1978 average freight car capacity as a percentage of the 1966 average freight car capacity. The base year 1966 was chosen because it provides the oldest reliable data available at the time of this study. The increase in average car capacity arises directly from the purchase of 70-ton and 100-ton capacity cars to replace older 50-ton cars being retired from service.

TABLE 3-15

FREIGHT TONNAGE ORIGINATED

Year	Total Tonnage Originated by Class I Railroad (billion tons)
1965	1.39
1966	1.45
1967	1.41
1968	1.43
1969	1.47
1970	1.48
1971	1.39
1972	1.45
1973	1.53
1974	1.53
1975	1.40
1976	1.41
1977	1.39
1978	1.39
Average	1.44

Source: AAR Yearbook of Railroad Facts, 1979



Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-15 TOTAL FLEET CAPACITY AND CLASS 1 RAILROAD FLEET CAPACITY BY YEAR

This purchasing trend is shown in a summary of new car orders obtained from Railway Age magazine. Table 3-18 shows, for 1976 to 1978, that over two-thirds of new car orders are for 100-ton capacity cars. Of the car types shown, all but box car and flat car orders have a high percentage of 100-ton cars. Since box cars and flats, which generally carry low-density freight, will reach volume capacity limits before reaching weight capacity load limits. Therefore, the acquisition of the large 100-ton freight cars is not always necessary. Table 3-19 gives a detailed view of new car orders of 1978 only.

TABLE 3-16

FREIGHT CAR CAPACITY BY CAR TYPE – CLASS I RAILROADS ONLY, TONS

Car Type	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Box	55.1	54.2	55.3	56.6	57.8	58.4	59.4	60.3	61.7	62.5	63.5	64.8	65.9
Flat	61.4	63.1	64.6	66.2	67.5	68.0	68.1	68.6	68.9	69.4	69.7	70.3	69.9
Covered Hopper	80.6	83.3	84.3	84.5	86.2	87.2	87.9	88.9	89.8	91.1	91.3	91.8	92.6
Open Hopper	66.9	68.4	70.1	71.6	72.9	74.4	76.0	76.6	77.5	79.1	80.8	82.2	83.4
Gondola	65.5	67.1	68.7	69.8	71.9	72.6	73.9	74.7	75.7	77.4	78.8	79.8	80.6
Refrigerator	59.5	60.2	62.0	63.4	64.5	66.1	67.0	67.3	68.3	69.0	68.4	69.5	70.2
Stock	40.3	40.3	40.9	41.3	41.4	41.5	41.7	41.8	42.0	41.8	41.7	42.9	NA
Tank	55.4	55.8	57.4	57.8	59.6	60.4	61.0	61.5	62.7	65.0	66.0	67.8	68.9
Others	55.8	58.5	59.9	60.8	63.1	63.6	63.2	64.1	64.7	64.9	64.6	65.5	64.1
Fleet Average	61.4	63.4	64.3	65.8	67.1	68.4	69.6	70.5	71.6	72.9	73.8	75.5	76.7

Source: AAR Car Service Division

TABLE 3-17

1978 AVERAGE CAR CAPACITY AS A PERCENTAGE OF 1966 AVERAGE CAR CAPACITY (CLASS I RAILROADS ONLY)

Car Type	Percent
Box	120
Flat	114
Gondola	123
Covered Hopper	115
Open Hopper	125
Refrigerated	118
Stock	107 (estimated)
Tank	124
Others	125
Fleet Average Car Capacity	125

Source: AAR Car Service Division

TABLE 3-18

NEW CAR ORDERS 1976-1978

	1976	1977	1978
Fleet Total New Car Orders	33,495	42,378	143,825
100-Ton Car Orders	23,952	29,276	91,193
(Percent of Fleet Total)	(72%)	(69%)	(63%)
Box			
Total New Car Orders	7,067	14,320	44,941
100-Ton Car Orders	2,400	3,475	6,227
(Percent of Total)	(34%)	(24%)	(14%)
Flat			
Total New Car Orders	4,517	2,667	15,674
100-Ton Car Orders	1,237	850	1,956
(Percent of Total)	(27%)	(32%)	(12%)
Gondola			
Total New Car Orders	4,248	Missing	10,688
100-Ton Car Orders	4,076	Data	10,488
(Percent of Total)	(99%)		(98%)
Hopper			
Total New Car Orders	15,089	21,439	66,497
100-Ton Car Orders	14,940	20,639	64,547
(Percent of Total)	(99%)	(96%)	(97%)
Tank			
Total New Car Orders	2,574	1,588	5,025
100-Ton Car Orders	2,574*	1,588*	5,025*
(Percent of Total)	(100%)	(100%)	(100%)

*Assumed: Data incomplete

Source: Railway Age

TABLE 3-19

NEW CAR ORDERS, BY TYPE AND CAPACITY, 1978

Type	Capacity (tons)	Number
Box	70	37054
Box	75	150
Box	80	600
Box	90	200
Box	100	4480
XL Box	70	200
Ref	70	200
Side Slider	70	210
Newsprint	70	100
Hi Cube	100	432
Ins. Box	100	981
Hi Roof	100	272
XL Hi Roof	100	11
Equipment	100	51
Flat	70	13012
Flat	55	500
Flat	100	645
Pulpwood	70	100
Coil Steel	100	450
With Auto Racks	90	16
Bulkhead	100	761
TOFC	50	90
COFC	100	100
Auto Racks		
Tri-Level	Not Available	805
Tri-Level	70	205
Tri-Level	60	11
Enc-bi-Level	60	383
Bi-Level	Not Available	345
Bi-Level	70	30
Gondola	100	7726
Open-Top	100	347
Coal Porter	100	1584
R.D.	100	831
Wood Chip	80	200
Hopper	100	17945
Covered	100	42946
R.D. Coal	100	632
Air-Slide Covered	100	60
Covered	Not Available	1950
R.D. Limestone	100	24
R.D. Coal	100	502
R.D. Aggregate	100	147
Coal	100	2291
Tank	100	1981
Tank	Not Available	4044

Source: Railway Age

3.5 HISTORY OF TANK CARS

Most hazardous materials (HAZMAT), such as flammable compressed gases and industrial chemicals, are shipped by rail in tank cars. Accidents involving tank cars are therefore more likely to evoke severe consequences and public concern over the shipment of HAZMAT has increased in recent years. For this reason, tank cars received special attention in this study.

Tank cars have been under effective federal regulation since July 1, 1927, when the ICC issued a set of specifications for "Tank Cars Handling Explosives and Other Dangerous Commodities." These cars, which on this date became the ICC105 class car, had been originally specified in 1918 by the Master Car Builders' Association (MCBA).

The tank on these cars had an especially heavy construction and was developed to transport volatile flammable products whose properties had the increased potential for loss of life in the event of rupture. The outstanding feature of these cars, other than their rugged mechanical construction, was the requirement that they have at least 2 inches of insulation covered by a jacket of 1/8-inch-thick steel.

In the early 1930s, the shipment of liquefied compressed hydrocarbon gases was confined to these specially designed tank cars. The shippers, however, wanted a tank car designed to the characteristics of their specific products. As a result, a new class of cars was specified, ICC 105A200 through ICC 105A600 cars, which allowed minimum plate thickness, safety relief valve start-to-discharge pressure, test pressure, etc., to be varied directly with tank design pressure. All of these cars, and in particular the 105A300 which was to transport liquefied petroleum gas (LPG), still required a minimum thickness of 2 inches of insulation and the 1/8-inch steel jacket.

About 1960, the drive for economy, an attempt to achieve decreased cost per ton-mile by the use of larger capacity cars, led to still another change in these specifications. This car specification, for the 112A400W series car, was an outgrowth of the 105A400 specification, except for the removal of the requirement for insulation. Concurrently, changes in other governing specifications allowed the removal of expansion domes and side running boards and an increase in the allowable weight on the rails. (Series 114A cars are similar to 112A cars except for valving, and these two series of cars are treated as one in this report.) These changes, acting together, allowed car capacity in service to reach first 20,000 to 30,000 gallons and then, on a prototype basis, 50,000 to 60,000 gallons. The DOT has since set limits of 34,500-gallon and 263,000-pound total rail weight. These limits apply to all cars built after November 30, 1970, and are defined specifically in the Code of Federal Regulations, Title 49, Part 179.13.

Tank cars carrying flammable ladings have been involved in numerous accidents over the years. Particularly since the advent of class 112A/114A cars, the amount of dollar losses as a result of tank car involvement in accidents has been substantial. The RPI and the AAR undertook a cooperative program titled "Railroad Tank Car Safety Research and Test Project." The RPI/AAR determined that 3853 tank cars were damaged in 2321 accidents in the United States and Canada during the 6-year period 1965 through 1970. It was also determined that total losses resulting from mechanical damage of tank cars were more than $23 million and that total losses from fires from tank car loadings were over $15 million. (These values are not necessarily additive because some of the fire losses were initiated by mechanical damage.)

The largest accidents reported were at Laurel, Mississippi, on January 25, 1969 ($7.8 million) and at Crescent City, Illinois, on June 21, 1970 ($1 million). Since the RPI/AAR report, there have been several accidents, each resulting in losses of millions of dollars.

The concern over the transportation of hazardous materials (which occurs mainly in tank cars) arises from both the past history of accidents and the rapid growth in the quantities being transported. Estimates prepared by the Transportation Systems Center of the U.S. Department of Transportation indicate that the tonnage of hazardous materials transported by rail grew from 38.4 million tons in 1972 to approximately 47 million tons in 1977, an increase of 22%. The ton-miles of hazardous materials increased at a somewhat higher rate, as lengths of haul increased. In the same period, the revenue ton-miles of all railroad freight increased by only 6.4%. Forecasts indicate that the rapid growth in hazardous materials transportation by rail will continue in the foreseeable future.

3.6 CURRENT TANK CAR FLEET

Tank cars come in a range of capabilities. Significant variations also exist in their charactistics:

- Welded or riveted;
- Pressure or nonpressure;
- Insulated or uninsulated;
- Bottom or top filling; and
- With or without an expansion dome.

A range of DOT and AAR specifications covers the construction of tanks for tank cars and is summarized in Table 3-20.

Most regulated commodities are carried in DOT-103, DOT-105, DOT-112 and DOT-114 specification tanks, the latter three predominant in the transport of liquefied flammable gases and flammable liquids.

TABLE 3-20

TANK SPECIFICATIONS FOR TANK CARS

FREIGHT CARS: Tank

Specifications for Tanks for Tank Cars

Until 1969 the AAR had an elaborate system of mechanical designations for tank cars which indicated the type of container on each. This has been superseded by a general classification of "T" for all such cars. Details on the container can be indicated by reference to the appropriate DOT or AAR classification, as shown in the following table:

Class	Service	Safety Valve Setting (psi)	Description
Hazardous Commodities			
DOT 103	Non-pressure	35 to 45	Uninsulated riveted or welded tank of steel, aluminum alloy or nickel with expansion dome.
DOT 104	Non-pressure	35	Insulated riveted or welded tank with dome.
DOT 105	Pressure	75 to 450	Insulated welded tank of aluminum alloy or steel.
DOT 106	Pressure	375 to 600	Multiple tanks on carbody, removable for loading or unloading.
DOT 107	Pressure	*	Multiple seamless tanks on carbody for high-pressure service.
DOT 109	Pressure	75 to 250	Welded steel or aluminum alloy tank for general service.
DOT 110	Pressure	375 to 750	Multiple tanks on carbody, permanently attached.
DOT 111	Non-pressure	35 to 75	Domeless tank of steel, alloy steel or aluminum alloy.
DOT 112	Pressure	150 to 375	Welded, uninsulated steel tank.
DOT 113	Pressure	30 to 115	Inner container within outer shell; annular space insulated or evacuated.
DOT 114	Pressure	255 to 300	Uninsulated welded steel tank for compressed gases.
DOT 115	Non-pressure	35	Inner container within outer shell; annular space insulated or evacuated.
DOT 116	Pressure	*	Welded, multi-layer steel tank for high-pressure service.
DOT 117	Pressure	255	Uninsulated welded steel tank for dual service—compressed gases and flammable liquids.
DOT 119	Pressure	35	Insulated welded steel tank for refrigerated compressed gases.
DOT 120	Pressure	225	Insulated welded steel tank for dual service—compressed gases and flammable liquids.
DOT 121	Pressure	375	Insulated welded steel tank for compressed gases.
Non-Hazardous Commodities			
AAR 203	Non-pressure	35 to 40	Corresponds to DOT 103.
AAR 204	Pressure	30 to 115	Corresponds to DOT 113.
AAR 205	Non-pressure	35	Corresponds to DOT 115.
AAR 206	Pressure	375 to 600	Corresponds to DOT 106.
AAR 207	Pressure	*	Welded tank for granular commodities and designed for pneumatic unloading at 15 psi, or more.
AAR 208	Non-pressure	None	Wooden-stave, metal hooped tank, lined or coated.
AAR 211	Non-pressure	35 to 75	Corresponds to DOT 111.

*—Safety valve setting determined by design of pressure vessel.

Source: "Car and Locomotive Cyclopedia of American Practices," 3d Edition, Simmons-Broadman, 1974.

3.7 OPERATING PRACTICES

Economic pressures have made the effective utilization of the freight car fleet increasingly more important. One significant descriptor of utilization is the average number of ton-miles traveled per freight car per year. Figure 3-16 shows that the ton-mileage per car has increased steadily since 1965; in fact, the 1978 value is 144% of the 1965 value. The average mileage per freight car per year, however, has held rather constant, as shown on Figure 3-17. Thus, the increase in ton-mileage is due more to the increased average carload weight shipped. Figure 3-18 shows the trend of the average carload from 49 tons in 1965 to 62 tons in 1978. The average carloads, however, have remained at a relatively constant proportion of the average car capacity, at about 83% (Figure 3-18).

The typical freight train has changed in similar fashion toward increased productivity since 1965. While the yearly total of freight train miles held somewhat constant (Figure 3-19), the number of cars per train decreased by about 5% (Figure 3-20). However, the average load per train increased by almost 20% (Figure 3-21).

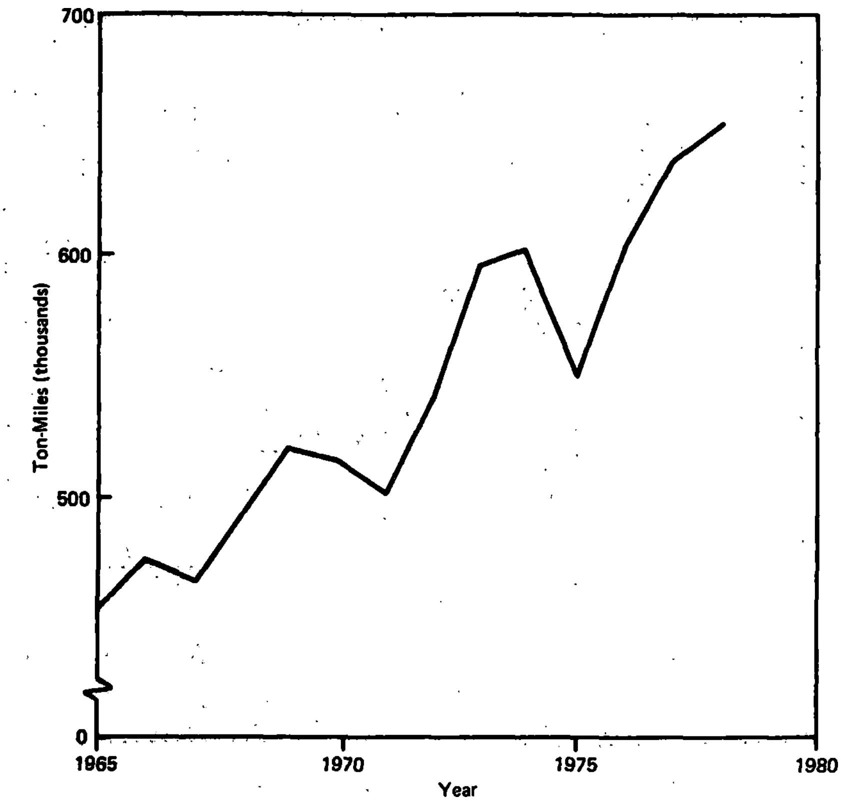
One specific development deserves special note. To enhance productivity, the industry is attempting to implement regular dedicated train service with a high percentage of capacity loading. These trains, usually assigned a specific commodity, are called unit trains. Also, these generally homogeneous car types avoid the specific problems of a train with mixed car types (specifically, the placement of a short car next to a long one).

3.8 SUMMARY

- The overall number of freight cars is decreasing slowly; it has changed 3% since 1975. However, certain car types, namely covered hoppers, flat cars, and tank cars, are increasing in population.
- Fleet average car weights and lengths have progressively increased over the years. At present, a dominant portion of new large and heavy cars are replacing smaller older cars in the fleet. This holds true for all car types.
- Tank cars, specifically, have reached maximum allowable capacity limitations set by the DOT because of the increased risk of transporting larger volumes of hazardous materials. Safety-related tank insulation has improved in recent years.
- Freight car utilization has increased primarily as a result of increased capacity.
- Similarly, the average payload carried by a freight train has increased, even though the number of cars in the train has decreased.

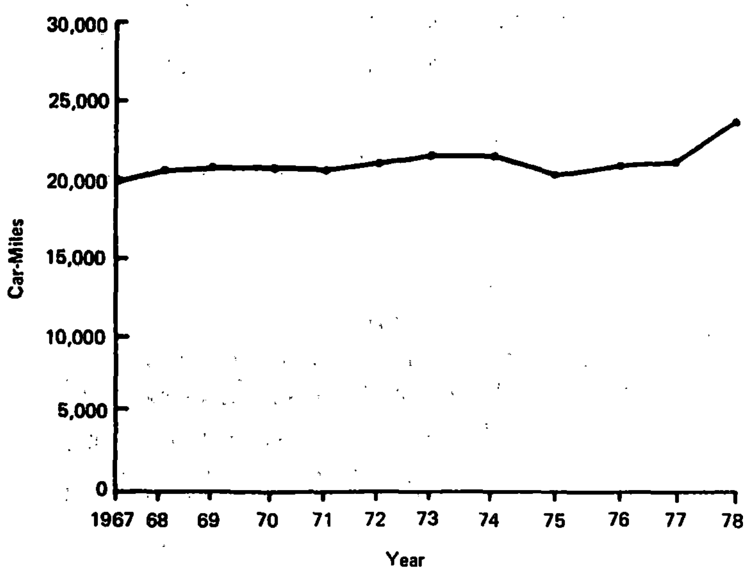
REFERENCE

1. DiMasi, F.P., "Fleet Characterization and RAIS/UMLER Data for Assessing Relationships Between Derailment Incidence and Frequency and Physical Characteristics of Freight Vehicles," preliminary memorandum, Transportation Systems Center, Report No. PM-74-C-403-50, July 1979.



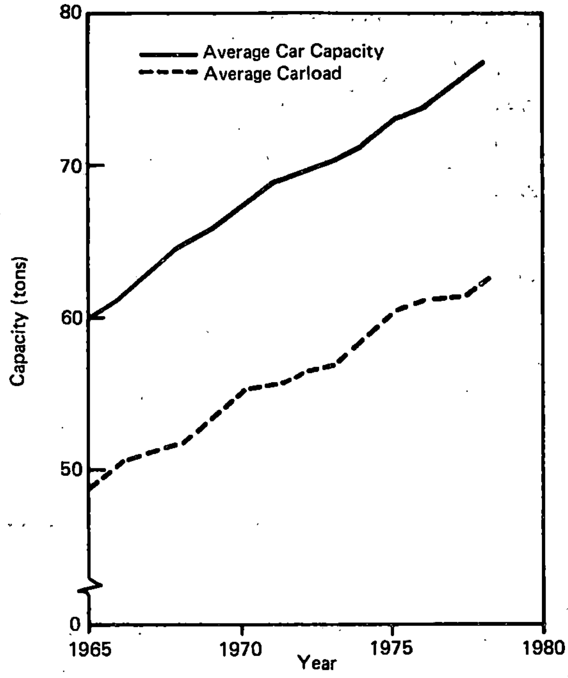
Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-16 TON-MILES PER FREIGHT CAR — CLASS 1 RAILROADS ONLY



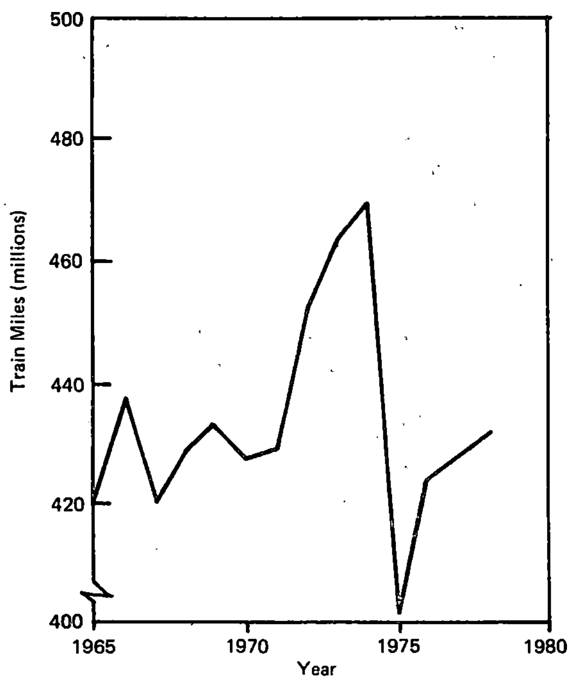
Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-17 AVERAGE CAR-MILES PER CAR, CLASS 1 RAILROADS



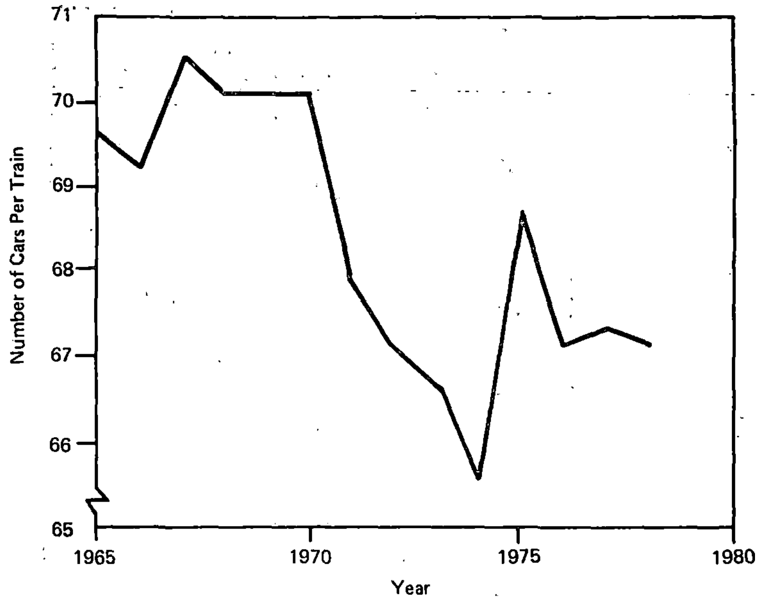
Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-18 AVERAGE CAR CAPACITY AND AVERAGE CARLOAD



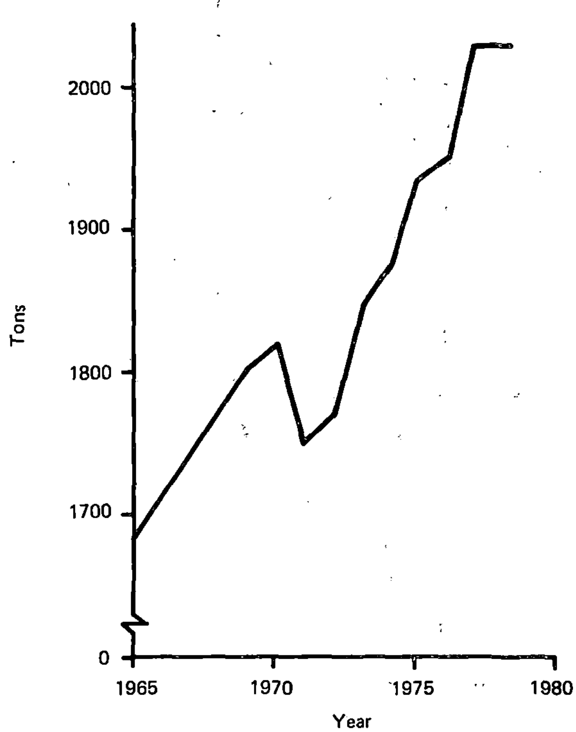
Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-19 FREIGHT TRAIN MILES – CLASS 1 RAILROADS



Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-20 CARS PER AVERAGE FREIGHT TRAIN



Source: AAR Yearbook of Railroad Facts, 1979

FIGURE 3-21 AVERAGE FREIGHT TRAIN LOAD

4. CAR SAFETY RECORDS

4.1 ABSTRACT

A major concern in any analysis of railroad safety is the number of fatalities that occur in railroad operations. In this context, it is found that the maximum number of fatalities that can possibly be attributed to the size, weight, and length of railroad cars has averaged 4.5 per year over the period from 1975 to 1978. This amounts to 0.29 percent of all railroad fatalities. This finding does not imply that a clear relationship has been established between fatalities associated with the size, weight, and length of freight cars and those associated with all causes, only that factors other than car size, weight, and length reduce the possibility to about 4.5 fatalities per year.

The size, weight, and length of freight cars can potentially influence safety in two primary areas: mainline derailments and switch yard activities. Mainline derailments are characterized by statistical accident frequencies — by car type, weight, and length. Yard problems, which are usually personnel injuries, are primarily evaluated by reports from railroad employees.

Accident statistics can be extremely misleading if not carefully evaluated. For this study, several alternative methods of stating accident frequencies were explored, and it was concluded that the two appropriate frequency measures for study were accidents per net ton-mile and accidents per car-mile, both measures of railroad activity. Evaluating safety data according to these two measures allows for the fact that a larger industrial activity will naturally tend to have a larger number of accidents in a year than a smaller activity.

If one considers accidents per car-mile, lighter cars are safer than heavier cars; if one considers accidents per net ton-mile, heavier cars are safer. No trend in safety is observed as car lengths increase, although two specific lengths stand out: those that match rail lengths and those greater than 90 feet. The most significant variations in accident frequency are found to be due to variations in "car type," a phrase describing differences in car appearance, design, and function. Covered hopper cars appear to have a particular safety problem. The TOFC cars and auto-rack cars also appear to have particular safety problems.

Another major concern in railroad safety is the release of hazardous materials as a result of a train accident. Although the record has not been catastrophic to date, the prognosis is less reassuring.

Investigations of the accident frequencies of tank cars reveal that uninsulated tank cars are more likely to release their contents in an accident than insulated cars are. Moreover, a majority of releases have occurred through a puncture in the head (or end) of the tanks. As a result of these investigations, regulatory actions were taken that include requiring specific types of tank cars to be equipped with head shields, coupler restraints, and thermal protection. A schedule has been imposed on the railroad industry for implementing these changes in tank car design; the railroad changes for 50 percent of the affected tank cars must be completed by January 1, 1980; all affected tank cars must be completed by January 1, 1982.

It is possible to obtain information on size, weight, and length of freight cars from historical accident data only for the first car involved. Since little information on the dimensions of tank cars is available unless a tank car was the first car involved in the accident, it has not been possible through use of the historical accident data to convincingly relate the risk of shipping hazardous materials by rail to the size of tank cars. (Projections of what this relationship may be are contained in Chapter 6.)

4.2 ACCIDENT DATA

4.2.1 Fatalities and Casualties

A major concern in any study of railroad safety is the number of people who are killed during railroad operations. For this study, it must also be determined whether or not these fatalities are related to the size, weight, and length of freight cars. To address this issue, it is necessary to use the following FRA accident categories:

- *Train Accidents* — Any collision, derailment, fire, explosion, act of God, or any other event involving the operation of railroad on-track equipment (standing or moving) which results in more than $2,900 in damages to railroad on-track equipment, signals, track, track structures, and roadbed.
- *Train Incidents* — Any event arising from the movement of an equipment consist, which results in a reportable death, injury, or illness, but not more than $2,900 in damages to railroad on-track equipment, track, track structures, and roadbed.*
- *Non-Train Incidents* — Any event arising from the operation of a railroad, but not from the movement of an equipment consist, which results in a reportable death, injury, or illness.
- *Reportable Death, Injuries* — Any event arising from the operation of a railroad which results in the death of one or more persons; an injury to one or more persons, other than railroad employees, that requires medical treatment; or an injury to one or more employees that requires medical treatment or results in restriction of work or motion for one or more days, one or more lost workdays, transfer to another job, termination of employment, or loss of consciousness.

A prima facie case can be made that not all train accidents are influenced by car size, weight, and length: collisions, for example, are due to human error. Grade-crossing accidents also are caused mainly by human error and are therefore independent or car dimensions. The major remaining accident category is derailments, which make up approximately 78% of all rail accidents. Similarly, only certain yard operations resulting in train accidents are justifiably connected with car dimensions, whereas few non-train incidents can be so connected. Also, few reportable deaths and injuries connected with job activities can be related to car size, weight, and length. (To be precise, it is difficult to determine from historical data whether a relationship exists or not, since the reporting system for incidents does not require that the type of car be identified.)

*The reporting threshold has increased from the original threshold of $650 in years prior to 1975 to $1750 in 1975-76, to $2300 in 1977-78, to the present dollar threshold of $2900 for 1979-80.

During the period of 1975 through 1978, a total of 33 derailments occurred, each of which had at least one fatality. Of these derailments, 13 may possibly be related to the size, weight, and length of a freight car. The other 20 derailments are attributable to the locomotive or caboose, to track damage caused by vandalism or washouts, or to other miscellaneous causes including human error. The 13 relevant derailments that possibly related to the size, weight, and length of cars resulted in a total of 18 fatalities. On an annual basis, the number of deaths ranged from 1 to 9 during the 4-year period, with an average of 4.5 fatalities per year. This average per year amounts to 0.29 percent of the total industry fatalities. Table 4-1 shows the dates for the fatal derailments as well as the possible relationship to the size, weight, and length of freight cars. Therefore, the determination of safer sizes, weights, and lengths than are now used for cars would, at best, result in about an 0.3% reduction in the rate of fatalities resulting from derailments. Although no clear-cut relationship has been established between railroad fatalities and car size, weight, and length, the number of fatalities possibly caused is small compared to the total number of fatalities. It is crucial that all of the analyses presented in this report be viewed in the context of this fact.

4.2.2 Derailments

Derailments form the principal group of accidents that might be influenced by the size, weight, and length of cars. In 1977, there were 8073 derailments on the U.S. railroads. The trend in the number of derailments has been as follows:

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Number of Derailments	5487	5960	5602	5131	5509	7389	8513	6328	7934	8073

There has been a definite upward trend in the number of reported derailments over the years. Some of the increase is due to more conscientious reporting by the railroads and some due to inflation, which has rendered reportable accidents that once would not have been reportable (the criterion for reportability being the monetary loss from damage to track and equipment). Even after these factors are accounted for, however, there is a residual gradual increase in the number of derailments that occur each year.

4.2.3 Derailments and Car Weight

The weight capacity of the first car involved in each derailment was determined by using procedures described in Chapter 2. The weights were grouped as being approximately 50 tons, 70 tons, and 100 tons, with a small fourth category of cars weighing over 100 tons. Accident data were aggregated for the years 1974 through 1977, and derailments were grouped according to the weight of the first car, leading to the result shown in Table 4-2. This table shows the number of derailments for each weight range, with no consideration of relative usage or population.

TABLE 4-1

FATAL DERAILMENTS POSSIBLY RELATED TO THE SIZE, WEIGHT, AND LENGTH OF FREIGHT CARS, 1975 TO 1978

	Date	Number of Fatalities	Possible Relationship to Size, Weight, and Length	Component
1975	3/6/75	1		Locomotive
	8/5/75	1	√	
1976	1/8/76	1	√	
	3/27/76	1		Switch Point Worn
	4/18/76	1		Locomotive
	5/21/76	1	√	
	6/20/76	1	√	
	6/27/76	2	√	
	6/30/76	1		Passenger Train
	7/25/76	1		Locomotive
	8/5/76	1	√	
	10/9/76	1	√	
	11/26/76	2	√	
	12/16/76	1		
	12/22/76	1		Locomotive Cars Left Foul
1977	2/12/77	1	√	
	5/3/77	1	√	
	6/22/77	1		Locomotive
	6/27/77	1	√	
	7/28/77	1		Locomotive
	8/15/77	1		Caboose
	8/24/77	1		Object on or Fouling Track
	11/8/77	1		Locomotive
1978	1/18/78	1		Track Appliance Caused
	2/22/78	16		Human Factors Caused
	2/26/78	8		Track Vandalism
	2/6/78	2		Track Damage Due to Washout/Rain/Slide, etc.
	3/7/78	1		Object on or Fouling Track
	8/18/78	1		Locomotive
	8/28/78	1		Equipment on or Fouling Track
	9/10/78	3	√	
	10/4/78	2	√	
	12/31/78	6		Passenger

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-2

DERAILMENTS AND CAR WEIGHT, 1974-1977

	Capacity (Tons)				
	50	70	100	>100	Total
No. of Accidents	3800	5586	8321	225	17,932

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-3

DERAILMENTS AND CAR LENGTH, 1974-1977

Car Length (Ft)	No. of Accidents
Less than 40	1,085
40 to 49	3,824
50 to 59	8,462
60 to 69	2,600
70 to 79	411
80 to 89	319
Greater than 90	1,231
TOTAL	17,932

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

4.2.4 Derailments and Car Length

Derailments were classified according to the length of the first car involved by using procedures similar to those described above. These derailments are shown in Table 4-3. This table shows the number of derailments for various length ranges, independent of consideration of relative usage or population.

4.2.5 Derailments and Car Type

A third analysis was performed on derailments according to the type of the first car involved. The results are shown in Table 4-4. No consideration of relative usage or population is shown in the table.

TABLE 4-4

DERAILMENTS AND CAR TYPE, 1974-1977

Car Type	No. of Accidents
Box Car	3,781
Auto Flat	554
General Flat	68
TOFC	1,610
Gondola	1,280
Covered Hopper	5,193
Open Hopper	3,134
Refrigerator	998
Tank Car	1,314
TOTAL	17,932

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

4.3 INTERPRETATION OF ACCIDENT DATA

It is difficult to draw meaningful conclusions from the derailment accident data presented in the preceding section without further analysis. For example, one cannot conclude that 100-ton cars are less safe than 70-ton cars based solely on the statement that 100-ton cars caused 8,321 derailments, while 70-ton cars caused 5,585 derailments. The first and most obvious question is: how many accidents were there per vehicle in each tonnage range? The answer is shown in Table 4-5.

TABLE 4-5

CAR WEIGHT: ACCIDENTS PER VEHICLE, 1974-1977

	Capacity (Tons)		
	50	70	100
Accidents per Vehicle	0.0091	0.0078	0.0158

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

The conclusion still seems to hold that 100-ton vehicles are less safe than 70-ton cars. However, what if each 100-ton car travels further than each 70-ton car in a year? In that case, a 100-ton car is not really equivalent to a 70-ton car, and therefore, the 100-ton car would have to be replaced by more than one 70-ton car. Accidents must be measured relative to the car-miles in each category to determine whether this is, in fact, the case. The car-mile data (over 4 years) are shown in Table 4-6. The frequency of accidents per mile traveled can now be determined, as shown in Table 4-7. The table shows that the 100-ton cars still appear to be worse than the others.

Two further arguments can be made, however. First, in traveling one mile, a 100-ton car hauls a larger quantity of lading than does a 70-ton car. The importance of this fact can be seen from the following example.

TABLE 4-6

CAR WEIGHT: TOTAL CAR-MILES, 1974-1977

	Capacity (Tons)		
	50	70	100
Total Car-Miles (10 Million)	1930	2410	2070

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-7

CAR WEIGHT: ACCIDENT FREQUENCY PER MILE TRAVELED

	Capacity (Tons)		
	50	70	100
Accidents per 10 Million Car-Miles	2.0	2.3	4.0

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

To transport 7000 tons of freight a distance of 1000 miles, one would need 100 fully loaded 70-ton cars and would generate 100,000 car miles. With fully loaded 100-ton cars, on the other hand, one would need only 70 cars and would generate 70,000 car-miles. Thus, even if the accident frequency per car-mile were higher for the 100-ton car than for the 70-ton car, the number of accidents in hauling the 7000 tons over 1000 miles may not be higher, since the 100-ton car needs fewer car-miles. The appropriate measure of accident frequency in this case, therefore, is accidents per ton-mile. If this frequency is equal for two different weight categories, the total number of accidents while hauling a certain number of tons of freight over a certain distance will also be equal. This is of primary interest because the demand for railroad services is defined in terms of net ton-miles rather than car-miles.

Table 4-8 gives accident frequencies per net ton-mile. The reduction in the apparent disparity between the 70-ton and 100-ton cars is striking.

Finally, as stated before, all derailments reported to the FRA were not included equally in the analysis. The premise is that large numbers of very low-speed accidents occur on branch lines and in yards in which relatively little damage is done and the risk generated is low. It is therefore misleading to include these low-speed accidents in analyses of railroad safety: their impact is largely in rail economics rather than in rail safety. That low-speed accidents contribute little to risk can be seen by their generally lower severity, as reflected in their dollar damage shown in Table 4-9. Thus, slow speed accidents were eliminated from the analysis. Table 4-10 shows the results of this elimination. The reversal in the ranking of the 70- and 100-ton cars resulted from the elimination of the low-speed derailments.

TABLE 4-8

CAR WEIGHT: ACCIDENT FREQUENCY PER NET TON-MILE

	Capacity (Tons)		
	50	70	100
Billion Net Ton-Miles	360	640	870
Accident Per Billion Net Ton-Miles	10.6	8.7	9.6

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Data

TABLE 4-9

DOLLAR DAMAGES AND SPEED OF ACCIDENT

	Accident Speed (mph)	
	10 or Less	More Than 10
Average Dollar Loss Per Accident	$11,000	$52,000

Source: FRA Accident Bulletin

TABLE 4-10

CAR WEIGHT: ACCIDENT FREQUENCY (SPEED >10 MPH)

	Capacity (Tons)		
	50	70	100
Accidents Per Billion Net Ton-Miles (Speed >10 mph)	4.3	3.4	2.6

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Data

The conclusion that emerges from this analysis is that the assessment one makes of the relative safety of different car types, or of cars of different weight or length, will vary markedly according to how one measures "safety." A number of measures have been used in evaluating accident data: number of accidents, accidents per car, accidents per car loading, accidents per ton originated, accidents per car-mile, and accidents per ton-mile. Furthermore, neither the number of accidents per year nor the number of accidents per year per car are appropriate measures of safety since distance traveled is not taken into account. If the objective of an analysis of accident data is to compare two alternatives for hauling the same freight a given distance, then the appropriate safety measure is net ton-miles. If, on the other hand, the objective is to identify what cars have the best safety performance so that, for example, hazardous materials cars may be placed near them, then the appropriate measure is car-miles.

The approach adopted in developing the data presented in the next section reflects two conclusions from the preceding analysis: low-speed accidents (less than 10 mph) have economic rather than safety impact and are therefore eliminated in subsequent analyses, and accident statistics are presented in terms of frequency per car-mile and per net ton-mile since these safety measures include distance of haul as a factor. The importance of adopting this approach cannot be exaggerated. Innumerable past studies of rail safety set forth misleading conclusions because they ignored the need for "normalized" data — accidents measured relative to some indicator of railroad activity such as car-miles or ton-miles.

4.4 ACCIDENT* FREQUENCIES

4.4.1 Introduction

The procedures described in the preceding section were applied to the FRA derailment data to obtain accident frequencies for cars of different tonnages and lengths and for the various car types. The results of this analysis are presented in the following paragraphs.

*From this point on, "accidents" and "derailments" are used synonymously.

Some of the raw data from which these accident frequencies were derived are shown in Tables 4-11 through 4-15. Table 4-11 shows the 4-year total of derailments occurring at speeds greater than 10 mph, classified according to the type of car that was the cause of the derailment (or was the first to derail along the train) and according to its tonnage capacity. Table 4-12 shows the net ton-miles for the same groupings of cars based on three years' (1975-77) waybill data. As mentioned in Chapter 2, the grand total will be low compared to the annual statistics published by the AAR since it was decided that corrections to the ton-mile data would not be attempted. Table 4-13 shows the loaded car-miles and Table 4-14 the total (empty and loaded) car-miles. Finally, Table 4-15 shows the weight of the average carload, obtained by dividing the net ton-miles by the loaded car-miles.

4.4.2 Accident Frequencies and Car Weight

Accident frequencies for derailments occurring at speeds greater than 10 mph are shown in Table 4-16. The aggregate data are also shown in pictorial form in Figure 4-1 and, on a yearly basis, in Figure 4-2. The striking conclusion that emerges from these data is that the trend as car weight increases is toward increased safety if accidents are stated relative to net ton-miles. Therefore, the merits and demerits of the heavy cars differ according to the safety performance measures used in the evaluation.

TABLE 4-11

ACCIDENTS, 1974-1977

	Capacity (Tons)			
Car Type	**50**	**70**	**100**	**More Than 100**
Box	693	727	73	0
Auto Flat	190	27	0	4
General Flat	0	13	0	0
TOFC	281	243	55	22
Gondola	38	246	171	8
Covered Hopper	27	293	1216	5
Open Hopper	77	362	447	0
Refrigerator	129	236	42	0
Tank	106	78	216	8
ALL	1541	2225	2220	47

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-12

BILLION NET TON-MILES (FOUR-YEAR ESTIMATE)

Car Type	Capacity (Tons) 50	70	100	More Than 100
Box	152.4	235.5	45.6	0
Auto Flat	27.7	7.3	0.0	0.2
General Flat	0	3.6	0.0	0
TOFC	81.2	89.0	16.9	1.8
Gondola	5.9	46.5	84.9	6.1
Covered Hopper	3.7	48.3	334.8	3.7
Open Hopper	22.8	121.3	241.6	0
Refrigerator	42.6	99.3	19.2	0
Tank	20.9	12.6	126.9	5.5
ALL	357.2	663.4	869.9	17.3

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-13

LOADED CAR-MILES, TEN MILLIONS (FOUR-YEAR ESTIMATE)

Car Type	Capacity (Tons) 50	70	100	More Than 100
Box	495	610	87	0
Auto Flat	122	36	0	0.07
General Flat	0	5	0	0
TOFC	322	295	28	0.27
Gondola	12	88	114	0.54
Covered Hopper	8	74	374	0.35
Open Hopper	39	172	263	0
Refrigerator	114	228	36	0
Tank	52	21	151	0.48
ALL	1164	1529	1053	1.7

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-14

LOADED AND EMPTY CAR-MILES, TEN MILLIONS
(FOUR-YEAR ESTIMATE)

Car Type	Capacity (Tons) 50	70	100	More Than 100
Box	827	1019	145	0
Auto Flat	244	71	0	0.15
General Flat	0	9	0	0
TOFC	473	433	41	0.4
Gondola	22	163	211	1.0
Covered Hopper	15	148	752	0.7
Open Hopper	74	326	499	0
Refrigerator	194	387	61	0
Tank	109	45	316	1.0
ALL	1962	2601	2025	3.25

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-15

AVERAGE LOAD (TONS)

Car Type	Capacity (Tons) 50	70	100	More Than 100
Box	30.8	38.6	52.4	*
Auto Flat	22.7	20.3	*	28.6
General Flat	*	75.0	*	*
TOFC	25.2	30.2	60.4	66.7
Gondola	48.4	52.8	74.5	113.0
Covered Hopper	49.3	65.3	89.5	105.7
Open Hopper	58.5	70.5	91.9	*
Refrigerator	37.4	43.6	53.3	*
Tank	40.2	60.0	84.0	114.6
Average	30.7	43.4	82.6	101.8

*Small Sample

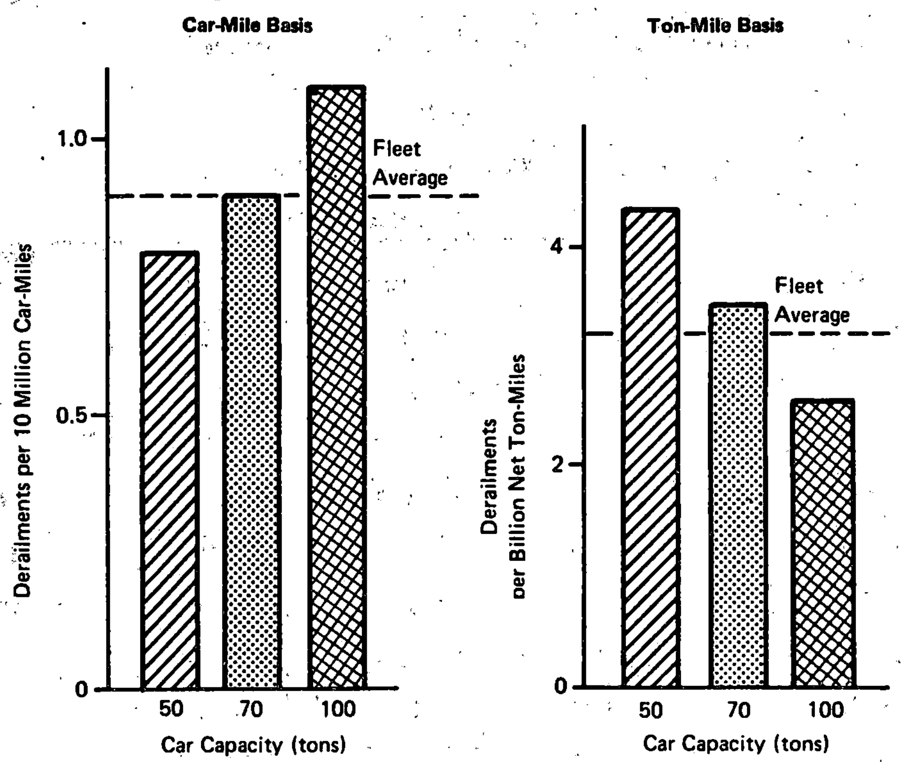
Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-16

ACCIDENT FREQUENCIES AND CAR WEIGHT (SPEED >10 MPH)

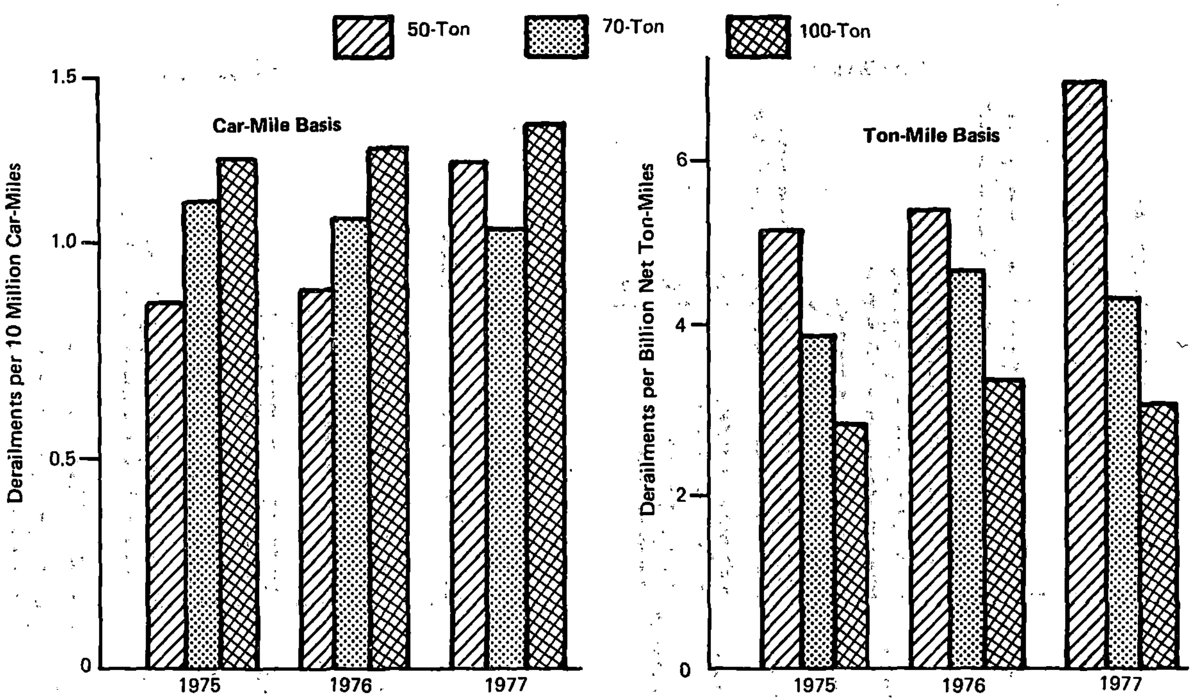
Capacity (Tons)	Accidents Per 10 Million Car-Miles	Accidents Per Billion Net Ton-Miles
50	0.8	4.3
70	0.9	3.4
100	1.1	2.6
ALL	0.9	3.2

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Data



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample.

FIGURE 4-1 DERAILMENT FREQUENCIES FOR CARS OF VARIOUS TONNAGE CAPACITIES 1975–1978 (SPEED GREATER THAN 10 MPH)



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 4-2 RELATIVE ACCIDENT HISTORY ON CAR-MILE AND TON-MILE BASIS (SPEED GREATER THAN 10 MPH)

4.4.3 Accident Frequencies and Car Length

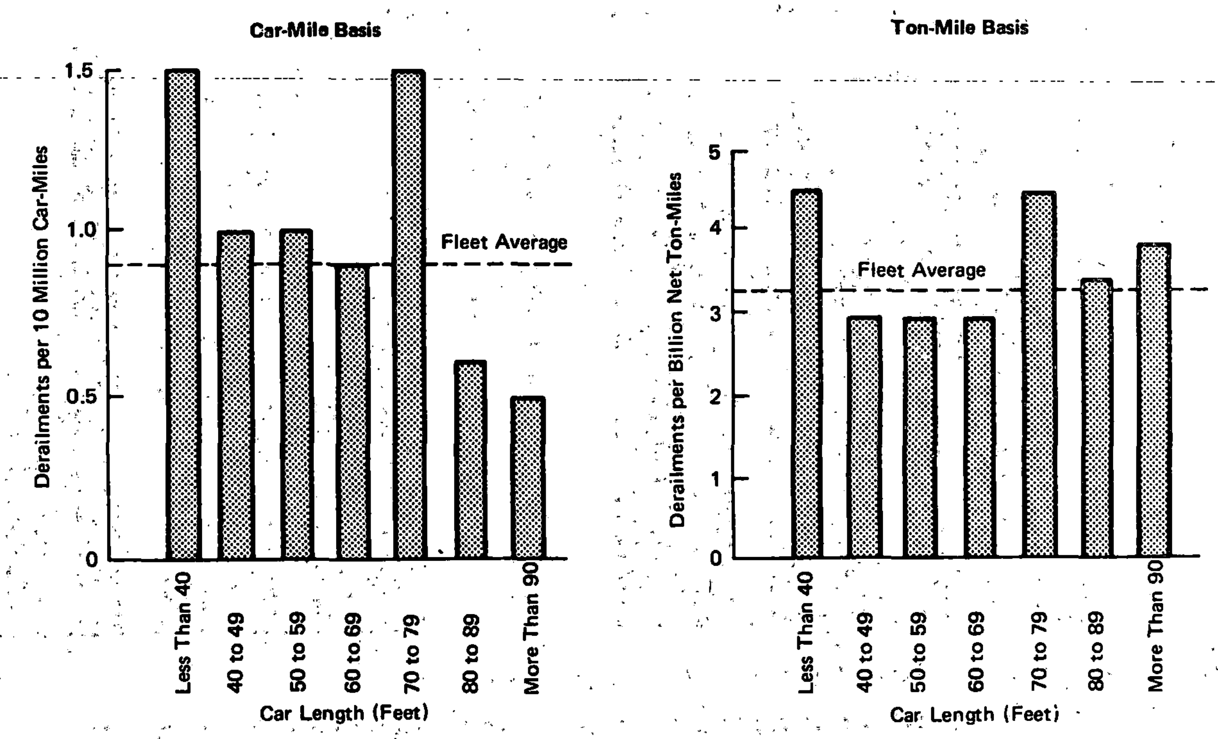
For derailments occurring at speeds greater than 10 mph, the accident frequency depends on car length as shown in Table 4-17. These data are also shown in pictorial form in Figure 4-3. It is evident that no specific trend in accident frequency exists — regardless of how it is measured — as car length increases.

TABLE 4-17

ACCIDENT FREQUENCIES AND CAR LENGTH (SPEED >10 MPH)

Car Lengths (Ft)	Accidents Per 10 Million Car-Miles	Accidents Per Billion Net Ton-Miles
Less than 40	1.5	4.5
40 to 49	1.0	3.0
50 to 59	1.0	3.0
60 to 69	0.9	3.0
70 to 79	1.5	4.5
80 to 89	0.6	3.5
Greater than 90	0.5	3.9
ALL	0.9	3.2

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 4-3 DERAILMENT FREQUENCIES FOR CARS OF VARIOUS LENGTHS, BY CAR-MILES AND TON-MILES, 1975–1978

4.4.4 Accident Frequencies and Car Type

For derailments occurring at speeds greater than 10 mph, accident frequencies vary significantly from one type of car to another as shown in Table 4-18. These data are also shown in pictorial form in Figure 4-4.

The vehicles that appear less safe than the others are:

- Covered hoppers, independent of the measure of accident frequency;
- Gondola, based on accidents per car-mile;
- General flat cars, based on accidents per car-mile; and
- Auto flats, based on accidents per net ton-mile.

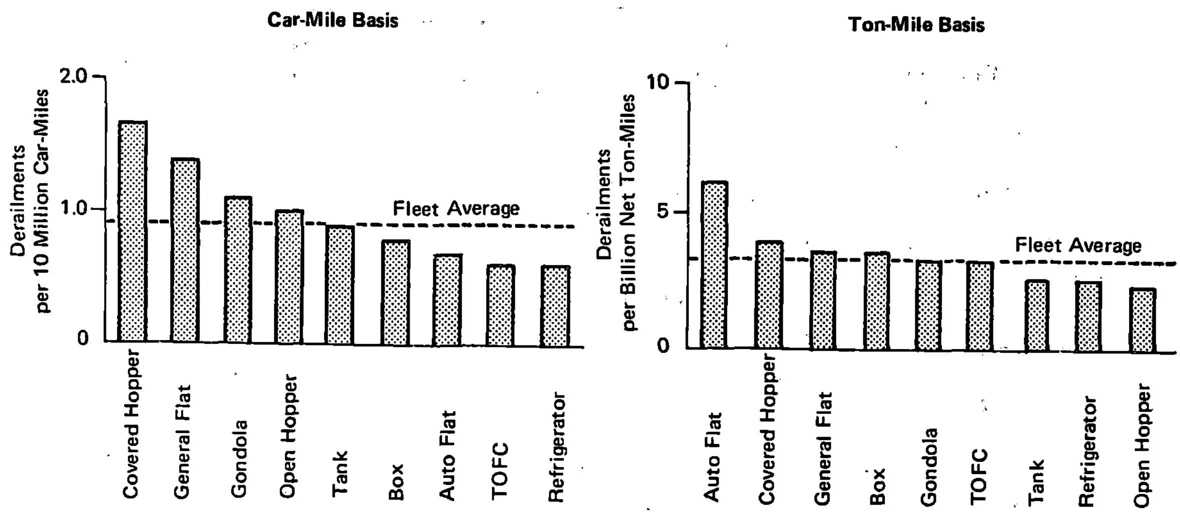
However, despite their relatively high accident frequency, the overall contribution of general flats and auto flats to risk is small since they form a small portion of the fleet. Table 4-19 shows derailments of these cars occurring at speeds over 10 mph.

TABLE 4-18

ACCIDENT FREQUENCIES AND CAR TYPE (SPEED >10 MPH)

Car Type	Accidents Per 10 Million Car-Miles	Accidents Per Billion Net Ton-Miles
Box	0.8	3.4
Auto Flat	0.7	6.3
General Flat	1.4	3.6
TOFC	0.6	3.2
Gondola	1.1	3.2
Covered Hopper	1.7	4.0
Open Hopper	1.0	2.3
Refrigerator	0.6	2.5
Tank Car	0.9	2.5
ALL	0.9	3.2

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample



Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

FIGURE 4-4 DERAILMENT FREQUENCIES FOR CARS OF VARIOUS TYPES BY CAR-MILES AND TON-MILES

TABLE 4-19

GENERAL FLAT/AUTO FLAT ACCIDENT HISTORY
(SPEED >10 MPH)

	Number	Percent of Total
Total Accidents	6033	100.00
General Flat Accidents	13	0.22
Auto Flat Accidents	221	3.66

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

Thus, the single prominent type of car with an apparent safety problem is the covered hopper.

4.4.5 Accident Frequency: Car Type and Car Weight

Accident frequencies for each type of car and for various tonnage capacities are shown in Tables 4-20 and 4-21. Based on the car-mile frequencies, the 70-ton open hopper and the 50- and 70-ton covered hoppers are the "worst actors."

TABLE 4-20

ACCIDENTS PER 10 MILLION CAR-MILES

	Capacity (Tons)			
Car Type	50	70	100	ALL
Box	0.8	0.7	0.5	0.8
Auto Flat	0.8	0.4	*	0.7
General Flat	*	1.4	*	1.4
TOFC	0.6	0.6	1.4	0.6
Gondola	1.7	1.5	0.8	1.1
Covered Hopper	1.8	2.0	1.6	1.7
Open Hopper	1.1	2.1	0.9	1.0
Refrigerator	0.7	0.6	0.7	0.6
Tank	1.0	1.7	0.7	0.9
ALL	0.8	0.9	1.1	0.9

*Small Sample

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-21

DERAILMENTS PER BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	ALL
Box	4.6	3.1	1.6	3.4
Auto Flat	6.0	3.7	*	6.3
General Flat	*	3.6	*	3.6
TOFC	3.5	2.7	3.3	3.2
Gondola	6.4	5.3	2.0	3.2
Covered Hopper	7.2	6.1	3.6	4.0
Open Hopper	3.4	3.0	1.9	2.3
Refrigerator	3.0	2.4	2.2	2.5
Tank	5.1	6.2	2.6	3.2
ALL	4.3	3.4	2.6	3.2

*Small Sample

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

4.4.6 Accident Frequency: Car Type and Weight and Accident Cause

In reporting information pertaining to an accident, railroads include an assessment of the cause of the accident which is recorded in the form of a cause code. Approximately 180 individual cause codes cover the general categories of track causes, equipment causes, human factors causes, and miscellaneous causes. In the determination of which causes may be connected with car size, weight, and length, four subgroups of cause codes were selected for analyses:

- Wide Gage (Cause Codes 110-113);
- Irregular Cross-Level of Track (Cause Codes 119-120);
- Bearing and Axle Failures (Cause Codes 450-459);
- Wheel Failures (Cause Codes 460-469).

The first two groups are track causes related to degradation of the track structure; therefore, accidents resulting from these causes may be related to the larger loads carried by freight cars. The last two groups are equipment causes that also may be correlated with the size, weight, and length of cars. These cause codes have been historically important in the accident reports and are responsible for the more severe accidents.

Tables 4-22 through 4-25 show derailments frequency per ten billion net ton-miles for the four cause groups. Each table provides the derailment frequency as a function of car type and weight. The following observations are based on these four tabulations:

- General flat cars have a very high susceptibility to wide gage derailments in comparison with the fleet.
- The 50-ton gondolas and open hoppers, as well as 70-ton tank cars, also show a relatively high rate of wide gage derailment.
- Across all car types, the rate of cross-level derailments does not depend strongly on the tonnage capacity.
- Among car types, the rate of cross-level derailments varies significantly, the worst actors being covered hoppers and auto flats.
- When both car type and tonnage capacity are considered, the worst actors for cross-level derailments are covered hoppers of all tonnage capacities (50-ton cars being the worst), 50- and 70-ton auto flats, and 70-ton tank cars.
- The 100-ton cars have a relatively low rate of axle- or bearing-caused derailments.
- The 50- and 70-ton gondolas have an extremely high rate of axle/bearing derailments in relation to the fleet average. The 50- and 70-ton hoppers also have a relatively high rate.
- Wheel failure derailments occur at a much higher rate on 50-ton cars than on 100-ton cars.
- The worst actors for wheel failure derailments are 50-ton auto flats, 100-ton TOFCs, and 50-ton refrigerator cars.

TABLE 4-22

WIDE GAGE

DERAILMENTS PER TEN BILLION NET TON-MILES

	Capacity (Tons)			
Car Type	50	70	100	ALL
Box	1.3	0.5	0.7	0.8
Auto Flat	1.4	1.4	*	1.4
General Flat	*	5.6	*	5.6
TOFC	0.4	0.7	*	0.5
Gondola	1.7	1.1	1.1	1.1
Covered Hopper	*	0.4	1.0	0.9
Open Hopper	1.6	1.3	0.8	1.1
Refrigerator	0.9	0.4	0.5	0.6
Tank Car	1.4	1.6	0.6	0.8
ALL	1.2	0.7	0.8	0.9

*Small Sample

Fleet Average = 0.9

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-23

CROSS-LEVEL

DERAILMENTS PER TEN BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	ALL
Box	5.4	5.7	1.8	5.1
Auto Flat	6.1	9.6	*	6.8
General Flat	*	*	*	*
TOFC	2.0	1.4	3.0	1.9
Gondola	1.7	1.9	1.9	1.8
Covered Hopper	13.3	9.1	8.6	8.7
Open Hopper	3.4	3.5	3.1	3.4
Refrigerator	3.1	4.5	4.7	4.2
Tank	4.8	8.0	2.7	3.3
ALL	4.4	4.6	5.0	4.7

*Small Sample

Fleet Average = 4.7

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-24

BEARING AND AXLE FAILURE

DERAILMENTS PER TEN BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	ALL
Box	0.7	0.1	0.2	0.4
Auto Flat	*	*	*	*
General Flat	*	*	*	*
TOFC	0.1	0.6	*	0.3
Gondola	3.4	3.4	0.5	1.5
Covered Hopper	*	0.6	0.1	0.2
Open Hopper	1.0	0.8	*	0.5
Refrigerator	0.9	0.3	*	0.4
Tank	*	*	0.1	0.1
ALL	0.6	0.6	0.2	0.4

*Small Sample

Fleet Average = 0.4

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

TABLE 4-25

WHEEL FAILURE

DERAILMENTS PER TEN BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	ALL
Box	3.9	4.3	2.9	4.0
Auto Flat	16.3	1.4	*	14.2
General Flat	*	*	*	*
TOFC	5.9	3.3	7.7	5.0
Gondola	5.1	3.9	1.8	2.6
Covered Hopper	2.7	3.3	2.0	2.2
Open Hopper	1.3	4.3	1.3	2.3
Refrigerator	6.1	2.9	3.6	3.9
Tank	1.9	2.4	1.7	1.8
ALL	5.4	3.8	1.9	3.3

*Small Sample

Fleet Average = 3.3

Source: FRA Safety Data/AAR UMLER Files/1% Waybill Sample

4.4.7 Derailments and Car Type for Loaded/Unloaded Cars

Derailment frequencies for the various types of cars were determined for both the loaded and unloaded state. Table 4-26 shows the ratio of the loaded derailment frequency to the unloaded derailment frequency for each car type. The loaded/unloaded ratios for covered and open hoppers are distinctly higher than those for other car types, meaning that derailments involving these car types most often occur when the cars are loaded. This can be related to the height of the center of gravity of these car types when loaded, which gives rise to the rock-and-roll problem.

TABLE 4-26

DERAILMENT FREQUENCY BY CAR TYPE, LOADED AND UNLOADED (MAINLINE, TRACK CLASSES 2-6, SPEED > 10 MPH)

Car Type	Ratio of Derailment Frequency Loaded/Unloaded
Box	1.31
Auto Flat	1.08
General Flat	2.10
Gondola	2.90
Covered Hopper	7.24
Open Hopper	6.37
Refrigerator	1.05
Stock	—
Tank	1.8

Source: Transportation Systems Center

4.5 HAZARDOUS MATERIALS

4.5.1 The Magnitude of the Problem

The transportation of hazardous materials constitutes one of the greatest risks to which society is exposed by the railroads. The risk lies not so much in the number of casualties that are caused, on the average, in a year by the accidental release of hazardous material, as in the possibility that catastrophic accidents can happen.

The consequences of those hazardous materials accidents that occurred over the years 1971 through 1978 were analyzed and projections were developed as shown in Tables 4-27 and 4-28. These tables show the future probability of catastrophic accidents if past trends are maintained. It should be noted, however, that the DOT has in the last two years instituted important changes in the regulation of hazardous materials transport by rail, and these changes can be expected to significantly alter the projections in the tables. These changes are discussed later in this chapter.

TABLE 4-27

PROJECTIONS OF MAXIMUM INJURIES IN RAIL MOVEMENT OF HAZARDOUS MATERIALS

Maximum Number of Injuries in an Accident in a Year	Probability That This Number will be Equaled or Exceeded (Percent)	Inverse Probability or Return Period (Number of Years for Number to be Exceeded)
50	29.3	3.4
100	19.8	5.1
150	15.6	6.4
250	11.5	8.7
350	9.3	10.7
500	7.5	13.4
1000	4.8	20.7
2000	3.1	32.1
5000	1.7	57.8

Source: Hassler, F.L., "Analysis of 1976 Rail Hazardous Material Flows," Transportation Systems Center, Report No. SS-20-VI-40, April 1978.

TABLE 4-28

PROJECTIONS OF MAXIMUM FATALITIES IN RAIL MOVEMENT OF HAZARDOUS MATERIALS

Maximum Number of Fatalities in an Accident in a Year	Probability That This Number will be Equaled or Exceeded (Percent)	Inverse Probability or Return Period (Years)
10	28.7	3.48
20	18.5	5.4
50	9.9	10.0
100	6.1	16.3
500	1.9	51.5

Source: Hassler, F.L., "Analysis of 1976 Rail Hazardous Material Flows," Transportation Systems Center, Report No. SS-20-VI-40, April 1978.

It is most difficult to acquire data on the size, weight, and length of cars involved in rail accidents while carrying hazardous materials. The FRA accident data provide no information on car dimensions, although it may be possible to determine car dimensions for the first car involved (and only the first car) by accessing the AAR UMLER file with the car identification number reported to FRA. However, it is not possible to determine what the first car was carrying. The Materials Transportation Bureau (MTB) data on hazardous materials releases has a minimum amount of information on car type and capacity. Perhaps, the most comprehensive analyses to data of cars involved in hazardous materials accidents and releases were done under the joint RPI/AAR Railroad Tank Car Safety Research and Test Project (approximately 85% of hazardous materials cars involved in rail accidents are tank cars). During this study, which analyzed tank car accidents from 1958 through 1970, detailed records of the tank car parameters, safety devices, and failure description were collected and analyzed.

Precise statements on the effects of the size, weight, and length of hazardous materials cars on rail safety cannot be made because of the scarcity of information for this special class of accidents. However, analyses can be done and have led to identifying, implementing, and evaluating improved safety measures for hazardous materials cars and transportation procedures that reduce the risk and minimize the possibility of catastrophic accidents.

4.5.2 Accident Scenarios and Safety Measures

The particular effects of a release of a hazardous material depend on the properties of the material released, the quantity released, and the accident scenario. Historically, the major sources of concern have been:

- Boiling liquid expanding vapor explosion (BLEVE), which occurs when a tank containing a liquefied flammable gas is exposed to fire and ruptures violently;
- Tank rocketing, in which a portion of the tank is propelled like a rocket by its internal pressure; and

- Toxic or asphyxiating clouds of gas that travel with the winds, possibly in the vicinity of populated areas.

These possible occurrences in hazardous materials accidents, which may happen several days after a train accident and without warning, are considered catastrophic scenarios that present a high degree of risk to people, property, and the environment. The possible causes of these scenarios are listed in Table 4-29. The probable safety measures to reduce the possibility of such catastrophic scenarios from happening are listed in Table 4-30. These results are based on the RPI/AAR Tank Car Safety Research and Test Project. The principal conclusions from this project are:

- Mechanical punctures of the tank car head are the primary cause of release of large quantities of material;
- Non-insulated tank cars are considerably less safe than insulated tank cars, either because they are uninsulated and thus more susceptible to fire hazards, or because they are generally much larger.

Finally, the actions taken by the DOT in effecting changes in tank car design to improve safety performance are provided in Table 4-31.

TABLE 4-29

FAILURE MODES IN TANK CAR ACCIDENTS (MECHANICAL DAMAGE)

- Shell Puncture
- Head Puncture
- Attachment Damage
- Top Fitting Damage
- Bottom Fitting Damage
- Leak at Riveted Seam
- Exposure to Fire

Source: Railway Progress Institute/Association of American Railroads

TABLE 4-30

METHODS OF INCREASING SAFETY OF TANK CARS

- Operational Changes
- Head Shields
- Modified Couplers
- Thermal Insulation
- Tank Material Changes
- Safety Relief Valve Modifications

Source: Adams, D.E. et al, "Rail Hazardous Material Tank Car Design Study, CALSPAN Report No. 2L5226-D-L, Preliminary Report Prepared for Department of Transportation, Federal Railroad Administration, April 1975.

TABLE 4-31

CHANGES IN TANK CAR DESIGN

- Cars built after 30 November 1970 – not to exceed 34,500 gallons capacity (or 263,000 tons gross weight)
- Cars built after 1 January 1971 – equipped with interlocking automatic couplers
- Cars built after 30 August 1974 – 112A and 114A tanks equipped with head shields
- Cars built after 31 December 1977
  - 112A and 114A – coupler restraints
  - 112S and 114S – coupler restraints and tank head shields
  - 112J, 112T, 114J, 114T – coupler restraints, head shields, and safety relief valves

Schedule:
20% done by 1 January 1979
20% done by 1 January 1980
80% done by 1 January 1981
100% done by 1 January 1982

Source: Code of Federal Regulations, Title 49, Part 175

4.5.3 Characteristics of Hazardous Materials Accidents

Approximately 5% of the total amount of ton-miles shipped by the railroads, are hazardous materials. Looking at this in another way, approximately 4% of the total rail car-miles are hazardous materials.* The railroad accident record shows that approximately 1% of the total number of rail accidents result in the release of a hazardous material. Also, 1% of the total reported dollar damages are due to hazardous materials rail accidents.

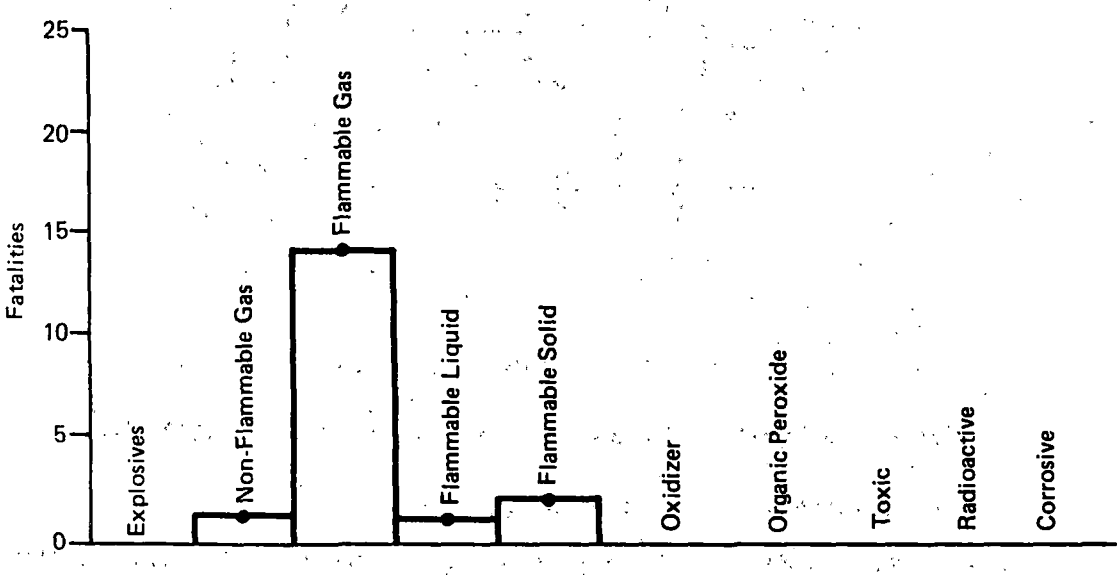
The materials that are classified as hazardous and that are transported by rail may be grouped under the following categories:

- Explosives
- Non-flammable gas
- Flammable gas

*From Waybill Sample.

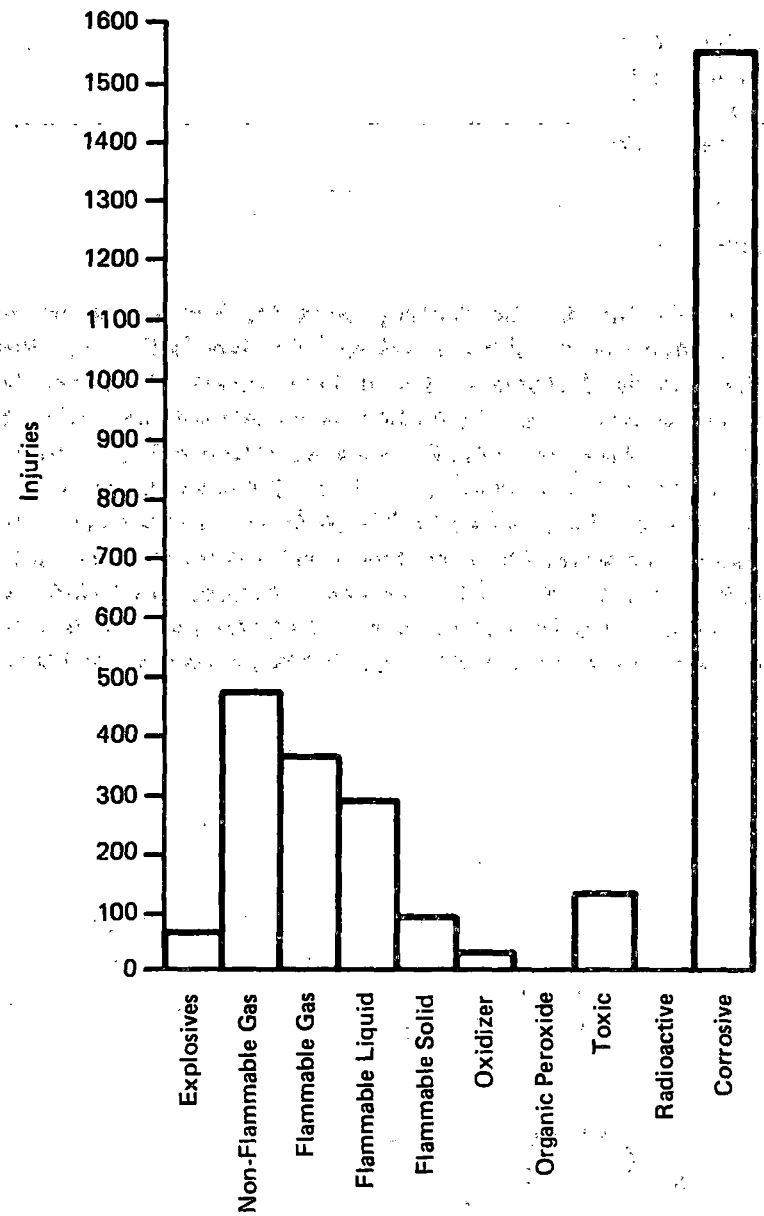
- Flammable liquid
- Flammable solid
- Oxidizer
- Organic perioxide
- Toxic
- Radioactive
- Corrosive

When these materials are accidentally released, they can adversely affect people, property, and the environment. Figures 4-5 and 4-6 and Table 4-32 show the number of people killed, the number of people injured, and the percent of releases with dollar damages in the specified ranges for each of the hazardous materials commodity groups, respectively (based on seven years' data). Flammable gases are responsible for the greatest number of fatalities in hazardous materials accidents, while corrosives injure more people than any other hazardous materials shipped by rail. The table on dollar damages shows that 88.5% of the releases of hazardous materials in rail transportation result in dollar damages of $1,000 or less. These results indicate that there are a large number of accidents with small releases of hazardous materials. Further investigation has shown that the high number of injuries from releases of corrosive materials are minor burns received while loading and unloading tank cars.



Source: Arthur D. Little, Inc. Estimates

FIGURE 4-5 FATALITIES BY COMMODITY GROUP BASED ON RELEASES, 1971–1977



Source: Arthur D. Little, Inc. Estimates

FIGURE 4-6 INJURIES BY COMMODITY GROUP BASED ON RELEASES, 1971–1977

4.5.4 Hazardous Materials Accident Frequencies

Accident frequencies based on net ton-miles and car miles for hazardous materials shipped by rail were determined for each hazardous materials commodity group and are presented according to the resulting dollar damages in Tables 4-33 and 4-34. These data show that by imposing a dollar threshold even as low as $100 (that is, eliminating releases with damages of $100 or less), the accident frequencies decrease by approximately 75%. If a threshold of $5,000 is used, then the accident frequency, based on historical reports of releases by rail, is reduced by approximately 95%. These data again point to the fact that the majority of reported hazardous materials releases in rail accidents are minor spills.

TABLE 4-32

PERCENT OF RELEASES IN HAZARDOUS MATERIALS COMMODITIES GROUPS BY DOLLAR DAMAGE RANGE

		Damages (Thousand Dollars)								
	No. of Releases	0	0-1	1-10	10-30	50-100	100-500	500-500,000	1,000-2,000	Greater Than 2,000
Explosives	42	29	36	5	10	14	5	2	2	2
Non-Flam. Gas	378	50	43	5	2					
Flam. Gas	562	45	42	4	4	2	2	$\sim$0	$\sim$0	$\sim$0
Flam. Liquid	1043	31	54	9	6	1	1			
Flam. Solid	86	33	54	11	2	$\sim$0				
Oxidizer	325	10	80	8	3					
Organic Peroxide	1	100								
Toxic	190	21	63	10	5	1	1			
Radioactive	6		50	33	17					
Corrosive	1749	41	51	6	2	$\sim$0	$\sim$0			
TOTAL	4382									

Source: Arthur D. Little, Inc., Estimates

TABLE 4-33

ACCIDENT FREQUENCIES PER BILLION TON-MILES FOR HAZARDOUS MATERIALS COMMODITIES

	Damage Threshold		
	$0	>$100	>$5000
Explosives	26.0	13.0	4.30
Non-Flammable Gas	15.0	2.2	0.27
Flammable Gas	13.0	2.7	1.30
Flammable Liquid	17.0	4.7	1.60
Flammable Solid	11.0	2.9	0.95
Oxidizer	21.0	8.8	0.91
Organic Peroxide	17.0	18.0	-
Toxic	18.0	7.3	1.30
Radioactive	66.0	28.0	9.40
Corrosive	31.0	5.6	1.10
All Hazardous Material	20.0	4.7	1.20

Source: MTB Data 1971-77; Arthur D. Little, Inc., Estimates

TABLE 4-34

ACCIDENT FREQUENCIES PER MILLION CAR-MILES FOR HAZARDOUS MATERIALS COMMODITIES

	Damage Threshold		
	$0	>$100	>$5000
Explosives	1.30	0.63	0.210
Non-Flammable Gas	1.00	0.15	0.019
Flammable Gas	0.94	0.20	0.094
Flammable Liquid	1.20	0.32	0.110
Flammable Solid	0.69	0.17	0.058
Oxidizer	1.60	0.66	0.069
Organic Peroxide	1.40	1.40	-
Toxic	1.10	0.43	0.079
Radioactive	3.00	1.30	0.420
Corrosive	2.50	0.45	0.090
All Hazardous Material	1.40	0.33	0.086

Source: MTB Data 1971-77; Arthur D. Little, Inc., Estimates

4.5.5 Release Probability

The number of hazardous materials cars derailing and the number releasing in rail accidents are shown in Table 4-35. If one defines the probability of a hazardous materials car releasing to be the ratio of the number of hazardous materials cars releasing to the number derailing (that is, the probability that a hazardous materials car will release if it has derailed), the historical accident data show that there is a 16% chance that a hazardous materials car will release some or all of its contents if it were derailed in a train accident.

4.5.6 Tank Car Accidents and Tank Car Capacity

The Materials Transportation Board (MTB) requires that all releases of hazardous materials, no matter how small, be reported for all modes of transportation. The reporting form includes such information as name of container, capacity of container, and quantity spilled. With these data, it is possible to examine release accidents of tank car size, thus eliminating the minor (small quantity) spills. Tank cars often are identified in this data base by their DOT specification number. A brief description of the characteristics of the various types of tank cars was provided in Table 3-20.

TABLE 4-35

RELEASE PROBABILITY

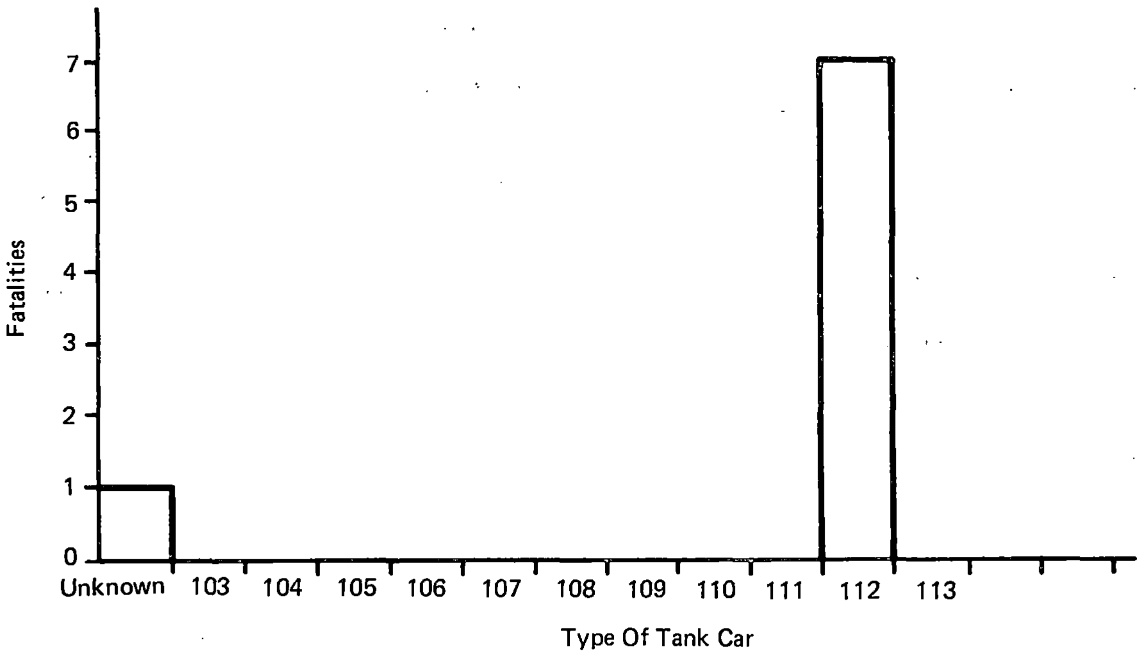
	1975	1976	1977	Total
Number of Hazardous Materials Cars Derailing (N_{HD})	976	947	1072	2895
Number of Hazardous Materials Cars Releasing (N_{HR})	135	166	173	474
Release Probability ($N_{HR} \div N_{HD}$)	0.14	0.20	0.16	0.16

Source: FRA Accident Bulletins; Arthur D. Little, Inc., Estimates

Releases reported to the MTB involving tank car size containers for the period 1971 - 1977 were analyzed to determine the number of fatalities and injuries for the various types of tank cars and a range of tank car capacity. It should be pointed out that fatalities and injuries reported to the MTB are the direct result of the release of the hazardous material and not due to the train accident.

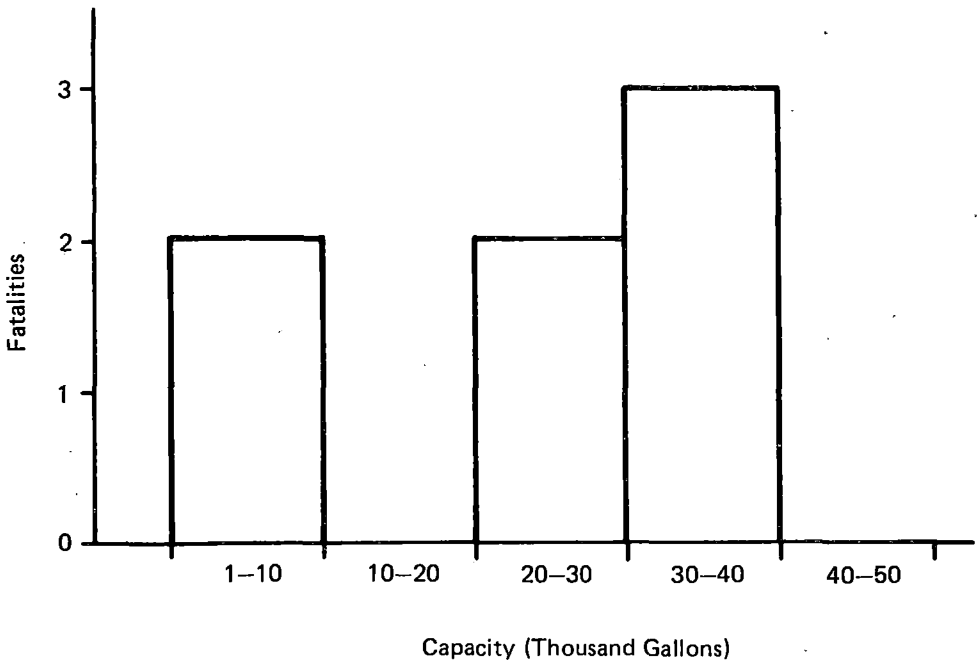
Figure 4-7 shows the number of fatalities associated with a hazardous materials release for each of the tank car types. The numbers 103, 104, etc., refer to the DOT specification. If the specification was not known, the container type was reported as "tank car." Figures 4-8 and 4-9 show the number of fatalities for each of the two tank car types ("112" and "tank car") as a function of the gallon capacity of the car. Again, these data are for fatalities directly related to the release of a hazardous material. Although no clear-cut relationship can be seen relating fatalities to large capacity tank cars, there is some indication that the 112 tank cars, which ship liquefied compressed gases, are a major contributor to tank car safety problems. This is consistent with the results of the RPI/AAR tank car study. Actions taken by DOT which address the safety problems for this class of tank car were discussed earlier.

Figure 4-10 shows the number of injuries for each tank car type. Figures 4-11 through 4-15 show the injuries for each tank car type according to the tank car capacity. Again, although no clear-cut relationship can be seen, there is some indication that the larger size 112 tank cars present a greater risk.



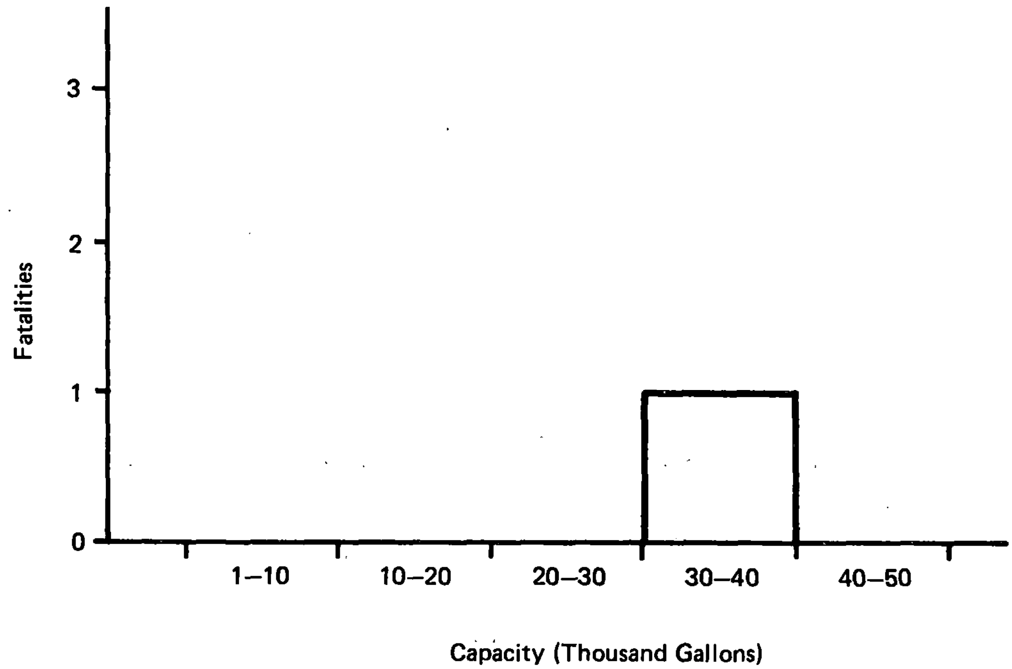
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-7 FATALITIES BY TYPE OF TANK CAR, 1971–1977



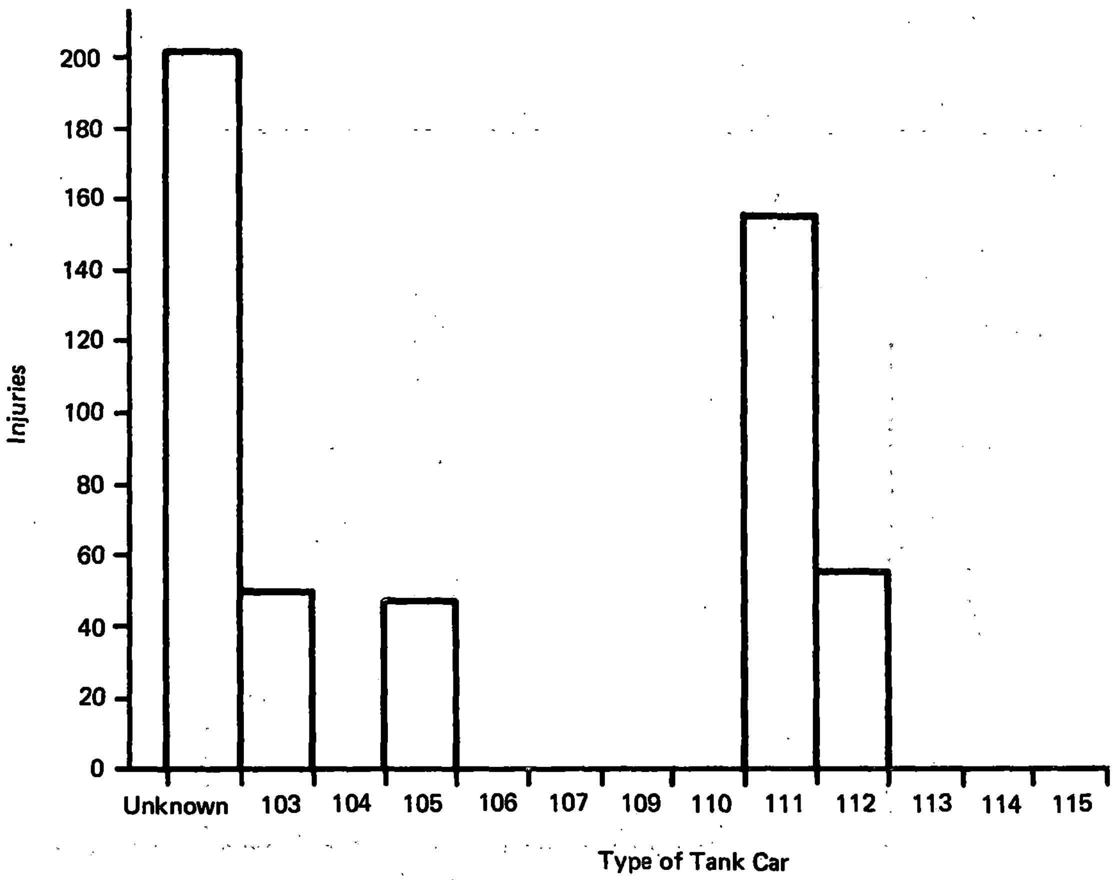
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-8 FATALITIES BY TANK CAR CAPACITY, TYPE "112," 1971–1977



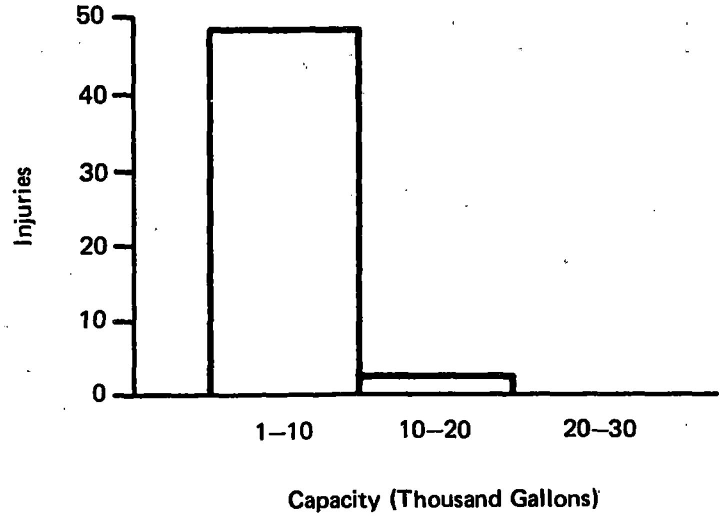
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-9 FATALITIES BY TANK CAR CAPACITY, TYPE "TANK CAR," 1971–1977



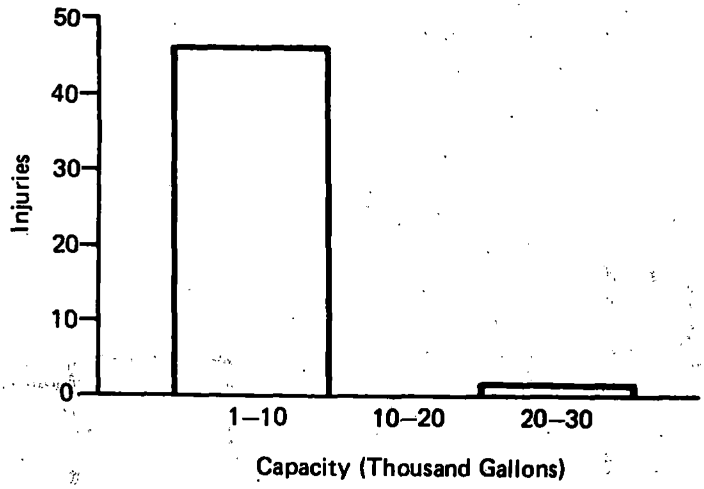
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-10 INJURIES BY TYPE OF TANK CAR, 1971–1977



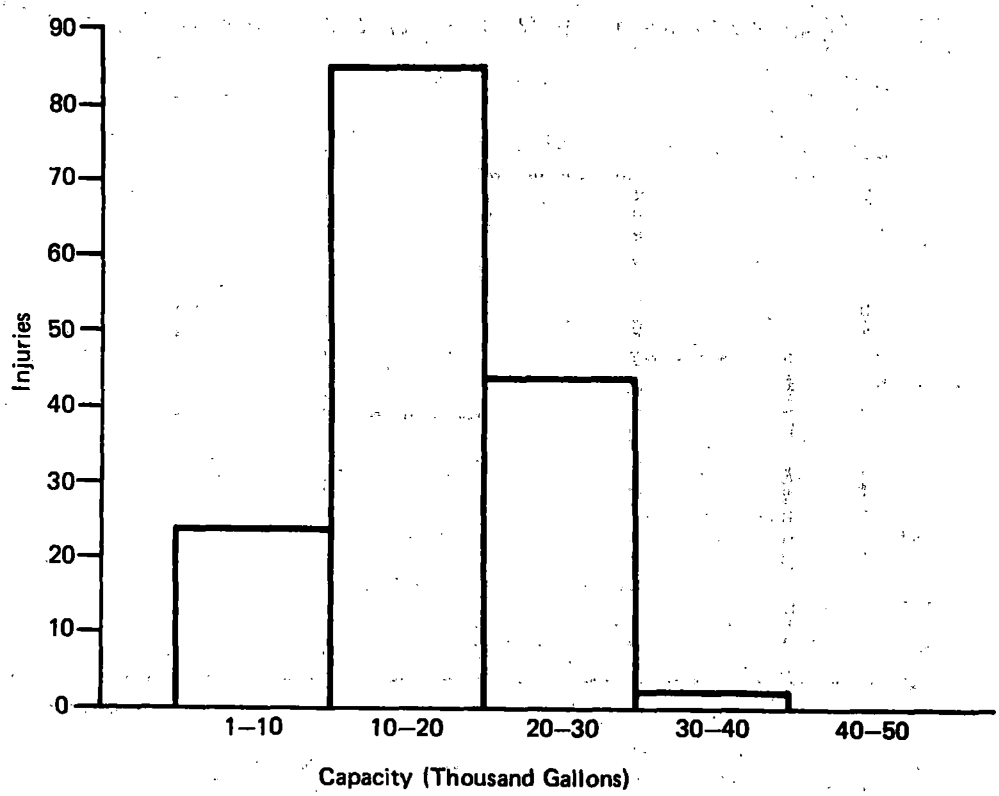
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-11 INJURIES BY TANK CAR CAPACITY, TYPE "103," 1971–1977



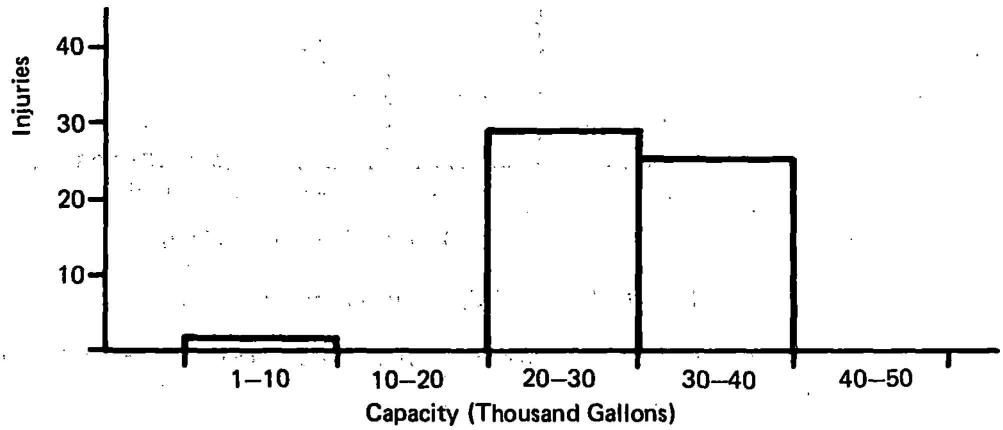
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-12 INJURIES BY TANK CAR CAPACITY, TYPE "105," 1971–1977



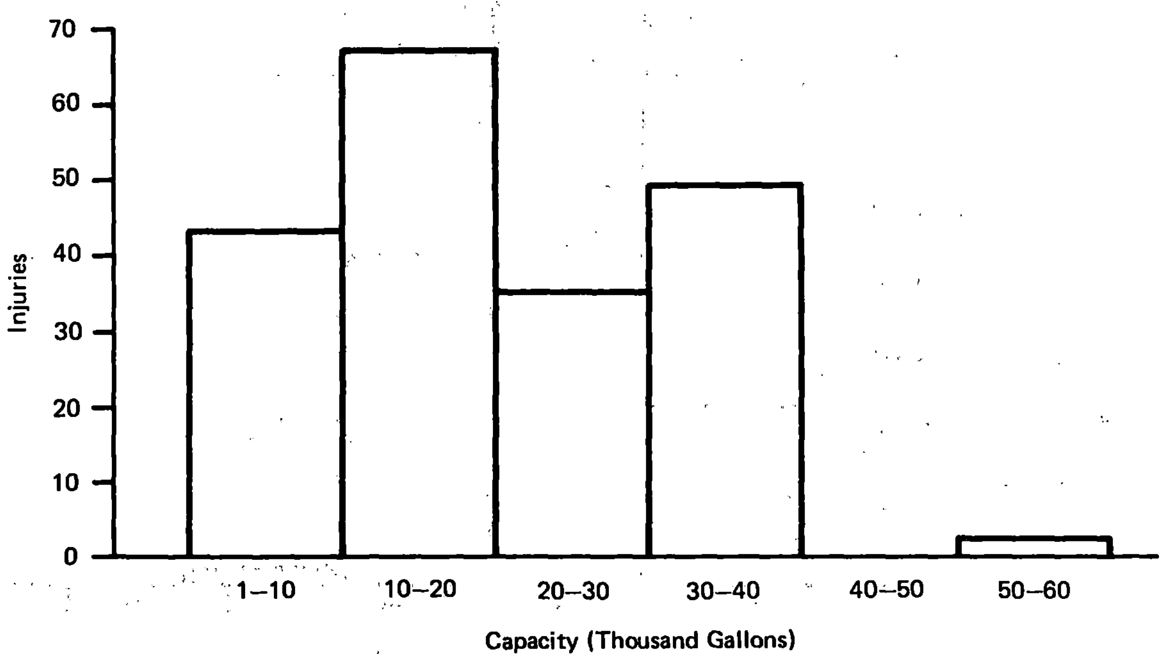
Source: Arthur D. Little, Inc., Estimates

FIGURE 4-13 INJURIES BY TANK CAR CAPACITY, TYPE "111," 1971–1977



Source: Arthur D. Little, Inc., Estimates

FIGURE 4-14 INJURIES BY TANK CAR CAPACITY, TYPE "112," 1971–1977



Source: Arthur D. Little, Inc., Estimates

FIGURE 4-15 INJURIES BY TANK CAR CAPACITY, TYPE "TANK CAR," 1971–1977

5. PROBLEM PERSPECTIVE AND DERAILMENT ANALYSIS

5.1 ABSTRACT

An understanding of the reasons underlying the accident statistics presented in Chapter 4 is gained by using two complementary approaches. The first is a pair of surveys, one of railroad employees and the other of railroad management, seeking their opinions on the causes of accidents and the importance of the size, weight, and length of railroad cars. The second is an analysis of the physical processes that lead to derailments. The same result was arrived at when these two approaches were used.

Fundamentally, it was found that there is not necessarily a correlation between accident frequency and the size, weight, and length of cars. However, cars with a high center of gravity and long cars can be more susceptible to poor dynamic behavior if thorough design practices are not adhered to.

Cars with high axle loads exert larger loads on track structures and can cause more rapid deterioration of track. If adequate track maintenance is not carried out, then the heavier cars can develop a greater tendency to derailment than the lighter cars. It is important to note that the required maintenance is well within the capacity of many railroads which routinely operate 100-ton cars.

5.2 INTRODUCTION

The quantitative accident data shown in Chapter 4 exhibit no particular pattern. Occasional combinations of size, weight, and length are worse than others; and heavy cars appear to be better than lighter cars if viewed on the basis of accidents per ton-mile averaged over the entire fleet of cars. This is not necessarily true, on the other hand, for any one type of car. Understanding and interpreting these quantitative data require understanding how the data are gathered, taking into account trends in equipment development, and examining the physical processes that cause derailments. These influences are examined in this chapter.

The accident data presented in Chapter 4 pertain either to the car that causes a derailment or to the first derailing car in the train, the latter applying to accidents caused by track failure or by human error. The identification of the car that caused an accident is not always an easy task, and insofar as errors occur, they will be reflected in the statistical data. Since the magnitude of the error that might be involved is impossible to estimate, the quantitative data must be approached with caution, qualifying the data based on experience and analytical understanding.

A second factor that influences the data is the fact that the lighter (50- to 70-ton) cars are, on the average, older than the heavier 100-ton cars. This fact has two possible implications. First, the older cars may experience a greater rate of component failure, merely by virtue of the fact that those components have been in service longer, not because of any connection with car weight. Second, the newer cars may have more sophisticated designs of components and subassemblies which have a longer service life. Thus, variations in accident frequencies can occur as a result of hidden factors which have little to do with the size, weight, and length of railroad cars.

Finally, the statistical data provide insight only into the approximate cause of an accident and not into underlying causes. As an example, a derailment may be classified as being caused by "Cause Code 119 — cross-level of track irregular (at joints)," which is a track defect. In fact, however, the vehicle involved may equally be at fault. Its design may be such that it develops a particularly violent oscillation as it traverses track with cross-level irregularities. Other vehicles may not experience this problem.

Similarly, it is necessary to know (when accidents are caused by track defects) why track deterioration occurs. Weakness and fatigue caused by passage of freight cars and lack of appropriate maintenance are the most important factors. Also possible, however, is the fact that the loads exerted by vehicles are larger than those of past experience, which leads to a faster rate of track deterioration than normally expected, thus making maintenance costs yet higher. If this is so, it becomes necessary to know the relationship between wheel-rail loads and the size, weight, and length of cars.

The remaining portions of this chapter address one of the deficiencies in the statistical data that can be rectified by analysis: a thorough evaluation is made of the underlying causes of railroad accidents and of how these causes are related to the size, weight, and length of cars.

5.3 PERCEPTIONS

5.3.1 Introduction

Concern over the size, weight, and length of railroad cars and their influence on safety and economics has been a reality for the railroads since their earliest beginnings. A vast amount of literature is devoted to a study of this problem.[1] For example, Appendix A includes a bibliography of pertinent information regarding these concerns.

Today's concern is that, as some portions of the nation's track deteriorate, as trains and cars become larger, longer, and heavier, and as the quantity of hazardous materials transported by the railroads rapidly increases, the potential for ever more frequent and catastrophic accidents is rapidly increasing. The railroad industry claims that it has made significant improvements concomitantly with the introduction of larger cars, and that these improvements have acted to neutralize any potentially deleterious effects of the larger cars on safety. Their examples of these improvements are the use of heavier rails, the laying of continuous welded rail, the development of improved train-handling techniques, and the use of larger wheels, roller bearings, new brake valves, and improved suspensions.

Two surveys were conducted to obtain further insights into the positions of railroad employees and railroad management. A brief summary of these surveys follows.

5.3.2 A Recent Survey by the United Transportation Union

Railroad personnel accident reports do not usually relate fatalities or injuries to the characteristics or types of railroad cars that may have been involved. They simply state the manner in which the person was hurt; e.g., "while aligning the couplers." Because of this lack of quantitative data from which to assess railroad personnel safety in terms of the effects of size, weight, and length of freight cars, the UTU initiated a survey of railroad employees through a questionnaire.

The questionnaire was designed to gain, from experienced railroad employees, their practical understanding of the safety of these cars, particularly the safety of long, high-capacity cars. They were asked to express their concerns both in response to specific questions such as which type of car they felt might have a greater tendency to derail, as well as their intuitive feelings about how injuries occur and how they can be reduced.

The employees did not express strong concerns regarding the effects of car size, weight, and length on safety. However, they did feel that larger, 100-ton cars were more prone to derailment. They were also concerned with the clearance of longer cars during yard service and on curves. Specifically, the survey, with approximately 900 respondents, indicated the following:

Derailments:

- Jumbo tanks, covered hoppers, TOFCs, and auto-racks were chosen as having the highest derailment frequencies. These cars were chosen more than twice as often as the other car types.
- All flat car types were noted as having a higher derailment rate when empty.
- In addition to the above car types, open hoppers and covered hopper cars on unit trains were chosen as more likely to have poor dynamic behavior than other car types, particularly on poorly maintained, jointed track.
- The characteristics of adjacent cars in a train have the most important influence on the probability of derailment of a car. Given this effect, the heaviest and longest cars of each type were selected as having the highest derailment frequency. The frequency of derailment appears to be proportional to the weight and length of the car.
- The longer the train, the more likely it is to have cars derail. Especially long trains with over 100 cars were singled out as having higher derailment rates.

Personal Injury:

- The size, weight, and length of cars were not felt to have a strong influence on the likelihood of personal injury by the majority of respondents. However, about 40% felt that the longer, heavier cars were more likely to cause personal injury than the shorter, lighter cars.

- The five car types most likely to be involved in personal injury are:

  Flat-autorack
  Flat-TOFC
  Flat-"other"
  Tank-jumbo
  Tank-"other"

In questions pertaining to areas of hazards or risks associated with the size, weight, or length of rail cars, employees responded that track maintenance (26%) and consist makeup and handling (21%) were more important.

A sample questionnaire and the results of specific questions are included in Appendix C.

5.3.3 A Recent Survey of Railroad Management

In a survey conducted by the AAR of the management personnel of some representative U.S. railroads (Appendix D), one of the questions posed was:

- If the average capacity of freight cars was increased by 15 percent with no change in car lengths, what would be the likely impact associated with the safety and economics of operating your company?

Representatives responses follow:

- "It is not acceptable to arbitrarily increase (the) capacity of cars beyond the present design maximums which would accelerate equipment and track failures. Present technology and materials dictate that the four-axle freight car with 263,000 lbs gross rail weight to be the optimum vehicle capacity from economic and operating viewpoints.

  "It is acceptable to increase average car capacity by replacing 70-ton cars with 100-ton cars, which has been general practice for a number of years. This practice results in a per car capacity increase of approximately 17% and contributes to an average increase of car capacity for a fleet of cars."
- "It is our opinion that the present 100-ton car loaded to 263,000 lbs on four axles represents the maximum practicable limit."
- "We cannot realistically look at existing average capacity, since increasing it would require retrucking of freight cars, beefing up body bolsters and center sills, etc., all of which would be prohibitive in regard to costs. Therefore, we must look at increased capacity in regard to new equipment. We are now at the reasonable maximum for four-axle cars at 263,000 lbs (6-1/2 x 12 inch journals); further increase creates the use of 7 x 12 inch journals with wheel and rail loading pushing limits of present design.

  "It would be our opinion for normal operations that further increases of capacity over present 100-ton nominal cars would have a negative economic effect. Safety-wise, increased wheel loading increases likelihood of wheel or rail failure since we are very close to or have entered an area of physical permanent deformation of wheel/rail contact areas leading to accelerated wear patterns or structural failure."

- "The cost/benefit ratio for heavier wheel loads is route specific, and there is no "optimum" level for even an individual carrier or route segment. It is evident that 125-ton four-axle cars have reached the limit of destructive effect on rail without current compensated costs for track deterioration and the potential of derailment. It is assumed that the hypothetical 15% increase in average capacity of all freight cars would require a corresponding increase in the rail weight of all existing 95-ton hoppers to 110 net tons or greater. The operation of such equipment would increase costs and increase accident potential as previously illustrated. Average car weights of bulk commodities should be retained at the approximate 90- to 95-ton car limit."

5.4 CAUSES OF DERAILMENT

In recent years, the following picture of the causes of derailment has been developed:

1. The actual event of derailment may be due to a failure of a vehicle or track component, or it may be due to the dynamic behavior of the track or the train. Human error in train operation may exacerbate dynamic behavior.
2. Component failures are largely due to high loads on the various components of the vehicle-track system, but may also occur from lack of maintenance, leading to failure caused by bearing starvation or overheated wheels.
3. High loads on the system are caused by a combination of poor track geometry and the existence of certain modes of dynamic behavior of the vehicle-track system. These modes can also cause derailments without component failure. Furthermore, high loads may occur from the use of heavy cars.
4. Poor track geometry results from track wear and fatigue, caused by a combination of initially high loads (i.e., with new track), the environment, and inadequate track maintenance.
5. Initially, high loads on track are caused by the use of heavy cars (particularly those with high axle loads) and by the existence of certain modes of dynamic and static behavior of the vehicle-track system which can occur on new track. Examples of these modes are truck hunting instabilities and the development of high steady forces during curve negotiation.
6. Train dynamic behavior can be a cause of derailment and is affected by how the train is made up, how it is controlled by the operator, and by the characteristics of the individual cars.

This description suggests that controlling derailments necessitates an understanding of the following phenomena:

- Vehicle-track interaction, both when the system is in good condition and when it has deteriorated;
- The behavior of trains, particularly their longitudinal dynamics;
- Component failures; and
- Track degradation.

In the context of this report, it is particularly important to determine how the size, weight, and length of railroad cars influence these phenomena.

The following sections of this chapter develop an understanding of these phenomena and of the role played in them by the size, weight, and length of railroad cars. Because of the extremely complex nature of the problem, a variety of techniques and sources of information has been used, and the answers obtained are sometimes ambiguous. This ambiguity is a forewarning that no simple solutions exist in the endeavor to improve railroad safety.

5.5 VEHICLE-TRACK INTERACTION

5.5.1 Dynamic Modes of Behavior of the Vehicle-Track System

The primary concern in investigating vehicle-track interaction is to understand how large dynamic forces or oscillations of vehicles arise. The effects of these forces or of large static forces on the system are examined in Sections 5.7 (Component Failures) and 5.8 (Track Degradation).

Extensive investigations have been conducted under the aegis of both the FRA and the AAR. These investigations have resulted in the identification of the following phenomena as being of primary concern in understanding vehicle-track interaction:

- *Hunting* — a form of oscillation that is also termed an "instability." It can arise on perfect track and feeds on itself once it is started. It is one of the most complex dynamic phenomena observed in the railroad environment, and a complete understanding of it does not exist. It is known, however, that many aspects of the design of the trucks and the carbody are important, including specifically the design of the suspension system. Hunting occurs in certain speed ranges, demarcated by "critical speeds." It is often the objective of the vehicle designer to achieve critical speeds which lie outside the speed range in which the vehicle is expected to operate.
- *Rock and Roll* — a form of externally excited oscillation in which the vehicle oscillates about an axis parallel to the train. This oscillation has historically been associated with cars with a high center of gravity whose truck spacing lies in a fairly narrow range of lengths, and on track with staggered-joint bolted rail construction that has been poorly maintained, giving rise to severely "dipped" joints.

- *Pitch and Bounce* — externally excited vertical oscillations of the body of the vehicle, caused by poorly maintained track. Usually of greater concern for human comfort (as in locomotives) and lading damage (in freight cars), pitch and bounce may occasionally contribute to derailments.
- *Yaw and Sway* — externally excited transverse oscillations of the body of the vehicle, caused by poorly maintained track. Yaw and sway can contribute to derailment by generating large lateral forces between wheels and rails.
- *Steady-State Curving* — where large steady-state lateral forces are generated between the rails and the wheels of a vehicle, even when track conditions are excellent. Contributing factors are trucks of large wheelbase on sharp curves and poor maintenance of parts such as side-bearings and centerplates, so that trucks cannot freely swivel, relative to the carbody, in a curve.
- *Spiral Negotiation* — where the twisted track may cause loss of vertical contact between a wheel and rail, while large lateral wheel-rail forces are being generated. This is typically associated with either improper track construction and maintenance, so that the track is improperly superelevated, or with tortionally stiff and long carbodies, which are unable to accommodate the twist in the track.
- *Dynamic Curving* — in which high lateral forces are generated between wheel and rail in a curve. Dynamic curving is still a relatively poorly understood phenomenon. High forces have been observed typically with vehicles having high axle loads. Other vehicle factors, not yet clearly identified, also play an important role, however.
- *Response to Joints and Special Trackwork* — in which high forces of short duration are caused as a wheel passes over joints, switches, crossovers, grade crossings, etc. This phenomenon occurs on all vehicles, but its details are still poorly understood.

Gaining a complete understanding of these dynamic response modes requires knowing the following for each mode:

- The type of track required;
- The important aspects of vehicle response;
- A detailed description of the required track geometry input and of operational variables such as speed; and
- A listing of vehicle design parameters that are important.

A qualitative summary of the above is presented in Table 5-1. It is also necessary to develop a qualitative understanding of the detailed mechanism by which vehicle-track interaction eventually causes a derailment.

TABLE 5-1

DYNAMIC RESPONSE MODES

Performance Safety Issue	Required Excitation Inputs	Important Response Variables	Important Truck & Operational Variables	Important Vehicle Design Variables
1. Hunting	Lateral Transients	L, L/V, Axle Truck and Body Motions	Speed, Lateral Displacement, Amplitude Rail Friction	Wheel Profile, Weight
2. Rock and Roll	Vertical Displacement	Vertical Force Roll Angle of Truck and Body	Freq., Ampl. and Phase Relationship of Inputs to Each Wheel	Truck Center Distance, Center of Gravity Height, Roll, Moment of Inertia
3. Pitch and Bounce	Vertical Displacement	Vertical Force Roll Angle of Truck and Body	Freq., Ampl. and Phase Relationship of Inputs to Each Wheel	Truck Center Distance, Center of Gravity Height, Pitch, Moment of Inertia
4. Yaw and Sway	Lateral Displacement	L/V, Yaw and Sway Movement of Truck and Body	Freq., Ampl. and Phase Relationship of Inputs to Each Wheel	Truck Center Distance, Yaw Moment of Inertia
5. Steady State Curving	Curve	L, L/V	Curvature, Speed, Super Elevation	Axle Distance Length, Width, Truck Center Distance
6. Spiral Negotiation	Spiral	L/V; Truck and Body Motion	Rate of Change of Curvature and Super Elev., Speed	Axle Distance, Truck Center Distance
7. Dynamic Curving	Curves with Perturbation	L, L/V; Truck and Body Motion	Curvature, Super Elev., Speed, Perturbation Ampl. and Location	Axle Distance, Length, Truck Center Distance Moment of Inertia Weight
8. Response to Joints and Special Trackwork	Curve or Tangent with Joints, Switches, Frogs, etc.	L, V; Truck and Body Motion	Curvature, Speed, Super Elev., Joint Perturbation Ampl. and Location	Wheel Profile, Axle Distance, Truck Center Distance, Weight of Axle

Source: Arthur D. Little, Inc.

5.5.2 Derailment Mechanisms

For a derailment to occur, at least one wheel in a train must end up either on the ties between the rails or outside its rail. This can happen in the following ways:

- The gage is wide due to poor maintenance, and the wheel drops in.
- The wheel exerts a large lateral force on the rail and causes it to push out, thereby widening the gage. The wheel may drop in between the rails, or if the rail rolls over, it may ride on the web of the rail and eventually fall outside.
- Because of a severe oscillation such as rock-and-roll, the wheel may lift off the rail. If at the same time that wheel is moving laterally, it can fall outside the rail.
- If there is a large lateral force and a low vertical force between a wheel and a rail, if the rail is adequately fastened to the ties so that it does not move, and if the friction between the wheel flange and rail is adequately high, the wheel may climb onto the rail and derail. The phenomenon is similar to what happens when an automobile tire strikes a curb while running parallel to it.

All of these mechanisms of derailment require a combination of either high lateral forces (designated L) between wheel and rail or low vertical forces (designated V) or both. In many instances, a "safety criterion" may be developed which combines both L and V and specifies that the ratio L/V should remain below a certain value. This criterion ensures that very high lateral forces and very low vertical forces do not occur simultaneously — a dangerous situation.

Criteria have been developed to prevent, for example, rail rollover or wheel climb. In addition, based on extensive testing, the Japanese National Railways have developed an empirical criterion which recognizes that permissible L/V values increase as the length of time for which they occur decreases. This is a recognition of the fact that it takes a finite length of time for a rail to roll over or for a wheel to climb the rail.

Similar criteria are presently being developed to limit the value of the lateral force resulting from a single axle or from several adjacent axles. These criteria are intended to prevent lateral rail displacement or shifting of the track structure.

Although the specific details of these criteria are not of concern to this report, the fact that they highlight the forces between wheels and rails is. Thus, regardless of the particular vehicle-track interaction mode that is being discussed, the primary area of focus can be on wheel forces. The following pages present investigations of the dynamic modes discussed in Section 5.5.1 in the light of this observation. In addition, the question of the effect of car size, weight, and length on safety is addressed as explicitly as is possible at present.

5.5.3 Hunting

Hunting has been the subject of study for almost a century. Although understanding of the phenomenon has certainly increased, a cure has not been obtained, primarily due to three factors:

- It is sometimes difficult to prevent hunting both when the car is loaded and when it is empty.
- As wear takes place or suspension components age, the hunting behavior of the vehicle changes.
- There is an apparent conflict between requirements in vehicle design for preventing hunting and those for enhancing the ability to negotiate curves, although new truck designs may overcome this problem.

Three different hunting modes have been identified:

- Axle hunting;
- Truck hunting; and
- Carbody hunting.

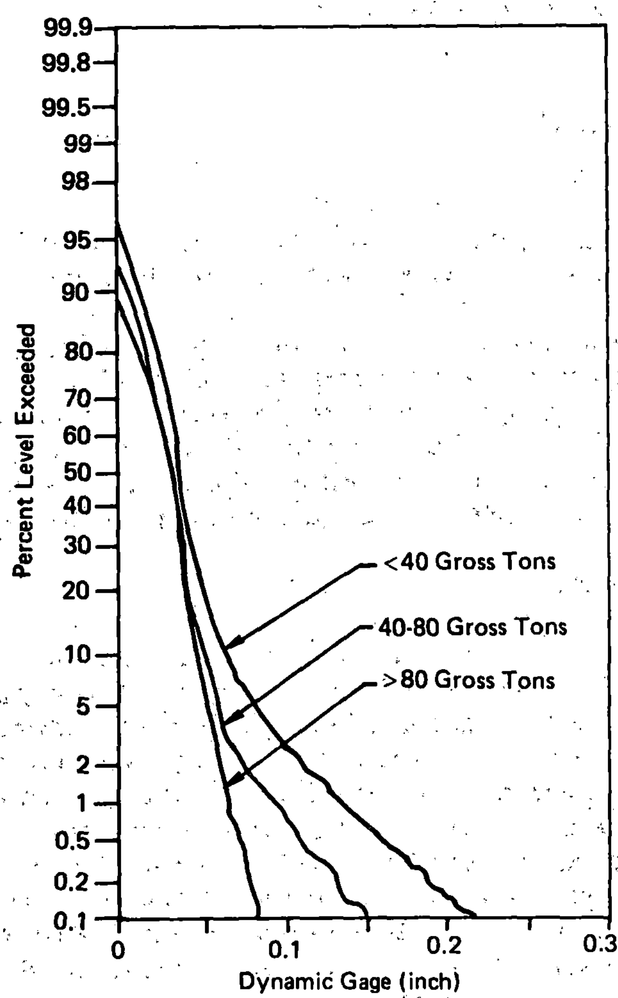
For each mode, a critical speed exists below which hunting will not occur, and above which it will occur. There may be a yet higher speed beyond which hunting will again vanish.

This extremely complex phenomenon can be discussed briefly only via illustrative examples, and this approach is adopted here. Although brief, the following examples do demonstrate that there is no specific correlation between the size, nominal weight (loaded), and length of railroad vehicles and the occurrence of hunting. Rather, hunting is a phenomenon that can afflict cars of all sizes, weights, and lengths, and its elimination is a matter of careful attention to design, coupled with adequate prototype testing.

Wide Gage Investigation

A project was sponsored by the AAR, with the assistance of the Union Pacific Railroad, to define the mechanisms involved in the generation of wide gage on high-speed tangent track. A wide gage is developed as a result of a fatigue failure of the track to maintain the original gage and is typically evidenced by tie cutting or crushing at the field side of the tie plate, permanent deformation of spikes from lateral shear, and cutting of the spike holes in the tie. In the area chosen for tests, near Minidoka, Idaho, the Union Pacific observed that at the beginning of one winter, the track was approximately 1/2-inch wide, but within a 4-month period, had widened to as much as 1-1/4 inches. The track was regaged, and two hold-down spikes per tie plate were added to the original two rail spikes per tie plate. Freight train speeds up to 79 mph were then recorded over this track. The primary cause of the high lateral loads and permanent gage widening was found to be the vehicle "hunting" phenomenon. A second factor in gage widening was determined to be the frozen ballast conditions encountered during the winter.

The effect of the vertical wheel load on the gage is shown in Figure 5-1, where the passing freight cars were sorted by gross weight on the rail into three categories: 40, 40 to 80, and 80 gross tons. In this type of plot, the lower probability events are of greater interest, and as can be seen, the data tend to fall into a different statistical distribution below approximately the 10 percent level. The higher amplitude, lower probability dynamic gage (lateral load) events are due to occasional lateral impacts from hunting trucks. In Figure 5-1, there is little evidence of high lateral loads caused by truck hunting under loaded freight cars (those with more than 80 gross tons on rail), while conversely, there is evidence that about 10 percent of the passing axles under light cars (those with less than 40 gross tons) were hunting.



Source: Battelle Columbus Laboratories

FIGURE 5-1 EFFECTS OF CAR GROSS WEIGHT (AXLE LOAD), ALL SPEEDS, RAIL TEMPERATURE <80°F

Derailment Investigation

Two similar derailments occurred on the Southern Pacific line in Southern California west of Yuma, Arizona, within an 11-day period of 1975. These derailments occurred in desert areas where blowing sand tends to infiltrate the ballast, collect between the rail base and tie plate, and sandblast the rail running surface. Several similar derailments on both the Santa Fe and Union Pacific Railroads under similar circumstances were also noted. Vehicle tests were undertaken by the Southern Pacific, and simultaneous track measurements were sponsored by the AAR TTD Program, to investigate the causes of these derailments. Battelle Columbus Laboratories provided technical support in the data acquisition and analysis.

An analysis of the track measurements showed that a substantially higher level of truck-hunting activity was occurring at the Southern California site than at the comparable tangent-track site on the Union Pacific in Idaho. Both sites consisted of good continuous welded rail track, but the type of surroundings were different. The Idaho desert consists predominantly of lava rock and wind-blown fines, while the California desert consists of wind-blown sand. Analysis of track dynamic gage measurements showed a larger percentage of passing wheels in hard flange contact, and critical hunting speeds roughly 10 mph lower. Severe truck hunting was observed at speeds as low as 35 mph. The primary cause for this was felt to be the sand-blasted condition of the rail, with higher creep forces and adhesion limit, possibly combined with variations in rail cant caused by blown sand between the rail and the tie plate.

Also, certain types of cars were found to be more prone to truck hunting than other types. For example, the 50-foot boxcars (Class B5Y), empty or lightly loaded, accounted for 27 percent of those cars identified as hunting (dynamic gage exceeding 0.2 inch), but constituted roughly 5 percent of the higher speed train population in the investigation. Out of a total of 331 identified hunting cars, only 24 were listed on the tonnage report as loaded. On the other hand, empty mechanical refrigerator cars, about 6 percent of the total population (11,365 cars), accounted for 5 percent of the identified hunting cars. While flat cars did not account for an unusual percentage of hunting cars, more than half of the highest dynamic gage peaks (greater than 0.35 inch) were produced by flat cars.

The more common types of freight cars are listed in Table 5-2 for the higher speed trains in the test period. A "hunting index" was developed in this table by dividing the percent of identified hunting cars by the percent in the population less than 50 tons gross weight on rail. From this, the most troublesome cars when running empty are the 50-foot boxcar (B5Y), the refrigerator car (RB5), the open hopper car (HO), the bulkhead flat car (FB6), and the tri-level auto rack flat car (F3), in descending order of index. No direct dependence of the hunting index on the size, weight, and length of cars was observed.

5.5.4 Rock-and-Roll Oscillations

Severe problems of rock-and-roll oscillations were experienced in the mid-1960's with covered hopper cars. The peculiarities of these cars are:

- They have a high center of gravity when loaded; and
- Their truck spacing tends to be such that staggered-joint bolted-rail track tends to strongly excite the roll resonance.

TABLE 5-2

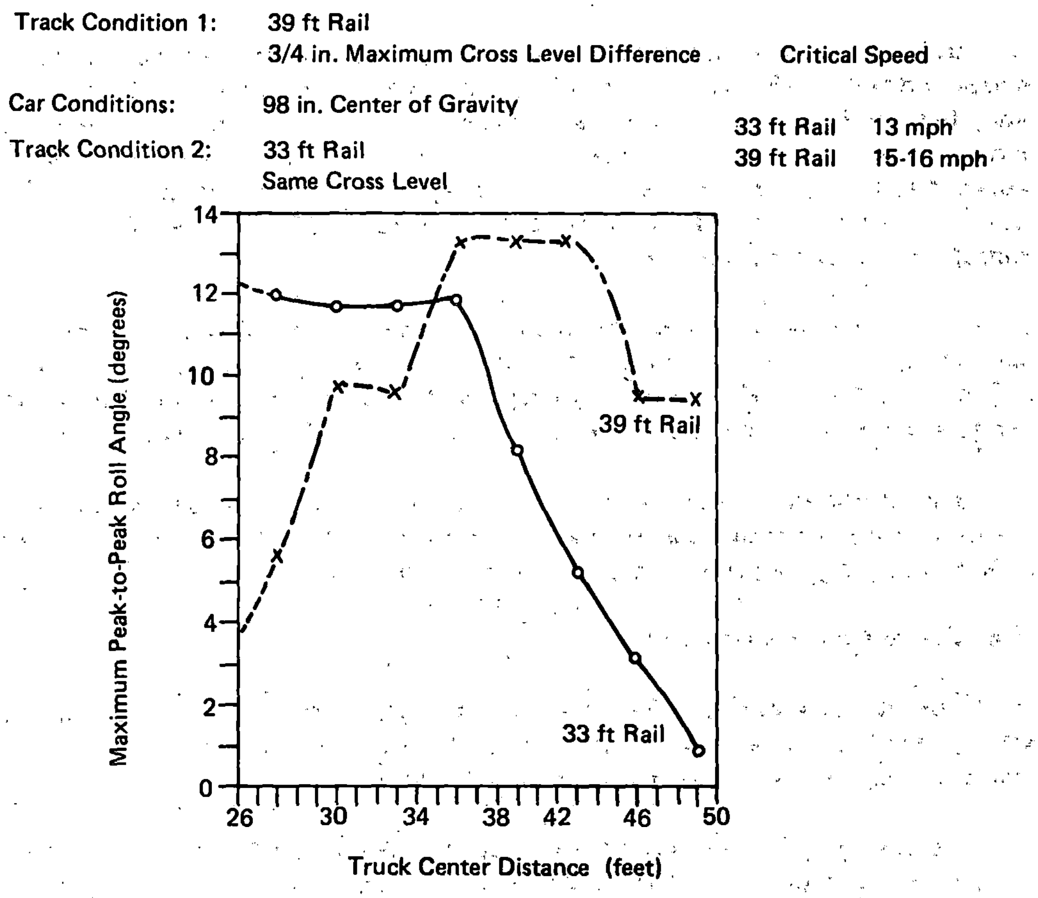
TYPES OF FREIGHT CARS IDENTIFIED AS HUNTING ON TANGENT CAR TRACK

Car Type	Class*	Population (%)** <50T	Population (%)** >50T	Percent of Hunting Cars†	Hunting Index•
Auto parts car	A5	0.1	0.8	0.3	
Auto parts car	A6	0	2.3	0	
Box car, 40 ft	B4	2.2	0.4	0.3	0.1
Box car, 50 ft	B5	5.8	2.4	8.5	1.5
Box car, 50 ft	B5Y	3.5	1.3	27.5	7.9
Covered hopper car	CH3	1.0	0.1	1.5	1.5
Covered hopper car	CH4	0.9	1.7	2.4	2.7
Damage-free box car, <60 ft	D5	0.9	6.1	1.5	1.7
Damage-free box car, <70 ft	D6	0.1	6.5	1.2	
Flat car, bilevel	F2	0	1.5	0	
Flat car, trilevel	F3	2.3	1.3	7.3	3.2
Flat car, <60 ft	F5	3.8	0.2	6.9	1.8
Flat car, container	FC/FC2	0.8	9.6	0.9	1.1
Flat car, bulkhead	FB6	0.8	0.1	3.3	4.1
Gondola	GB	3.0	0	0	0
Hopper car	HO	0.8	0.2	3.9	4.9
Refrigerator car	R5	2.1	2.8	8.2	2.0
Refrigerator, bunkerless	RB4	1.1	0.2	0	0
Refrigerator, bunkerless	RB5	0.8	0.5	6.0	7.5
Refrigerator car	R6	0.1	2.1	0	
Refrigerator, mechanical	RM/RML	6.3	0.4	4.8	0.8
Tank car	T	2.5	2.8	4.5	1.8

Note: Not a complete listing of cars

*Designation per Conductor's Tonnage Reports (Manifest)
**For westbound (downgrade) trains in higher speed bands only
†331 cars identified out of 361 hunting, 11,365 cars recorded
•(% of hunting cars)/(% of population <50T GWT)

Source: Battelle Columbus Laboratories



Source: Track Train Dynamics

FIGURE 5-2 EFFECTS OF TRACK CENTER DISTANCE ON THE MAXIMUM PEAK-TO-PEAK ROLL ANGLE

In addition, these cars — often used for hauling grain — tend to operate on track of relatively poor quality, so that first, strong variations in the cross-level of the track might be expected and, second, operating speeds are low because of track conditions. This peculiar set of circumstances — high center of gravity, unfortunate truck spacing, poor quality track and slow speeds — caused a strong rock-and-roll resonance, leading to several derailments.

The strong influence of truck center distance on the rock-and-roll oscillation may be seen in the computer-derived curves shown in Figure 5-2. With 39-foot rail lengths, the large roll angles that occur with a truck center distance of 36 feet to 43 feet begin to drop off as the truck center distance approaches 50 feet. For 33-foot rail, the maximum value of the roll angle drops rapidly as the truck center distance takes values greater than about 40 feet.

It is apparent that the rock-and-roll problem is caused by particular combinations of size (as determined by the height of the center of gravity), weight, and length. In particular, the problem occurs with cars that have a high center of gravity and a truck spacing that is close to the 39-foot spacing of joints in jointed track. The means for avoiding the problem are discussed in Chapter 7.

5.5.5 Pitch and Bounce Oscillations

Pitch and bounce oscillations are excited by variations in the surface of the track, just as rock-and-roll oscillations are excited by variations in the cross-level. They are of concern partly because they result in large oscillations, which can result in discomfort to occupants or damage to lading; partly because they may generate high dynamic vertical loads that damage the track; and partly because they may generate low vertical loads which, if they occur in conjunction with high lateral loads — because of hunting or curve negotiation, for example — can cause derailments.

No evidence exists of derailments having been caused by pitch and bounce oscillations. This may be a consequence of the fact that they were among the first vibration modes studied in the history of vehicle technology and that the techniques for controlling them are therefore fairly well understood. Occasional examples of poor design do occur, however.

Limiting the size, weight, and length of cars will not help eliminate bounce and pitch problems. It is more appropriate to specify minimum performance requirements. Procedures for developing such requirements are discussed in Chapter 8.

5.5.6 Yaw and Sway Oscillations

Both yaw and sway involve lateral motions of the carbody. In a yaw oscillation, the carbody pivots about a vertical axis halfway between the trucks. In a sway oscillation, it moved laterally, always remaining parallel to the track.

Yaw and sway oscillations have not so far been indicated as causes of railroad accidents. However, they occur in carbody hunting — admittedly in a complex way — and may participate in the generation of high forces in dynamic curving. Furthermore, they can create severe occupant discomfort, since people are far less able to withstand lateral oscillations than they can vertical oscillations.

Yaw and sway resonances depend in a complex way on the size, weight, and length of railroad cars, as with rock and roll and pitch and bounce. Furthermore, the design of the suspensions is a crucial determinant of the extent to which yaw and sway oscillations will occur. There is no evidence at present that there are particular combinations of size, weight, and length of cars for which severe problems of yaw and sway oscillations necessarily exist.

5.5.7 Steady-State Curving Problems

When a vehicle negotiates a curve, it is inevitable that lateral forces will develop between its wheels and the rails, even when the track is perfect. Generally, however, these forces will not fluctuate (hence, the term "steady-state") and will be low on perfect track. There are designs, however, for which high steady-state lateral curving forces can occur.

There are three conditions that tend to worsen the steady-state curving behavior of a vehicle:

- The spacing between the axles of its trucks is large;
- The axles in a truck are rigidly constrained to remain parallel to one another, instead of being allowed to align themselves with the curve; and
- The design of the truck is such that when it enters a curve, it cannot easily rotate (yaw) with respect to the carbody in order to align itself with the curve. This is primarily a case of poor design, but it may also be caused by poor maintenance, resulting in excessive friction in the centerplate and at the size bearings.

None of these conditions that lead to poor steady-state curving behavior is associated with any particular combination of size, weight, and length of freight cars, with this exception: very large axle spacings occur in three-axle trucks, which are used in special-duty, extra-heavy cars. The population of these cars is exceedingly small, however, and there is no evidence that they have contributed to a lack of safety.

5.5.8 Spiral Negotiation

A spiral is that portion of track that connects a tangent (straight) section to a curved section. When a vehicle enters a spiral from a tangent, it experiences both a lateral excitation (since it is being made to depart from its previous straight path) and a crosslevel excitation. The former can cause high lateral wheel-rail forces to be generated, while the latter may cause low vertical forces. Between them, these two phenomena could lead to high L/V ratios and thus to derailment. In point of fact, the latter problem — how vertical wheel forces due to torsionally stiff carbodies — is the only documented problem in spiral negotiation. For low vertical wheel forces to occur, a car must be both long and torsionally stiff. The torsional stiffness of the car usually decreases as its length increases. Thus, the spiral negotiation problem arises only in special circumstances, wherein the ratio of torsional stiffness to length is low. There is no indication that the existence of this problem is correlated with large size, weight, or length.

5.5.9 Dynamic Curving Problems

When the alignment of the rails in a curve varies from its nominal value, large dynamic lateral forces can be generated between the wheels of a vehicle negotiating that curve and the rails.

The phenomenon of dynamic curving is poorly understood at present, and there is no evidence that it has been the cause of problems in the past. Factors that contribute are:

- Large axle weights (unsprung masses);
- Yaw and sway oscillations of the carbody that are attuned to alignment variations in the track;

- Truck designs that do not easily allow the truck to yaw relative to the carbody — either because of excessive friction or because the yaw moment of inertia of the truck is high; and
- The existence of steady-state curving problems (see Section 5.5.7), which make it more likely that a wheel will be forced to maintain flange contact with its rail and thus experience the alignment variations of that rail.

There is some evidence from recent tests conducted at Pueblo by the Federal Railroad Administration that dynamic curving problems are partially correlated with high axle loads. On the other hand, there is no specific instance in which a derailment has been attributed to dynamic curving problems in a freight car. The more appropriate concern is whether poor dynamic curving behavior leads to rapid track degradation. The answer is, it can. It is desirable to seek means of improving the dynamic behavior of railroad cars. The cures may lie equally in restricting axle loads to their present limits in unrestricted interchange and in the correct design of trucks and their suspension systems.

5.5.10 Response to Joints and Special Trackwork

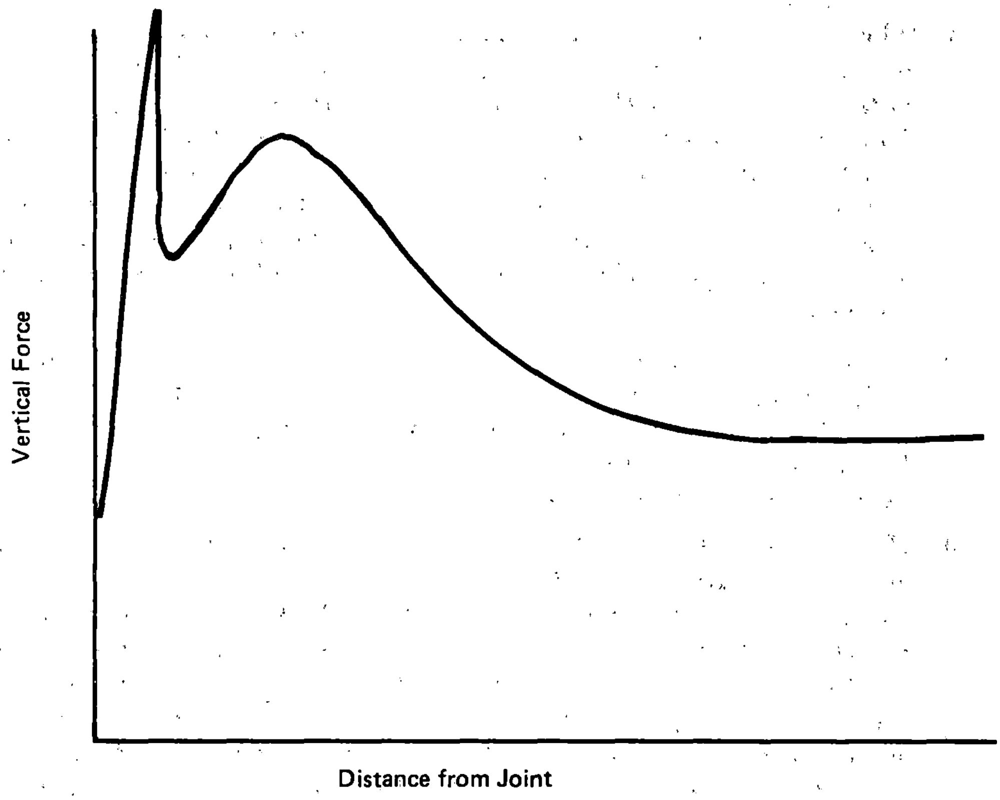
High vertical forces can occur near a joint as an axle traverses it as shown in the hypothetical example in Figure 5-3. The magnitude of the peak vertical forces is determined primarily by the weight of the axle and the dynamic behavior of the track structure. Since heavy cars tend to have larger wheels and, therefore, heavier axles, higher dynamic vertical loads can be expected with them. When these high dynamic loads are added to the high static wheel loads, the situation is further exacerbated.

The generation of high lateral forces at joints is a more complex phenomenon. In the first instance, a wheel must "see" a joint to react to it; in other words, the wheel flange must be pressed against the rail as the wheel rolls over the joint, for otherwise, no lateral discontinuity will be experienced. Wheel flanging occurs principally in two situations: when the vehicle is in a curve, or when the vehicle is hunting. Hunting occurs primarily on tangent track; its causes are discussed in Section 5.5.1.

In curve negotiation, whether or not a wheel will be flanging near a joint depends on the design of the suspension system. Long irregularities in the alignment of the rail cause yaw and sway oscillations of the truck and carbody, so that the truck may oscillate from flanging on one rail to flanging on the other. If a joint occurs when the truck is pushing the axles against a rail, high wheel-rail forces may be caused. The response of the truck and carbody is determined by the design of the suspension.

Wheel flanging in curves may also be caused by rigid truck designs, which are desirable to eliminating hunting. If the two axles in a truck are rigidly constrained to remain parallel to each other, the coned wheel tread is insufficient for guiding the axle through any but the shallowest of curves, and guidance occurs by wheel flanging.

Finally, wheel flanging can be caused by large buff-and-draft forces while the train is accelerating or braking in a curve. This phenomenon is discussed in Section 5.6. Its influence on wheel response to joints is this: if a long car is placed next to a short car in a train and



Source: Arthur D. Little, Inc.

FIGURE 5-3 HYPOTHETICAL VERTICAL FORCE VALUES

large buff-and-draft forces are generated, wheel flanging is almost certain to occur. High dynamic lateral forces are then sure to be generated at joints in the curve. In addition, long cars will experience flanging more easily than short cars under steady buff forces in a curve and may, therefore, generate high lateral forces at joints more often.

In summary, high axle loads, coupled with heavy axles and either the wheel flanging phenomenon or hunting, lead to high vertical and lateral forces at joints and other discontinuities in the track. These forces are the starting point of much track degradation and are the cause of many track and equipment component failures.

5.6 TRAIN ACTION

5.6.1 Introduction

The behavior of individual cars was discussed in Section 5.5. Equally important to safety is the behavior of trains. The following paragraphs contain an investigation of the relationship between train behavior and railroad safety, with particular emphasis on how train behavior is influenced by the size, weight, and length of railroad cars.

The characteristics of long trains that may lead to accidents are the following:

- When the brakes are applied (at high levels of deceleration, as in emergency braking or full service braking), high compressive or "buff" forces can develop in the train. These buff forces cause an accordion-like buckling motion of the train. In this buckling motion, cars may yaw (rotate about a vertical axis) or be pushed sideways, resulting in large lateral forces between wheels and rails. With light (empty) cars, high L/V ratios may develop, eventually leading to derailment. This phenomenon occurs both on tangent and curved track. The high buff forces are primarily the result of the different deceleration rates of loaded and empty cars.
- If the locomotive is operating at high tractive effort while negotiating a curve — for example, when climbing a gradient at low speeds — high tensile or "draft" forces develop in the train. These forces tend to straighten the train or "stringline it," thus creating a tendency for cars to be derailed by being pulled to the inside of the curve.
- If a long train is traversing undulating terrain, some portions of it may be descending a gradient while other portions are ascending it. The descending portions are pulled forward by gravity, while the ascending portions are pulled backward. In this manner, several longitudinal oscillations of the train may develop, which can only partially be controlled by the train operator through the use of throttle and brakes. The longitudinal oscillations generate high buff and draft forces, which can result in derailment by wheel climb or in broken couplers. When a coupler breaks, the train also breaks into two parts, and the air brake line is severed. This results in automatic application of the emergency brakes, leading to the possibility of either a derailment or a collision between the two portions of the train.

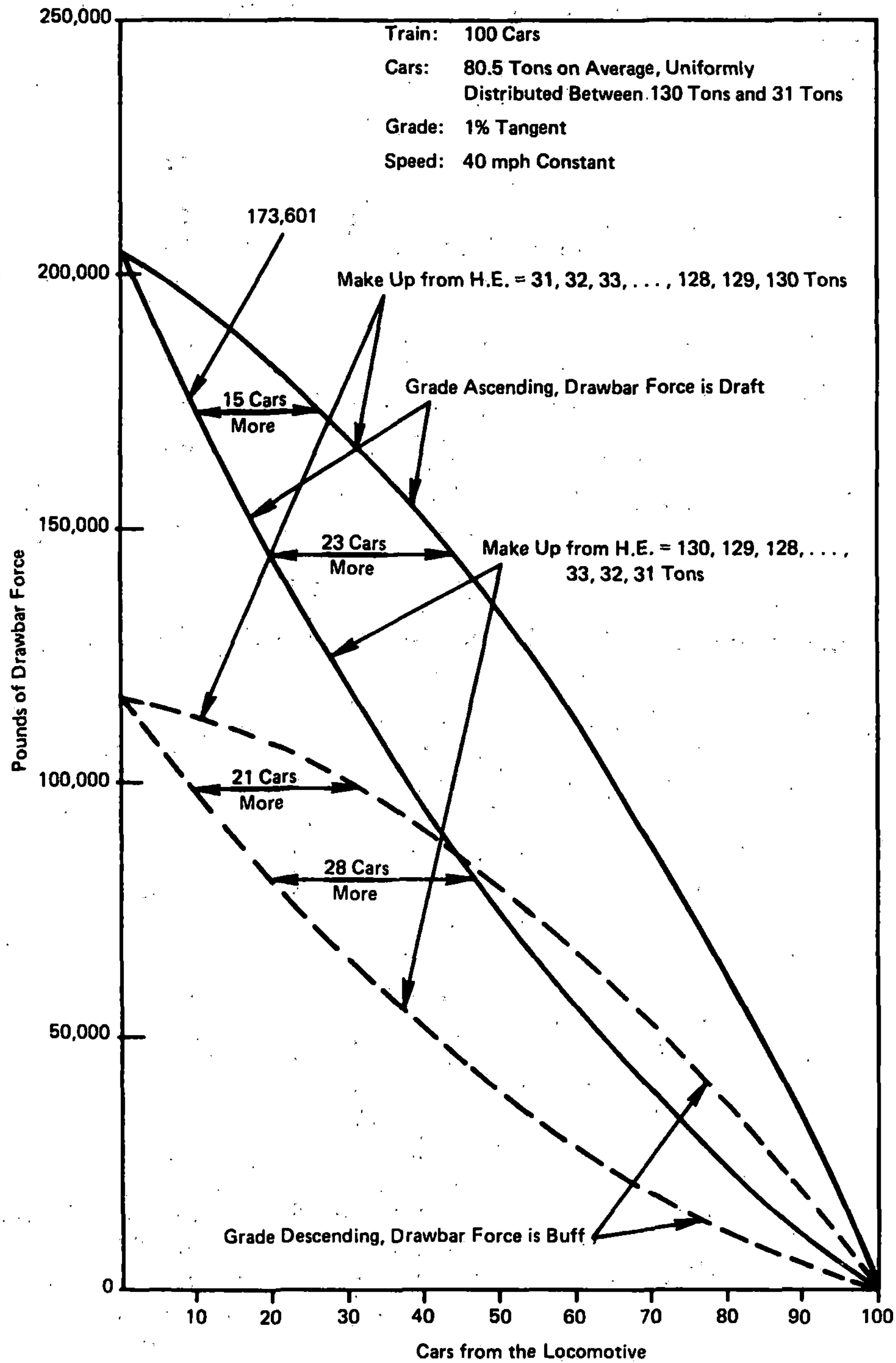
Historically, train action problems began to be apparent in the 1960s, as increasingly longer trains were introduced into service. In recognition of these problems, the Track Train Dynamics Program, jointly sponsored by the Federal Government and by industry, undertook extensive investigations of train action in the early 1970s. Many of these investigations were based on a computerized model of train action called the Train Operations Simulator (TOS). The TOS was developed specifically for the purpose of studying train action.

The following results were obtained both from the Track Train Dynamics investigations and from additional investigations made specifically for the present report. The new investigations were based on the use of TOS to specifically study the effects of the size, weight, and length of railroad cars on the possibility of derailment being caused by train action.

5.6.2 Placement of Loaded and Empty Cars

When a train contains both loaded and empty cars, it is preferable to place the loaded cars at the front end of the train. Loaded cars usually experience the same braking force as empty cars and, because of their larger weight, decelerate at a lower rate than empty cars. If they were placed toward the end of the train, they would push against the light, empty cars at the front end of the train, creating high buff forces and L/V ratios.

Figure 5-4 graphically shows the effects described above. The upper two curves show the maximum draft forces as two 100-car trains ascend a grade. One of the trains has an empty car next to the locomotive, and progressively heavier cars from that point on. In the other train, this car placement order is reversed. The lower two curves are for the same trains on a descending grade, and show buff forces.



Source: Track Train Dynamics

FIGURE 5-4 DRAWBAR FORCE TRANSMITTED BY A CAR TO THE TRAILING CAR (THEORETICAL)

Although the largest coupler forces are the same for both trains, they occur on an empty car for the train that is light in front and on a heavy car for the train that is light in the rear. The former will have much higher L/V ratios than the latter, and is thus exposed to a greater risk of derailment.

Similar results may be seen in Table 5-3, which compares two 60-car consists during emergency braking on a 4-degree curve. Consist A has 30 empty cars weighing 23 tons each, followed by 30 loaded cars weighing 123 tons each. Consist B has the loaded and empty cars in reverse order. All cars are 40-foot box cars.

TABLE 5-3

EFFECT OF PLACEMENT OF LOADED AND EMPTY CAR GROUPS ON TRAIN ACTION

	Consist A	Consist B
Max. Buff Force	204,000 lb	117,000 lb
Max. L/V Ratio	0.72	0.36

Consist A:	2 locomotives +30 cars (23 tons, 40 ft each) + 30 cars (123 tons, 40 ft each) + 1 caboose.
Consist B:	2 locomotives + 30 cars (123 tons, 40 ft each) + 30 cars (23 tons, 40 ft each) + 1 caboose.
Conditions:	Emergency braking from 40 mph in a 4-degree curve.

5.6.3 Car Length

Car length by itself does not significantly influence the possibility of its derailment in a train. Table 5-4 compares the buff forces and L/V ratios of two train consists that are identical in every respect except that one contains 40-foot cars and the other, 80-foot cars. Although the buff forces for the train with long cars are about 20 percent higher and the L/V ratios, 50 percent higher, the absolute values are still well below any safety threshold.

TABLE 5-4

EFFECT OF CAR LENGTH ON TRAIN ACTION

	Consist A	Consist B
Max. Buff Force	180,000 lb	218,000 lb
Max. L/V Ratio	0.19	0.32

Consist A:	2 locomotives + 60 cars (40 ft, 123 tons each) + 1 caboose.
Consist B:	2 locomotives + 60 cars (80 ft, 123 tons each) + 1 caboose.
Conditions:	Emergency braking from 40 mph in a 4 degree curve.

However, variations in the lengths of cars within a train are more significant: placing a short car next to a long car worsens the coupler angle problem described above. Table 5-5 shows what happens when one car in a train made entirely of 40-foot cars is replaced by an 80-foot car: although the maximum value of the buff force decreases by about 13 percent, the maximum L/V ratio increases by almost 40 percent.

TABLE 5-5

EFFECT OF REPLACING ONE CAR IN CONSIST WITH LONGER CAR

	Consist A	Consist B
Max. Buff Force	199,000 lb	173,000 lb
Max. L/V Ratio	0.69	0.99

Consist A: 2 locomotives + 30 cars (23 tons, 40 ft each) + 30 cars (125 tons, 40 ft each) + 1 caboose

Consist B: 2 locomotives + 30 cars (23 tons, 40 ft each) + 1 car (123 tons, 80 ft) + 29 cars (123 tons, 40 ft each) + 1 caboose

Conditions: Emergency braking from 40 mph in a 4 degree curve.

5.6.4 Train Length

The length of the train, as defined by the number of cars in it, has little effect on derailment tendency during braking if other problems of consist makeup, such as those described above, do not exist. Table 5-6 compares a short train with a long train, one with no helper locomotives as well as with a long one with helpers. The data are for full service braking and show that the L/V ratios vary only marginally from one consist to the next.

Train length is important, however, if one considers train control on undulating terrain. Trailing tonnage, which depends on both the number of cars in the train and their load, is important in draft situations, such as grade-climbing, where high tensile forces may be set up along the train. These tensile problems can be controlled to some extent by the use of remote-controlled "slave" locomotive units in the middle of the train.[2] In ascending grade territory, for example, if one uses two head-end units and two mid-terrain slave units, the maximum draft forces will be approximately half of what would be obtained with four head-end units.

5.6.5 Car Weight

Not many cars are equipped with self-adjusting brakes, which adjust the braking ratio according to the weight of the car. As a consequence, most cars experience the same total retarding force, regardless of whether they are empty or loaded. The rate of deceleration will then be inversely proportional to the weight of the car. For example, an empty 23-ton car will decelerate at over five times the rate of a loaded 123-ton car. Thus, if empty cars are followed by heavy cars in a train, large compressive forces can develop in the train, as shown in Section 5.6.2.

TABLE 5-6

EFFECTS ON TRAIN ACTION OF SHORT TRAIN AND LONG TRAIN WITH AND WITHOUT HELPER LOCOMOTIVE

	Consist A	Consist B	Consist C
Max. Buff Force	199,000 lb	204,000 lb	181,000 lb
Max. L/V Ratio	0.69	0.71	0.66

Consist A: 2 locomotives + 30 cars (23 ton, 40 ft)
+ 30 cars (123 ton, 40 ft) + 1 caboose.

Consist B: 4 locomotives + 30 cars (23 ton, 40 ft)
+ 30 cars (123 ton, 40 ft)
+ 30 cars (23 ton, 40 ft)
+ 30 cars (123 ton, 40 ft)
+ 1 caboose.

Consist C: 2 locomotives + 30 cars (23 ton, 40 ft)
+ 30 cars (123 ton, 40 ft)
+ 2 slave locomotives
+ 30 cars (23 ton, 40 ft)
+ 30 cars (123 ft, 40 ft)
+ 1 caboose

Condition: Full service braking from 40 mph on a 4-degree curve.

5.7 COMPONENT FAILURES

Tables 5-7 and 5-8 show the rate of derailments caused by two specific types of component failure, as a function of the type of car and the nominal weight capacity of the car. As can be seen from these two tables, component failure frequencies do not necessarily correlate with the weight of cars or with the type of car. This is because many vehicle components are sized so that the levels of stress within them do not vary as car weight or length increase. For example, heavier cars have heavier trucks, larger bearings, and larger wheels. The occurrence of a component failure is connected more with the quality of inspection and maintenance performed on the car than with its size, weight, and length.

Track component failures, on the other hand, are hastened by large wheel-rail loads. If the vehicle-track interaction modes described in Section 5.5 or the train action modes described in Section 5.6 are intensely excited, they contribute to track component failure. Poor quality track suffers the majority of component failures, since it experiences large loads and stresses and is infrequently inspected and maintained.

In addition, two important equipment components are subject to failures that are the result of neither vehicle-track interaction nor train action. Plain journal bearing failures are subject to seizure from an absence of lubricant in the journal box. Such a failure can be catastrophic in those instances in which the axle can no longer rotate freely. Wheels are subject to thermal fatigue failures, which are apparently caused by a few cycles of excessive heating caused by stuck brakes, misapplied brake shoes, or drag braking for extended periods on descending grades.

TABLE 5-7

WHEEL FAILURE
DERAILMENTS PER TEN BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	All
Box	3.9	4.3	1.9	4.0
Auto Flat	16.3	1.4	*	14.2
General Flat	*	*	*	*
TOFC	5.9	3.3	7.7	5.0
Gondola	5.1	3.9	1.8	2.6
Covered Hopper	2.7	3.3	2.0	2.2
Open Hopper	1.3	4.3	1.3	2.3
Refrigerator	6.1	2.9	3.6	3.9
Tank	1.9	2.4	1.7	1.8
ALL	5.4	3.8	1.9	3.3

*Small Sample

Fleet Average = 3.3

To gain a more complete understanding of the nature and incidence of component failures, we analyzed the data obtained in the FRA's RAIRS to determine which track and equipment components contribute most to derailments. The results are shown in Table 5-9. It appears, at first glance, that track component failures are of major importance. This is indeed true if one is concerned simply with the total number of accidents. From a risk point of view, however, one might wish to examine severe accidents and determine what role component failures play in them. To do this, a simple definition of severity was used: the speed at which the accident occurs; the higher the speed, the more severe the accident. The relationship between accident speed and damage to equipment and track is shown in Figure 5-5.

The specific speed ranges chosen were 0 to 10 mph; 11 to 30 mph; and greater than 30 mph. The most important component failures in each of these speed ranges are shown in Tables 5-11 and 5-12. What is apparent is that for more severe accidents, equipment component failures predominate as cause, as opposed to track component failures for less severe accidents. The reason is not difficult to find. If track conditions are poor, track component failures are likely to occur. However, train speeds will also be low, in recognition of the poor quality of the track, and accidents will generally not be very severe.

TABLE 5-8

BEARING AND AXLE FEATURE DERAILMENTS PER TEN BILLION NET TON-MILES

Car Type	Capacity (Tons) 50	70	100	All
Box	0.7	0.1	0.2	0.4
Auto Flat	*	*	*	*
General Flat	*	*	*	*
TOFC	0.1	0.6	*	0.3
Gondola	3.4	3.4	0.5	1.5
Covered Hopper	*	0.6	*	0.5
Open Hopper	1.0	0.8	*	0.5
Refrigerator	0.9	0.3	*	0.4
Tank	*	*	0.1	0.1
ALL	0.6	0.6	0.2	0.4

*Small Sample

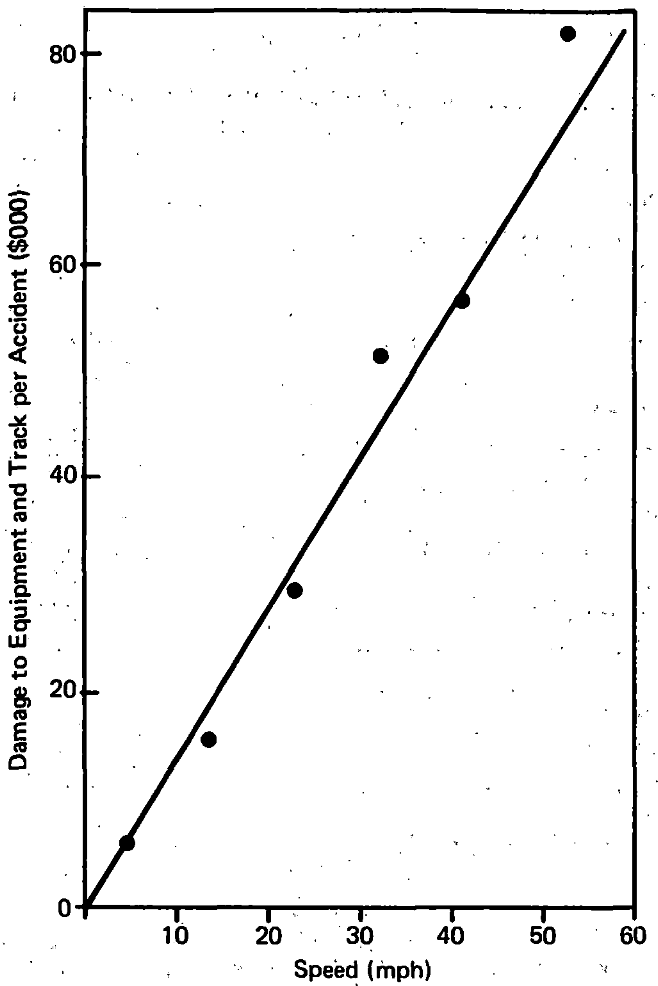
Fleet Average = 0.4

TABLE 5-9

1977-1978 FRA ACCIDENT DATA FOR ALL SPEEDS

All Accidents			
Track or Equipment Component Failures*		9343	
Track Degradation		5109	
All Other Causes		12101	
TOTAL		26553	
Component Failures			
1. Rails and Joint Bars		2768	(29.6%)
2. Frogs, Switches and Track Appliances		2180	(23.3%)
3. Wheels		901	(9.6%)
4. Couplers and Draft System		654	(7.0%)
5. Axle Bearings		572	(6.1%)
Plain	429		
Roller	143		
6. Brakes		542	(5.8%)
7. Side Bearings		534	(5.7%)
8. Center Plate and Pin		304	(3.3%)
9. All Others		888	(9.5%)
TOTAL		9343	

*Excludes locomotive components



Source: Arthur D. Little, Inc., Analysis of FRA Data

FIGURE 5-5 RELATIONSHIP BETWEEN ACCIDENT SPEED AND EQUIPMENT AND TRACK DAMAGE

The data presented in Tables 5-11 and 5-12 indicate that the following track and equipment components are of primary interest as far as component failures are concerned:

- Wheels
- Plain journal and roller bearings
- Couplers and draft gear
- Side bearings
- Rails and joint bars
- Ties (whose failure leads to wide gage and other track geometry defects).

The failures of all of these components — with the exception of plain journal bearings and sometimes wheels — are the direct consequence of wear and fatigue caused by vehicle-track interaction and train action, coupled with inadequate maintenance and inspection. It is worth reiterating the fact that component failure frequencies show no particular trends as the size, weight, or length of cars is increased.

TABLE 5-10

1977-1978 FRA ACCIDENT DATA FOR SPEEDS OF 0 TO 10 MPH

All Accidents			
Track or Equipment Component Failures*		6189	
Track Degradation		3814	
All Other Causes		9452	
TOTAL		19455	
Component Failures*			
1. Frogs, Switches and Track Appliances		2067	(33.4%)
2. Rails and Joint Bars		2032	(32.8%)
3. Wheels		472	(7.6%)
4. Coupler and Draft System		329	(5.3%)
5. Brakes		295	(4.8%)
6. Side Bearings		269	(4.4%)
7. Axle Bearings		104	(1.7%)
Journal	82		
Roller	22		
8. All Others		621	(10.0%)
TOTAL		6189	

*Excludes Locomotive components

TABLE 5-11

1977-1978 FRA ACCIDENT DATA FOR SPEEDS OF 11 TO 30 MPH

All Accidents			
Track or Equipment Component Failures*		1931	
Track Degradation		1079	
All Other Causes		1726	
TOTAL		4736	
Component Failures*			
1. Rails and Joint Bars		553	(28.6%)
2. Axle Bearings		231	(12.0%)
Plain	174		
Roller	57		
3. Side Bearings		222	(11.5%)
4. Wheels		173	(9.0%)
5. Coupler and Draft System		163	(8.4%)
6. Brakes		151	(7.8%)
7. All Others		438	(22.7%)
TOTAL		1931	

*Excludes locomotive components

TABLE 5-12

1977-1978 FRA ACCIDENT DATA FOR SPEEDS GREATER THAN 30 MPH

All Accidents			
Track or Equipment Component Failures*		1257	
Track Degradation		200	
All Other Causes		905	
TOTAL		2362	
Component Failures*			
1. Axle Bearings		237	(18.9%)
Plain	173		
Roller	64		
2. Wheels		199	(15.8%)
3. Rails and Joint Bars		164	(13.1%)
4. Couplers and Draft Systems		162	(12.9%)
5. Other		495	(39.0%)
TOTAL		1257	

*Excludes locomotive components

5.8 TRACK DEGRADATION

5.8.1 Introduction

Railroad track is a mechanical structure which, like other mechanical structures, has a load-bearing capability that cannot be exceeded without causing rapid deterioration. Also, if deterioration commences and maintenance is inadequate, the rate of deterioration becomes progressively faster.

Track deterioration under heavy wheel loads appears in many forms — loss of surface and line; conversion of subgrade and ballast sections into plastic masses that pump mud and water; wide gage, plate cut, split, and spike-killed ties; rapid abrasive wear; battered rail ends; and the formation of corrugated and shelly rails, the last with the potential for detail fractures. This situation has not been helped by the extent of deferred maintenance on many miles of line.[3]

5.8.2 Track Deflection

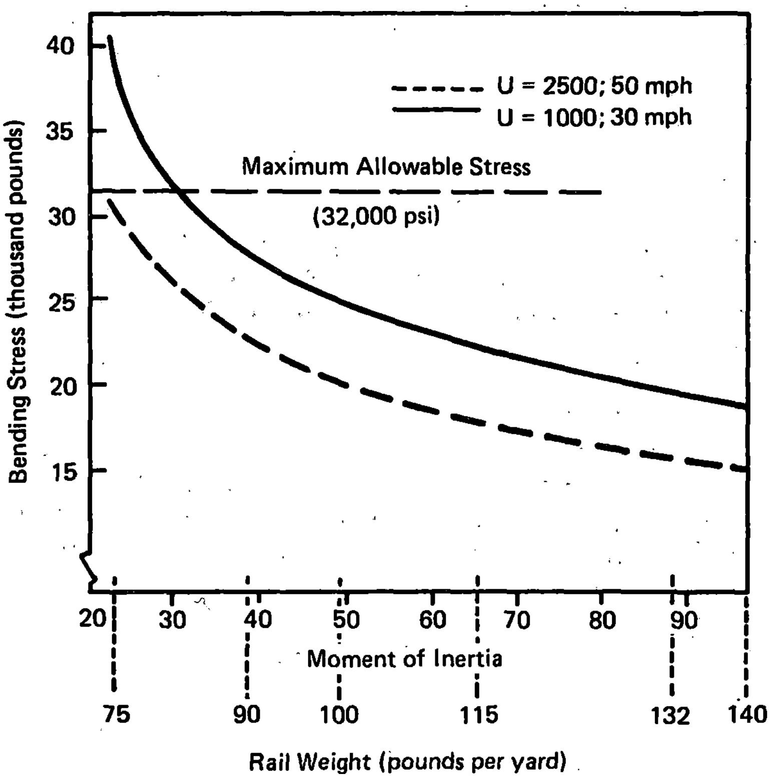
Track deflection is a necessary precursor of track deterioration. Heavy wheel loads increase track deflection as well as the relative movement between track components that accelerates wear. The frequency of loading and unloading cycles combines with deflection to hasten degradation. With a stiff track support, not only is deflection reduced, but the load of cycles of individual wheels can be merged to lessen their frequency. For example, the two axles of a car truck may cause an effective single cycle because their deflection curves have merged.

As with all structures, a first requisite of heavier loads is a stronger foundation. However, more can be accomplished by increasing the stiffness of support than by laying heavier rail. An increase in rail weight has a relatively insignificant effect on reducing deflections in contrast to reductions secured by increasing the modulus of track elasticity.

5.8.3 Rail Fatigue and Plastic Flow

The effect of heavy wheel loads is most often visible in its effect on rails. Battered rail ends, bolt-hole breaks and broken joint bars, head checking, spalling, shelling, corrugating, horizontal and vertical split heads, piped rails, and detail fractures are related in part to the incidence of heavy wheel loads through impact and contract stress effects.

The problem of rail breakage most often arises on branch lines laid with light rails. Figure 5-6 shows the effects of rail weight on bending stresses in the rail. At a speed of 50 mph and a track support modulus of 2,500 pounds per inch, all rails in common use are within an allowable bending stress of 32,000 psi, but when the modulus is reduced to 1,000 and speed to 30 mph (a frequent branch line condition), the stresses developed in 75-pound rail greatly exceed the allowable stresses. The 90- and 100-pound rails are not far below this level.



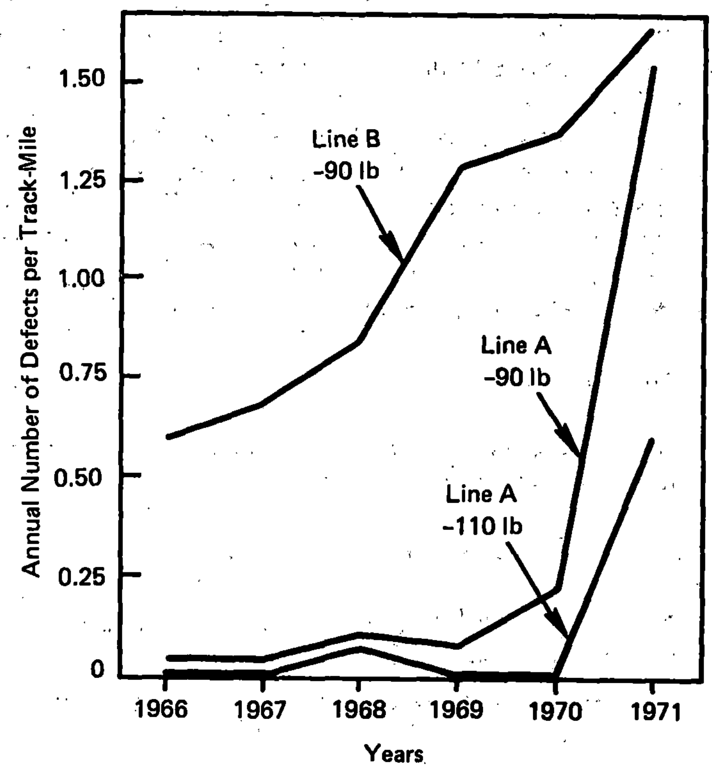
Source: Dr. William W. Hay, "Track Structures for Heavy Wheel Loads," 12th Annual Railroad Engineering Conference, 1975

FIGURE 5-6 BENDING STRESS VERSUS MOMENT OF INERTIA (AND WEIGHT OF RAIL)

Figure 5-7 shows the increase in broken rails on two branch lines laid with 90- and 100-pound rails following the introduction of 100-ton cars. Broken joint bars prove to be correspondingly numerous. The conclusions are inescapable. Where heavy wheel loads are in use, rail should be 115 pounds or heavier to withstand bending stresses, and the modulus of track support should be in the 2,000 pounds per inch range or higher.

Heavier rail is not a solution to problems of contact stresses created directly beneath the point of wheel load application. The problem here is one of shearing and of rail steel quality. The literature, theory, and experience give ample evidence that heavy wheel loads lead to contact-stress-related defects – head checking, spalling, shelling – a hazardous group that can develop into detail fractures. Horizontal fissures and railhead mashing also occur. Corrugated rail is related to contact stresses, as are battered rail ends. Wheel loads of 30,000 pounds or more on 36-inch wheels are overstressing the rail in shear based on an allowable value of 50,000 psi.

Studies of the plastic deformation of rails, sponsored by the FRA, are under way at the Illinois Institute of Technology. They stress the effect of large wheel loads in causing significant plastic flow, which may be strongly correlated with fatigue failures of rails. A report on the status of these studies is contained in Appendix E.



Source: Dr. William W. Hay, "Track Structures for Heavy Wheel Loads," 12th Annual Railroad Engineering Conference, 1975

FIGURE 5-7 ANNUAL NUMBER OF BOLT-HOLE BREAKS PER TRACK MILE VERSUS YEARS

5.8.4 Rail Wear

As a wheel rolls along a rail, small amounts of slippage occur between the wheel and the rail. This slippage is particularly pronounced in curves, and when the brakes are being applied. The slippage results in wear of both the wheel and the rail. Wear of the rail is usually of greater concern because of the greater difficulty of maintaining rails compared with maintaining wheels.

Rail wear leads to a reduction in the load-bearing capacity of the rail because of the reduction in its cross-sectional area. When wear has accumulated to this point, the rail must be removed and either discarded or placed in a line with lighter axle loads. If this is not done, fatigue failures of the rail will occur, and a safety problem is generated.

Rail head wear on the gage side of the rail can occur in such a way that it becomes easier for wheels to derail by climbing up the rail. On the positive side, however, it has been claimed[5] that a small rate of wear on the running surface of the rail is desirable because it prevents fatigue failures caused by high contact stresses. In this view, the rail material in the layer just under the surface is very highly stressed, and this is where fatique cracks are initiated. If this layer is worn away, a new, relatively unstressed layer is continually brought into contact with the wheel, and the fatigue cracks do not have the opportunity to grow to the point where they present a danger. However, the rate of wear required to prevent fatigue failures may be so high that it is uneconomical. In this instance, one has a problem either way: plast deformation, cracks and rail failures; or rapid wear and economic loss.

There is increasing evidence that the high axle loads being used nowadays do, occasionally, create the double-edged problem described above. However, most of the evidence comes from mining railroads operating unit train consists.[5] The data are inconclusive as far as operations with mixed axle loads are concerned. The situation warrants continued and extensive investigation; rapid rail wear with 100-ton and 125-ton cars can create enough of an economic problem that safety levels fall as a consequence.

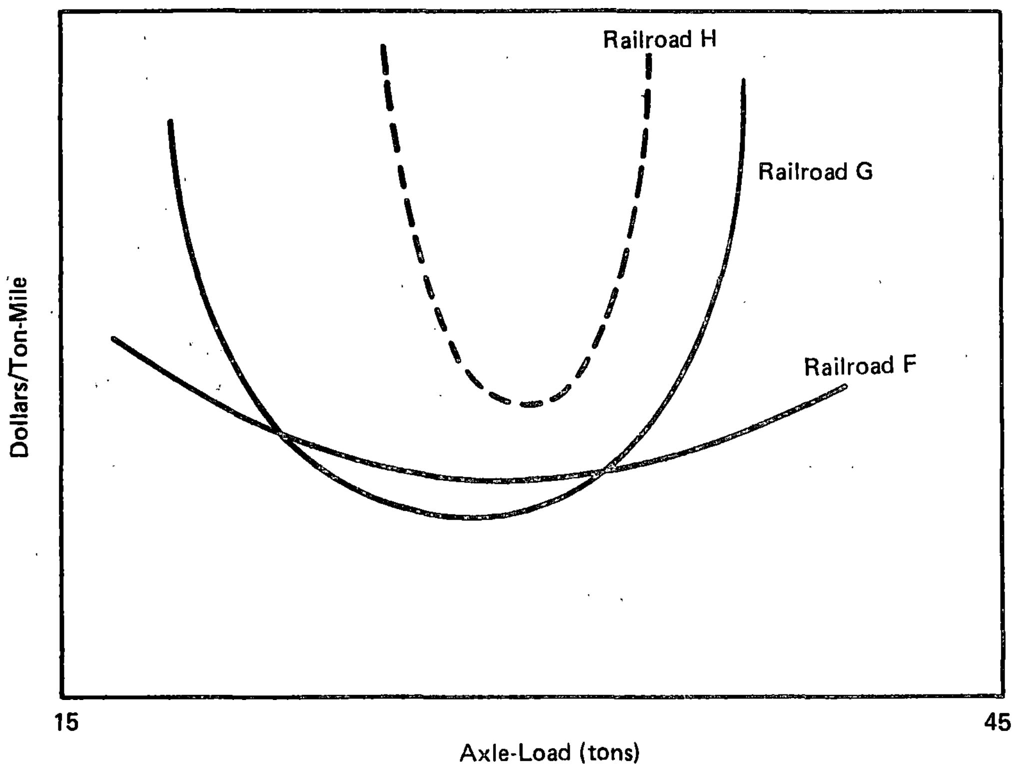
5.8.5 Economic Considerations

Which car size is the most economical has been questioned for many years. The answers available are informative, but ambiguous.

A recent paper[6] suggests that as axle loads increase:

- Freight car acquisition and maintenance costs per net ton-mile decrease, as does the transportation cost; while
- Maintenance-of-way expense per net ton-mile increases, as may the cost of accidents and delays.

The variations in these costs result in the bathtub shaped cost curve shown in Figure 5-8. This curve suggests that there is an optimum axle load and that variations from it can result in significant diseconomies.



Source: American Railway Engineering Association Bulletin 673

FIGURE 5-8 VARIATIONS OF TOTAL COSTS PER TON-MILE

An accompanying study provides the following quantitative cost estimates.[7]

Comparative Costs
(Cents per Net Ton-Mile)

	Maintenance	Transportation	Freight Car Repair	Car Capital	Total
70-ton Hopper Cars	.107	.374	.014	.037	.532
100-Ton Hopper Cars	.135	.348	.010	.029	.522

8000 Gross-Ton Unit Trains;
780 Mile, One-Way Loaded Trip

The very small difference in total cost per net ton-mile between the 70-ton and 100-ton cars (which have axle loads of 25 tons and 32 tons approximately) suggests that the bottom of the curve in Figure 5-8 lies in the neighborhood of a 32-ton axle load, the current limit imposed by the AAR for unrestricted interchange.

The same study makes the additional pertinent point that the detailed shape of the bathtub curve, as well as the location of its minimum, depends strongly on the particular operating circumstances: the nature of the subgrade, the extent of curves and grades, operating speeds, and the type of commodity being handled. The complexity of these relationships makes the actual total cost unpredictable. It is not surprising to find, therefore, that some railroads have experienced severe problems with heavy axle loads,[5] while others have not.[8] Another way of stating this conclusion is this: the optimum axle load varies from one railroad to another. The variation from railroad to railroad makes it impossible to choose a single optimum axle load or car weight. It may be true that 70-ton cars are optimal for railroads with poor track maintenance, but are uneconomical for financially healthy railroads with good track. For the latter, the 100-ton car may be optimal; but it may be both uneconomical and unsafe on poorly maintained track.

5.9 SUMMARY

There are three principal reasons why a particular design of car may be considered to be a safety problem:

- Its own dynamic behavior, whether as a single car or as part of a train, is such that it is prone to derailment.
- It accelerates track degradation because of the large wheel-rail forces it causes, thus exposing all cars to unsafe situations.
- It exposes railroad employees to hazardous situations.

Evidence of the first of these can be found in accident statistics, but evidence of the latter two cannot. For the latter two, information has been obtained in this chapter by synthesizing the results of experimental research and analysis on the one hand, and experience on the other.

The picture resulting from examining safety from the two distinct points of view described above is as follows:

1. Many individual-car dynamic response modes exist which can result in safety problems for that car as well as for other cars through track degradation. These modes can occur and be severe for virtually any combination of size, weight, and length of car. Preventing their occurrence is more a matter of careful attention to design and through safety assessment of the prototype, than of specific restrictions on size, weight, and length.

The exceptions to this general conclusion are:

- Cars with a high center of gravity are more prone to the development of rock-and-roll oscillations than are other cars.
- Heavy cars will generally have heavier axle loads and generate larger vertical forces at joints, switching, frogs, and other trackwork.

Historically, the most pronounced problems have been the hunting of empty cars and the rock-and-roll oscillations of cars with a high center of gravity.

2. Large wheel-rail forces and L/V ratios or large coupler forces may be generated by the behavior of trains in the following situations:

- A long car is placed next to a short car in a train, and emergency braking occurs.
- Empty cars are placed toward the front end of the train and loaded cars at the rear.
- Long trains are operated with slave units.

3. Component failures are accelerated by the occurrence of large carbody or truck oscillations, which cause wear and fatigue and of large wheel-rail forces, which create high stresses. The failures that cause severe accidents often occur on:

- Plain journal bearings
- Roller bearings
- Wheels
- Rails and joint bars
- Couplers

4. Track degradation is accelerated by the use of heavy or long cars, or of car designs in which severe vehicle-track interaction modes exist.

5. The optimum car weight or axle load, taking into account both safety and economics, varies from one railroad to another. Railroads with poor track will find that lighter (70 ton) cars the optimum, whereas railroads with good track will find that the 100-ton cars are better.

6. Heavy or long cars pose some hazard to railroad employees working in yards.

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6. SPECIAL SAFETY CONSIDERATIONS

6.1 ABSTRACT

Specific areas of railroad safety that deserve special attention are hazardous materials transport, grade-crossing accidents, and personnel safety.

Accidents involving hazardous materials tank cars can lead to catastrophic results. Typical scenarios include boiling liquid expanding vapor explosion (BLEVE) and tub rocketing. The risk to the working and residential population at accident sites is shown to be related to the potential tub-rocketing distance and, therefore, the tank car size.

Grade-crossing accidents are the single most important railroad safety problem. The frequency of these accidents is related to the frequencies of the trains at the grade crossings and the lack of protection at grade crossings rather than to rail car characteristics.

Personnel safety, especially in yards, is investigated in this chapter. The occurrences of accidents and injuries are related to functions that do not depend on car size.

6.2 TANK CAR ACCIDENTS

6.2.1 Introduction

This section addresses the relationship between the risk of accidents involving hazardous materials tank cars and the tank car size. The size of the car does not affect the frequency of accidents, but rather determines the size of the population which is potentially at risk from a given accident. Since the risk is dependent on the range over which the lading car can spread and the tank car can potentially rocket, it is therefore dependent on the size of the tank car. This section first presents the scenario of a tank car accident and then examines the relationship between tank car size, the rocketing range, and population at risk. In brief, the potential risk will generally increase with tank car size.

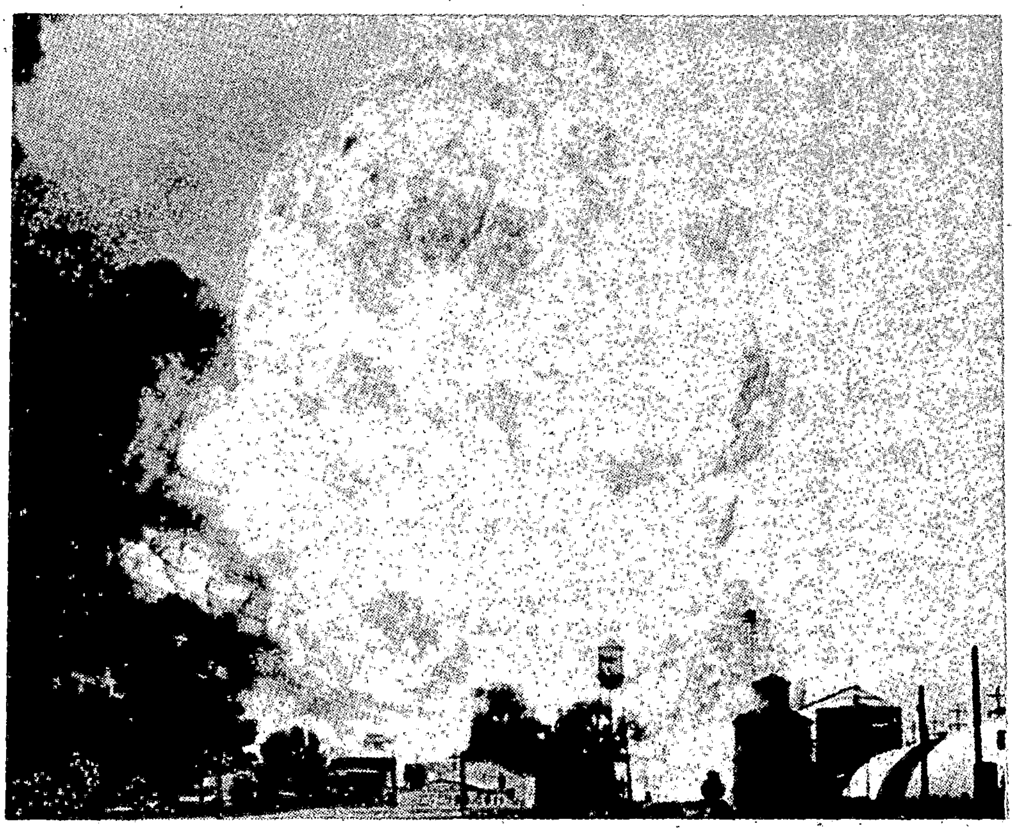
6.2.2 Tank Car Accident Scenarios

The following sequence of events typifies an accident that involves a tank car with compressed liquefied gas lading and that results in large dollar losses. During a derailment or other abnormal occurrence, a tank car is punctured, and the lading is subsequently ignited. The fire causes some damage in the surrounding area and heats one or more tank cars that have remained intact during the initial accident. The tank cars that are heated by the fire react as follows.

As the lading increases in temperature, it expands and tends to fill the ullage space with liquid. After the ullage space is filled, the liquid continues to expand and forces open the safety relief valve with which each tank must be equipped. On further heating, the saturation pressure of the lading reaches the start-to-discharge pressure of the relief valve, and the liquid level recedes as lading is released. While the lading is being heated, the tank shell is also increasing in temperature. Because of the low heat transfer coefficient from the tank shell to gaseous portions of the lading, the portions of the shell in contact with gaseous lading increase in temperature at a faster rate than portions of the shell in contact with liquid lading.

If, at any time during the heating, the stresses in the shell generated by internal pressure and, to a small degree by thermal stress, exceed the safe stress for rupture at the elevated temperature, the tank will fail. Tank failures have often taken the form of large, rapidly propagating cracks with large, nearly instantaneous release of burning lading. As the pressure is released, large amounts of lading are converted to the gaseous state. The result has been that portions of tanks weighing tons have rocketed hundreds of feet, with resulting physical destruction and fire spread. Even without rocketing, the area of damage increases greatly when a tank ruptures.

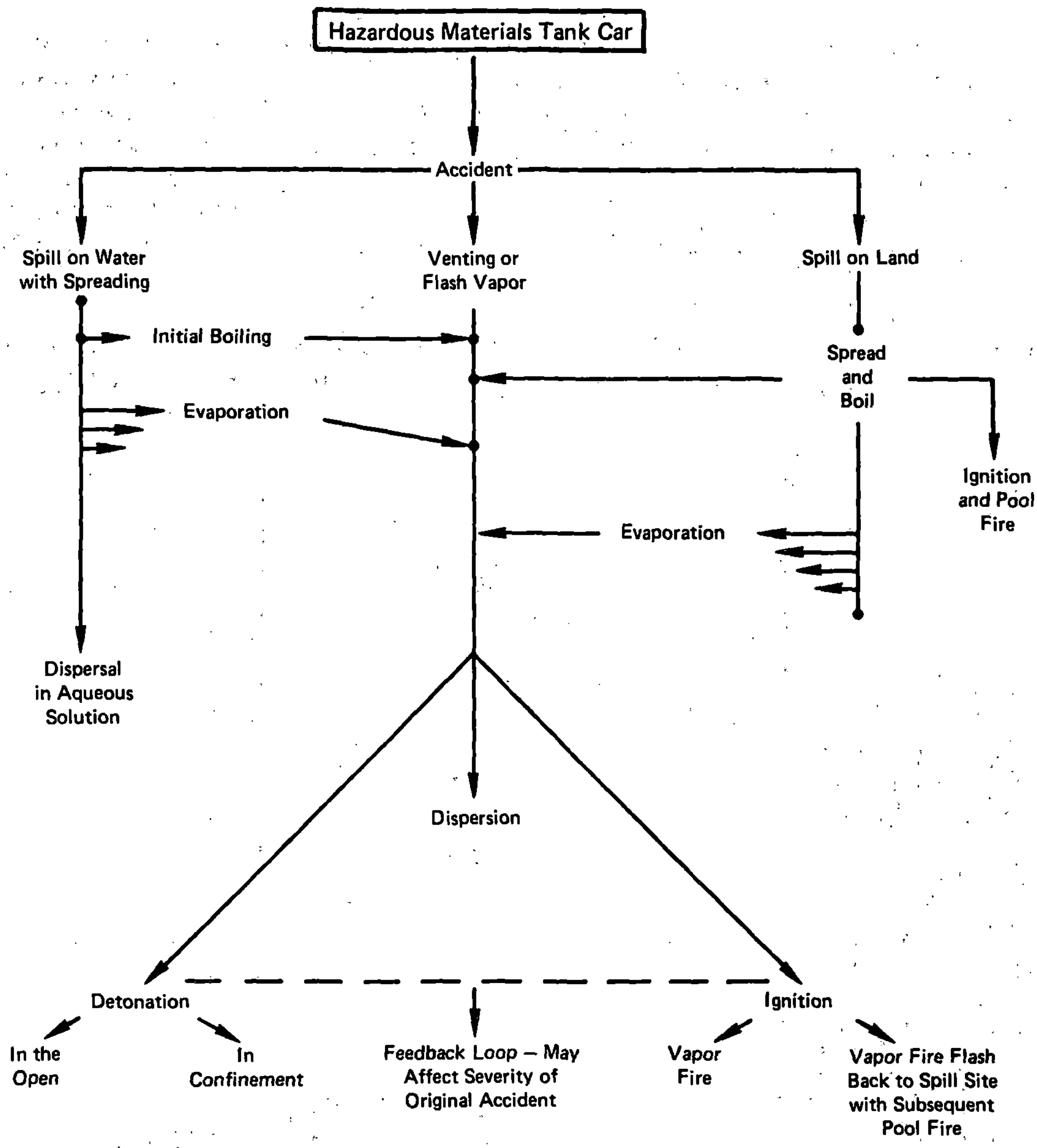
An idea of what happened in a BLEVE is shown in the photograph in Figure 6-1, which was taken in Crescent City, Illinois, on June 21, 1970. The material involved was propane.



Source: "Hazardous Materials Transportation Accidents," NFPA Publications Number SPP-49, photograph by Anderson, Watseka, Illinois

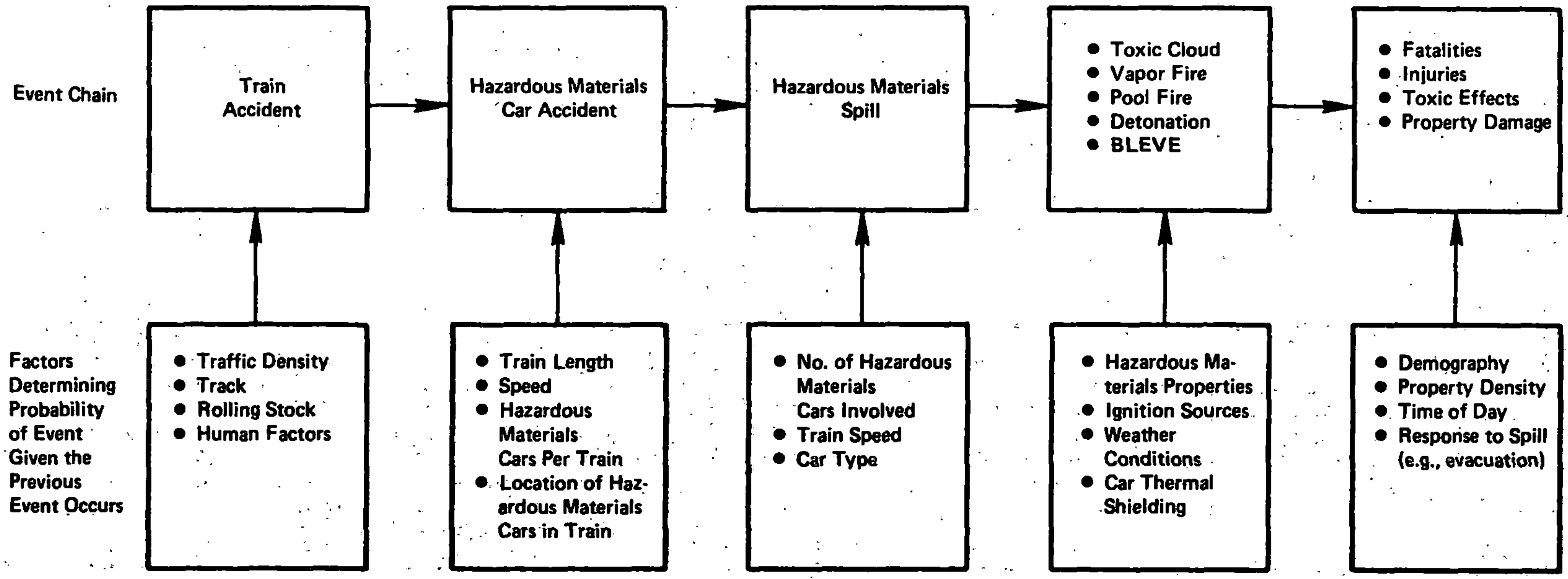
FIGURE 6-1 FREIGHT TRAIN DERAILMENT AND FIRE (Crescent City, Illinois)

A somewhat more general picture of events following a release of hazardous materials is shown in Figure 6-2. A comprehensive description of hazardous materials accidents, including a listing of important factors controlling the chain of events, is shown in Figure 6-3.



Source: Arthur D. Little, Inc.

FIGURE 6-2 SCHEMATIC OF EVENTS FOLLOWING HAZARDOUS MATERIALS TANK CAR ACCIDENT



Source: Arthur D. Little, Inc.

FIGURE 6-3 STRUCTURE OF A HAZARDOUS MATERIALS RAILROAD INCIDENT

These figures indicate that tank car size does not influence the nature of events following an accident. However, the magnitude of economic losses and injuries will depend on the size of the population at risk. This, in turn, is dependent on the range over which the lading can spread and the tank car can rocket. The next section will examine the relationship between risk through rocketing and car size for a particular case study.

6.2.3 Tank Car Length and Risk

An analysis of tank car tub rocketing was conducted through a case study to acquire a quantitative understanding of how risk to the public in a hazardous materials accident depends on the size of the tank car involved. The phenomenon of tank car tub rocketing occurs with enough frequency to justify consideration of the tank car size. Large pieces of the tank car fly considerable distance, exposing large numbers of the surrounding population to risk.

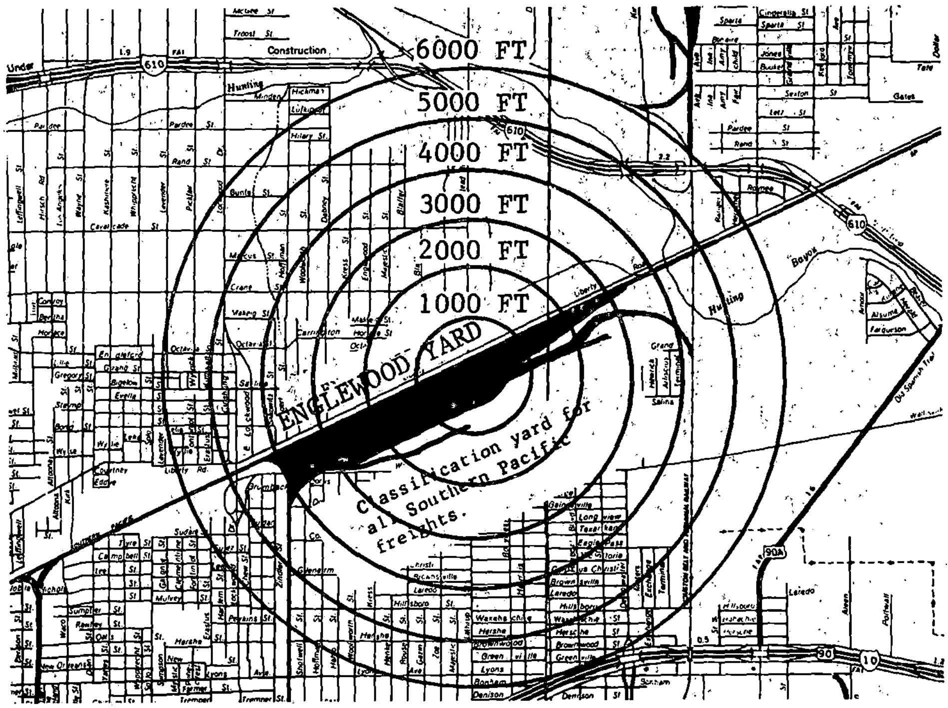
The particular case study chosen for the analysis was the following. A DOT 1124340 tank car carrying vinyl chloride derails and develops a rocketing tub. It is assumed that the tub is as long as the car, which poses the worst hazard since the distance that the tub rockets is proportional to the length of the tub. Because of this, the area and the population exposed to risk increase as the tank car length increases. Moreover, since tank diameters are at their limit, the volumetric capacities of tanks are proportional to their lengths. Thus, the size of the population at risk increases as the volumetric capacity of the tank car increases.

Since the City of Houston transships large quantities of hazardous materials and has also been the scene of two major hazardous materials accidents in recent years, three hypothetical accident sites were chosen within Houston. These three locations are a railroad yard, and two rights-of-way, at a low- and a high-density population site. These locations are shown in Figures 6-4 through 6-6. A detailed estimate was made of the daytime (working) and night-time (residential) populations within 1000-foot increments of each of the accident sites. These estimates were prepared with the assistance of personnel from the Houston Chamber of Commerce and the Texas Department of Highways and Public Transportation. Tables 6-1 through 6-3 show the cumulative residential and working population for a given radius from the accident site. Also provided are qualitative descriptions of the buildings and facilities lying within these radii of the hypothetical accident sites.

The magnitude of risk is more readily observed through graphical display of the population within the radii shown in Figures 6-7 through 6-9. For each of the three sites, the population included appears to increase substantially at radii of 4000 or 5000 feet.

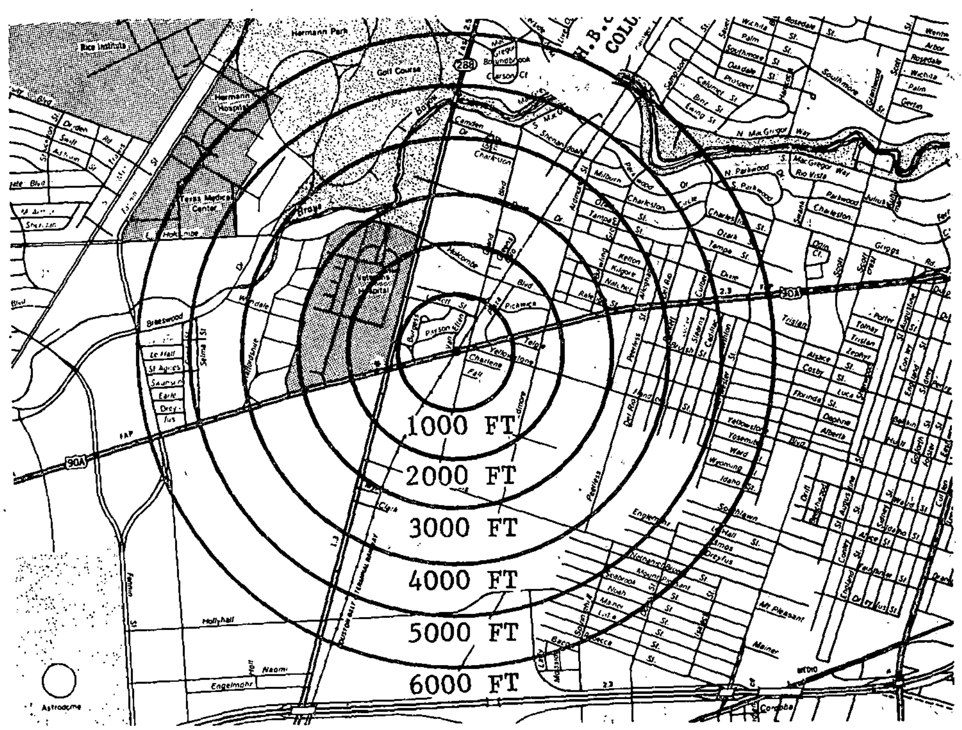
The risk is converted from a function of potential rocketing distance to a function of tank car size through the relationship between tank capacity and rocketing range. This relationship is shown in Figure 6-10 as the maximum tub rocketing distance as a function of tank size in gallons. This upper-bound estimate is based on an analytical model developed by Battelle Columbus Laboratories[1].

The data in Figures 6-7 through 6-9 are then combined to obtain estimates of the exposed population — the population at risk — for each of the three sites as a function of tank capacity. The results are shown in Figures 6-11 through 6-13.



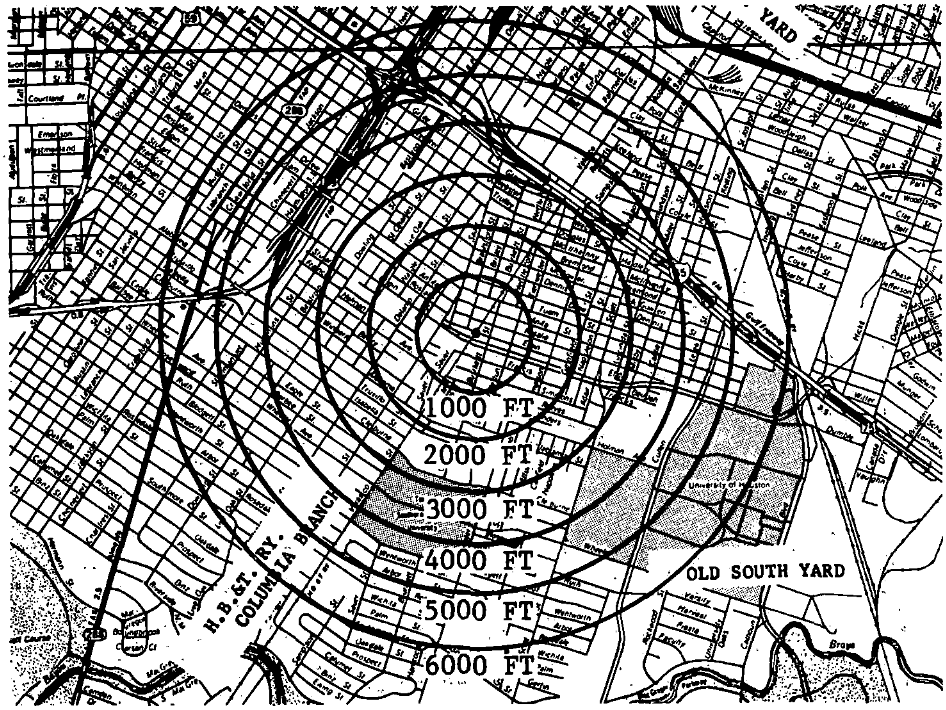
Source: Arthur D. Little, Inc.

FIGURE 6-4 HYPOTHETICAL ACCIDENT SITE – ENGLEWOOD YARD



Source: Arthur D. Little, Inc.

FIGURE 6-5 HYPOTHETICAL ACCIDENT SITE – LOWER POPULATION DENSITY



Source: Arthur D. Little, Inc.

FIGURE 6-6 HYPOTHETICAL ACCIDENT SITE – HIGHER POPULATION DENSITY

TABLE 6-1
ESTIMATES OF RESIDENTIAL AND WORKING POPULATION EXPOSED TO RISK – YARD SITE

Englewood Yard (Center Point)

Surrounding Area With Radius Of	Residential Population	Working Population	Area Description
1,000 ft	0	100	Railroad yard,
2,000 ft	240	500	Railroad yard, residential, industry (warehouses)
3,000 ft	2,400	900	Railroad yard, residential, industry (warehouses)
4,000 ft	3,720	1,500	Railroad yard, residential, industry (warehouses)
5,000 ft	8,100	2,500	Residential, apartments, industry (warehouses)
6,000 ft	13,560	3,500	Residential, apartments, industry (warehouses), oil tanks

Source: Arthur D. Little, Inc., Estimates

TABLE 6-2

ESTIMATES OF RESIDENTIAL AND WORKING POPULATION EXPOSED TO RISK – LOWER DENSITY SITE

HB&T RY and Rt 90A (OST)

Surrounding Area With Radius Of	Residential Population	Working Population	Area Description
1,000 ft	180	300	Few residential streets, few warehouses
2,000 ft	2,280	1,200	Residential, industry, veteran's hospital (≈50%)
3,000 ft	3,840	3,200	Residential, industry, veteran's hospital
4,000 ft	5,340	4,200	Residential, industry
5,000 ft	7,880	18,000	Residential, industry, recreational area, Texas Medical Center (≈40%)
6,000 ft	12,765	21,850	Residential, industry, zoo, Texas Medical Center (≈10%)

Source: Arthur D. Little, Inc., Estimates

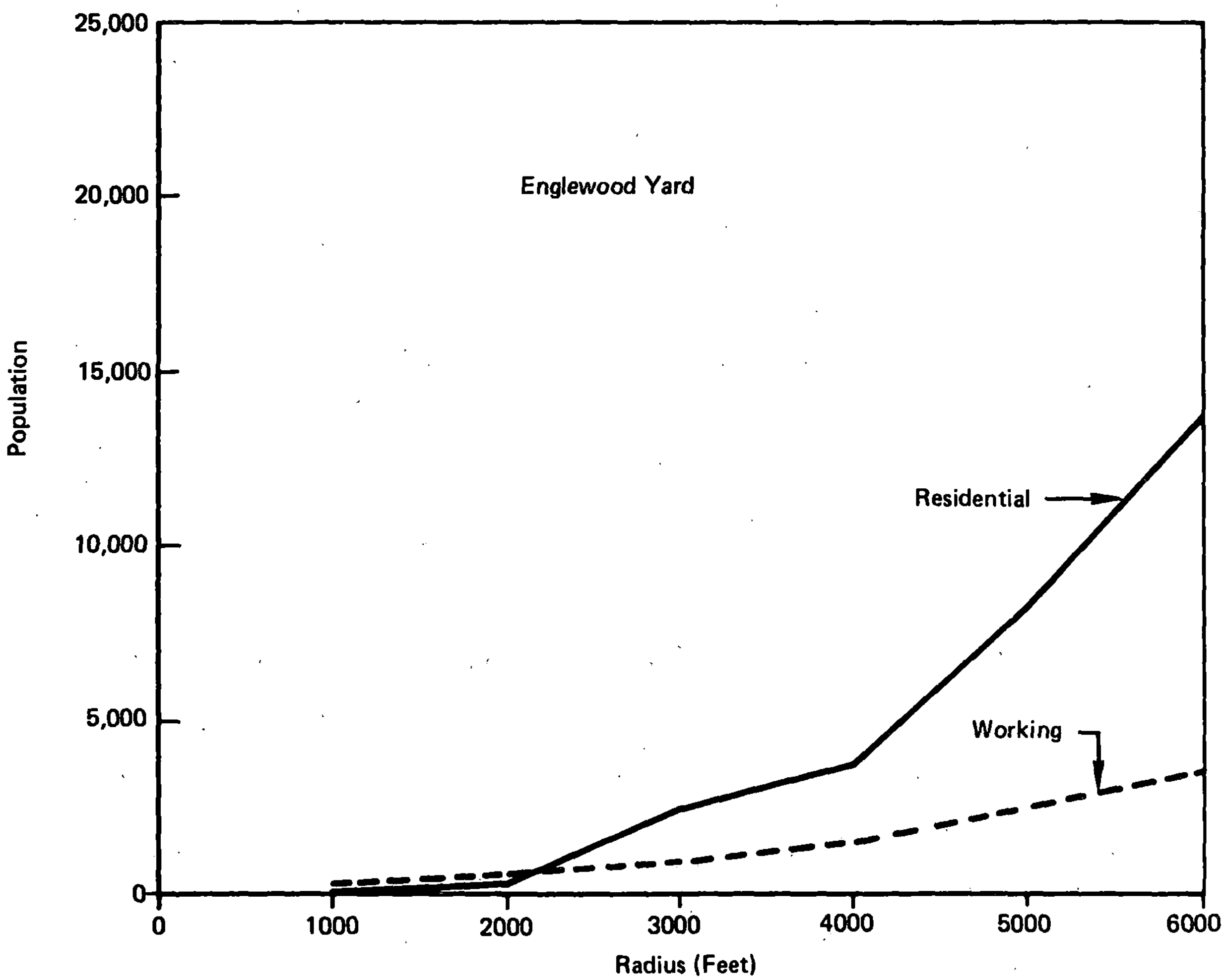
TABLE 6-3

ESTIMATES OF RESIDENTIAL AND WORKING POPULATION EXPOSED TO RISK – HIGHER DENSITY SITE

HB&T RY and Elgin St.

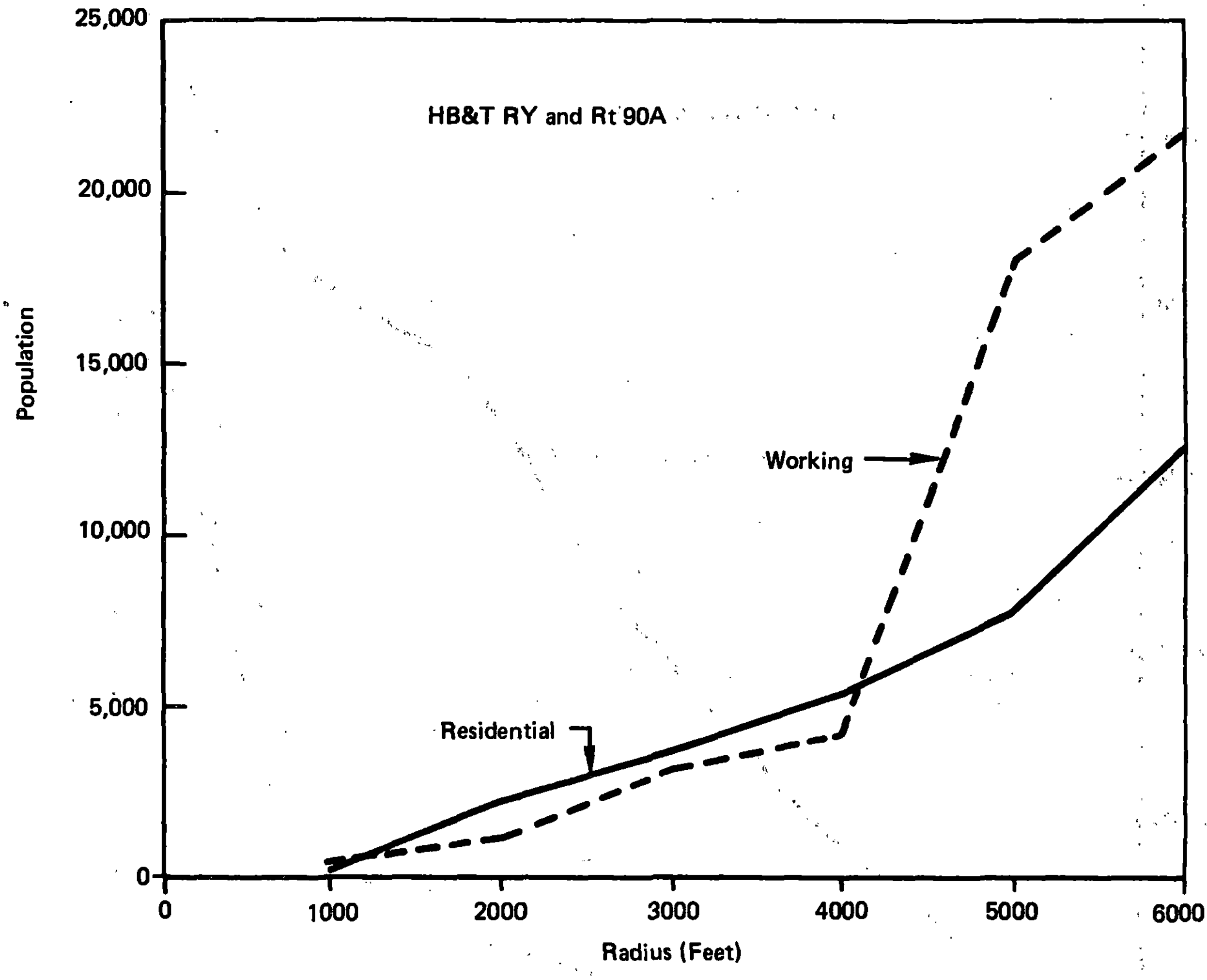
Surrounding Area With Radius Of	Residential Population	Working Population	Area Description
1,000 ft	1,260	0	Residential
2,000 ft	5,250	0	Residential, apartments
3,000 ft	10,960	50	Residential, apartments, industry (warehouses)
4,000 ft	18,440	1,770	Residential, industry (warehouses), Texas State University
5,000 ft	21,310	4,570	Residential, apartments, industry (warehouses and truck dealers), University of Houston (partial)
6,000 ft	29,830	23,570	Residential, University of Houston (majority), Southwest tip of down-town

Source: Arthur D. Little, Inc., Estimates



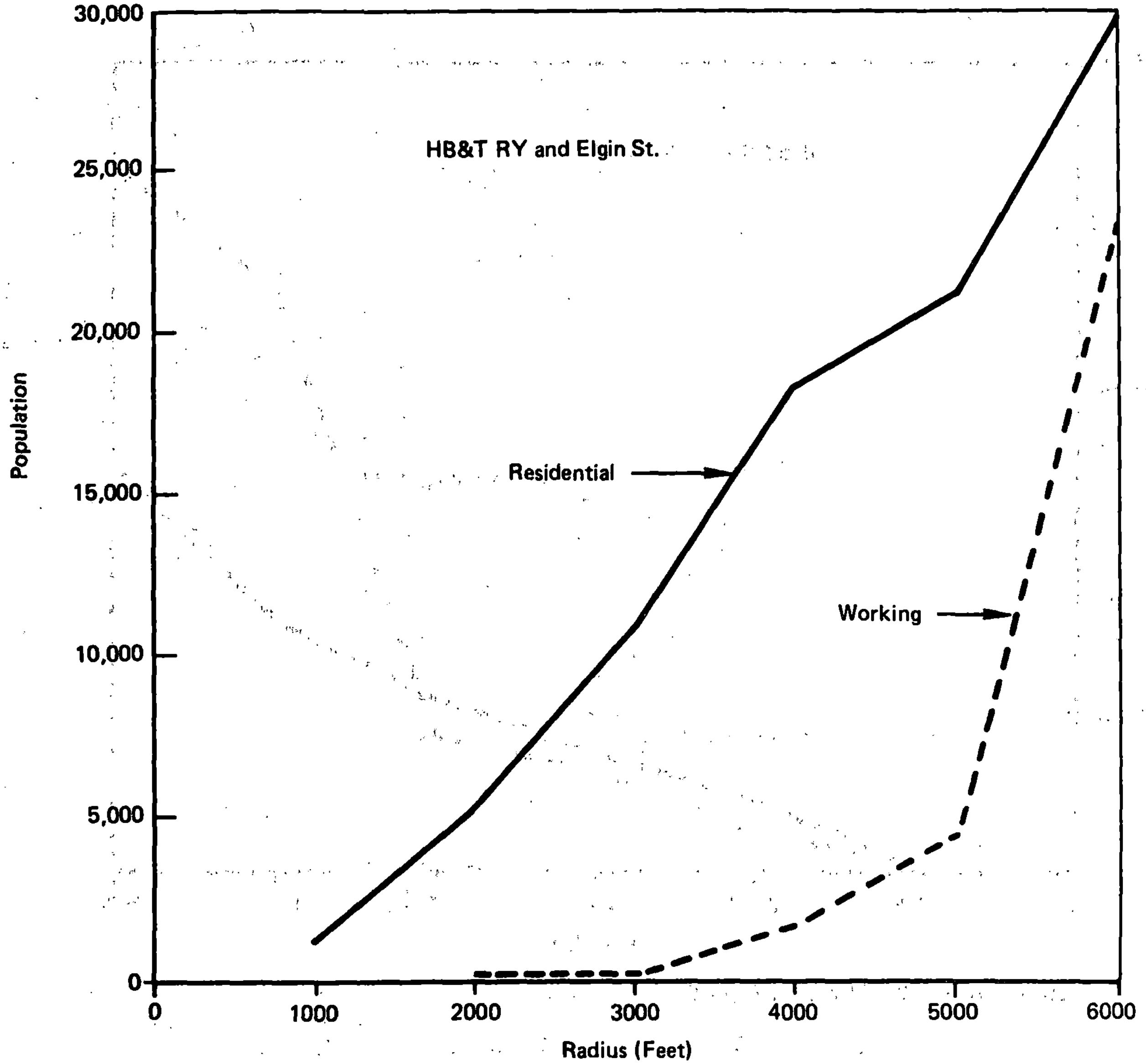
Source: Arthur D. Little, Inc., Estimates

FIGURE 6-7 POPULATION EXPOSED TO RISK – YARD SITE



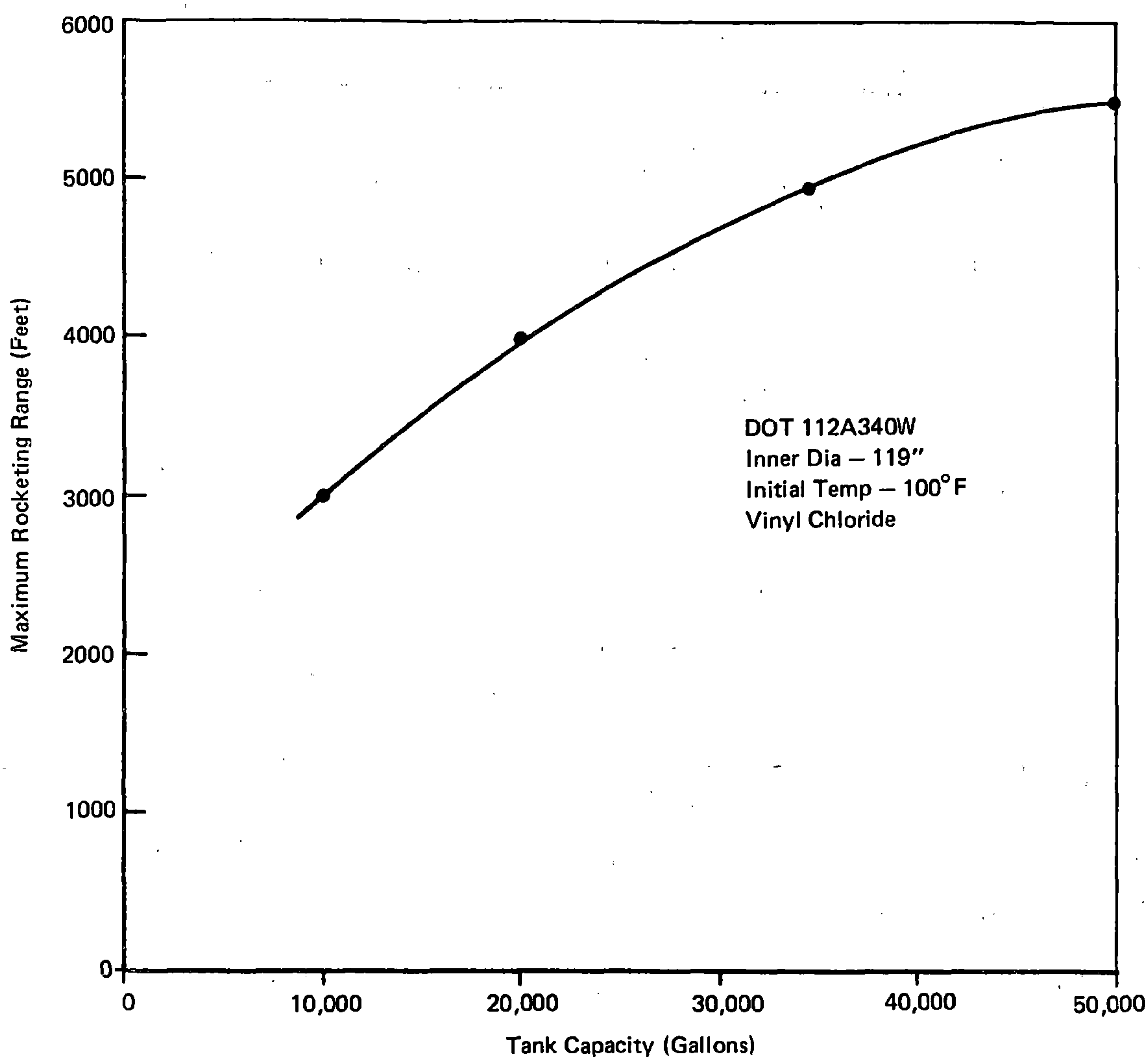
Source: Arthur D. Little, Inc., Estimates

FIGURE 6-8 POPULATION EXPOSED TO RISK – LOWER DENSITY SITE



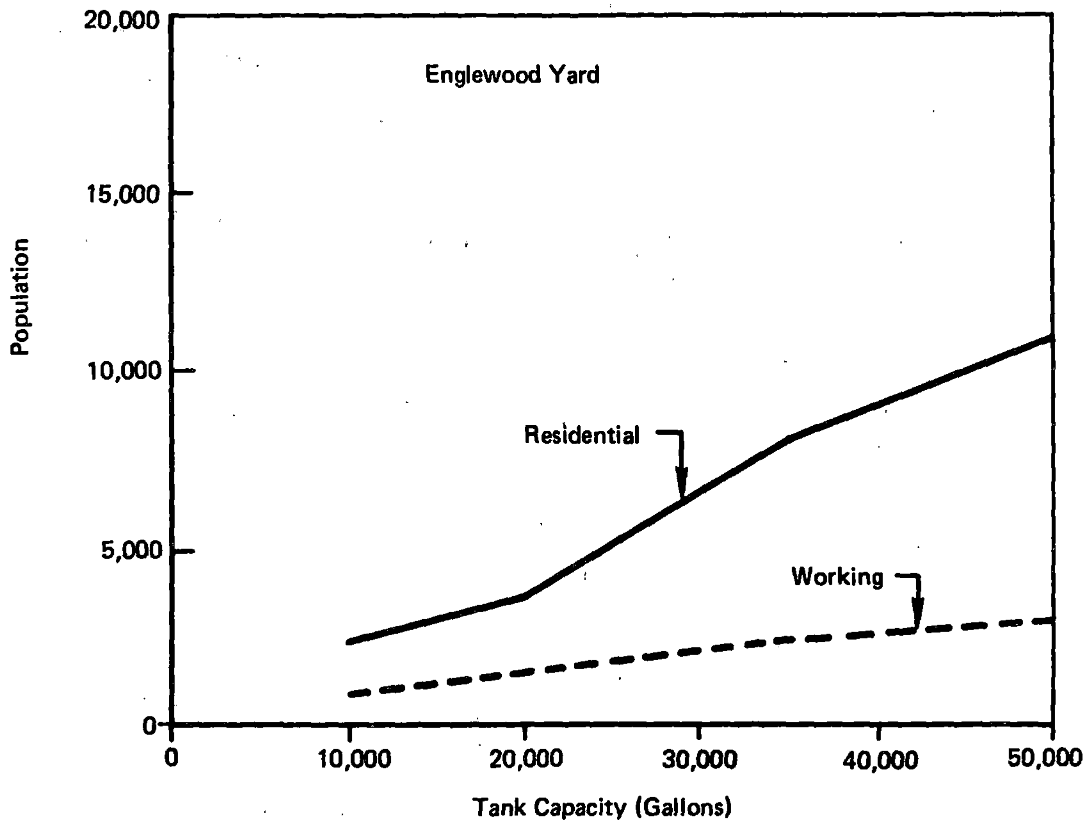
Source: Arthur D. Little, Inc., Estimates

FIGURE 6-9 POPULATION EXPOSED TO RISK – HIGHER DENSITY SITE



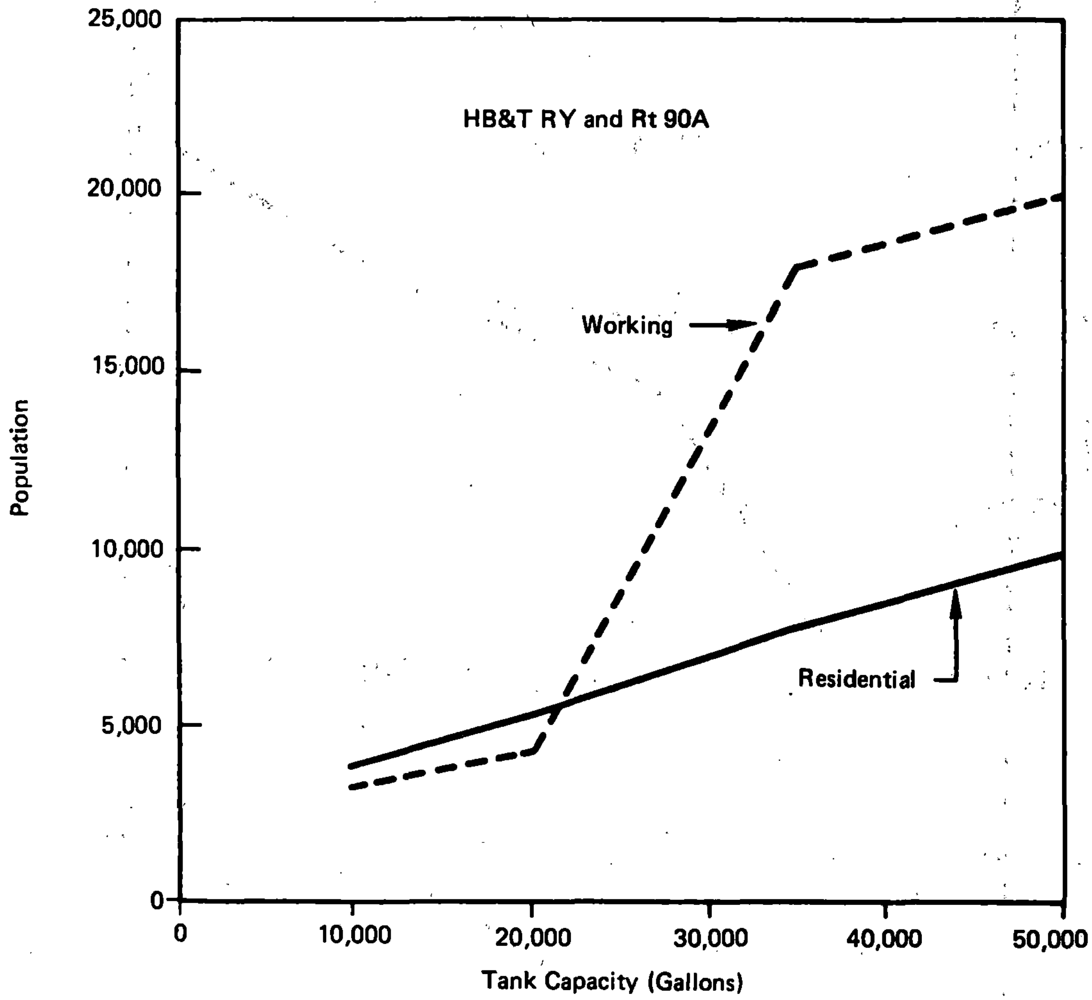
Source: Arthur D. Little, Inc., Estimates

FIGURE 6-10 TUB ROCKETING DISTANCE



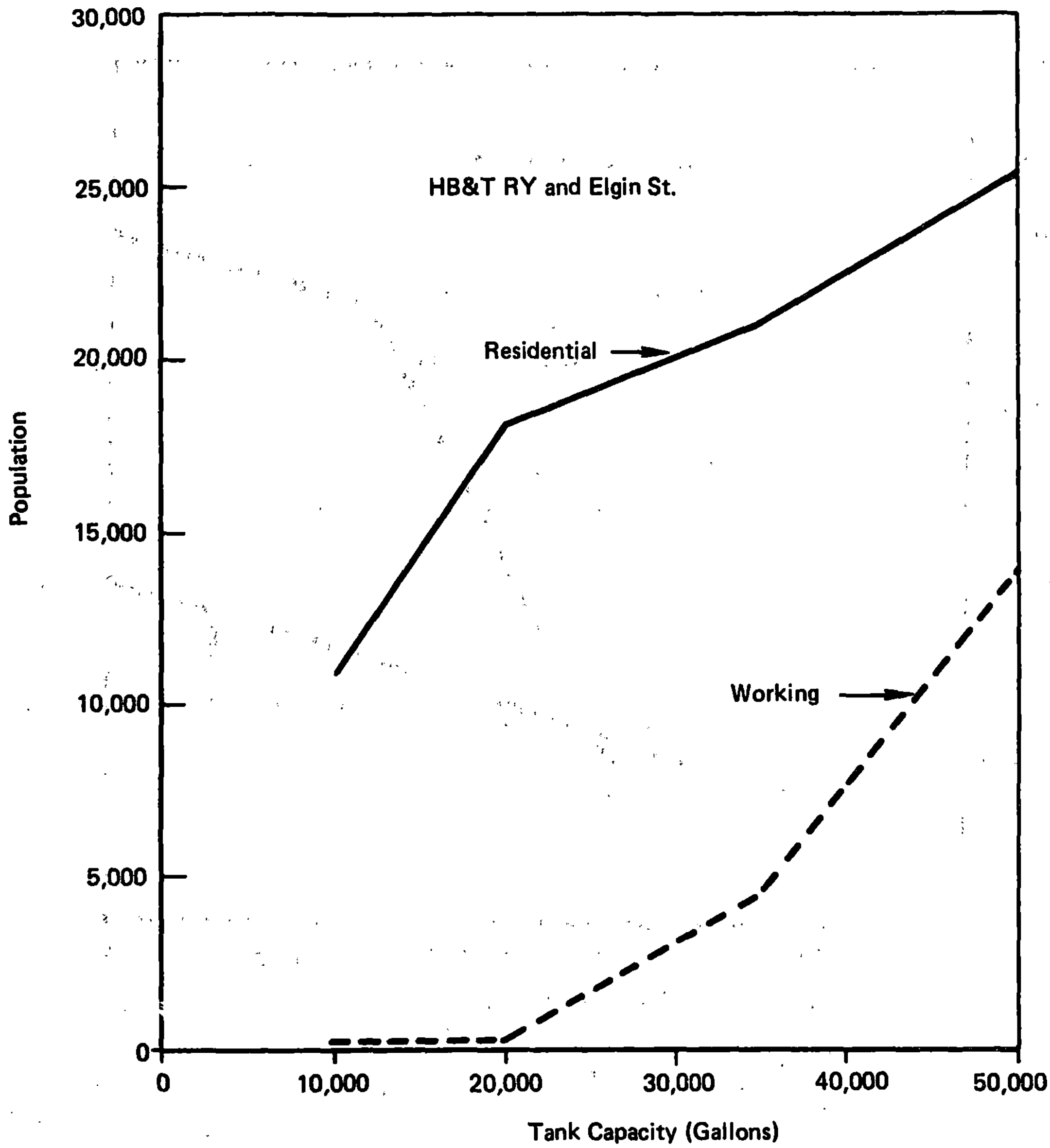
Source: Arthur D. Little, Inc., Estimates

FIGURE 6-11 POPULATION EXPOSURE AS A FUNCTION OF TANK CAPACITY – YARD SITE



Source: Arthur D. Little, Inc., Estimates

FIGURE 6-12 POPULATION EXPOSURE AS A FUNCTION OF TANK CAPACITY – LOWER DENSITY SITE



Source: Arthur D. Little, Inc., Estimates

FIGURE 6-13 POPULATION EXPOSURE AS A FUNCTION OF TANK CAPACITY – HIGHER DENSITY SITE

The nature of the risk has two components: the number of persons actually injured and the population evacuated because of the risk of the rocketing tub. As the maximum rocketing range increases, the area exposed increases with the square of the rocketing range. If population densities are fairly uniform, as appears to be the case in this study, then the population exposed would also increase quadratically. Since the relationship between tank capacity and rocketing range slightly differs, the population exposed increases at somewhat less than the square of tank size. However, increase in maximum tank loading would bring more than proportional increase in population at risk.

6.3 GRADE-CROSSING ACCIDENTS

In recognition of the fact that accidents at highway grade crossings are the single most important safety problem connected with railroad transportation, the FRA has been pursuing intensive research programs that seek an understanding of the causal factors for these accidents. These programs have demonstrated the following[2]:

- Two other factors found to be of some importance are first, the ability to see the train — how well it can be seen at night — and second, the ability of the motorist to see along the track and determine whether a train is approaching.
- Factors determining the frequency with which accidents might be expected at a given grade crossing are:
  - the number of trains per day;
  - the number of automobiles per day;
  - the type of warning device or protection system.
- There is no evidence that the size, weight, and length of railroad cars passing through a grade crossing have any influence on the probability or severity of an accident at that grade crossing, for a particular train.
- Since accident frequency is a function of train frequency, policies that constrain the size, weight, and length of cars in such a way as to increase the frequency of trains will lead to a small, but perceptible, increase in the frequency of grade-crossing accidents. Specifically, an approximate relationship between the number of fatalities in a year and the number of trains in a year at a grade crossing is

  $$\text{Fatalities} = \text{Constant} \times \text{Number of Automobiles} \times (\text{Trains})^{0.15}$$

  Thus, if the number of trains were to go up by 10% at any crossing, the number of fatalities would go up by 1.5%. Nationwide, this would amount to approximately ten additional fatalities each year.

6.4 PERSONNEL INJURIES

During a study to determine what impact changes in car size, weight, and length might have on the number and severity of personnel injuries, the man/machine system was defined, identifying typical railroad employees and their daily activities. Different car types were used, with special attention to the various points of interaction such as safety appliances, couplers, and brake systems. It was found that over 90% of accidents and injuries occur during the conduct of the following functions:

- Getting on or off cars;
- Coupling or uncoupling cars;
- Applying or releasing handbrakes;
- Operating manual switches;
- Connecting or disconnecting air hoses; and
- Manipulating air valves.

In most cases, these functions are independent of the car size, weight, or length. The primary exception is that long cars (over 90 feet) are more difficult to couple on curved track than are short cars. Also, longer cars allow less clearance between the ends of the car and cars on adjacent track because of the associated overhang from truck center to the end of the car. However, the study did not show that a moderate increase in the size, weight, or length of freight cars will significantly affect personnel safety. Rather, it is postulated that utilization of higher capacity freight cars will result in a reduced number of cars per train and/or number of trains. This will have a positive impact on employee safety, for a reduction in frequency of exposure implies a lower degree of risk. The type of analysis conducted for derailments was not possible since car number is not collected by the FRA for personnel injury accidents.

6.5 SUMMARY

While incidence of personnel injuries is slightly related to car length, there is no overwhelming evidence of frequency of these accidents depending on the car size, except to the extent that car size affects train frequency. This is partially due to a lack of data, since FRA personnel injury records are not identified by car number.

The tank car size in an accident involving hazardous materials affects the potential rocketing distance and, therefore, the magnitude of the population at risk. The potential damage increases with tank car size for a given accident. Therefore, restricting the maximum rocketing range appears justified.

Grade-crossing accidents are influenced by the type of warning at a particular crossing as well as by the action taken by the motorist approaching the crossing. The number of accidents is related to the number of trains in operation. The characteristics of the freight cars in each train do not appear to be important.

The incidence and severity of personnel injuries are related more to the function being performed than to the car size. The vast majority of accidents and injuries occur during conduct of train formations, which are not related to car size.

REFERENCES

1 "Analysis of Tank Car Tub Rocketing in Accidents," RPI/AAR Railroad Tank Car Safety Research and Test Project, Report No. RA-12-2-23, 1972.

2 Mengert, P., "Rail-Highway Crossing Hazard Prediction Research Results," Report No. FRA-RRS-80-02, 1980.

7. MEASURES FOR SAFER RAIL TRANSPORTATION

7.1 ABSTRACT

There are well-identified solutions to many of the dynamic behavior problems discussed in Chapter 5. These solutions range from large-scale improvements to the permanent right of way through better design and development procedures, to the retrofitting of specific mechanical improvements to freight cars that possess specific behavior problems. Most of these solutions can be identified by the application of well-understood engineering analytical techniques, although their development may require extensive testing to improve reliability and reduce cost.

7.2 INTRODUCTION

This chapter describes various actions for mitigating or eliminating the causes that lead to the accidents discussed in Chapter 5.

Table 7-1 lists the 20 major causes of derailments. A total of 5,868 accidents are included, which represent 80 percent of the total reported derailments. The rest of the derailments are distributed over other less important causal categories. An analysis of these major causes, shown in Table 7-2, gives a qualitative understanding of the important factors for each cause type as well as the relationship to car size, weight, or length. The countermeasures for each of the major causes of derailments are summarized in Table 7-3. The appropriate corrective actions for each major group of causes are discussed in the remainder of this chapter.

7.3 DERAILMENTS CAUSED BY VEHICLE-TRACK INTERACTIONS: WHEEL LIFT

Vehicle-track interactions that result in excessive weight transfer to one side of the truck can cause the wheel to lift free of the rail. The guiding influence of the wheel flange is then no longer present, and the wheel-axle set is subject to derailment. Wheel lift is usually caused by severe "rock-and-roll" motions of a car. The factors that contribute to this phenomenon are:

- Periodic discontinuities in the cross-level of the track (e.g., at rail joints);
- A high center of gravity of the car;
- Large torsional stiffness of the car;
- A truck center distance that is close to the rail joint spacing;
- A poorly damped suspension system in the car;
- Movement of the car over a track with periodic cross-level discontinuities at a speed so that the rate of passing the discontinuities coincides with the natural rolling frequency of the car.

TABLE 7-1

MAJOR CAUSES OF DERAILMENTS

Category	Cause	No. of Accidents
1	Wide gage (110-113)*	859
2	Rail defects (131, 136-138, 141, 142)	732
3	Irregular cross-levels (119-120)	673
4	Effects of longitudinal train and wheel-rail interaction forces (570, 572, 713)	572
5	Worn or broken switch points (165)	433
6	Improper use of switches (560-563)	320
7	Rail joint defects (130, 145-149)	318
8	Roadbed settlement (101, 102, 109)	221
9	Switch defects (161-163, 166, 174, 176)	209
10	Track alignment irregular or buckled (114, 115)	199
11	Worn rails (113, 143)	190
12	Plain journal failure from overheating (451)	178
13	Problems with loads (704-707)	170
14	Worn wheel flanges (464)	156
15	Broken wheels (460-463)	148
16	Improper side-bearing clearances (440)	144
17	Broken or defective couplers (430, 432, 436)	135
18	Broken or missing truck components (441-444, 447)	115
19	Passed couplers (574)	108
20	Improper truck performance (445-446)	96
	SUBTOTAL	5,868

*Numbers in parentheses denote FRA accident categories.

Source: IIT Research Institute

TABLE 7-2

ANALYSIS OF DERAILMENT CATEGORIES

Category	Cause	Nature of Failure	Rate of Failure	Applicable Specification	Dependent on Car Size/Weight	Nature of Forces	Factors Controlling Force Level*	Force Level Dependent on Size/Weight	Force Dependent on Train Makeup
1	Wide gage	Rail Displacement	Slow	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
2	Rail defects	Fracture	Slow/Fast	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
3	Irregular cross-levels	Rail Displacement	Slow	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
4	Effects of longitudinal train and wheel-rail interaction forces	Wheel Climb	Fast	—	No	Longitudinal Train	TH/D/P	Yes	Yes
5	Worn or broken switch points	Wear/Displacement	Slow	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
6	Improper use of switches	—	—	—	—	—	—	—	No
7	Rail joint defects	Fracture	Slow/Fast	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
8	Roadbed settlement	Rail Displacement	Slow	FRA Track Standards	No	W-R Interaction	S/SP/TI	Yes	No
9	Switch defects	—	—	—	—	—	—	—	No
10	Track alignment irregular or buckled	Rail Displacement	Slow	FRA Track Standards	No	W-R Interaction	—	—	No
11	Worn rails	Wear	Slow	—	No	W-R Interaction	S/SP/TI	Yes	No
12	Plain journal failure from overheating	—	—	—	—	—	—	—	—
13	Problems with loads	—	—	—	—	—	—	—	—
14	Worn wheel flanges	Wear	Slow	FRA Equipment Standards	No	W-R Interaction	S/SP/TI	Yes	No
15	Broken wheels	Fracture	Slow/Fast	FRA Equipment Standards	Yes	—	S/SP/TI/B	Yes	No
16	Improper side-bearing clearances	Wheel-Climb	Slow/Fast	AAR Interchange Rules	No	—	—	—	No
17	Broken or defective couplers	Fracture	Slow/Fast	FRA Equipment Standards	Yes	Longitudinal Train	TH/D/P	Yes	Yes
18	Broken or missing truck components	Fracture	Slow/Fast	FRA Equipment Standards	Yes	Longitudinal Train	TH/D/P	Yes	No
19	Passed couplers	—	Fast	—	—	—	—	—	No
20	Improper truck performance	—	Slow/Fast	—	—	W/R Interaction	—	—	No

*Legend:
W/R Interaction — Wheel-Rail Interaction
S — Speed
TI — Track Irregularities
TH — Train Handling
D — Draft Gear
B — Braking
P — Car Placement
WD — Wheel Diameter
SP — Suspension System Dynamics

Source: IIT Research Institute

TABLE 7-3

COUNTERMEASURE ANALYSIS

Category	Derailment Cause	More Frequent Track Inspection	More Frequent Track Repair	Reduced Speed	Better Trucks	Better Car Placement Guidelines	Improved Draft Gear	Better Train Handling	Larger Wheel Diameter	Improved Handbrakes	More Reliable Braking System	Improved Side Bearings	Improved Coupler Designs
1	Wide gage	X	X	X	X								
2	Rail defects	X	X	X	X				X				
3	Irregular Cross-levels	X	X	X	X								
4	Effects on longitudinal train and wheel-rail interaction forces					X	X	X					
5	Worn or broken switch points	X	X	X	X								
6	Improper use of switches*												
7	Rail joint defects	X	X	X	X								
8	Roadbed settlements	X	X	X	X								
9	Switch defects	X	X										
10	Track alignment irregular or buckled	X	X	X	X								
11	Worn rails	X	X	X	X								
12	Plain journal failure from overheating*												
13	Problems with loads*												
14	Worn wheel flanges				X								
15	Broken wheels									X	X		
16	Improper side-bearing clearances											X	
17	Broken or defective couplers					X	X	X					X
18	Broken or missing truck components		X	X	X							X	
19	Passed couplers				X								X
20	Improper truck performance				X								

Source: IIT Research Institute

*Requires specific countermeasures not shown here.

One or more of these factors present at the same time may be sufficient to cause excessive roll motions that will result in wheel lift.

The following corrective actions are applicable:

- Repair track to minimize excessive rail displacement at rail joints.
- Install welded rail.
- Increase damping action parallel with the primary suspension system.
- Reduce the height of the vehicle's center of gravity.
- Modify the truck center distance.
- Modify the train speed.

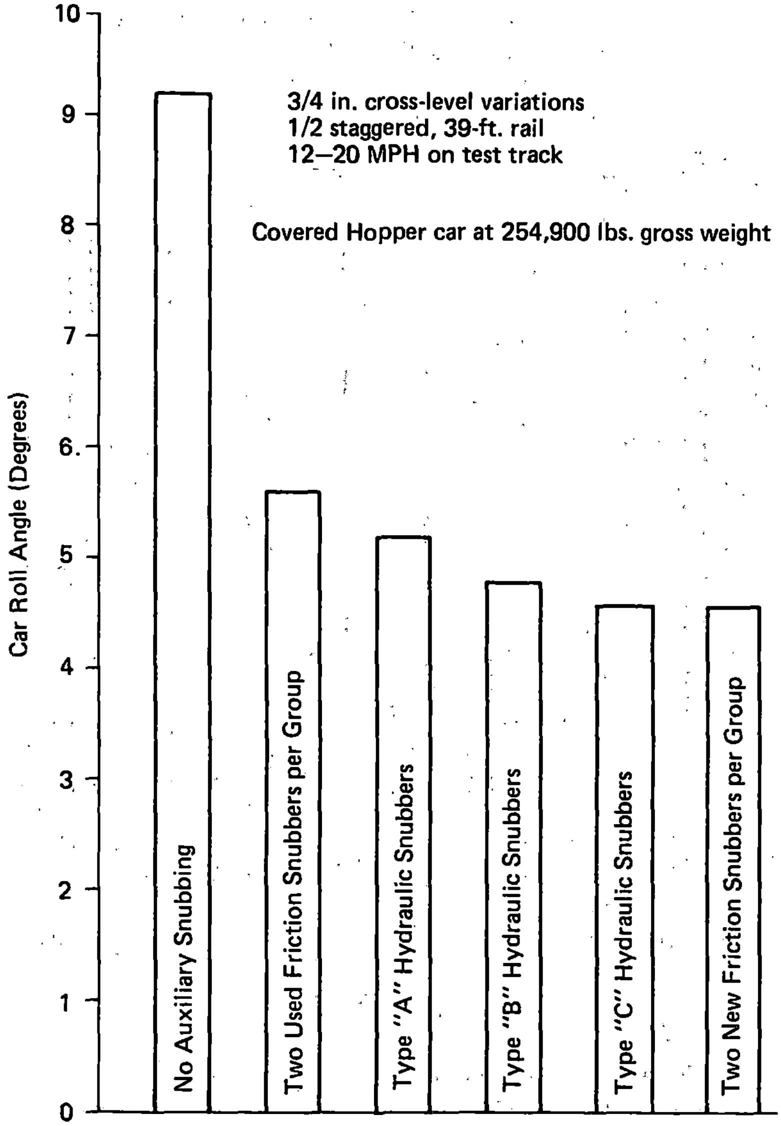
The track can be repaired to minimize excessive rail displacement at rail joints. Welded rail is often installed to eliminate this problem; however, it is important that the subgrade also be upgraded to remove any softness resulting from prolonged excessive displacement at the joint.

Proper damping of the primary suspension system is essential for the minimization of rock-and-roll phenomena. This is illustrated by the data presented in Appendix E. Most modern truck configurations will provide sufficient damping. A number of auxiliary devices are also available to provide additional control that will prevent excessive displacements under most conditions.

Truck center distances can be modified so that they will not coincide with rail length. However, the height of the center of gravity of the loaded car is a difficult parameter to modify since car designs are established on the basis of the allowable clearance diagram and the specific weight of the commodities that they move. As a result, certain cars, such as covered hopper cars which carry relatively low-density products, tend to have a high center of gravity.

The high degree of torsional stiffness that exists in certain types of cars like tank cars or covered hopper cars is another parameter that is difficult to modify. Therefore, one must rely on other types of corrective actions to control excessive carbody roll. The speed of train movement through a region with periodic cross-level disturbances can be increased or decreased so that the critical roll frequency does not coincide with the rate of passage of the rail joints. The critical speed will vary with the truck center distance, so that where there are mixed cars in the consist, it is difficult to define an optimum speed.

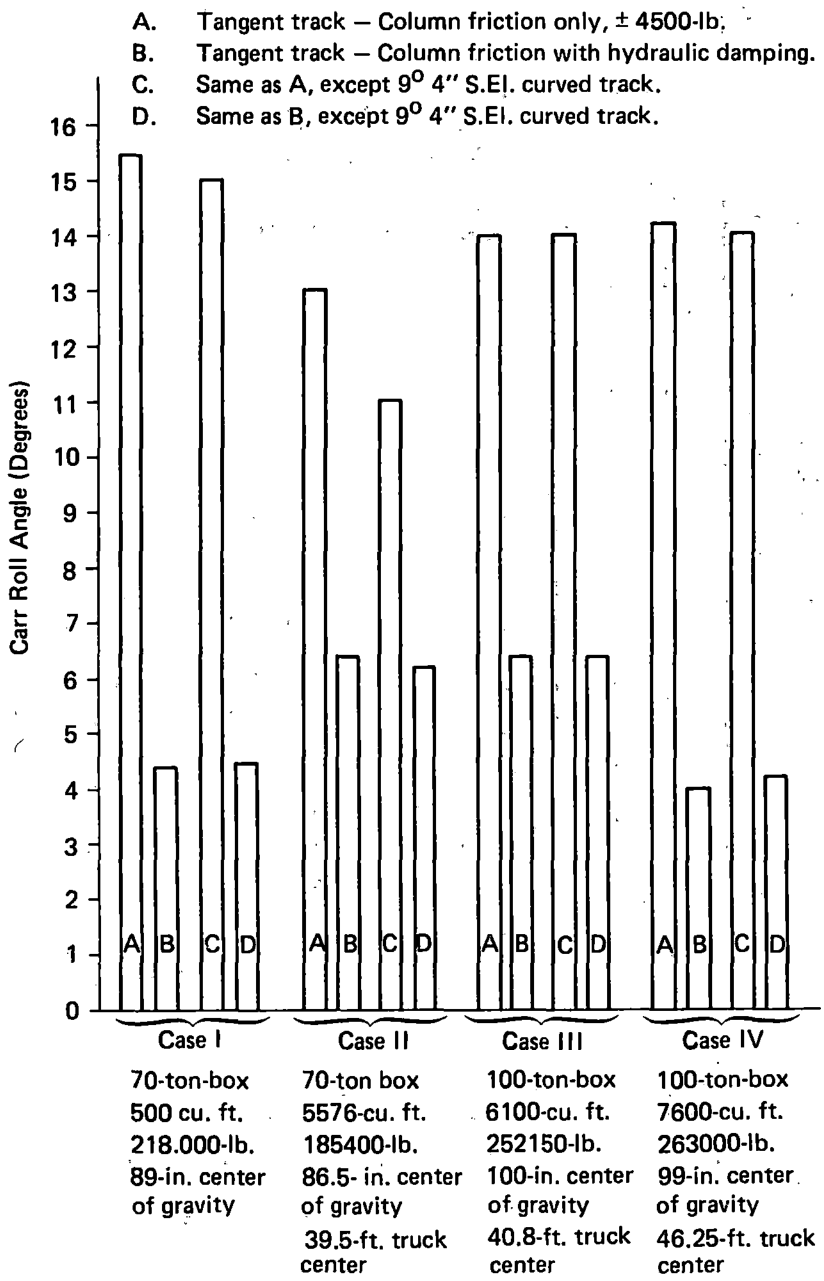
Figures 7-1, 7-2, and 7-3 are examples of the degree to which countermeasures applied to cars can be effective in controlling car dynamics over relatively severe track conditions.



Source: A Member Railroad of the AAR (see Appendix F)

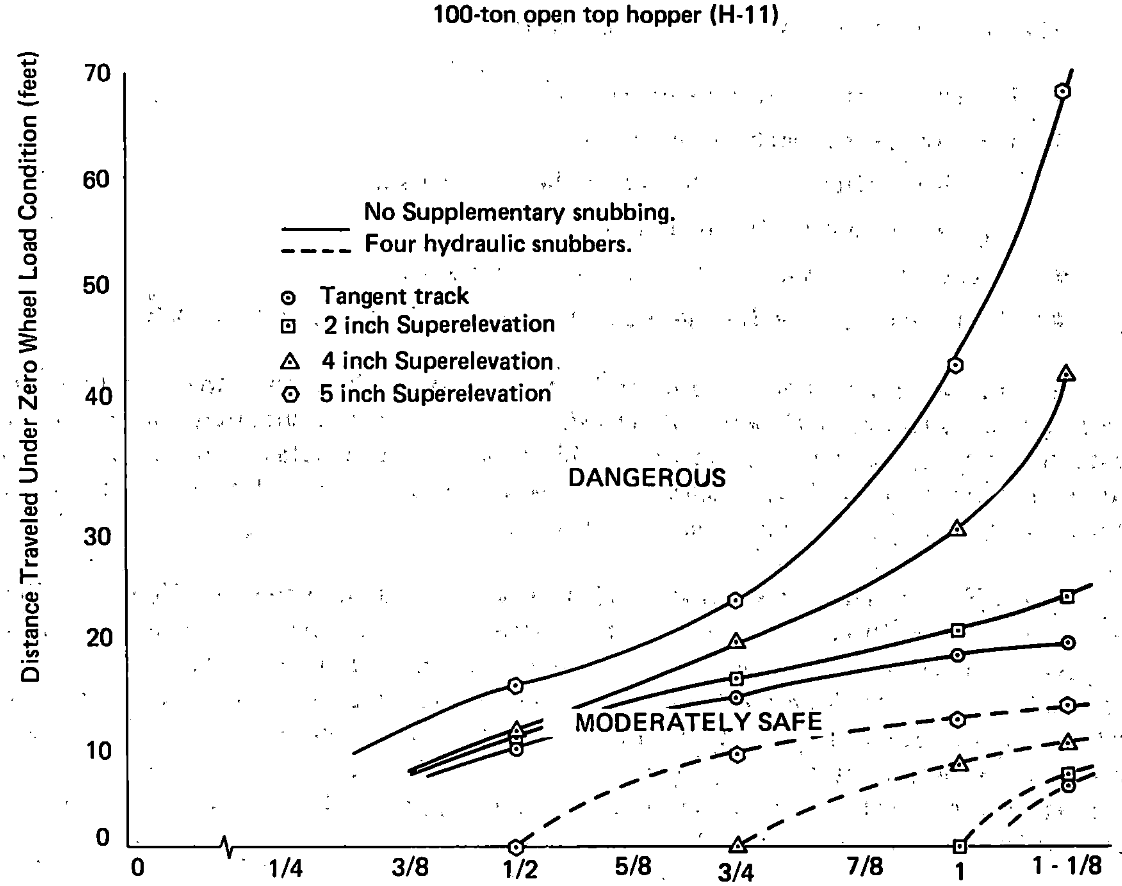
FIGURE 7-1 MAXIMUM CAR ROLL ANGLE

(1-inch surface variation, 1/2 stagger, 39-ft. rail, 13-19 mph)



Source: A Member Railroad of the AAR (see Appendix F)

FIGURE 7-2 ROCKING RESONANCE - CAR BODY ROLL



Source: A Member Railroad of the AAR (see Appendix F)

Track Profile Cross-Level Difference (Inches)

FIGURE 7-3 DISTANCE TRAVELED UNDER ZERO WHEEL LOAD CONDITION AT RESONANT SPEED FOR VARIOUS TRACK CONDITIONS

7.4 DERAILMENTS CAUSED BY VEHICLE-TRACK INTERACTION: WHEEL CLIMB

Wheel climb over the rail is caused by large wheel-rail lateral-vertical force ratios of sufficient duration to cause the wheel to move up over the rail. Factors contributing to this phenomenon are:

- Wheel-rail lateral forces associated with the traversal of curved track;
- Resistance to truck swiveling motion when traversing curved track;
- The development of transient lateral curving forces during the traversal of curved track (e.g., forces excited by rail gage variation or reduction in lateral stiffness; transient forces are often developed at rail joints);
- Large steady-state buff forces in the train;
- Transient buff forces in the train (due to train action);
- Curve traversal substantially under or over balance speed;
- The state of wheel and rail wear.

The following corrective actions are applicable:

- Lower the truck swivel resistance.
- Use stronger rail anchors on curves.
- Use better placement of the cars in the train consist.
- Use better train control techniques.
- Operate the train near balance speed on curves.
- Use higher capacity draft gear to minimize transient longitudinal forces.

The probability of wheel climb can be minimized by eliminating the situations which lead to large lateral-vertical ratios. Trucks should be installed so that they will swivel freely without offering excessive resistance to this motion. The excitation of transient lateral forces can be minimized by ensuring that the rail is properly anchored so that uniform curvature is maintained through rail joint areas.

The effect of large steady-state buff forces can be minimized by placing the lower weight cars at positions in the train consist where minimum buff forces are anticipated. Transient buff forces can be minimized by exercising proper train control. The utilization of higher capacity draft gear and other end-of-car cushioning devices offer additional possibilities for the attenuation of transient longitudinal forces, but these devices must be utilized with an overall evaluation of their effect on train control. The movement of the train through curved track at or near balance speed will prevent the development of excessive lateral forces.

7.5 TRACK DAMAGE CAUSED BY VEHICLE-TRACK INTERACTIONS

Vehicle-track interactions which lead to large wheel-rail forces can indirectly lead to derailments by accelerating the rate of track degradation. The principal vertical and lateral loading phenomena are discussed below.

7.5.1 Vertical Load

The excitation of excessive oscillations of the primary suspension system can lead to the development of severe vertical loadings at the wheel-rail interface. The two principal phenomena which develop large transient forces are rock-and roll motions of the car, where the weight is alternately transferred from one side of the track to the other, and pitch and bounce motions of the car, where the load path remains close to the center of each truck. The roll motions are usually most severe at speeds around 20 mph, whereas the pitch and bounce motions are generally excited at speeds over 45 mph. The transient forces associated with bounce and pitch motions can become quite large if the main suspension springs are driven solid.

The following corrective actions are applicable:

- Provide adequate damping for main suspension springs.
- Use longer travel main suspension springs.
- Improve the track profile.

Both types of motions can be minimized by the use of adequate damping which acts in parallel with the main suspension springs. This is also illustrated by the material presented in Appendix E. The use of longer travel suspension springs also reduces the tendency for the development of severe motions. Vehicle excitation can be minimized by maintaining track with a minimum of profile variations and, especially, the elimination of periodic variations.

7.5.2 Lateral Load

Lateral wheel-rail loads have been found to be at their most damaging levels during high-speed movements of empty or lightly loaded cars under truck hunting conditions. Truck hunting, a self-excited type of vibration, causes severe lateral impacts between the wheel flange and rail, resulting in large forces that cause wear and other damage to both wheel and rail. The development of large wheel-rail lateral loads during curve traversal can also damage the track.

The following corrective actions are applicable:

- Increase truck resistance to parallelogramming.
- Increase damping of the truck swivel motions.
- Maintain close control over wheel profiles.
- Limit maximum speed.

Truck hunting motions can be minimized by the use of acceptable truck construction. Several methods have proved to be effective in delaying the onset of truck hunting motions, including maintaining carefully controlled profiles of the wheel tread, increasing the resistance of the truck to out-of-square distortion, and increasing damping with respect to truck swivel motions. The use of constant-contact side bearings is one method of obtaining additional swivel damping.

7.5.3 Rate of Track Damage

Most track-related defects develop slowly over a long period of time before a failure condition is reached. This fact suggests that one ought to be able to detect and correct these conditions in time to prevent derailments. The FRA accident statistics suggest that this is the case because when accidents caused by track factors are summarized for major railroads, large differences are found. For example, the average derailment rate for three major railroads with the poorest record is over ten times that for three of the major railroads with the best record. The railroads having the best record also have a reputation for maintaining high-quality track. Thus it would appear that a much higher degree of safety in rail transportation can be obtained if stricter standards are used for track maintenance. The data suggest that large size/weight cars can be accommodated without any decrease in safety.

Large heavy cars wear out the track faster than lighter cars. The problem becomes one of maintenance expense and the additional costs to maintain the tracks when using the higher capacity cars. Thus, heavier cars are not unsafe in themselves if they lead to an increased rate of track degradation provided that track conditions are monitored and maintained to provide for safe operations.

7.6 DERAILMENTS CAUSED BY VEHICLE COMPONENT FAILURE

7.6.1 Wheel Failure

The most serious safety hazard associated with wheel failure is a sudden fracture on a moving train, which usually results in a serious derailment. The principal reason for this type of failure is the overheating of the wheel because of the improper application of the tread brake. The residual stress field is altered in an overheated wheel, making it more susceptible to the development of cracks in the rim or plate.

The following corrective actions are applicable:

- Development of procedures that would minimize the likelihood of leaving handbrakes applied;
- Development of hardware that would limit the total thermal loads going into a wheel during any single brake application;
- Development of reliable procedures for inspecting wheels to determine if they have been overheated to the point where they are more susceptible to failure;
- Utilization of off-tread brake systems.

7.6.2 Coupler Failures

Coupler failures are primarily due to excessive longitudinal train forces. Longitudinal train forces are influenced by the length of the train, the mix and placement of light and heavy cars in the consist, undulations in the terrain over which operations take place, the manner in which the train is operated, and the properties of draft gear and other end-of-car cushioning devices. As a general rule, as the weight of the cars increases, there is a tendency for the development of larger longitudinal train forces, although proper train handling can do much to minimize the development of severe transients. The skill of the locomotive engineer is of prime importance in the minimization of longitudinal train forces.

The following corrective actions are applicable:

- Development of guidelines for placement of the cars in the train by weight and type:
- Use of more effective draft gear or end-of-car cushioning devices to mitigate transient force buildup in the train;
- Improvement of the skill of locomotive engineers in train handling to allow the operation of the train with smaller transient forces;
- Development of stronger coupler components, including the use of steels that are less susceptible to fracture;
- Development of braking systems which allow greater flexibility in the way braking forces are applied to the train.

7.6.3 Side-Bearing Failure

Two types of side-bearing failures that can lead to derailment are recognized. First, a side bearing can become detached from the bolster, which will permit excessive carbody roll. Second, the side-bearing clearance distance might not be maintained, and the entire weight of the car could be applied to two diagonally opposite side bearings. If, at the same time, the car is undergoing an oscillatory motion of the suspension system, it is possible that one side of the truck will be relieved of vertical load while still under the action of lateral loads, a situation which can lead to wheel climb and derailment.

Improper side-bearing clearance is more critical with some cars than others. Some car structures are flexible enough to accommodate differences in cross-level over the length of a car. Other cars, such as tank cars and covered hopper cars, are stiff torsionally and cannot accommodate significant differences.

The following correction actions are applicable:

- Maintenance of cross-level standards for the track;
- Development of side bearings with a greater range of control;
- Development of way-side inspection systems that can detect cars with missing side bearings.

7.6.4 Plain Bearing Journal Failures

Since all new or rebuilt cars must be equipped with roller bearings, the derailment rate caused by plain bearing journal failures should decrease in the future. The major corrective action taken in recent years to reduce the probability of derailment from this cause is the installation of hot box detectors along the railroad right-of-way. Since the bearings generally become overheated before they fail, detection of a hot box allows the defective car to be set out from the consist before the bearing fails.

7.7 GRADE CROSSINGS

The FRA extensively reviewed the grade-crossing safety problem and found that the effect of car size, weight and length on grade-crossing safety is minimal. Accordingly, efforts to improve grade-crossing safety include both the consideration of more effective locomotive warning devices, such as strobe lights, and the use of more effective highway and pedestrian alarms, rather than freight car design changes.

7.8 SUMMARY AND CONCLUSIONS

Effective correction actions were developed for most of the problems encountered in the operation of 100-ton capacity freight cars. Many of these actions involve modifications to existing equipment and design changes on new equipment. Others relate to changes in operating procedures and to more stringent design, inspection, and maintenance standards for track. These corrective actions, when fully implemented, will lead to safer rail transportation. Applied research and test programs must be continued to gain better understanding of certain phenomena associated with the use of heavy cars and, especially, to optimize train-handling procedures in trains of mixed light and heavy cars.

8. INDUSTRY ACTIONS TO IMPROVE SAFETY AND PERFORMANCE

8.1 ABSTRACT

The introduction of longer and larger capacity freight cars led to some initial equipment maintenance and operating problems. Railroads and equipment manufacturers have taken many actions to overcome these problems. In most instances, these actions have been timely and expeditious, but there are examples — the covered hopper rock-and-roll problem is one — in which the industry's response has been dilatory. Often, however, the pace of change or of improvements is dictated by the size of the fleet and the logistical and financial problems that are implied. There are a number of current and proposed research and test programs, sponsored by government and by industry, that are directed at both economic and safety needs. Examples of these programs include the Track Train Dynamics program, the Facility for Accelerated Service Testing, the Rail Dynamics Laboratory, the Track Design Optimization Program, the Locomotive Research and Train Handling Evaluator, and the Stability Assessment Facility for Equipment.

8.2 DIFFERENCES AMONG RAILROADS

When evaluating the actions taken by various railroads to improve safety and performance, one must recognize the significant differences among the railroads based on their operating experiences and economic conditions. For example, some railroads have had more favorable operating experience with heavier cars than other railroads. Other railroads are aware of modifications that should be made to handle heavier cars more effectively, but do not have the funds to implement the changes.

The Bessemer and Lake Erie Railroad (B&LE), one of the earliest railroads to move bulk commodities in large-capacity cars, has had favorable experience with the heavier cars. Beginning in 1931, they acquired a fleet of 6000, 90-ton capacity hopper cars.[1] These cars were operated with a rated load of 90 tons until 1962 when the loads were increased to 100 tons per car. A relatively low rate of rail wear has been experienced with these cars. Some sections of rail have accumulated 650 million gross tons of traffic with vertical head wear of less than 1/8 inch. This experience is generally better than other railroads with similar traffic patterns.

The reasons for the low rate of wear and other generally good track experience on the B&LE cannot be completely identified. Some of the practices that are followed on the B&LE include operation with a 35-mph speed limit for bulk commodity trains and a policy of using heavy welded rail sections. The railroad has also followed a rigorous program of track inspection and maintenance, with prompt correction of any track defects.

8.3 SURVEY OF RAILROAD ACTIONS

The AAR contacted a number of railroads to determine practices that they had developed to accommodate the operation of the heavier 100-ton cars. The reported actions included modifications to both equipment and track, changes in operating procedures, and the upgrading of inspection procedures.

The equipment modifications that were mentioned emphasized the use of higher quality components such as high alloy grade C bolster castings and grade E couplers. Better alloys are also being used for spring construction, as well as class C wheels for improved wheel wear. Center plates have been increased in diameter to 16 inches, and some heat treated center plates are being used. Many of the heavier cars are now being equipped with better suspension system elements, constant-contact side bearings, and high-performance draft gear. Brake systems are being improved with the use of the ABDW valve, which provides faster application and release times, and some cars are being equipped with empty/loaded brakes which provide for more effective braking of the heavier cars.

Many changes were reported that deal with improved track structures. The use of larger tie plates and additional spiking and more rail anchors were reported for achieving greater rail stability. Also, there is a general tendency to go to heavier rail sections, such as the use of 115-pound rail in yards, 132-pound rail on mainline tracks, and premium heat treated rail on curves. Welded rail is becoming an industry standard, and many railroads are replacing jointed rail with welded rail even before the jointed rail has reached the normal replacement cycle. Thermite welding of jointed rail is also being utilized to eliminate rail joints.

Greater attention to the track subgrade was reported, with the use of more and higher quality ballast as well as special procedures such as the installation of fabric to protect the ballast where poor soil conditions exist. The use of heavier cars is also requiring strengthening of some bridges. The super-elevation of curves is being modified in some cases so that the high center of gravity cars can be accommodated.

Case studies show that specific railroads have been able to profitably operate larger cars while maintaining a good comparative safety record. Those railroads attribute their success to having made additional investments in track inspection and maintenance. The data in Table 8-1 quantify the maintenance performed from 1955 through 1978 by one railroad that operates a substantial number of larger cars.

Train-handling procedures are being revised. Train makeup is being standardized to utilize recommendations from the Track Train Dynamics program, generally involving placement of heavy cars toward the front of the train. The training of locomotive engineers is also being improved with the use of simulators on many railroads. Limits are being placed on the speed variations which are allowed on curve track to limit the unbalance speed of high center of gravity cars. Larger capacity car retarders are also being used in classification yards so that the yard operations with heavier cars can be more closely controlled. Radio-controlled braking equipment is being utilized under some circumstances to permit shorter stopping distances, faster initial charging times, and a reduction in longitudinal train forces because of the more uniform brake response.

TABLE 8-1

TRACK MAINTENANCE RECORD OF A SELECTED RAILROAD

Time Frame	Tie Replacements per Year	Rail Replacement in Tons per Year
1955-59	38,800	3,900
1960-64	45,100	3,400
1965-69	68,800	5,700
1970-74	70,520	6,460
1975-78	74,150	6,075

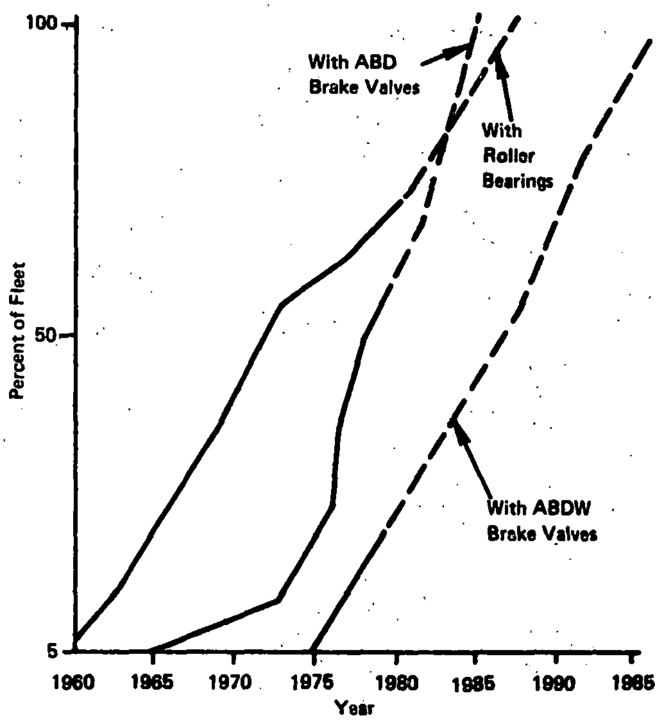
Source: AAR Railroad Industry Survey

The railroads reported that more attention is being given to inspection techniques so that problems can be detected before they result in accidents. Many railroads have developed programs for the frequent measurement of track geometry parameters to detect changes in track conditions. Rail flaw detection equipment is also being utilized more frequently. Maintenance procedures are being geared to these track inspection procedures. The use of wayside inspection systems is also growing. These devices are being used for detecting broken wheel flanges, dragging equipment, and hot box detectors.

Although design changes are the first step in rectifying perceived problems, implementation of equipment changes may take several years. Figure 8-1 shows estimates of the amount of time required to incorporate typical design fixes and improvements.

A recent AAR survey of railroad management provided a list of significant steps taken by the industry to compensate for increases in size, weight, or length of rail cars. These steps are:

- Increased track inspection, both visual and with periodic operation of track geometry car and rail test vehicle;
- Anchor spiking to reduce gage widening;
- Increase in rail anchoring to minimize track buckling;
- Laying of welded rail;
- Increase in ballast section;
- Installation of fabric beneath track structure at problem locations;
- Laying of all-welded turnouts;

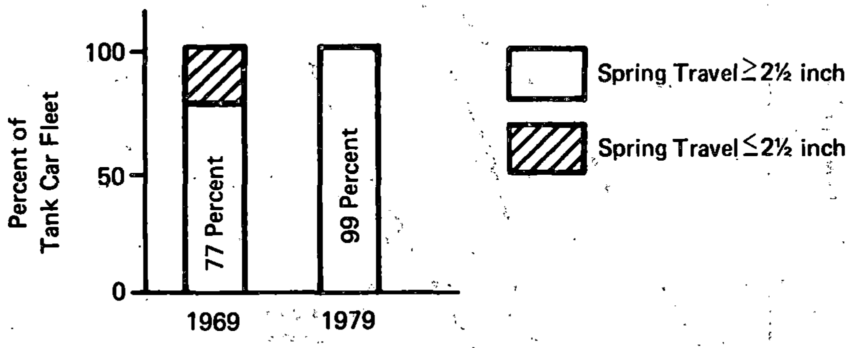


Information Source: AAR 4% Annual Projections for Roller Bearings Beyond 1979; Shaker Research for Roller Bearings Up to 1979; Manufacturers for Brake Valves.

FIGURE 8-1 SCHEDULES FOR INTRODUCTION OF CAR IMPROVEMENTS

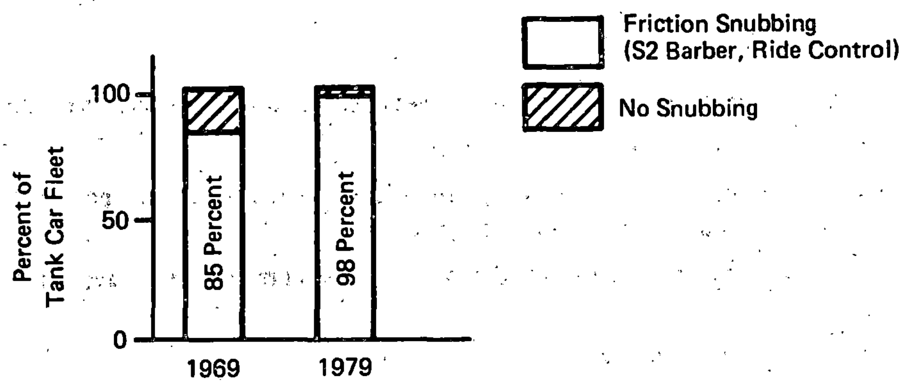
- Use of 132-pound rail as the standard section in heavy tonnage territories;
- Adoption of granite ballast as a standard;
- Changed requirements for elevating outside rail on a curve to account for higher vertical center of gravity on longer cars;
- Establishment of a maximum dimension for long cars moving in regular train service;
- Adoption of 36-inch wheels;
- Installation of broken wheel and flange detectors, automatic dragging equipment detectors, and hot box detectors;
- Use of larger diameter center plates (16 inch) on new equipment;
- Placement of blocks of heavy cars at the head end of trains;
- Incorporation of ABDW equipment and auxiliary brake pipe venting valves;
- Use of empty load brake systems;
- Use of welded brake pipes and fittings;
- Use of roller bearings;
- Use of improved snubbing devices;

Two examples of the industry's actions in improving vehicle dynamics are shown in Figure 8-2, which demonstrate the extent to which improved suspension systems have been deployed on tank cars over the last ten years.



Note: Today, only about 1% of tank cars, about ½ percent of coal hoppers, and a few other cars have D2 (less than 2½ inch travel) springs. The remaining D2 springs are primarily on 40- or 50-ton cars.

(a) Implementation Record: Improved Spring Travel on Tank Cars (based on a survey of approximately 75% of the tank car fleet)



(b) Implementation Record: Improved Snubbing on Tank Cars (based on a survey of approximately 75% of the tank car fleet)

Source: AAR Survey of Tank Car Owners.

FIGURE 8-2 EXAMPLES OF INDUSTRY COUNTERMEASURE IMPLEMENTATION

The above list was derived from responses to a specific question posed in this survey:

"List any significant steps that the railroad industry or your company have taken with regard to equipment, track, operation, inspection, and maintenance to compensate for increases in the size, weight, or length of railcars. (Where possible, indicate ten-year trends.)" What follows is a sample of the verbatim responses.

- "Construction specifications, inspections and maintenance of freight cars and track have evolved through the years from practices that accommodated 40-ton cars to our present accommodation of 100-ton cars. Changes in journal size, wheel size, journal design, air brakes, structural components, heavier rail, continuous welded rail, automated track maintenance and a myriad of other steps which are well-known have been taken to accommodate the present 100-ton cars and the present long length cars."
- "Adoption of 36-inch wheels, 18-inch tie plates, additional spiking, heavier rail, increased track inspection as well as maintenance cycles, broken wheel and flange detectors, automatic dragging equipment detectors, hot box detectors, passing train inspections, etc."
- "From the standpoint of safety, it has not been necessary to make extensive changes in train operation or track standards to accommodate increases in size, weight or length of rail cars. Train stopping distances required changes in signal spacing and/or maximum speed limits. There have been some changes in train handling and makeup. Bridges on some lines had to be strengthened. Additional rail anchors were installed to prevent rail running."
- "We have taken many steps from an engineering standpoint to compensate for the increased size and weight of rail cars. Next year we will complete the final phase of replacing all retarders with E-160 retarders that can effectively handle 100-ton equipment. We have rebuilt, with heavier track components, all yard trackage negotiated by unit coal trains. The minimum standard rail section has been increased to AREA Section 115.25 for yard and terminals and nothing is purchased with a smaller section modulus. 132# rail has been standardized upon for all main line operations. Welded rail has been installed on main line rail locations which would have lasted a minimum of 10 years longer had it not been for the advent of the heavier cars. Additional tamping equipment has been added to the work equipment fleet to take care of profile and alignment problems associated with heavier loads. A ballast cribber has also been used to take care of spot muddy conditions. Shoulder ballast cleaning has also been instituted in some main line areas."
- "In general, provision is made for blocks of heavily loaded cars to be placed at the head end of trains to avoid the possibility of harsh slack action as a result of loads running in from the rear in slow-downs and at certain critical grade locations. The reduction of such drawbar forces correspondingly reduces the potential for equipment failures (knuckle-coupler separations) and derailments."

- "Track geometry vehicles are operated at periodic intervals on our road to monitor cross-level deviations and emphasis has been placed on the monitoring of gage widening in curves thereby reducing the potential for derailment of high C.G. cars."
- "Our road has continued on a Programmed year-to-year basis to replace rail with continuously welded rail and thereby tend toward a reduction in "rock off" type derailments of high C.G. cars."
- "We have taken significant steps to compensate for increases in size, weight, and length of rail cars, as demonstrated by the following:

  a. Increased track inspection, both visual and with periodical operation of track geometry car and trail test vehicle.

  b. Anchor spiking to reduce gage widening.

  c. Increase in rail anchoring to minimize track buckling.

  d. Laying welded rail.

  e. Increase in ballast section . . ."
- "Braking of trains are being improved by incorporating ABDW equipment and auxiliary brake pipe venting valves to greatly reduce time required to achieve full brake application.

  "Empty-load brake systems are used on light-weight cars to provide safe level of braking effort: hi-phosphorous brake shoes are standard in lieu of former standard iron shoes to minimize hazard from sparking during braking of train.

  "All welded brake pipes and fittings are being used to eliminate leakage formerly experienced at compression and threaded fittings resulting in better train handling.

  "Roller bearings are used, thereby reducing hot boxes and other types of failures experienced with plain journal bearings.

  "Improved control of suspension system is used on cars through means of improved snubbing devices and supplementary snubbing on cars that are sensitive to harmonic dynamic actions."

8.4 SAFETY-RELATED RESEARCH

8.4.1 Federal Railroad Administration

The FRA has organized and directed an extensive program in railroad safety research. Some of the more important phases of this program pertinent to the freight car size, weight, and length issue are briefly described below.

Hazardous Materials Tank Cars

The risks associated with the shipment of hazardous materials by rail should diminish in the next few years as the retrofit of Type 114 and 112 tank cars becomes completed. The Hazardous Material Tank Car Program resulted in recommendations for modifications to these cars, which were incorporated into HM-144. These recommendations reduce the likelihood of the release of hazardous materials from tank cars involved in railroad accidents. The modifications include the provision of head shields at both ends of the car, which minimizes the change of coupler penetration into the head; the provision of thermal insulation, which minimizes the chance of the explosion of a car engulfed in a pool or torch fire; the addition of a coupler restraint system (shelf couplers), which reduces the probability of uncoupling in a derailment; and the provision of an adequate venting system.

Track Standards

The FRA organized a large program to determine ways of improving railroad track performance and the regulations regarding track standards. The program includes a series of projects currently under way in a number of key track safety areas. These projects are generating engineering and technical data and have been used to identify areas where existing regulations are deficient and where new safety standards or other regulatory modifications are desirable. The program includes vehicle and track interaction effects, rail inspection and remedial actions, the use of continuous welded rail, and methods for the identification of defective cross ties.

A notice of a proposal to amend the FRA regulations containing the track safety standards was recently issued. The amendment to these standards would update, consolidate, and clarify existing rules and would eliminate certain rules no longer considered necessary for safety.

Facility for Accelerated Service Testing

The FRA sponsored a joint government/industry program over the last several years at the Transportation Test Center to investigate the long-term effects of railroad operations on track and equipment. This work is being conducted on a special track facility which is made up of a number of different types of track construction. A mixed train of 100-ton capacity cars operates over the track to generate a high rate of usage. Data from the test are applicable both to the track structure and to the cars. Test results have shown how various types of track structure respond to heavily loaded cars. Also, much information has been gathered about the rates of wear that are experienced both on rail and on equipment. Future work on this facility will look into the effects of 70-ton capacity cars so that the rates of wear and other aspects of track degradation can be related to wheel-rail interaction loads.

Locomotive Research and Train-Handling Evaluator

The FRA is sponsoring a program for the construction of a locomotive and train-handling evaluator that will be used for research purposes. Its primary purpose is to examine human factors and their relationship to train handling. Other uses of the evaluator will be to develop optimum ways of train control for different combinations of cars in the consist. The influence of heavy cars and their placement in the train will also be investigated. The results will be used to provide recommendations for the most desirable type of train make-up from a safety standpoint, based upon the minimization of transient longitudinal train forces. It will also be possible to evaluate various train operating aids, such as draft-buff indicators, and to examine ways in which these aids can be used most effectively for better train control.

Stability Assessment Facility for Equipment

The objective of SAFE is to provide a standardized track facility for evaluating the dynamic response characteristics of rail vehicles at the Transportation Test Center in Pueblo, Colorado. The track is instrumented with strain gages to measure vertical, lateral, and longitudinal forces; linear differential transducers to measure vertical, lateral, and longitudinal displacements; and monument-based optical transducers to measure and record track modulus. This instrumentation is strategically located along the track that will contain known geometric variations to induce vehicle dynamic modes. It also contains variations in curvature which include various curves, spirals, and tangents. Portions of the track will include new and used profiles and will be welded and jointed rails. It is expected that the vehicles will be tested in two configurations: new and simulated worn condition.

Wayside Inspection

The utilization of advanced wayside inspection equipment offers the possibility of identifying and removing defective cars before they lead to accidents. Some wayside inspection systems, like hot box detectors, have been utilized for many years. Other equipment, such as that to detect improper dynamic operation of the suspension system, are in the early stages of development. The FRA organized a joint government/industry group to oversee the installation and operation of a wide variety of wayside inspection systems at the TTC. These devices are located on a special track section where cars containing known defects can be used to examine the responsiveness of the detection equipment. In addition, it is possible to inspect the cars in the FAST consist by running this train over the wayside detection site. The devices presently installed can be used to detect wheel cracks, out-of-gage wheels, loose wheels, dragging equipment, etc.

Rail Dynamics Laboratory

The RDL at the TTC makes possible laboratory evaluation of the dynamic characteristics of full-sized railroad freight vehicles. The major items of equipment in the laboratory are a roller unit which permits wheel-rail interactions to be studied over a wide range of simulated operating speeds, and a large-scale shaker, which can be used to excite and identify all principal natural frequencies of the carbody structure. The laboratory is available so that manufacturers can examine the full-scale dynamic behavior of their equipment as an effective supplement to road tests.

8.4.2 Track Train Dynamics Joint Government/Railroad/Industry Program

The introduction of longer heavier cars into general interchange service caused increased force levels in couplers and track structures as well as greater demands on air brake system performance and train handling for safe operation. The industry recognized the resulting need for better train makeup and handling, improved car components, strengthened track structures, and engineering economic studies of the effect of car size. A number of cooperative government/railroad/industry research tasks were started in 1972 under the Track Train Dynamics (TTD) program to address these and other issues. The following summarizes some of the recent program developments pertinent to the heavy and/or long car issue.

Better Train Makeup and Handling

Some of the operational guidelines and aids that were developed on an interim basis in Phase I of TTD dealt with car weight or length. These guidelines were developed through the cooperative efforts of dozens of railroads and a continuing committee of "TTD Implementation Officers." An update on the "Guidelines" and operation aids follows.

Revised TTD Guidelines

The General Committee of the AAR Operating-Transportation Division recently approved the first major revision of the "Guidelines" based on the most recent analysis capability developed and applied during Phase II and the increased experience and understanding of track-train dynamics. Information is presented on train stopping distance as a function of car weight, effect of blocking of heavy and light cars in the consist, how to accommodate long car/short car combinations, and other makeup and handling guidelines. The section on track structure was expanded and emphasizes the dependence of reliable train operations on the condition of the track and supporting structure.

Train Operation Aids

During Phase I, several operation aids such as the Train Mass Diagram or Train Tonnage Profile were developed to provide the operating crew with an effective graphic display of the distribution of car weight (and exceptional lengths) in their particular train. More ambitious tasks were undertaken in Phase III of TTD to provide the operating crew with real-time information on the current tractive effort, trainline continuity, locomotive condition, and indicators of the status of the air brake system. Performance specifications were developed for an on-board microprocessor and reliable power supply to support the prototype system. A cab makeup and air brake system simulator for preliminary testing is near completion at the AAR.

As stated in the revised guidelines: "The introduction of . . . longer and heavier freight trains demands a great amount of judgment be exercised by the engineer . . . ." Train operation aids such as those under development in TTD should bolster the engineer's "judgment" and insure safer operation of consists with heavy and long cars.

Improved Car Components

The heavier, longer, and often higher center of gravity cars put additional burdens on car component reliability. Many tasks in Phase II were directed at improvements.

Brake Shoe Tests

A series of stop distance and drag braking tests were completed by the AAR on a specially instrumented car. Four types of composition shoes and two types of cast iron shoes were included in the test. It is expected that these tests will provide guidelines for component specifications that will contribute to the prevention of excessively uneven braking in a train made up of loaded and empty cars of various sizes having different types of brake shoes.

Auxiliary Snubbing Tests

Completed at TTC in 1977, these tests of generic types of snubbing systems provided improved data for use in the computer program and design basis for control of carbody harmonic roll and bounce. Suspension groups with greater spring capacity (D-7 springs) and improved damping were recently made available by the supply industry. Studies by the TTD truck and suspension groups indicate a desirable balance is possible between snubbing and spring travel to improve both roll and bounce behavior of high-capacity freight cars.

Appendix F contains a report provided by a member railroad of the AAR which shows specific test and analysis results from such a study.

Coupler and Draft Gear Tests and Specifications

Under the Coupler Safety Project, more than 30,000 miles of test runs were conducted and service failure and wear rates studied. Characterization tests of draft gear were recently completed, and recommendations for AAR specification improvements were made. The changes to AAR specification M-201 include dynamic tear test energy values that will prevent the brittle type of fracture often observed in couplers. The use of quench and tempered steels (bainite-martensite) should reduce dramatically the incidence of broken couplers with heavy cars.

Freight Car Structural Reliability Studies

Design methods and specifications against fatigue were developed during Phase II on several tests.

Freight Equipment Environmental Sampling Test

The first Freight Equipment Environmental Sampling Test runs were completed. On future tests, unattended data recorders will collect "histogram" information on vertical and longitudinal carbody accelerations experienced by several freight car types in general road service. These data will complement and extend the representations of load environment now used in the Interim Guidelines for Fatigue Analysis of Freight Cars, developed as part of the TTD effort for inclusion in AAR Mechanical Division standards.

Fatigue Analysis Tests

The Fatigue Analysis Tests of six 100-ton freight cars on FAST were completed in 1978, and a final report is now under review. The relative benefits of several structural "fixes" to prevent the cracking of fabricated center sill ends were assessed. This issue is particularly timely because of the short supply of cast center sill ends.

Truck Fatigue Specification

A new specification for the AAR acceptence fatigue testing of truck bolsters was developed on the basis of an analysis of many thousands of miles of road data and hours of laboratory testing under the auspices of the Truck Safety Project.

Improved Wheel Specification

Because of the wear resistance requirements and economic constraints, higher hardness carbon steels are used in wheels. Therefore, the only practical method of ensuring wheel integrity under heavy axle loads is to limit stresses and control metallurgical quality. This approach was implemented by the AAR through developments in TTD, particularly through the development and required application of qualified stress analysis techniques on wheel designs.

Strengthening of Track Structures

Following the Phase II work which was aimed at avoidance of conditions related to derailments, recent cooperative AAR research has focused on improved basic understanding of track response to heavy wheel loads.

Lateral Track Strength Tests

The Track Strength Characterization Group, consisting of track engineers from many railroads, and the DOT directed a number of recent full-scale laboratory and field tests of lateral track strength under vertical and longitudinal loads. "Rail spreader" tests were recently completed using a specially designed vehicle that appears to correlate lateral track response variations with poor tie conditions. Since lateral resistance of rail depends strongly on longitudinal rail force, the development and application of techniques to measure this force were emphasized.

Perturbed Track Test

In addition to the instrumented locomotive tests conducted over specially perturbed tracks at Pueblo TTC, special lateral track compliance tests were conducted under TTD. During high-speed operation of heavy 6-axle locomotives over severe track geometry perturbation in a curve, maximum lateral loads of over 50,000 pounds were observed for a single axle with maximum dynamic gage widening of 1-¼ inches and track shift of 3 inches. In the track compliance tests with "hard" and "soft" sections, the forces were greater in the hard sections, but dynamic deflections were similar. Studies such as these are planned using heavy freight cars.

Wear Research

Laboratory testing at the IIT and the Colorado School of Mines is complete, and final reports are being prepared. These studies indicate a dramatic increase in wear rate associated with a change in wear mechanism at a critical level of contact stress and creepage or slip. Increases in hardness of one of the components — for example, rail — can have an adverse effect on wheel wear according to some of the laboratory studies. Tractive wheels, such as those of a locomotive, produce more wear per wheel than car wheels. However, as car size/weight increases, wear of nearly free rolling wheels approaches that of locomotive wheels on tangent track. For a 70-ton car, for example, the ratio of locomotive wheel to car wheel caused wear is 8, but it is 3 for a 100-ton car.

Wheel-Rail Load Test

Comprehensive tests were completed this summer at TTC to define the wheel-rail interface force environment under a variety of conditions on 100-ton capacity cars.

Rail Risk Analysis

A failure model was developed to support a strategy for reducing rail defects and failure through improved inspection, control of load, and improved maintenance. These studies, combined with some railroad rail defect statistics, indicate a defect occurrence rate that increases rapidly with usage measured in gross tons of traffic. A strong dependence on axle load is expected although load spectra data are not yet incorporated in the analysis.

Rail Fatigue

Recent AAR reports indicate a transition from wear to fatigue in dominant mode of rail failure as wheel load increases beyond that for the 70-ton car. As shown in the most recent analysis, increasing the rail section size appears to be an effective technique for extending rail service life and offsetting the increase in rail fracture expected with heavier wheel loads.

Advanced Freight Car Design

The Phase III program initiated research in preparation for advanced freight car designs to carry heavy loads with less damage to track and equipment.

AAR Optimum Car Size Study

An AAR engineering economics project of long standing produced preliminary results reported at recent AREA meetings. These papers by Way[2] and Sammon[3] provide a good overview of past railroad industry economic studies of the effect of car size such as the study by Ahlf.[4] In their preliminary analysis, a 780-mile, one-way loaded movement of two 8000-trailing-gross-ton unit trains is simulated. One train consisted of 100-ton hopper cars and the other of 70-ton cars. The cost comparison included four major categories: roadway maintenance, transportation, car capital, and car repair. On a car-mile basis, the larger car is more costly. However, on a net ton-mile basis, which is really the proper basis for comparison of car size, the 70- and 100-ton car costs are nearly identical. An advantage is expected for the larger car size on the empty return haul. The authors emphasize the limited data on which this example is based and state that there is no unique "optimum" car size independent of type of service, route, etc. They also acknowledge that the road maintenance model may not adequately account for rail failure as a result of fatigue.

Performance Specification Development for Dynamically Stable Car

A draft performance specification for a high performance/high cube covered hopper car 100 tons or greater was prepared as an initial task in Phase III. Competitive designs will be invited from the industry, and prototype testing is planned in 1982.

8.5 ASSOCIATION OF AMERICAN RAILROADS STANDARDS

Current federal regulations specify requirements on railroad equipment, facilities, and operation that are designed to enhance the safety of rail transportation. In addition, the AAR maintains an extensive number of specifications and standards which apply to all equipment used in interchange service. The AAR standards are designed both to ensure the compatibility of equipment operating on different railroads and that the equipment can be handled safely. The AAR standards are under continual review by standing committees which have the responsibility to take prompt action to modify the rules, should some specific situation develop that leads to an industry problem. Currently, the AAR standards govern many of the specific conditions which pertain to the car size, weight, and length issues, such as the maximum allowable axle load for interchange service, conditions under which supplementary snubbing devices are required, and maximum car height and width dimensions.

8.6 TRENDS IN RAILROAD EQUIPMENT DESIGN

Trends in the design of railroad equipment that are pertinent to the issues of rail safety are discussed below.

8.6.1 Improvements in Conventional 3-Piece Freight Car Trucks

The development of improvements and new design for the conventional freight car truck has been one of the most active fields in railroad product development. For example, recently requirements for the use of supplemental snubbing devices were extended. Freight car trucks must be equipped with snubbing devices to damp out the oscillations of the primary suspension system. The present AAR rules call for the use of supplemental snubbing devices on cars where the center of gravity exceeds 84 inches above the top of the rail and where the truck center distance is within the range from 28 to 48 feet. Until recently, the range had been 28 to 45 feet for truck center distances.

Another trend in the construction of conventional freight car trucks is utilization of longer spring travel. Most new cars now are equipped with 3-11/16 inch travel springs. Within the last 2 years, the use of the D-7 spring, which gives 4-¼ inch travel, was introduced. Wheel-rail interaction forces are significantly reduced by the use of longer travel suspension springs. Also, until about 2 years ago, the use of D-3 suspension springs (2-½ inch travel) was common on tank cars, but practically all new tank cars are now equipped with 3-11/16 inch travel springs.

The concern over truck hunting phenomena has led to the development of devices which prevent this unstable type of motion. One way of reducing the hunting tendency is to provide some damping restraint to truck swivel motions. The use of the center plate extension pad, C-PEP, provides this type of restraint. Another technique is the use of constant-contact side bearings.

Another approach to minimizing hunting tendencies is the development of devices to increase the truck's resistance to out-of-square deformations. There are many such devices, of which one is a split taper friction wedge.

The reliability of truck components against fatigue failure has also been improved. Guidelines for a proposed bolster fatigue test specification was recently submitted to the AAR. Presently, side frame truck castings are subject to a fatigue test specification, but there is no such specification for bolsters. Laboratory tests indicate that the fatigue performance of truck bolsters has become much more reliable in recent years as a result of changes in bolster design, particularly for the large 100-ton capacity car, and of better quality control over the steel used in the castings.

8.6.2 Development of "Type II" Trucks

Over the last several years, much activity has been directed toward the development of new types (designated Type II) of freight car trucks. The goal has been the development of trucks with features which will reduce wheel wear and wheel-rail interaction as well as increase safety and reliability. These trucks would be more expensive than conventional 3-piece freight car trucks, but the reduction in wheel wear and other beneficial effects would be expected to more than compensate for the added cost.

Different design philosophies are evident in these advanced truck designs. Truck hunting phenomena, for example, are minimized if the truck is rigidized to reduce its tendency for out-of-square deformations, and this feature is evident in most Type II trucks. Suspension systems vary with different manufacturers. One design, the ACF fabricated truck, reduces the unsprung mass by placing the primary suspension springs closer to the axle. Another design, the National Swing Motion Truck, has a conventional vertical suspension system, but offers increased lateral motions through the use of a pendulum support for the suspension springs. The principal design objective of other trucks is the reduction of wheel wear and wheel-rail forces on curves through the use of self-steering mechanisms. Several Type II trucks are in the developmental stage.

8.6.3 Freight Car Design

The tendency in railroad freight car construction has been toward the larger capacity car. The 100-ton capacity cars are utilized for almost all bulk commodity movements. Another tendency has been to design special-purpose cars for different commodities. For example, in covered hopper car design, one size car is designed primarily for the shipment of cement, a high-density product; another large capacity car design is used for the shipment of grain; a medium-density product; and a still larger car design is used for the shipment of low-density products like plastic pellets. On some cars, it has been possible to use innovative designs to reduce the center of gravity. For example, on some high side gondola cars which are used for the shipment of coal in unit trains, where they can be unloaded by a rotary dump, it has been possible to use recessed floor designs which more effectively uses the lower part of the clearance diagram. This permits the overall center of gravity of the car to be lower in comparison with more conventional hopper car designs.

8.6.4 Couplers

The reliability of couplers will be improved in the future by the revised AAR requirements for coupler construction. These requirements specify material changes which will reduce the probability of fracture and fatigue.

8.7 SUMMARY AND CONCLUSIONS

The railroad industry has been forced by competition and other economic factors to place increased reliance on the use of large-capacity cars. The industry has recognized the problems associated with the use of these cars and has instituted corrective actions where necessary. Research and development efforts are continuing to identify further solutions which will mitigate the effects of large and heavy cars. The railroad supply industry has introduced numerous products which are designed to minimize the problems associated with heavy car movement. It is unlikely that in the near future, pressures will develop for the use of higher axle loads. Research work will have to establish more precisely the full range of economic factors associated with the use of large-capacity cars before further increases in car weight capacity will be accepted.

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9. STRATEGIC OPTIONS

9.1 ABSTRACT

In the context of this report, "strategic options" are short- and long-term policies that enhance railroad safety. They differ from the measures described in Chapter 7 in that the measures are generally specific changes in car design, track maintenance, or train operation, whereas strategies are meant to facilitate the identification and implementation of such measures, or to eliminate the need for them.

An analysis of strategic options must take place within a framework of goals, constraints, and time frames. This chapter identifies those factors that must be taken into account.

9.2 INTRODUCTION

It is crucial, when evaluating strategies, that a systems analysis be made to ensure that reduced risk in one area is not gained at the expense of increased risk elsewhere. Several important other issues must also be addressed:

- The cost of improved safety and whether it is justified;
- The financial condition of the railroad industry, and its ability to effect improvements;
- The possible difference between future problems and past problems;
- The informational obstacles to a quantitative analysis of costs and benefits;
- The requirements of interchange;
- The need for compatibility with other regulatory actions; and
- The time span over which strategies can be implemented.

This chapter discusses these issues, the types of strategies, and areas for improvement.

9.3 STRATEGIC ISSUES

9.3.1 The Cost of Improved Safety

It is necessary to consider the costs of improved safety as well as its benefits to the railroad industry and to society. In a modern industrial society, the public is exposed to risks created by industrial activity. Also, a reduction in the level of risk may have a concomitant increase in the cost of providing services, or possibly even an effect on employment and production. As yet, there is no general agreement on what are acceptable levels of safety or what costs society is willing to impose on itself in order to gain those levels. Nevertheless, this issue must be addressed in developing strategic options for improving railroad safety.

Equally important to consider is the definition of "safety." This term can include any of the following:

- Casualties to railroad employees;
- Casualties to the general public;
- Damage to railroad property;
- Damage to shipper property;
- Damage to third-party property; and
- Damage to the environment.

Significantly different perspectives on the desirability of various strategic options can result, depending on how many of the above "impacts" are subsumed under the definition of "safety." For example, the data in Chapter 4 shows that while derailment costs are relatively high, few fatalities, if any, over the past five years can be attributed solely to the size of cars. Therefore, strategic options concerned with altering car size are likely to have little influence on safety, if safety is considered to be synonymous with fatalities.

9.3.2 The Financial Condition of the Railroad Industry

While there are significant exceptions, in general, U.S. railroads are in a financially depressed condition. Their ability to generate the capital or operating funds that may be required by various strategic options is, at present, quite limited. It is desirable that any new programs for improved safety not have a further debilitating effect on the industry, either through increased costs or through decreased competitiveness with other modes of transportation. The consequence of these outcomes will be to cause a further deterioration in the levels of safety that will arise from severe financial pressures to further defer maintenance and reduce inspection.

9.3.3 Future Problems

Strategic options must be concerned with likely problems in the future. This study has determined that the greatest threat from larger cars lies in the future, when such cars might accelerate track wear on segments of the network where the track owner is not in a financial position to perform appropriate maintenance. This could set in motion the downward spiral of lower speeds, poorer service, loss of traffic, and decreased revenues on an ever-increasing number of railroads. Furthermore, increased shipment of hazardous materials by rail in the future has the potential for dramatically expanding the consequences of derailments.

9.3.4 Obstacles to Quantitative Analysis

A rigorous determination of costs versus benefits of stipulated actions is hindered by the usual hazards of anticipating the magnitude of future problems (which is the controlling assessment in this case) and the degree to which current countermeasures on the part of the government or the industry will be effective. For example, consider a strategic option in which hazardous materials transport is banned on certain "weak link" railroads. To estimate the benefits of this option, one would have to consider what other mode of transportation could and would be used, and what the safety record of that mode is likely to be in comparison with that of the competing railroads. To estimate the costs, on the other hand, one would have to take into account:

- Changes in cost to shippers;
- Possible dislocation of industry;
- Financial impact on the directly concerned railroads, and its effect on their general level of safety; and
- Financial effect on other railroads that interchange traffic with the directly concerned railroads.

9.3.5 Requirements of Interchange

Despite the existence of separate corporate entities, the U.S. railroad industry is highly integrated. It is virtually impossible to develop policies that affect only a portion of it. For example, freight cars are freely interchanged over the entire system. Thus, a strategy designed to keep large cars off the track system of railroads with a poor safety record would so affect the operations of interchanging railroads that they might want to altogether eliminate the use of such cars, despite their being profitable. As another example, a car with improved safety features may cost its owner an extra amount. When that car passes out of the owner's system, the owner no longer gains the safety benefit from it, nor do present time-and-mileage charges from interchanging railroads adequately compensate the owner for their use of the car. The incentive to implement expensive, but potentially cost-effective, changes is thus reduced.

9.3.6 Compatibility with Other Regulatory Actions

A number of government and industry initiatives in various stages of implementation are aimed at safer hazardous materials transport, the creation of freight car and track specifications to enhance safety, and the guaranteeing of the viability of important rail connecting links in the national rail network. It is essential that any options arising out of the present study be considered in the context of these ongoing programs.

As an example, there is an ongoing study, also mandated by Public Law 95-574, to determine "the effect of the exclusive ownership and control of rights-of-way by individual railroads on the safety and efficiency of rail transportation, considering, among other things, whether or not such rights-of-way might be better employed under new structures of ownership or other conditions of joint usage." Other examples of ongoing actions include railroad deregulation, regulations aimed at improving the safety of hazardous materials transportation, programs to improve track safety standards, and research aimed at developing safer rail vehicles and operating procedures.

9.3.7 Differences Between Long-Term and Short-Term Options

Short-term options are those that make their effects felt within a period ranging from several months to 3 or 4 years. Long-term options have a time horizon ranging from 5 to 15 years and longer. The slow change that these time frames imply are a result of the maturity, size, structure, and financial condition of the railroad industry, as well as of the technology it implies.

An example of technological limitations on the rate of progress in improving safety is the use of improved draft gear to reduce the frequency of accidents caused by train action. The effectiveness of the improved design will be small until a large number of cars are fitted with it. However, car fleet is replaced at a rate of about 3% a year. If all new cars had the new design and if it were retrofitted on older cars at the rate of 3% a year, it would still take 10 years to have 50% of the fleet operating with the new coupler.

Truly short-term options would involve regulatory actions to deal with emergency situations. These actions might include the temporary banning of hazardous materials cars on poor track, the imposition of slow orders, or the mandating of frequent track inspections. The exercising of these options is current DOT practice, and an analysis of them is likely to yield little added insight.

Examples of long-term options include the following:

- Development and establishment of incentives for railroads to shorten the implementation period for improvements. The latest innovation to improve freight car curve negotiation (i.e., the self-steering truck) will, after lengthy trials, if proved beneficial, take an extended period to be installed on a significant portion of the fleet.
- Development, establishment, and use of performance criteria for the introduction of new cars, which in essence would dictate the kinds of track and the conditions under which the new car can run safely without undue wear or deterioration of components.
- Legislation and government/industry actions to ensure the health of railroads carrying hazardous materials so that even the crucial marginal ones will have track that can resist heavier loads. Deregulation and federal assistance are examples of support efforts now under way. The second study mandated by Public Law 95-574 addresses the roadbed problem and may uncover additional options.

9.4 TYPES OF STRATEGY

Strategies may usefully be classified under the following headings:

- Federal safety regulations;
- Economic incentives for improvement;
- Research and development;
- Industry initiatives;
- Financial recovery through deregulation.

These groupings differ both in the types of actions contemplated within them and in the group that will have to bear the burden of implementing the strategies.

Issues that might, in a strategic sense, be addressed by a federal safety regulation are:

- Track safety standards;
- Mandatory limits on car size, weight, and length;
- Restrictions on the operation and routing of trains carrying hazardous materials; and
- Standards for employee training.

The use of economic incentives for improvements to freight cars is an approach that directly addresses the financial inability of many carriers to make these improvements, even though they may fully understand their benefits. This approach is the diametric opposite of the approach based on levying penalties when regulations are violated. Nevertheless, the two approaches can complement each other, with penalties being used to reduce flagrant violations, and incentives being used to reward thoughtful efforts to improve safety. A specific example of an economic incentive would be that of granting a higher investment tax credit for safety improvements on freight cars.

Research and development strategies are designed to provide insights into safety problems and into ways of solving them; for example, improved knowledge is required regarding the relationship between the quality of track and its rate of deterioration under heavy axle loads. Similarly, information is required to better understand the mechanisms of car derailment and their control through car design.

Industry initiatives to improve safety are an alternative to federal regulation. They are a preferred alternative if industry acts responsibly, since they are more likely to be optimally designed for specific problems. The railroad industry has, in fact, had a long history of setting safety standards for itself, as evidenced by the activities of the Bureau of Explosives and by the extensive AAR standards and interchange requirements. New areas in which the industry could cooperate to gain improvements are:

- Safety performance evaluation of new equipment;
- Studies of track deterioration under heavy axle loads; and
- Use of premium time-and-mileage rates for cars with safety improvements.

Rate and exit deregulation is considered by many industry observers to be the ultimate solution to railroad safety problems. In this view, a poor safety record can usually be traced to inadequate rates of return on investment. Poor financial returns force management to cut corners to survive, and safety-oriented expenditures are often the first to be reduced. It is therefore conceivable that if the industry were granted rate freedom as well as the freedom to abandon unprofitable lines, the railroads would have a leaner, more efficient, and more profitable system, which would also have an improved safety record. That this thesis is right can be seen by an analysis of the safety and financial records of the various Class 1 railroads. Such an analysis shows that in general, profitable railroads have the best safety record, while unprofitable ones have the worst.

9.5 AREAS FOR IMPROVEMENT

The objective of any strategy is to gain improvements in safety by realizing improvements in some aspect of equipment and track design, maintenance or inspection, or railroad operations. This section provides an examination of those areas in which worthwhile opportunities exist.

9.5.1 Equipment

Several areas pertain to equipment design, use, and evaluation where improvements can be effected.

Among the most important is the safety evaluation of freight cars before they are put into use. Present industry practice does not call for a thorough evaluation of the dynamic performance or derailment tendencies of a new design of freight car. The adoption of an industry-wide program of pre-purchase testing would prevent problems such as those that occurred with covered hopper cars. The DOT is currently investigating the feasibility of using a test facility to facilitate this type of safety evaluation. This program could easily be adopted and managed by the industry; alternatively, it could be viewed as a procedure mandated by federal regulation.

Another aspect of freight cars that can be improved is their design. Research and development opportunities exist for improved suspension design, the optimization of the design of load-bearing (and failure-prone) members, the development of truck configurations which result in improved curve negotiation, the design of self-centering couplers, and the design of load-sensing braking systems. Opportunities also exist for the development of failure-monitoring or derailment-sensing diagnostic systems for installation on freight cars. These systems would work either to prevent derailments by warning of the impending failure of some component or to reduce the severity of derailment by providing a signal that a car has derailed. (Often, a derailed car may be dragged several miles before the train operator becomes aware that it has derailed. In this situation, more cars may derail; also, extensive track damage may occur.)

Improved equipment maintenance provides another route to greater safety. Methods which improve diagnosis or which reduce both the cost of maintenance and the time required for it will be helpful. Specific components with expensive, time-consuming maintenance are couplers, wheels, bearings, and center plates. In addition to improved methods, it may be necessary to devise accelerated maintenance schedules for freight cars that tend to wear out their components faster than other freight cars because of deficiencies in their design.

The costs and benefits of large cars need to be studied in an ongoing program. This report has concluded that depending on track conditions, terrain, work rules, wages, etc., there is probably an optimum size and weight of freight car for each commodity. However, enough information does not currently exist to decide what that optimum is. It would seem to be crucially important to the railroad industry to be able to define the optimum and thus avoid the possibility of a costly mistake in the future; for example, the use of yet higher wheel loads than are now permitted in interchange.

Should improved safety features become available on freight cars, it is likely that they will have attendant costs. Unless an AAR standard is developed requiring these improvements, their use will have to be decided on individually by each railroad. If a railroad decides to invest in some improvement, it will need some assurance that it, not someone else, will benefit from that investment. That assurance exists only so long as the improved fleet of cars remains on the owner's trackage. As soon as the cars are interchanged onto another railroad's track, the return occurs only through time-and mileage charges. These charges will need to be reviewed to ensure that the rate of return to the owner is adequate.

An area of industry cooperation that has yielded benefits in the past, but which is in need of greater emphasis is in the early identification of "bad actor" cars and the development of a plan to deal with them. Information systems are now in place which make this a relatively easy process.

Finally, as demonstrated by this study, there is much to be gained by cooperation between management and labor in their efforts to identify and solve safety problems. The extent to which the UTU survey corroborated the results of statistical analysis of accident data is extremely encouraging.

9.5.2 Track

This report is directly concerned only with car size, weight, and length as mandated by the Congress. However, one of its major conclusions is that the issues of car size, weight, and length and their relationship to safety and efficiency cannot be evaluated without referring to track quality. More specifically, it is entirely conceivable that large cars are both safe and economical if operated on well-maintained track. On the other hand, it is likely that they are both unsafe and uneconomical if operated on poor-quality track.

It is clear, therefore, that improved track safety standards must be developed which specifically address the issue of the required quality of track for cars of different sizes, weights, or lengths. Furthermore, present safety standards require a bare minimum of track quality; it may be desirable to define more practical and effective standards.

As a complement to the development of improved safety standards, improved structural designs of track need to be developed, evaluated, and used. The primary objectives of these designs would be to obtain track that was more stable, less subject to deterioration resulting from traffic, easier to install, and easier to maintain. While the initial cost of such trackage might be higher than that of current popular designs, it is certainly possible that the life-cycle system costs might be lower.

It is also likely that the development of cheaper and more effective maintenance and inspection procedures would reduce the financial burden caused by track maintenance and repair and, thus, provide an incentive to not defer maintenance. Examples of worthwhile developments are:

- Improved reliability of track maintenance equipment;
- Wider use of automated maintenance equipment;
- Development of improved field welding procedures; and
- Development of less expensive track geometry and rail flaw inspection equipment.

As stated earlier in this chapter, *improved financial condition* of the railroads would enhance safety. The abandonment of unprofitable lines would make more money available for the proper maintenance of important lines, thereby yielding the double benefit of being rid of unsafe trackage and gaining improved safety on the remaining trackage.

Finally, an alternative being addressed by an ongoing study, also mandated by the Congress, is different patterns of ownership of track, including such alternatives as joint ownership of track, large-scale mergers, or roadbed nationalization. These approaches would drastically alter the impact of trackage on safety.

9.5.3 Rail Operations

Changes in the operating procedures of railroads are discussed here only insofar as they may help to counteract problems created by the operation of large and heavy cars.

Speed reduction is an obvious safety measure. It will result in a reduction in the level of wheel-rail loads as long as certain critical resonant speed ranges are avoided. This, in turn, will result in a reduction in the rate of deterioration of track and also in a reduced probability of derailment caused by poor dynamic behavior. Furthermore, the severity of those accidents that do occur will decrease as the speed of trains is reduced, as was shown in Chapter 5 of this report. Therefore, this measure is of particular relevance in dealing with transportation of hazardous materials on poor quality track. However, reduced speeds have a profound effect on schedules, crew costs, and equipment utilization and, therefore, on the financial health of the railroad industry. This measure must, therefore, be exercised with the utmost caution to ensure that its costs do not outweigh its benefits.

One of the indirect safety-related effects of long or heavy cars is their adverse influence on train behavior when they are coupled with short or light cars, or when heavy cars are placed in the rear portions of trains. Techniques are available for making up trains so that the unsafe juxtaposition of cars is avoided and so that heavy cars are predominantly in the forward portion of trains. The TTD program has identified several important guidelines for train makeup. While any change in train makeup practice is bound to influence railroad productivity, it appears worthwhile that a detailed trade-off analysis be made of the guidelines.

Derailments may be caused by train action resulting from the improper use of brakes and throttle, which can exacerbate problems arising from the makeup of the consist. Opportunities exist for *improving the behavior of braking systems*, both by reducing the time lag for brake application and by the increased use of empty/loaded sensing devices on freight cars. These devices significantly reduce slack action caused by differing rates of deceleration of different cars in a train. Opportunities also exist for providing improved training to the operators of long trains, where the proper use of brakes and throttle is extremely important, especially on undulating terrain. One way of providing this improved training is the development and use of sophisticated *simulators*. An important program in this area has just been initiated by the FRA.

Although no pressing problems pertaining to yard operations were identified as being caused by car size, weight, or length in this study, indications do exist that long cars may create problems on sharp curves by swinging out. It is in the industry's interest to *review the layout of each yard* to determine whether such a problem exists.

In the specific area of operations concerned with the *transportation of hazardous materials*, several approaches are available in addition to those described above. *First* is the more widespread application of the measures mandated by HM-144: the use of shelf couplers, the installation of head shields, and the application of thermal shields. To date, these requirements exist only for certain classes of tank car: the 112 and 114 series. Extending their application to other types such as the 105 merits investigation.

Second, rerouting of traffic to avoid poor track or areas of high-population density provides a useful approach to reducing the risk of catastrophic accidents. The FRA has undertaken a research program to identify areas in the country where a significant reduction in risk can be obtained by rerouting.

Third, more stringent requirements on track quality may be contemplated if the transportation of hazardous materials by rail is to be allowed. The FRA study cited above is also developing estimates of risk for each of the six FRA track classifications. This will allow a quantitative estimate to be made of the risk reduction to be gained by track quality improvement.

Fourth, the placement of hazardous materials cars in trains should be analyzed to determine whether some locations are safer than others. A recent study[1] shows, in fact that the first and fourth quarters of trains are "safer" than the second and third quarters in the sense that cars in them have a lower probability of being derailed or damaged. However, that study did not investigate the effect that new train makeup procedures (aimed at placing hazardous materials cars in the first or fourth quarters) would have on switching operations and, therefore, on the risk in yard operations.

This last point is worth emphasizing: any measures aimed at reducing the risk caused by the transportation of hazardous materials must be thoroughly analyzed to determine the system-wide change in risk. In fact, it is necessary to agree upon a definition of "risk" before embarking on a program to reduce risk. For example, there is no agreement on whether one accident that results in the death of a hundred people poses the same risk to society as a hundred accidents, each of which results in one fatality. Depending on one's judgment on this issue, significantly different risk-reduction alternatives would appear attractive. The FRA study is aimed at developing systems analyses of rail transportation to estimate system-wide risk, however risk is defined. The precise definition of risk that should be used in future investigations remains a matter of policy.

REFERENCE

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10. ECONOMIC CONSIDERATIONS

10.1 ABSTRACT

The use of larger and heavier cars has been pursued by the railroad industry in the anticipation of financial benefits, largely in the area of reduced capital costs and train and yard labor. However, it is difficult to determine the car size which is most economical. It appears that the key factor determining this optimum size is the expected cost of maintenance-of-way, which is expected to vary significantly both as axle loads vary and from one railroad to another. It is likely that the optimum car size increases as the quality of track improves, which requires improved maintenance and, therefore, improved financial condition of the carriers.

A limited analysis of the economic consequences of reducing the maximum payload of 100-ton cars to 85 tons shows that such an action will inflict substantial financial hardship on the industry and may, in the short run, actually lead to a worsening of rail safety because of the increased car handling that will be required in yards and the larger number of trains that will need to be operated.

10.2 INTRODUCTION

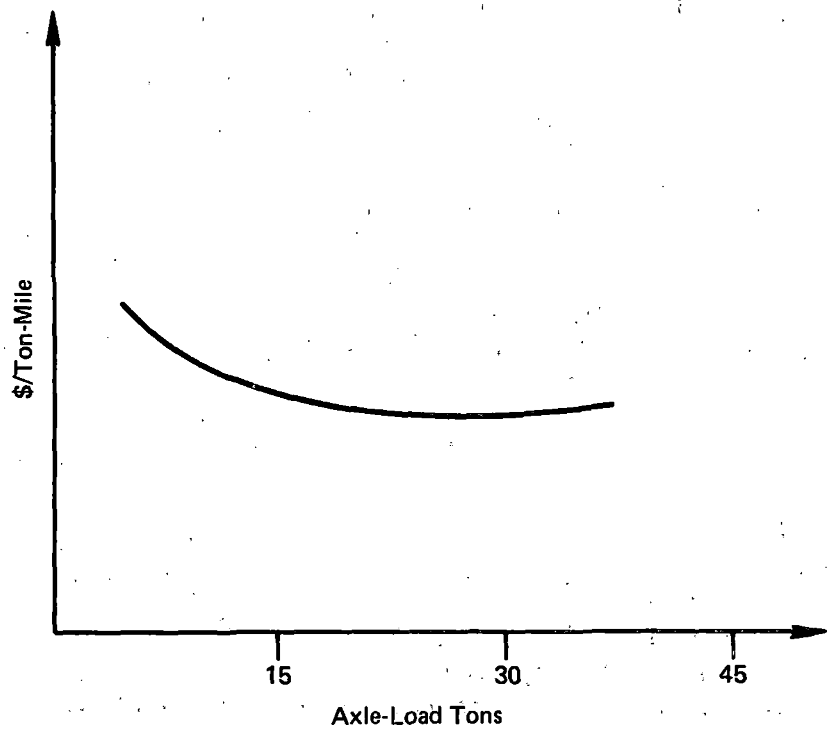
This chapter provides an overview of the economic considerations for the railroads in the choice of car size. The specific elements of costs and their relative dependence on car size are outlined. Estimates of the magnitude of the cost issues are then analyzed through the scenario of reducing the recommended maximum net load per car by 15%, from 100 tons to 85 tons. Industrywide data on 100-ton car shipments are presented, followed by an estimation of the cost of reducing maximum loads to 85 tons. Finally, the costs are extrapolated from an individual route to industrywide impacts.

10.3 COST COMPONENTS

The literature on the economics of car size is largely oriented to the operating cost issues. In addition, the capital costs of cars and locomotives (to the extent that number of trains is affected) and the effect of differential accident rates must be considered. Finally, the changes in train size (either in gross tonnage or number of cars) and the shipper's lot size implied by single car loading affect the reliability and competitiveness of railroad transportation. The specific cost components of concern and their relationship to car size are discussed below.

Operating Costs:

- *Equipment Maintenance Costs* — These costs tend to increase as car size increases on a car-mile basis, but these costs decrease on a net ton-mile basis (Figure 10-1).



Source: G.H. Way, "Economics of Freight Car Size," AREA Bulletin 673, Vol. 80.

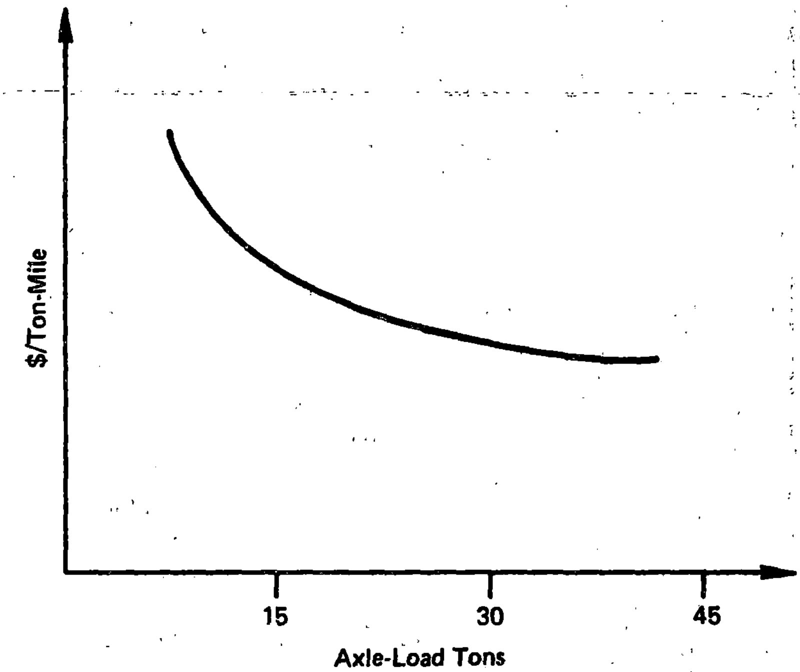
FIGURE 10-1 FREIGHT CAR MAINTENANCE

- *Transportation Expense* — This category includes fuel, transportation labor cost, etc. Costs are generally dependent on gross trailing tonnage, and therefore to the extent that car loading increases the ratio of net to gross tons, costs decrease in dollars per ton-mile as car size increases (Figure 10-2).

- *Maintenance-of-Way Expense* — Increased car size, or more specifically, increased axle loads, tend to cause more wear and tear on the track. Thus, maintenance-of-way costs, expressed in dollars per ton-mile, increase as axle loads increase (Figure 10-3). The effect of axle load on track wear rates can be seen in Table 10-1, which compares the experience of two railroads, the major difference between them being the average axle load. On the other hand, other comparisons indicate that maintenance-of-way expenses need not necessarily increase very rapidly. The Bessemer and Lake Erie, operating with a mix of high and medium axle loads (100-ton and 70-ton cars), has achieved adequate rail life.

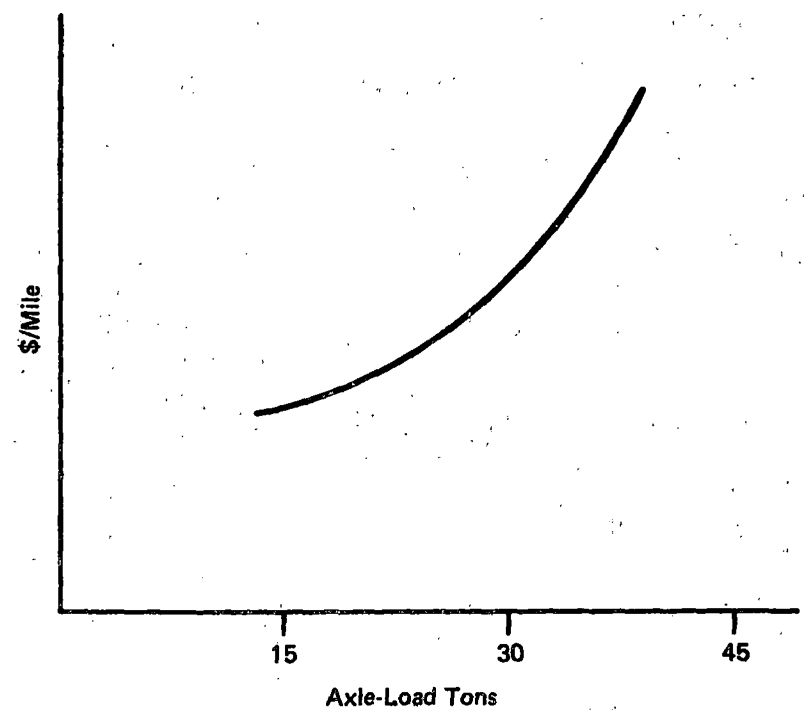
Capital Costs:

- *Freight Car Acquisition Costs* — Smaller loads per car will increase overall fleet requirements unless there are compensating increases in car utilization. Ignoring utilization effects, given relative costs of different car sizes, car acquisition costs will decrease, with increases in car loading.



Source: G. H. Way, "Economics of Freight Car Size," AREA Bulletin 673, Vol. 80.

FIGURE 10-2 TRANSPORTATION EXPENSE



Source: G.H. Way, "Economics of Freight Car Size," AREA Bulletin 673, Vol. 80.

FIGURE 10-3 MAINTENANCE-OF-WAY EXPENSE

- *Locomotive Acquisition Costs* — These costs will depend on the manner in which train size and number of trains are adjusted. Generally, the locomotive requirements, and hence acquisition costs, will decrease as car loadings increase.

TABLE 10-1

COMPARATIVE RAIL LIFE FOR DIFFERENT CAR SIZES

AVERAGE RAIL LIFE
(million gross tons)

Rail Location	BM&LP*	UPRR	125-Ton Life Reduction Factor
Curves	13	400	31 times
Tangent	35	650	19 times

*Estimated

UPRR (Union Pacific Railroad) = 60 Tons/Average Car

BM&LP (Black Mesa and Lake Powell) = 125 Tons/Average Car

Source: J.R. Sunnygard, "Effect of Heavy Cars on Rail," AREA Bulletin 663, Vol. 78.

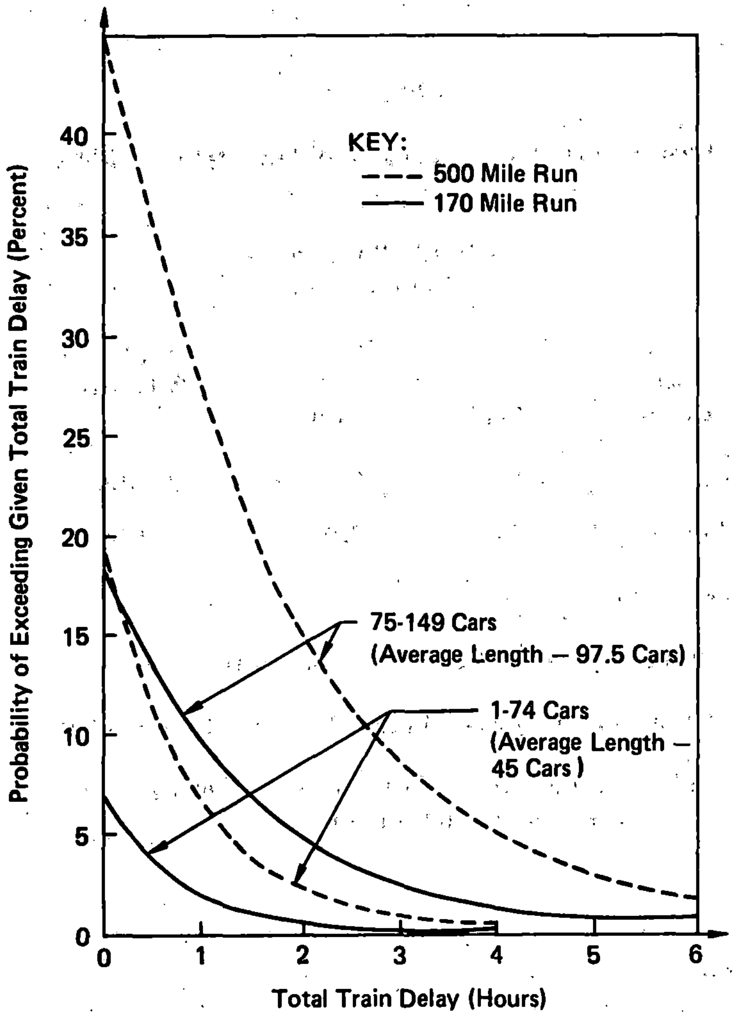
Accident Costs:

- Heavier cars may lead to a higher frequency of accidents or poor quality track, especially if the cars are of certain mechanical types. Accident rates will also be affected by the change in the number of trains to accommodate different car loadings. These effects are examined in Section 10.6 based on the accident rate analysis in Chapter 4.

Shipper Costs and Railroad Competitiveness:

- Shippers are affected directly by the transportation lot sizes implied by higher car loadings and indirectly by train frequencies that could change with car loadings. Increased car loadings lead to higher inventory carrying costs for shippers. However, these effects will only be perceived for shipments which are now in the one carload range; multicarload shippers would not notice any effect.

- The impact on competitiveness of railroads is a function of the effect of lot size on shippers and the reliability of train schedules, which is related to train size (Figure 10-4).



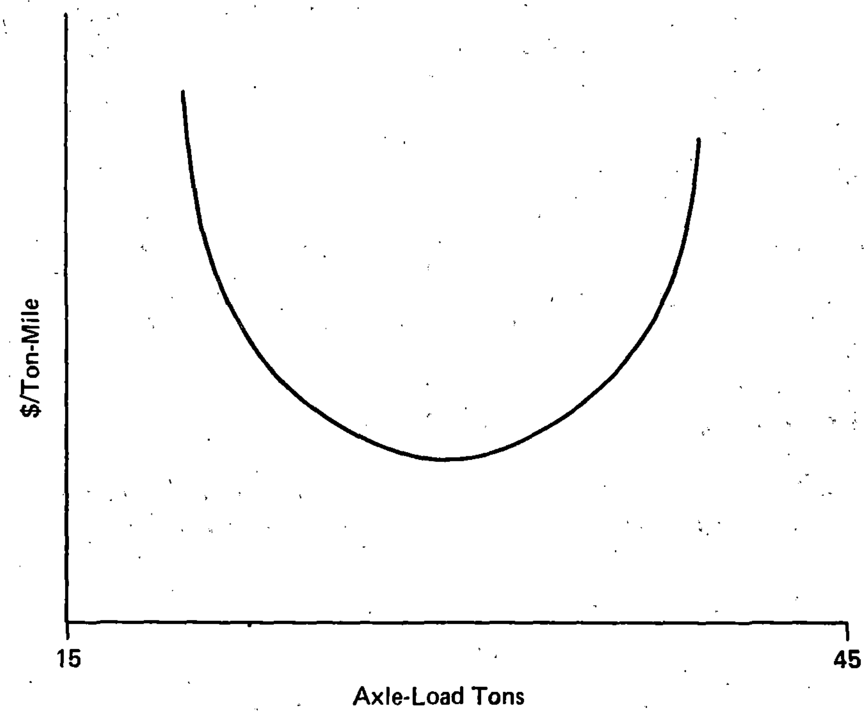
Source: R.H. Leilich, "Study of the Economics of Short Trains," prepared by Peat, Marwich, Mitchell & Co., Report No. PB-235-411, June 1974

FIGURE 10-4 TRAIN DELAY PROBABILITY DISTRIBUTION

The combination of all operating costs and car capital costs results in a bathtub shaped curve (Figure 10-5). Operation with axle loads near the bottom of the curve is the most economical. However, the precise shape of this curve cannot be analytically derived from current information, and it is therefore not possible to precisely estimate the cost penalties incurred by not operating at the optimum axle load. Moreover, the optimum axle load will be dependent on the following factors:

- Track conditions;
- Labor costs, which vary regionally;
- Terrain;
- Mechanical car type;
- Commodity.

Section 10.5 analyzes a number of these issues for a limited scenario.



Source: G. H. Way, "Economics of Freight Car Size," AREA Bulletin 673, Vol. 80.

FIGURE 10-5 TOTAL COST

10.4 CURRENT INDUSTRY UTILIZATION OF 100-TON CARS

The current state-of-the-art on car size economics does not allow an analytical formulation of the impacts of generalized changes in car loadings. Therefore, the specific case of reducing the maximum car loading from 100 tons to 85 tons is evaluated in Section 10.5. The industrywide data on 100-ton cars are presented in this section.

There are currently 527,200 100-ton cars in the railroad fleet. Table 10-2 presents data on industrywide utilization of 100-ton cars based on the FRA 1% Waybill Sample. (To obtain the volume of activity industrywide, the FRA Waybill data were multiplied by a correction factor of 1.8 to obtain the total rail volume activity of AAR data.)

TABLE 10-2

INDUSTRY UTILIZATION OF 100-TON CARS

Annual Car Loadings	11.6 Million
Annual Car-Miles	9.2 Billion
Net Ton-Miles	395 Billion

Source: FRA 1% Waybill Sample/AAR Yearbook of Railroad Facts, 1979

Given that 58.8% of car movements were loaded cars,[1] the number of loaded car-miles for 100-ton cars is:

$$0.588 \times \frac{29}{16} \times 5.1 \times 10^9 = 5.4 \text{ Billion Loaded Car-Miles Per Mile.}$$

Given the number of loaded car-miles and number of car loadings, the average length of haul of loaded cars is:

$$5.4 \times 10^9 \div 11.6 \times 10^6 = 467 \text{ Miles Per Loaded Car Movement}$$

The impact on capital costs will be estimated by the annual replacement of the car and locomotive fleet as a percentage of the required fleet size. Table 10-3 presents equipment replacement data.

TABLE 10-3

EQUIPMENT REPLACEMENT DATA

	Equipment In-Service	Equipment Replacement	% of Fleet Replaced
All Freight Car	1,652,774	67,074	4.06
Locomotives	27,772	1,166	4.20

Source: AAR Yearbook of Railroad Facts, 1979

10.5 SCENARIO ANALYSIS

Changes in several parameters of operations such as car-miles, ton-miles, and train-miles must be calculated to estimate the cost implications of changing from a recommended 100-ton to an 85-ton maximum net loading. Therefore, the following hypothesized scenario was analyzed to derive proportional changes in activity.

- Single origin-destination;
- 500-mile trip (roughly equal to average for 100-ton cars);
- 3000 trains per year (current frequency);
- 40 loaded cars per train;
- 25 empty cars per train (yielding roughly the industry average ratio of loaded cars to total cars);
- 65 total cars (roughly industry average cars per train);
- 100-ton net loading in 40 cars;
- 30-ton tare weight per car;
- 4000 net tons per train = 12 million net tons per year;
- 5950 gross tons per train = 30 tons x 65 cars + 100 tons x 40 cars.

With the reduction in maximum load in the future, the new train characteristics can be derived with several assumptions. First, it is assumed that the railroads maintained the same gross trailing tonnage per train. Further, car utilization remains constant, so that the proportion of loaded cars to total cars is constant. Therefore, the new train contains 45 loaded cars and 27 empty cars, satisfying the requirement on gross trailing tonnage:

Gross Trailing Tons = 45 cars x 85 tons + 72 cars x 30 tons = 5,985 gross tons, roughly equal to 5,950 existing gross tons per train. Based on these assumptions, the changes in activity and equipment requirements can be derived as shown in Table 10-4.

10.6 RAILROAD INDUSTRY IMPACTS

The impacts of the reduction in maximum net car loading from 100 tons to 85 tons are extrapolated from the above scenario to the nation's railroads, based on the industrywide data presented in Section 10.4. These impacts are only direct railroad industry effects. The analysis does not measure indirect impacts on the shippers resulting from changes in train frequency and car load size, such as an increase demand for rail transportation.

10.6.1 Capital Costs

The annual replacement cost of freight cars is based on 527,200 cars existing, a 15.8% increase in fleet requirements, and 4% fleet replacement per year. At an estimated $40,000 per car, the annual replacement cost is $133 million. The actual fleet grows by 83,300 cars.

The estimate of increase in the size of the locomotive fleet is based on the current ratio of locomotives to train-miles in the industry. In 1978, there were 27,800 locomotives in the fleet and 433 million train-miles, or 6.4×10^{-5} locomotives per train-mile. The increase in train-miles is based on 9.2×10^{9} car-miles per year for 100-ton cars, a 15.8% increase in car-miles, 30 tons empty per car, and 6,000 gross tons per train. The increase in train-miles is equal to 7.3×10^{6}, resulting in an increase of 465 locomotives. Assuming 4% fleet replacement per year and $0.7 million acquisition cost per locomotive, the increase in annual locomotive replacement cost is $13 million.

TABLE 10-4

SCENARIO ANALYSIS OF REDUCED CAR LOADING

Present	Future	% Increase
3000 trains/year	3137 trains/year	4.6
40 loads/train	45 loads	12.5
25 empties/train	27 empties	8
500 miles	500 miles	-
100 tons/load	85 tons/load	(17.6)
4000 net tons/train	3,825 net tons/train	(4.6)
12×10^6 tons originated	12×10^6 tons originated	-
5,950 gross tons/train	5,950 gross tons/train	-
60×10^8 net ton-miles/year	60×10^8 net ton-miles	-
90×10^8 gross ton-miles/year	93×10^8 gross ton-miles	3.7
195,000 car trips	225,864 car-trips	15.8
97.5×10^6 car-miles	112.9×10^6 car-miles	15.8

Source: *Arthur D. Little, Inc., Estimates*

10.6.2 Operating Costs

The increase in fuel consumption is based on an average of 386 gross ton-miles per gallon.* The increase in ton-miles is given by the 15.8% increase times 9.2×10^9 car-miles times 30 tons empty per car, equal to 43.6×10^9 gross ton-miles. At 386 ton-miles per gallon, the increase in fuel consumption is 113 million gallons. Based on an estimated 1978 cost of $.60 per gallon, the cost increase for fuel is $68 million.

Mainline and yard operating costs (not including fuel) were determined from average costs per train-mile. Table 10-5 shows the operating costs for the industry. Based on 433 million train-miles,[1] the average cost is $7.69 per train-mile. For an increase in train-miles of 7.3 million, the increase in costs is $56 million.

*Based on an average of 220 net ton-miles per gallon and a ratio of net ton-miles to gross ton-miles of 0.57.[1]

TABLE 10-5

YARD AND MAINLINE OPERATING COSTS

	ICC Account Category	1976 Freight Service Cost ($ thousands)
378	Yard Conductors and Brakemen	710,946
379	Yard Switch and Signal Tenders	28,047
380	Yard Enginemen	316,714
392	Train Enginemen	571,884
400	Servicing Train Locomotives	162,319
401	Trainmen	1,009,008
		2,798,918

1978 Cost = 1.19 x $2,798,918,000
= $3331 Million

Source: ICC Transport Statistics/AAR Index of Wage Rates

Maintenance costs depend on the relationship of axle load to wear and tear, for which analytical cost relationships are not readily available. The empirical costs per car-mile, published by the AAR, were used to estimate an order of magnitude of the costs (Table 10-6). The roadway maintenance costs for the 85-ton load were estimated at the average of the 70-ton and 100-ton cars. Based on these data, the following cost charges are derived.

Roadway Maintenance:

100-Ton Loadings 9.2×10^9 car-miles x $ .1350 = $1242 Million

70-Ton Loadings 10.7×10^9 car-miles x $ .1050 = $1124 Million

Cost Decrease = $118 Million

Car Maintenance:

Increased Car-Miles = 1.5×10^9

Cost Increase = 1.6×10^9 x $ .01 = $15 Million

TABLE 10-6

UNIT MAINTENANCE COSTS
(Cents Per Car-Mile)

	Roadway Maintenance	Freight Car Repair
70-Ton Car	7.50	1.00
100-Ton Car	13.50	1.00

Source: J. P. Sammon, "Preliminary Study of Rail Car Size," AREA Bulletin 673, Vol. 80.

10.6.3 Safety Costs

Accident frequency is dependent primarily on the number of car-miles and, to a lesser extent, on car size. Chapter 4 showed that accident frequency is correlated with car-size only for accidents at higher speeds. In the maximum car loading, the increase in car-miles is a more important effect than the lower accident frequency for the subset of accidents which depend on car size. The impact on safety costs is therefore calculated by estimating the increased number of accidents, given the increase of 1.5×10^9 car-miles. Costs are estimated based on an average of $26,969 per accident.[2]

Accident frequency is estimated at 3.6×10^{-7} accidents per car-mile, based on 10,362 accidents[1] and 28,749 million car-miles[2] for 1977. For the estimated increase in car-miles because of reduction in maximum car loading, the increased number of accidents is 540 accidents per year, with an estimated cost of $14.5 million.

10.6.4 Fatalities

Railroad fatalities are segmented into three types: train accidents, grade crossings, and yard. These fatalities are related to train-miles, trains, and yards respectively as follows:

- Train accident fatalities are proportional to train-miles
- Grade-crossing fatalities are proportional to $(\text{trains})^{0.15}$
- Yard fatalities are proportional to car loadings

The parameters of these relationships were derived from the following 1977 annual data:

Fatalities per Year[1]

Train Accidents	516
Grade Crossings	851
Yards	163

Railroad Activity per Year[2]

Train-Miles	427,686,000
Trains*	587,000
Car Loadings	23,173,000

The relationships are:

1.21×10^{-6} train accident fatalities per train-mile

$116 \times (\text{Train})^{0.15}$ grade-crossing accidents

7.03×10^{-6} yard fatalities per car loading

Based on these fatality rates, the increase in number of fatalities annually resulting from reduced maximum car loading is given by:

Train Accident Fatalities	$1.21 \times 10^{-6} \times 7.3 \times 10^{6}$	= 9
Grade-Crossing Fatalities		= 10**
Yard Fatalities	$7.03 \times 10^{-6} \times 1.8 \times 10^{6}$	= 13
TOTAL		32

10.6.5 Summary of Industry Impacts

Table 10-7 shows the estimated adverse industry impacts in this hypothetical scenario. There is basically an increase in operations, rolling stock requirements, fuel consumption, and accidents. Table 10-8 summarizes the cost implications. Again, the accuracy of these estimates is limited by the lack of consensus in the literature on maintenance costs and by the assumptions on equipment utilization.

*Derived by 23.2×10^{6} car loadings. (67.2 cars per train x .588 loaded cars per total cars).

**Increase in Numbers of Trains equals 1.8×10^{6} Car Loadings ÷ (67.2 cars per train x .588 loaded cars per total cars) = 4.6×10^{4}. Proportional change in number of fatalities given by $\frac{\Delta F}{F} = 0.15 \frac{\Delta T}{T}$, and $\frac{\Delta T}{T} = \frac{4.6 \times 10^{4}}{587{,}000}$, so that $\frac{\Delta F}{F} = .0116$ and $\Delta F = .0116 \times 851 = 10$

TABLE 10-7

ADVERSE INDUSTRY IMPACTS FROM A 15% REDUCTION IN THE MAXIMUM PERMISSIBLE LOADING IN 100-TON CARS

Item	Estimated Adverse Effect
Car Loadings	1.8 Million Additional Loadings
Car Trips	2.9 Million Additional Trips
Trains	46,000 Additional Trains
Freight Cars	83,300 Additional Cars
Locomotives	465 Additional Locomotives
Train-Miles	7.3 Million Additional Train-Miles
Car-Miles	1.5 Billion Additional Car-Miles
Fuel	113 Million Additional Gallons
Train Accidents	540 Additional Accidents
Fatalities Resulting from Train Accidents/ Incidents and Grade Crossing Accidents	32 Additional Fatalities

Source: Arthur D. Little, Inc., Estimates

TABLE 10-8

ESTIMATED INDUSTRY COST IMPACTS FROM 15% REDUCTION IN MAXIMUM CAR LOADING

Item	Annual Cost Increase (Decrease) ($ millions)
Capital Costs	
Freight Cars	100
Locomotives	9
Operating Costs	
Fuel	68
Mainline & Yard (Not Including Fuel)	56
Maintenance	103
Safety Costs (Not Including Dollar Loss of Fatalities)	14.5

Source: Arthur D. Little, Inc., Estimates

10.7 SUMMARY

This chapter outlined the economic considerations with regard to car size and developed estimates of the impact to the railroad industry of a hypothetical reduction in maximum loading from 100 tons to 85 tons. The costs directly related to car size are maintenance (equipment and roadway) and car acquisition costs. Car size indirectly affects transportation expense and locomotive acquisition costs, depending on the impacts on train size and car utilization. Finally, accident rates appear to be dependent on car size.

The precise economic impacts of car size on the railroad are difficult to measure because of the lack of analytical studies relating car size to railroad costs and also because of the uncertainty in the indirect effect of car size on car utilization and train size. However, the analysis of the hypothetical scenario indicated that car-miles, train-miles, cars, and locomotives in service, fuel consumption, and the number of accidents would rise. The magnitude in dollar costs can only be approximated because of uncertainties in operating practices and maintenance costs, but there would apparently be a cost increase to the industry.

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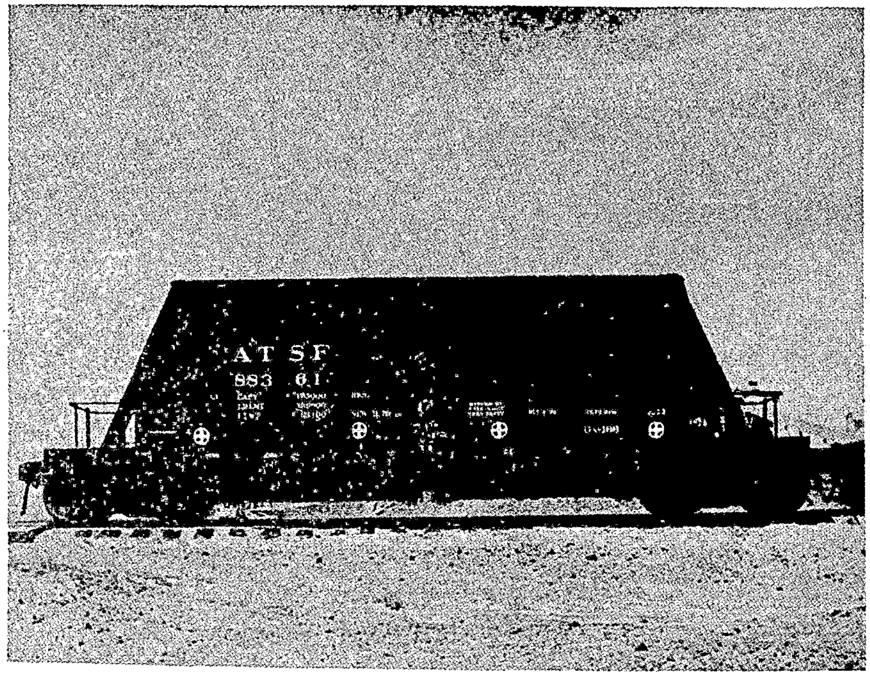
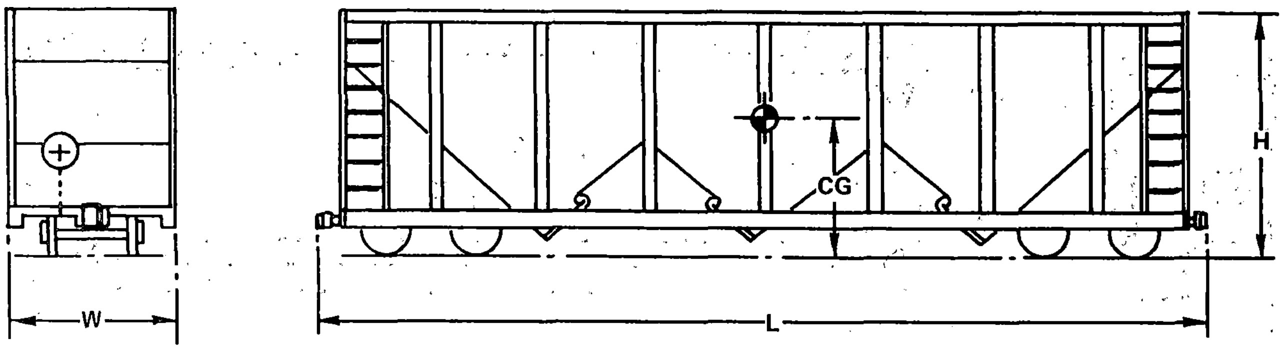
APPENDIX B

MECHANICAL FREIGHT CAR TYPES

This appendix provides information on the various types of freight cars discussed in this report. The differences in car body construction are generally related to the particular commodities which the cars are designed to haul. Within each car type, however, there is a range of dimensions of size, weight, and length, generally categorized by the approximate load carrying capacity (nominal weight capacity) of the car. The categories are labeled 50-, 70-, and 100-ton capacity. Typical dimensions of length, width, and height are defined and shown for each type.

OPEN HOPPER CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

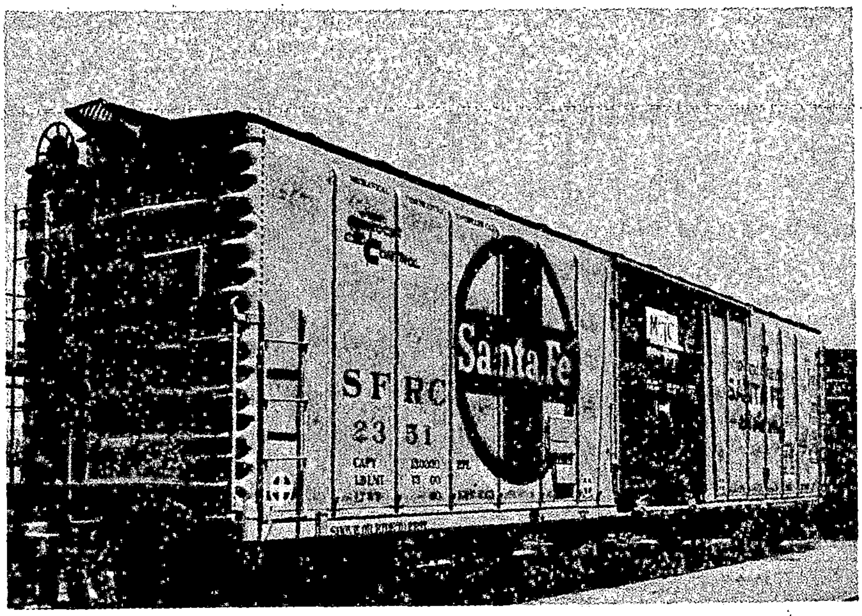
Dimension	50 Ton	70 Ton	100 Ton
Length	35 ft. 8 in.	35 ft. 2 in.	47 ft. 6 in.
Width	10 ft. 7 in.	10 ft. 8 in.	10 ft. 8 in.
Height	11 ft. 1 in.	11 ft. 9 in.	12 ft. 3 in.

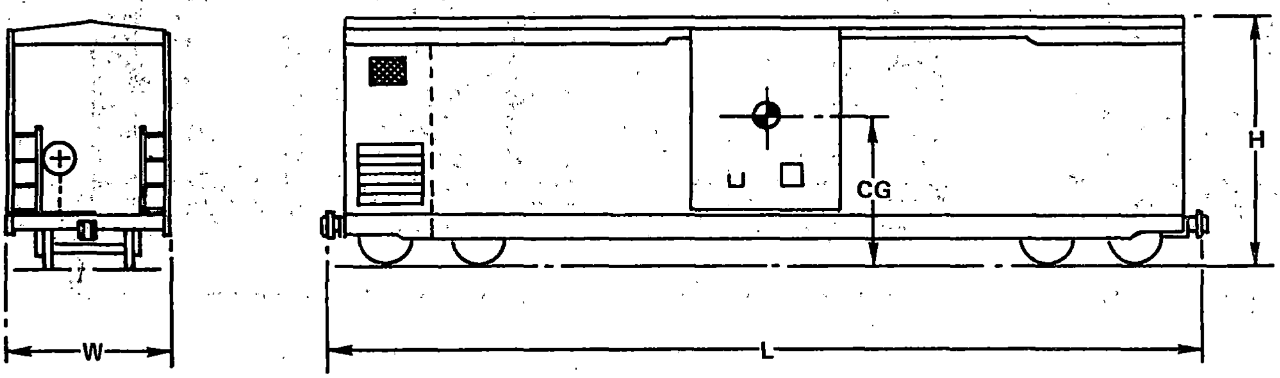
Center of Gravity Range for Open Top Hopper Cars (for car body only, from top of rail):

Empty: 58.2 in. - 80.9 in.

Loaded: 64.5 in. - 106.3 in.

REFRIGERATOR CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

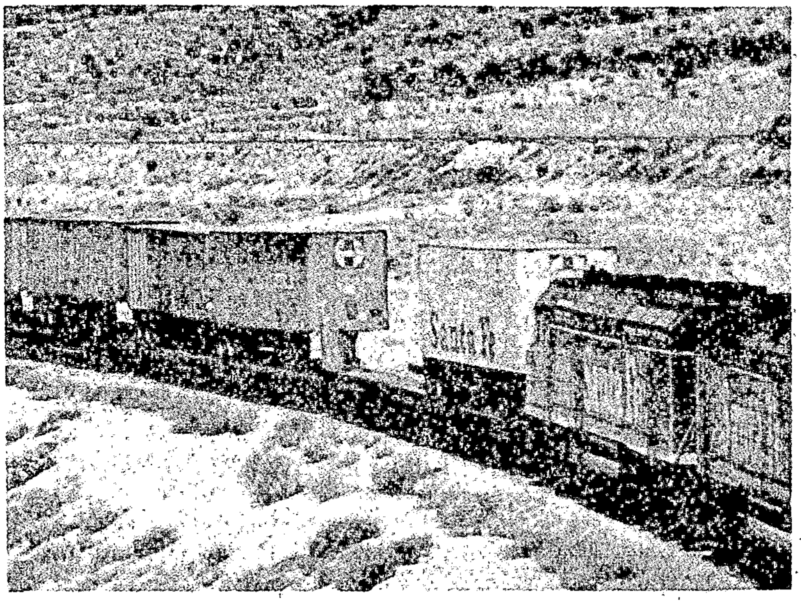
Dimension	50 Ton	70 Ton	100 Ton
Length	44 ft. 9 in.	58 ft. 0 in.	58 ft. 11 in.
Width	10 ft. 6 in.	10 ft. 8 in.	10 ft. 8 in.
Height	14 ft. 10 in.	15 ft. 2 in.	15 ft. 4 in.

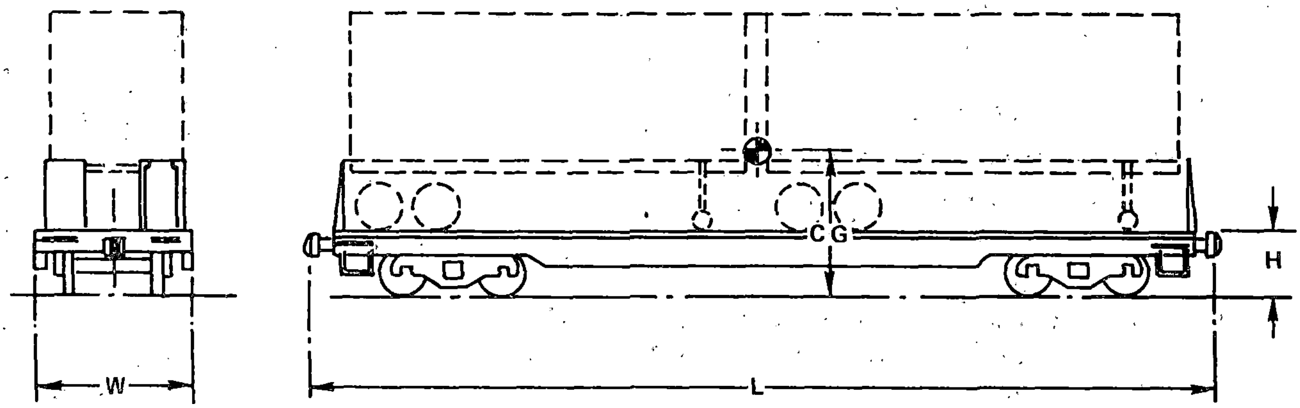
Center of Gravity Range for Refrigerator Cars (for car body only, from top of rail):

Empty: 68.4 in. - 71.7 in.

Loaded: 69.7 in. - 97.4 in.

TRAILER ON FLAT CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

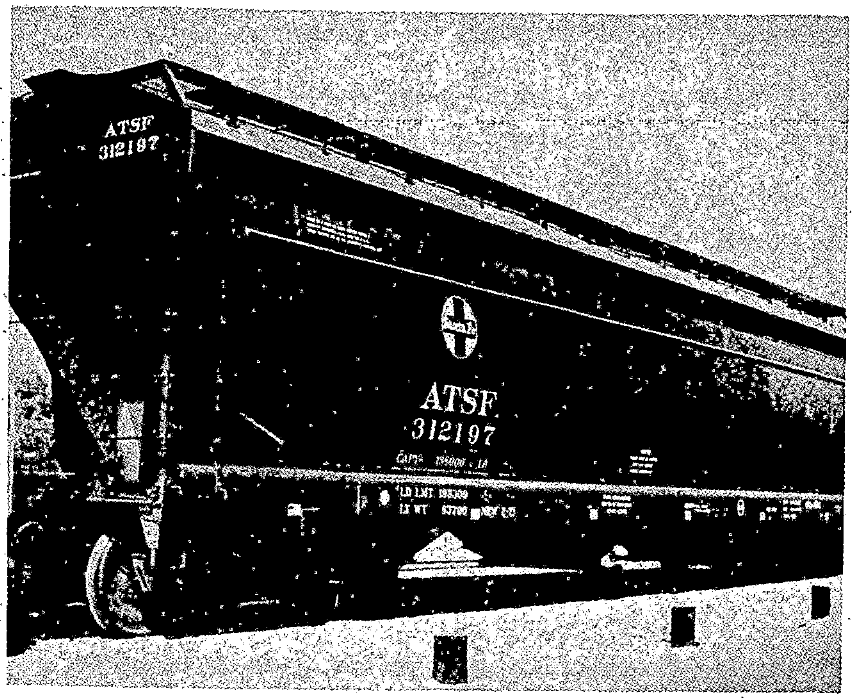
Dimension	50 Ton	70 Ton	100 Ton
Length	65 ft. 4 in.	73 ft. 4 in.	96 ft. 6 in.
Width	10 ft. 6 in.	10 ft. 5 in.	10 ft. 0 in.
Height	3 ft. 6 in.	4 ft. 1 in.	3 ft. 6 in.

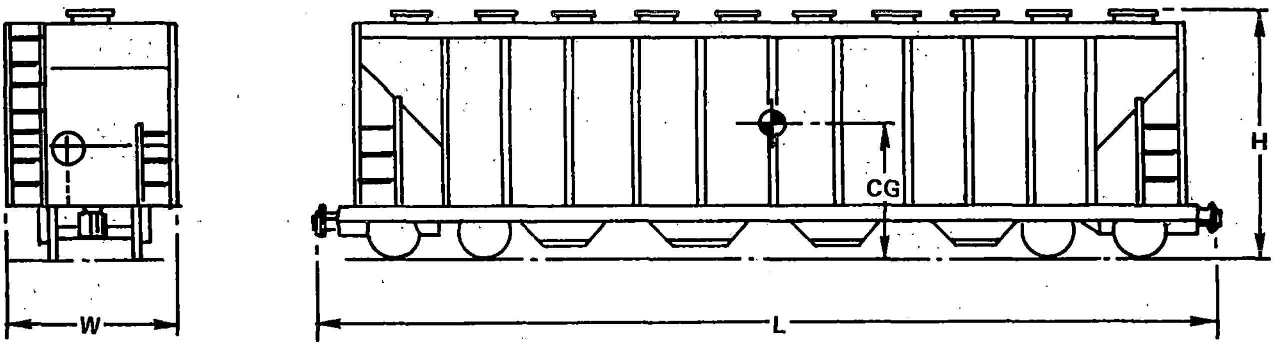
Center of Gravity Range for TOFC Cars (for car body only, from top of rail):

Empty: 24.5 in. - 34.4 in.

Loaded: 78.5 in. - 106.3 in.

COVERED HOPPER CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

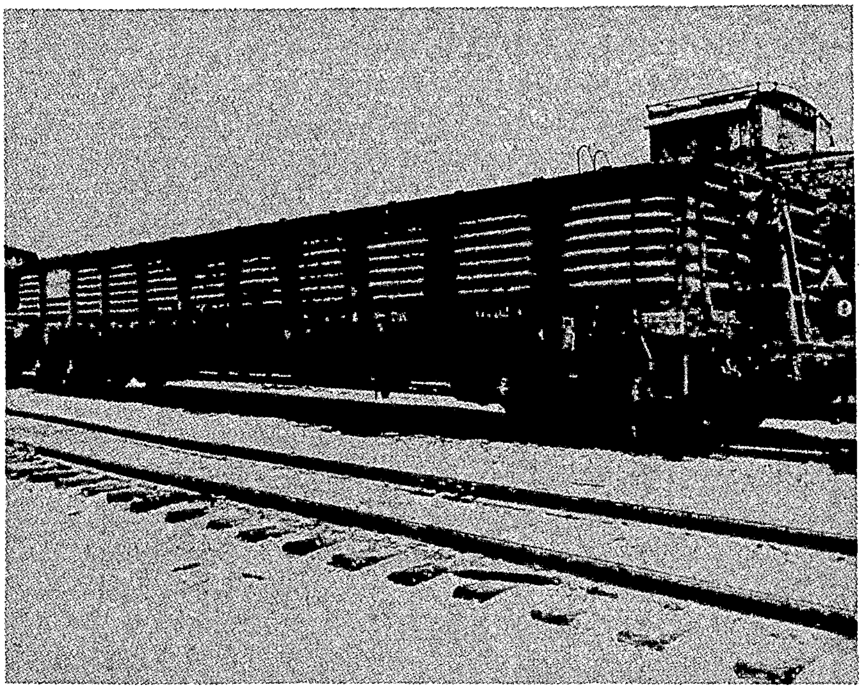
Dimension	50 Ton	70 Ton	100 Ton
Length	42 ft. 1 in.	49 ft. 7 in.	53 ft. 10 in.
Width	10 ft. 8 in.	10 ft. 3 in.	10 ft. 8 in.
Height	14 ft. 6 in.	14 ft. 11 in.	15 ft. 1 in.

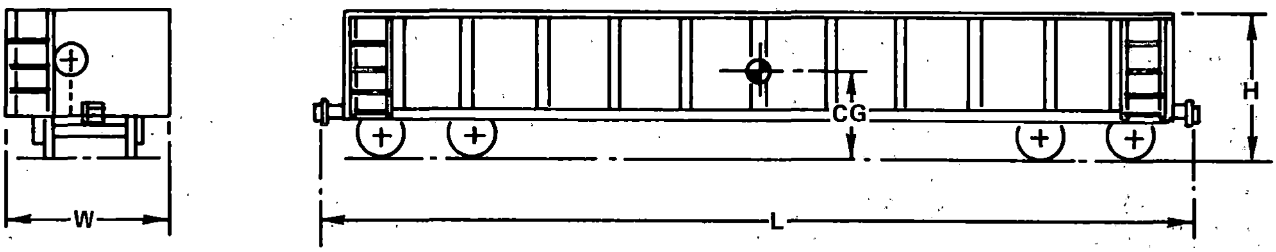
Center of Gravity Range for Covered Hopper Cars (for car body only, from top of rail):

Empty: 69.8 in. - 77.7 in.

Loaded: 66.0 in. - 107.8 in.

GONDOLA CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

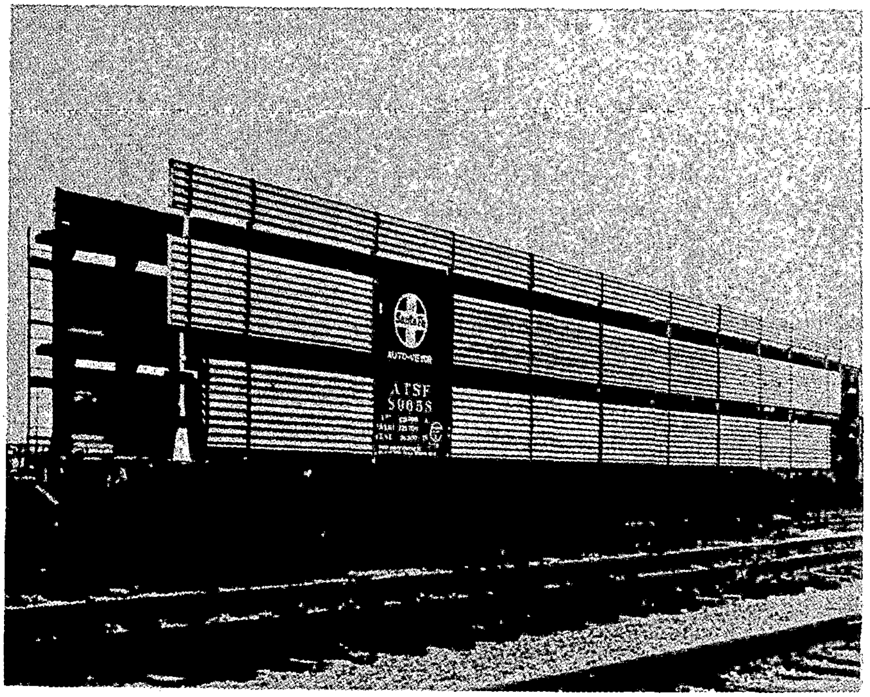
Dimension	50 Ton	70 Ton	100 Ton
Length	45 ft. 5 in.	57 ft. 7 in.	57 ft. 3 in.
Width	10 ft. 3 in.	10 ft. 4 in.	10 ft. 8 in.
Height	8 ft. 2 in.	7 ft. 6 in.	8 ft. 3 in.

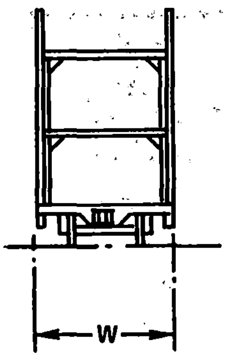
Center of Gravity Range for Gondola Cars (for car body only, from top of rail):

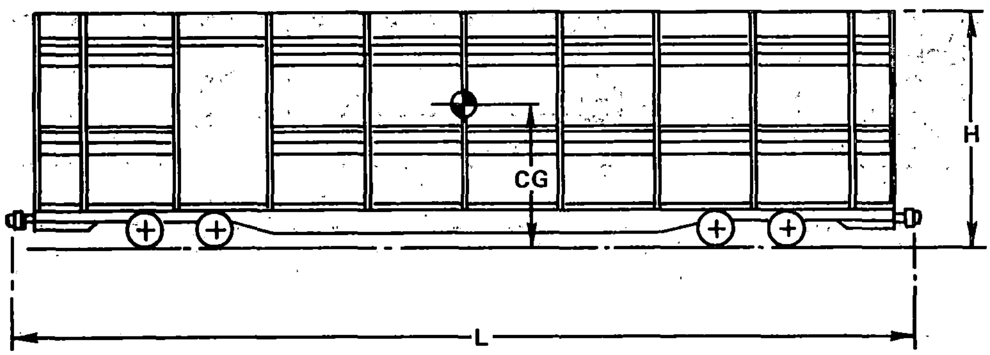
Empty: 39.4 in. - 77.7 in.

Loaded: 38.1 in. - 98.0 in.

AUTO-RACK CAR







Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-Ton Capacity Vehicle*

Dimension	50 Ton	70 Ton
Length	93 ft. 8 in.	93 ft. 8 in.
Width	10 ft. 2 in.	9 ft. 11 in.
Height	15 ft. 11 in.	15 ft. 6 in.

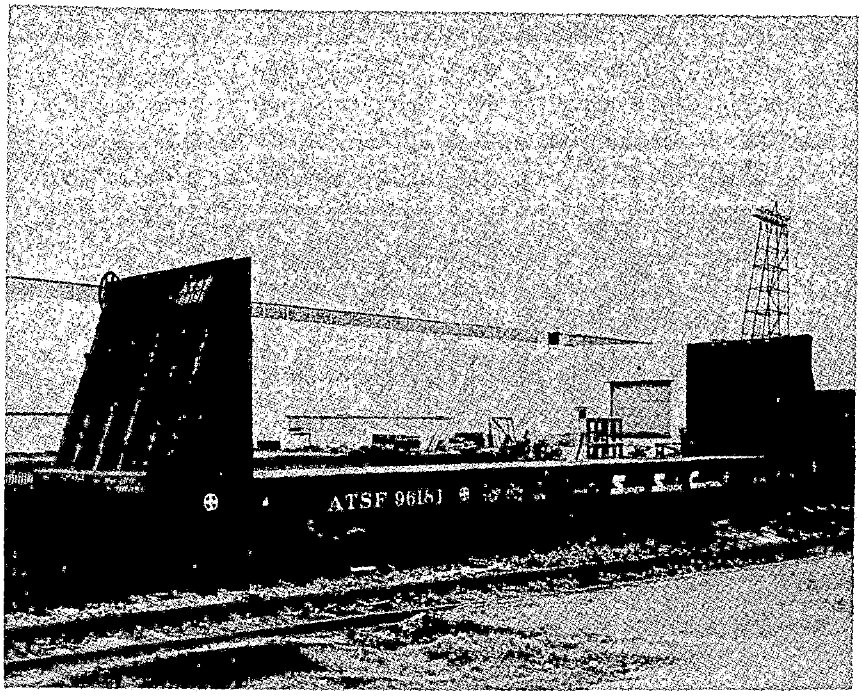
Center of Gravity Range for Auto Rack Flat Cars (for car body only, from top of rail):

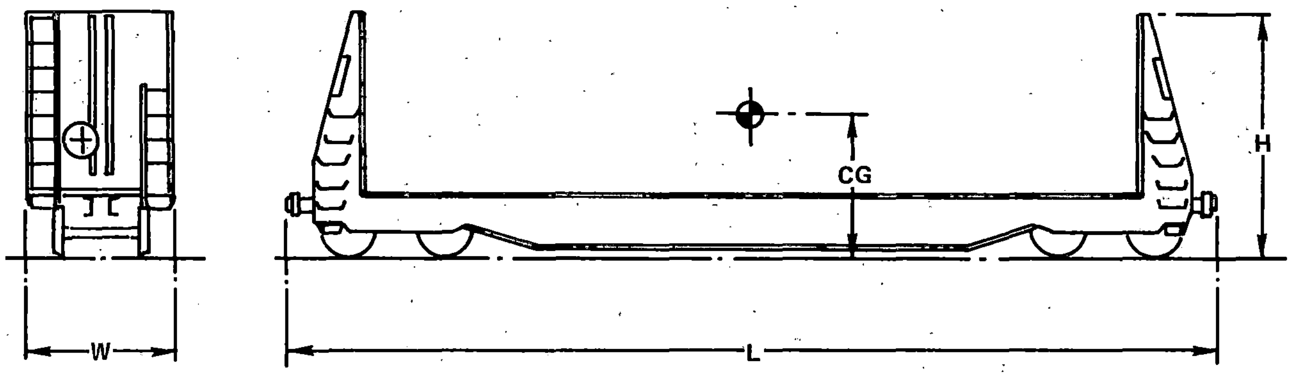
Empty: 56.5 in. - 92.0 in.

Loaded: 65.1 in. - 99.5 in.

*The 100-ton capacity is not applicable to this car type.

BULKHEAD FLAT CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

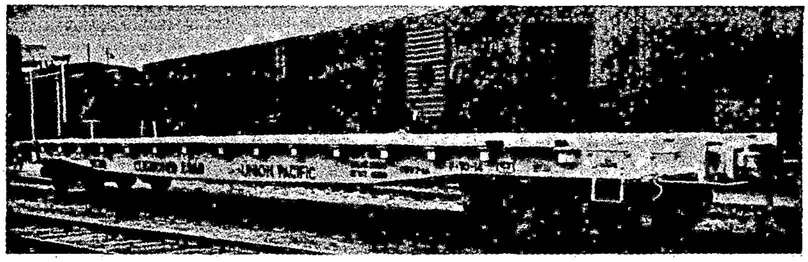
Dimension	50 Ton	70 Ton	100 Ton
Length	57 ft. 7 in.	56 ft. 9 in.	68 ft. 10 in.
Width	9 ft 10 in.	10 ft. 4 in.	9 ft. 3 in.
Height	7 ft. 0 in.	9 ft. 11 in.	15 ft. 6 in.

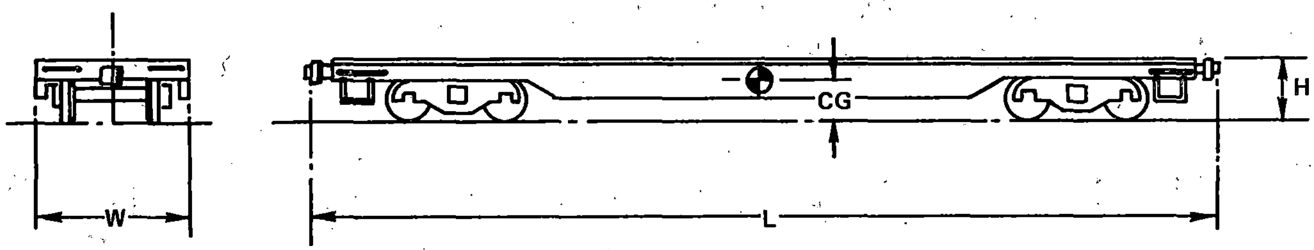
Center of Gravity Range for Bulkhead Flat Cars (for car body only, from top of rail):

Empty: 39.2 in. - 46.8 in.

Loaded: 47.2 in. - 100.5 in.

GENERAL FLAT CAR





Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

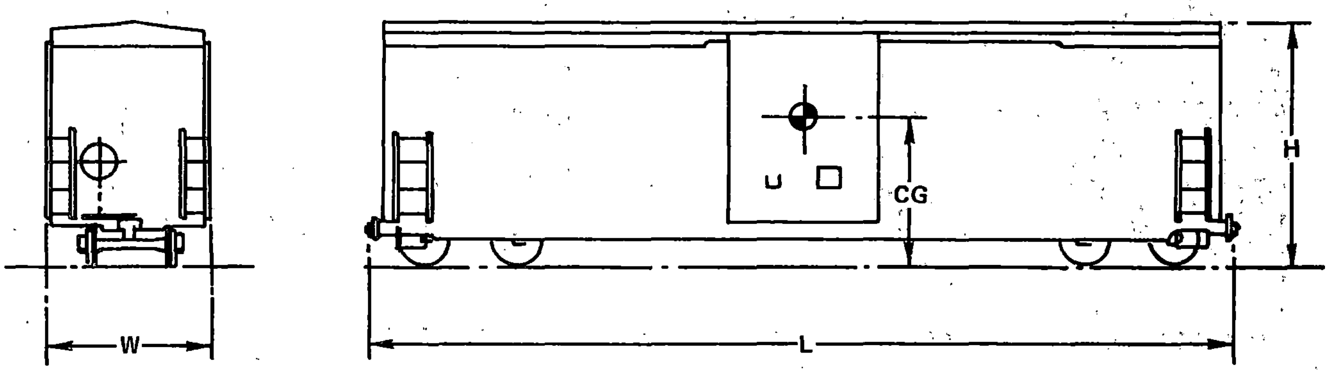
Dimension	50 Ton	70 Ton	100 Ton
Length	53 ft. 3 in.	56 ft. 9 in.	59 ft. 3 in.
Width	10 ft. 3 in.	10 ft. 4 in.	10 ft. 6 in.
Height	5 ft. 0 in.	5 ft. 2 in.	5 ft. 7 in.

Center of Gravity Range for General Flat Cars (for car body only, from top of rail):

Empty: 34.2 in. - 41.0 in.

Loaded: 43.3 in. - 106.3 in.

BOX CAR



Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a 50-, 70-, 100-Ton Capacity Vehicle

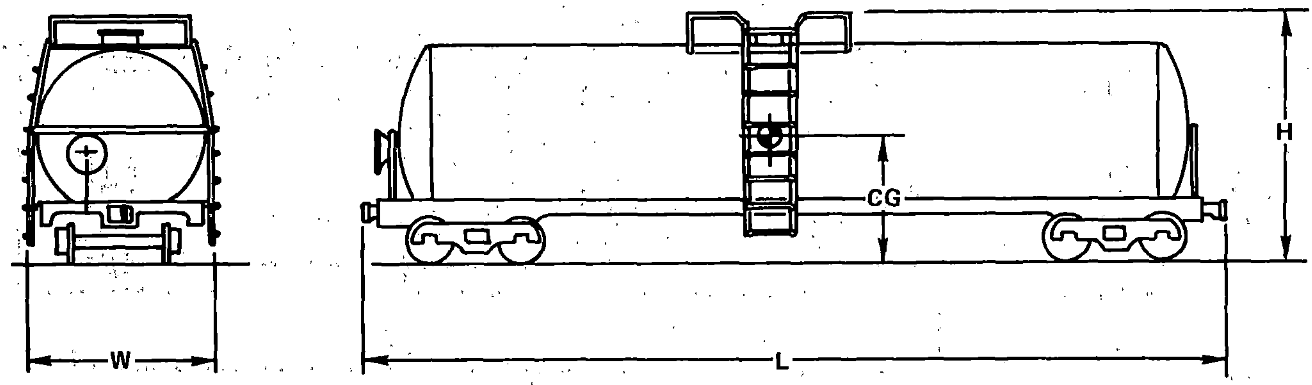
Dimension	50 Ton	70 Ton	100 Ton
Length	54 ft. 6 in.	57 ft. 11 in.	68 ft. 0 in.
Width	10 ft. 7 in.	10 ft. 6 in.	10 ft. 6 in.
Height	15 ft. 0 in.	15 ft. 2 in.	15 ft. 4 in.

Center of Gravity Range for Box Cars (for car body only, from top of rail):

Empty: 62.0 in. - 76.1 in.

Loaded: 54.4 in. - 103.7 in.

TANK CAR



Length: Measured between pulling faces of couplers (in normal position)

Width: Measured at eaves, tops of sides or platform

Height: Measured at eaves, tops of sides or platform

Typical Dimensions for a Nominal 11,000-, 21,000-, 33,000-Gallon Capacity Vehicle

Dimension	11,000 Gal.	21,000 Gal.	33,000 Gal.
Length	41 ft. 6 in.	56 ft. 8 in.	66 ft. 5 in.
Width	10 ft. 0 in.	10 ft. 1 in.	10 ft. 6 in.
Height	14 ft. 8 in.	15 ft. 0 in.	15 ft. 1 in.

Center of Gravity Range for Tank Cars (for car body only, from top of rail):

Empty: 78.6 in. - 95.1 in.

Loaded: 80.7 in. - 99.1 in.

APPENDIX C
SURVEY OF RAILROAD EMPLOYEES

This appendix summarizes the results of a survey of the general and local chairmen of the United Transportation Union to determine the concerns of railroad employees regarding the effects of size, weight, and length of railroad cars on safety. A sample questionnaire with the tabulated responses is included, followed by a discussion and summary of the result for each question.

The sample questionnaire shows the number of responses to each part of each question as well as the associated percentage. Each question does not have the same total number of responses since some respondents did not answer all questions, and some questions allowed multiple responses.

SAMPLE QUESTIONNAIRE

Instructions: Please complete all of the following questions. If you have additional comments on any question, write them on a separate sheet of paper and include them in the return envelope. Please indicate the number of the question to which your comments apply.

1. Please check the car types below which you feel have a tendency to derail more frequently than other cars. (Please check no more than 5)

NO.	%		
73	8.9	☐	a. Box-plain
102	12.4	☐	b. Box-other
23	2.8	☐	c. Refrigerator
97	11.8	☐	d. Gondola-plain
56	6.8	☐	e. Gondola-other
113	13.7	☐	f. Hopper-open
154	18.7	☐	g. Hopper-used in unit trains
379	46.1	☐	h. Hopper-covered
394	47.9	☐	i. Tank-jumbo
76	9.2	☐	j. Tank-other
312	37.9	☐	k. Flat-auto-rack
340	41.3	☐	l. Flat-TOFC
133	16.2	☐	m. Flat-other
86	10.4	☐	n. Other (specify________________________)
28	3.4	☐	o. Few derail more frequently

2. In your opinion, under which of the following conditions is a car likely to derail. Please check the appropriate column.

Car Type	Likely to derail under any circumstances		Likely to derail when empty		Likely to derail when loaded		Has low frequency of derailment under any circumstance	
	NO.	%	NO.	%	NO.	%	NO.	%
Box-plain	56	6.8	105	12.8	38	4.6	342	41.6
Box- other	89	10.8	84	10.2	67	8.1	274	33.3
Refrigerator	51	6.2	36	4.4	33	4.0	387	47.0
Gondola-plain	59	7.2	105	12.8	81	9.8	275	33.4
Gondola- other	59	7.2	85	10.3	88	10.7	243	29.5
Hopper- open	70	8.5	95	11.5	128	15.6	215	26.1
Hopper- used in unit trains	75	8.1	37	4.5	196	23.8	199	24.2
Hopper-covered	143	17.4	53	6.4	267	32.4	131	15.9
Tank-jumbo	250	30.4	76	9.2	188	22.8	100	12.2
Tank-other	83	10.1	74	8.0	82	10.0	224	27.2
Flat-autorack	182	22.1	191	23.2	75	9.1	126	15.3
Flat-TOFC	194	23.6	198	24.1	72	8.7	125	15.2
Flat-other	79	9.6	180	21.9	33	4.0	195	23.7
Other (please specify______)	32	3.9	13	1.6	12	1.5	21	2.6

3. For those cars which you consider more likely to derail, which of the following positions in a train is most likely to influence derailments?

NO.	%	
107	13.0	☐ a. front of the train
245	29.8	☐ b. middle of the train
106	12.9	☐ c. end of the train
384	46.7	☐ d. position in the train does not seem to influence derailment

4. For those cars which you consider more likely to derail, in which of the following trains are these cars most likely to derail?

NO.	%	
14	1.7	☐ a. short trains (less than 30 cars)
95	11.5	☐ b. medium trains (30-100 cars)
520	63.2	☐ c. long trains (longer than 100 cars)
193	23.5	☐ d. length of the train has a minor influence on derailment

5. For the following types of cars, please place an x in the column which best describes track conditions on which these cars behave more excitably than other cars on the track.

Type of Car	less stable when moving over well maintained welded track		less stable when moving over well maintained jointed track		less stable when moving over poorly maintained welded track		less stable when moving over poorly maintained jointed track		stable on most track conditions normally encountered	
	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
Box-plain	3	.4	5	.6	73	8.9	289	35.1	245	29.8
Box- other	3	.4	7	.9	81	9.8	333	40.5	189	23.0
Refrigerator	2	.2	4	.5	59	7.2	268	32.6	261	31.7
Gondola-plain	4	.5	8	1.0	73	8.9	298	36.2	213	25.9
Gondola- other	8	1.0	8	1.0	73	8.3	300	36.5	195	23.7
Hopper- open	7	.9	12	1.5	93	11.3	364	44.2	139	16.9
Hopper- used in unit trains	10	1.2	12	1.5	112	13.6	354	43.0	117	14.2
Hopper-covered	18	2.2	22	2.7	130	15.8	427	51.9	78	9.5
Tank-jumbo	21	2.6	21	2.6	141	17.1	418	50.8	81	9.8
Tank-other	5	.6	7	.9	88	10.7	300	36.5	181	22.0
Flat-autorack	24	2.9	16	1.9	125	15.2	399	48.5	81	9.8
Flat-TOFC	21	2.6	18	2.2	129	15.7	401	48.7	79	9.6
Flat-other	11	1.3	13	1.6	79	9.6	300	36.5	173	21.0
Other (specify ____)	11	1.3	6	.7	39	4.7	116	14.1	15	1.8

6. Of the following car length groups, which are most likely to contain cars which derail at above average rates?

NO.	%	
43	5.2	☐ a. less than 49 feet long
183	22.2	☐ b. 50-69 feet long
388	47.1	☐ c. 70 feet long or longer
84	10.2	☐ d. cars with varying lengths derail at approximately equal rates
421	51.2	☐ e. length and characteristics of adjacent cars can influence derailments

7. Of the following car weight groups, which are most likely to contain cars which derail at above average rates?

NO.	%	
73	8.9	☐ a. about 50 tons or less
40	4.9	☐ b. about 70 tons
197	23.9	☐ c. about 100 tons
325	39.5	☐ d. greater than 100 tons
96	11.7	☐ e. cars with varying weights derail at approximately equal rates
365	44.3	☐ f. weight and characteristics of adjacent cars can influence derailments.

8. Which groups of cars are most likely to be involved with accidents resulting in personal injuries?

NO.	%	
18	2.2	☐ a. less than 50 feet long
81	9.8	☐ b. 50-69 feet long
252	30.6	☐ c. 70 feet long or longer
484	58.8	☐ d. no particular length of car is most likely to be involved in accidents with personal injuries

9. Which groups of cars are most likely to be involved with accidents resulting in personal injuries?

NO.	%	
36	4.4	☐ a. about 50 tons or less
35	4.3	☐ b. about 70 tons
101	12.3	☐ c. about 100 tons
166	20.2	☐ d. over100 tons
481	58.4	☐ e. cars with varying lengths are involved in accidents with personal injuries at approximately equal rates.

10. What specific comments could you offer on how cars could be improved to reduce injury to employees? ______________________

____

____

____

____

11. In your opinion, which of the following conditions best describes each type of railcar with regard to personal injuries? Please check the appropriate column.

Type of Car	Likely to be involved in accidents with personal injuries when unloaded NO.	%	Likely to involved in accidents with personal injuries when loaded NO.	%	Likely to involved in accidents with personal injuries whether loaded or empty NO.	%	Not likely to be involved in accidents with personal injuries NO.	%
Box-plain	36	4.4	29	3.5	170	20.7	260	31.6
Box- other	34	4.1	33	4.0	209	25.4	215	26.1
Refrigerator	21	2.6	29	3.5	161	19.6	272	33.0
Gondola-plain	33	4.0	88	10.7	201	24.4	184	22.4
Gondola- other	28	3.4	81	9.8	197	23.9	181	22.0
Hopper- open	45	5.5	89	10.8	188	21.5	194	23.6
Hopper- used in unit trains	21	2.6	83	10.1	166	20.2	216	26.2
Hopper-covered	10	1.2	99	12.0	208	25.3	186	22.6
Tank-jumbo	21	2.6	111	13.5	379	46.1	80	9.7
Tank-other	24	2.9	75	9.1	323	39.2	113	13.7
Flat-autorack	54	6.6	62	7.5	362	44.0	108	13.1
Flat-TOFC	61	7.4	64	7.8	419	50.9	65	7.9
Flat-other	75	9.1	51	6.2	397	48.2	70	8.5
Other (specify)	6	.7	13	1.6	82	10.0	19	2.3

12. What operating practices which affect the size, weight and length of railcars could be improved to reduce the risk of personal injuries?

NO.	%	
286	34.8	☐ a. connecting air hoses
408	49.6	☐ b. getting on and off of cars
245	29.8	☐ c. inspecting
93	11.3	☐ d. loading
216	26.2	☐ e. coupling
32	3.9	☐ f. bleeding brakes
245	29.8	☐ g. riding
397	48.2	☐ h. setting hand brakes
319	38.8	☐ i. pulling pins
36	4.4	☐ j. other (please specify________________________)

13. Which of the following cars are hardest to get on and off?

NO.	%	
19	2.3	☐ a. less than 49 feet long
36	4.4	☐ b. 50-69 feet long
229	27.8	☐ c. 70 feet long and longer
505	61.4	☐ d. there are little differences in difficulty due to varying lengths

14. Which of the cars are hardest to get on and off?

NO	%	
10	1.2	☐ a. Box-plain
16	1.9	☐ b. Box-other
25	3.0	☐ c. Refrigerator
96	11.7	☐ d. Gondola-plain
82	10.0	☐ e. Gondola-other
7	.9	☐ f. Hopper-open
8	1.0	☐ g. Hopper-used in unit trains
16	1.9	☐ h. Hopper-covered
468	56.9	☐ i. Tank-Jumbo
522	63.4	☐ j. Tank-other
411	49.9	☐ k. Flat-autorack
634	77.0	☐ l. Flat-TOFC
690	83.8	☐ m. Flat-other
25	3.0	☐ n. Other (please specify ______)
14	1.7	☐ o. There are relatively little differences in difficulty

15. Are there any features of larger cars (over 70 feet or larger cube cars) which you feel increase the chance of personal injury in yards?

NO.	%	
534	64.9	☐ a. yes
209	25.4	☐ b. no

If yes, please explain which features increase the risk of personal injury and when these situations occur ______

______

______

______

16. Please explain any hazard or risk associated with the size, weight or length of railcars, not previously mentioned, that you feel have important influences on safety.

______

______

______

______

______

______

You may indicate the following information if you so desire:

Railroad: ______

State: ______

Major responsibility: ______ ______

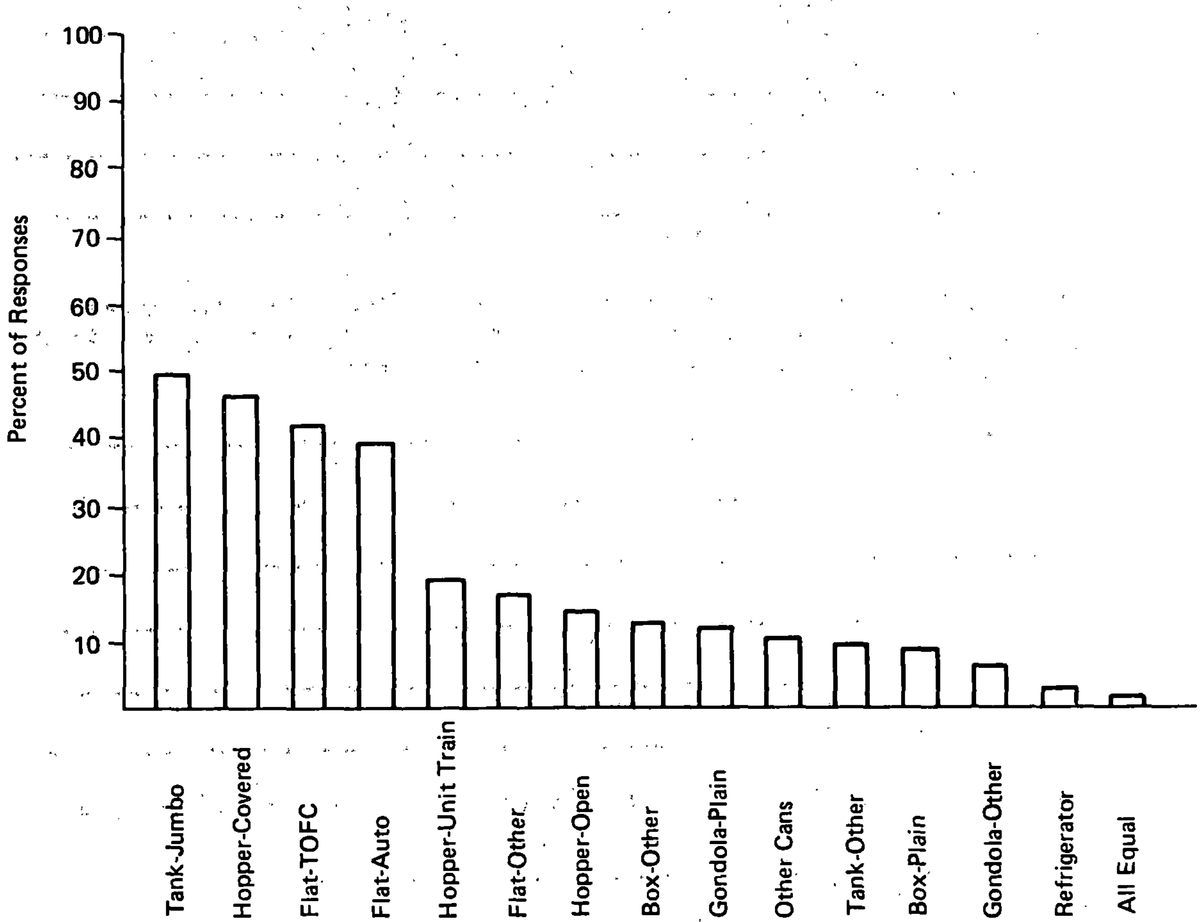
DISCUSSION OF QUESTIONNAIRE RESPONSES

Question 1: Which car types derail more frequently than other cars?

The answers to the frequency of derailment question were tabulated and the car types were ordered from most likely to least likely to derail. They were:

1. Tank	Jumbo	47.9%
2. Hopper	Covered	46.1
3. Flat	TOFC	41.3
4. Flat	Auto	37.9
5. Hopper	Unit Train	18.7
6. Flat	Other	12.4
7. Hopper	Open	13.7
8. Box	Other	12.4
9. Gondola	Plain	11.4
10. Other		10.4
11. Tank	Other	9.2
12. Box	Plain	8.9
13. Gondola	Other	6.8
14. All Equal		3.4
15. Refrigerator		2.8

Less than 4% of the respondents thought all car types were equally likely to derail. At 3.4%, it was the second least frequently chosen response. The first four car types in the list can be considered the most frequently derailing, as they were chosen more than twice as often as any other car type in the questionnaire.



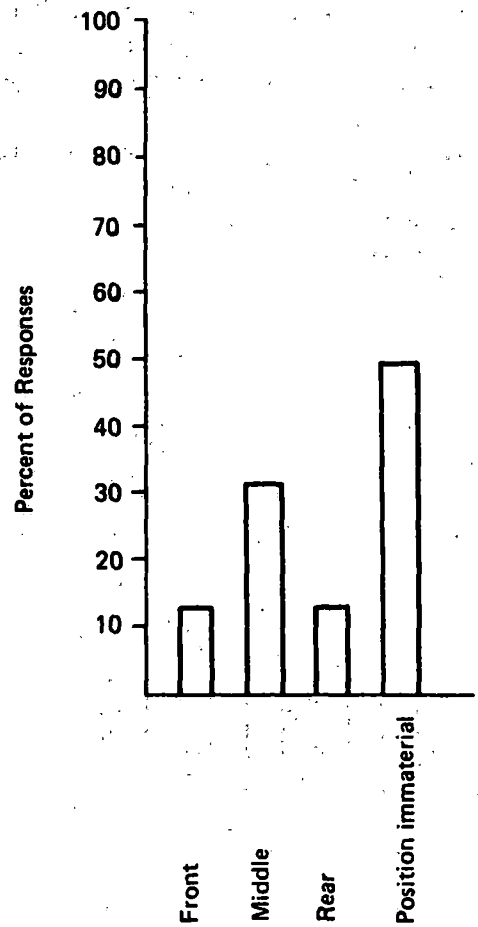
Question 2: Under what conditions is a car likely to derail (loaded vs. unloaded)?

This question seeks to assess whether a car type's derailment can be attributed to being loaded, being unloaded, or being derailment prone under any circumstances. Another answer of not likely to derail under any conditions is also available. The four derailment prone cars identified in the first question had the lowest frequency of respondents choosing this latter category. The jumbo tank cars were noted to derail under any circumstances by 30.4% of the respondents and loaded by 22.8%. The covered hoppers were chosen to derail primarily while loaded by 32.4% to 17.4% in all conditions. The two high frequency derailment flat cars were selected to derail more often while empty than under all circumstances; they were least likely to derail when loaded. For flat-TOFC cars the percentages were 24.1, 23.6, and 8.7, respectively, and for flat-autoracks they were 23.2, 22.1, and 9.1%, respectively. The tendency to derail while empty was also shared by the flat-others with 21.9%, although 23.7% of the respondents thought they had a low frequency of derailment. The hopper cars used on unit trains were chosen to derail while full by 23.8% of the respondents, but were also chosen as unlikely to derail by 24.2% of the respondents. Noted as having particularly low derailment frequencies were box and refrigerator cars.

Note: The percentage of responses for each car did not add to 100% as some respondents did not answer the question for all car types. The effect of adjusting for the non-responses would have been to raise the percentages shown. However, only unadjusted percentages have been used.

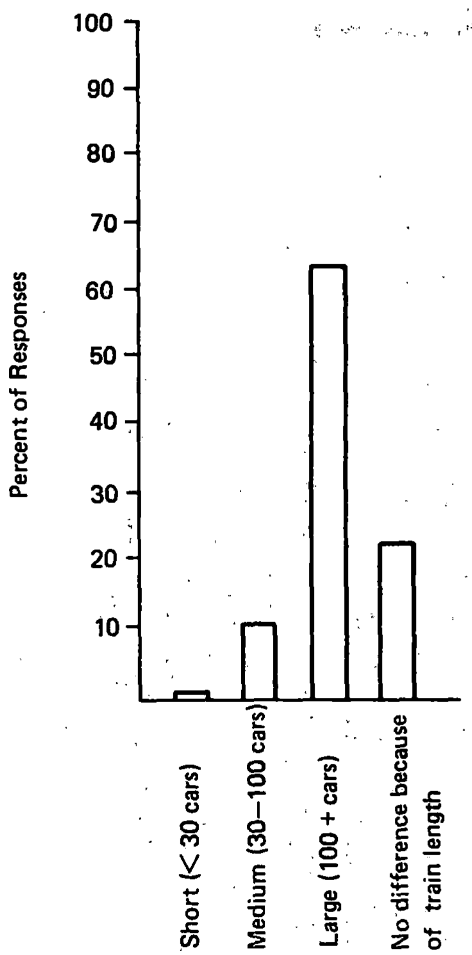
Question 3: ***For those cars which you consider more likely to derail, which of the following positions in a train are most likely to influence derailments?***

There was no clear consensus about the influence of car position in a train in car derailments. Half, 46.7%, thought it did not influence derailments while 29.8% chose the middle, with the front and rear splitting the remainder.



Question 4: For those cars which you consider more likely to derail, in which of the following train lengths are these cars most likely to derail?

Long trains, those with greater than 100 cars, were selected as likely to have derailed cars by 63.2% of the respondents. 23.5% felt train length had a minor influence on derailment, 11.5% chose medium length trains, and 1.7% chose short trains as most likely to have derailed cars. In general, the likelihood of derailment was proportional to train length.



Question 5: ***Give the track conditions on which a specific car type behaves more excitably than other car types.***

For all car types, there was a hierarchy of responses:

Well-maintained welded track (least effect on car)
Well-maintained jointed track
Poorly maintained welded track
Poorly maintained jointed track (greatest effect on car)

The percentage for every car type increased as one moved down the list of track conditions. The question answered was: which car types are most excitable and hence most likely to derail. The salient feature of the responses was the six car types for which the ratio of most excitable to stable on most track conditions was large (greater than 4 to 1).

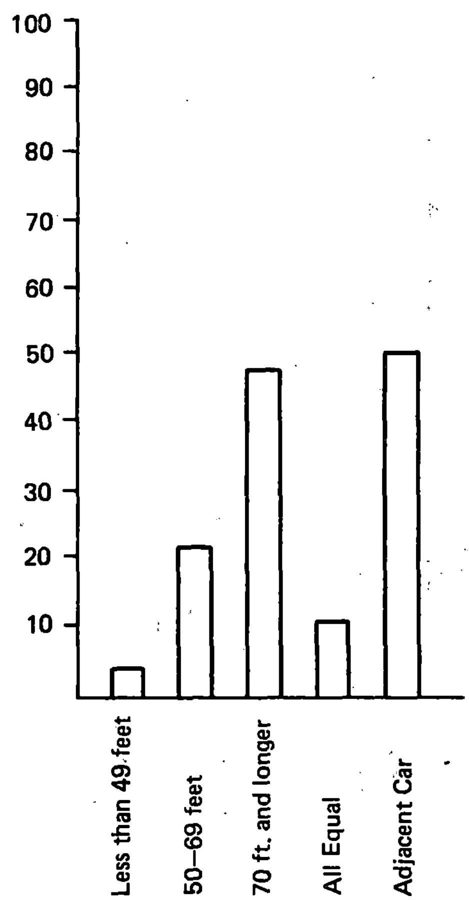
The six most excitable car types were:

Hopper	Open
Hopper	Unit Train
Hopper	Covered
Tank	Jumbo
Flat	TOFC

Question 6: Of the following car length groups, which are most likely to contain cars which derail at above average rates?

The majority of respondents, 51.2%, felt the length and characteristics of adjacent cars influence derailments. While 10.6% said that derailment rate was independent of length, the remainder indicated that derailment rate was proportional to length. Chosen as most likely to derail were:

70 ft. and longer	47.1%
50—69 ft.	22.2%
less than 50 ft.	5.2%

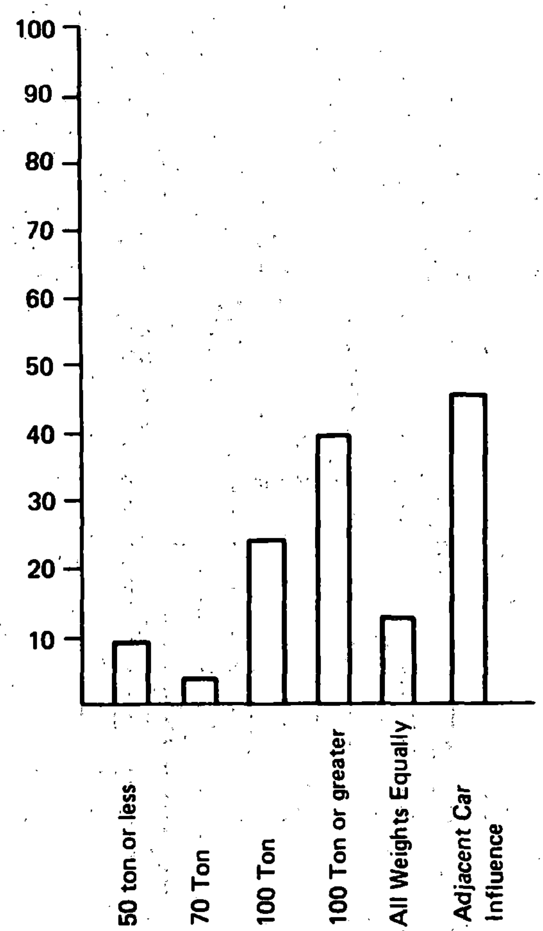


Question 7: Of the following weight groups, which are most likely to contain cars that derail at above average rates?

Of the respondents, 44.3% felt that the weight and characteristics of the adjacent car influenced derailments. This was the largest single answer chosen. 12% thought derailments were independent of weight. The heavier cars were singled out as more likely to derail, as shown below:

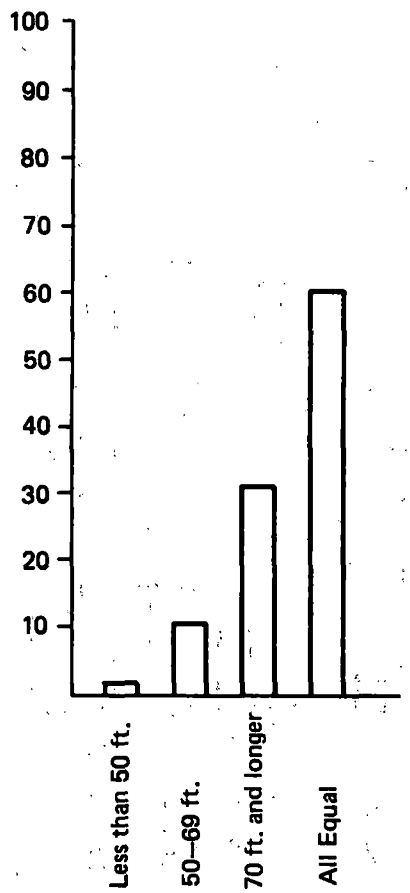
100+ Tons	39.5%
100 Tons	23.9%
70 Tons	4.9%
50 Tons	8.9%

Combining the 100 and 100+ ton car classes shows 63.4%, choosing the heaviest cars as most likely to derail. The slight increase in the 50-ton over the 70-ton class may be due to the greater number of 50-ton cars.



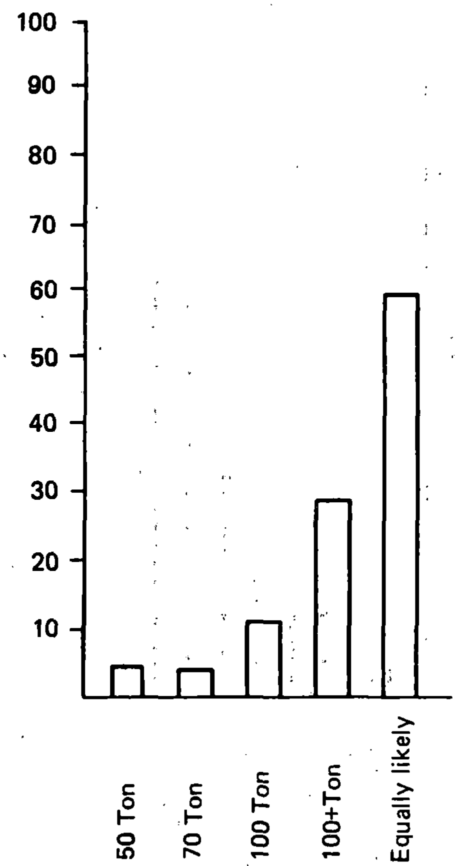
Question 8: Which groups of cars are most likely to be involved with accidents resulting in personal injuries? (Length)

The majority of respondents, 58.4%, felt that personal injury accidents were independent of car length. The remainder felt that the probability of personal injury accidents were proportional to length with 30.6% choosing 70 foot and longer cars, 9.8% choosing 50—69 foot cars, and 2.2% choosing cars less than 50 feet long.



Question 9: Which group of cars most likely to be involved with accidents resulting in personal injuries? (Weight)

The majority of respondents, 58.4%, felt that the weight of the car was not a factor and all weight groups were equally likely to be involved in personal injury accidents. The two heavier weight groups, 100 tons and 100+ tons, were selected by 12.3% and 20.2% of the respondents. Combining these two groups shows that 32.5% of the respondents thought the larger weight cars were most likely to be involved in personal injury accidents, a sizable minority. Less than 5% picked either the 50-ton or 70-ton weight groups.



Question 10: ***What specific comments could you offer on how cars could be improved to reduce injury to employees?***

The following categories show the areas in which improvements might be made to reduce injuries to employees:

Safety Appliances (Ladders, Handgrips)	29%
Car Inspections	22%
Brake System (Handbrakes, Air Coupling)	18%
Coupler and Draft Gear	7%
Track Maintenance	6%
Shorter Cars	5%
Lighter Cars	4%
Lower Cars	4%
Suspension System	2%
Shorter Trains	2%
Loading and Positioning of Empty Cars	2%

Representative responses include the following:

1. "Building the car lower to keep the center of gravity at the lowest possible level. Centralize brake wheel and platform along with retainers and angle locks, thereby eliminating the need for a man to do excess climbing, reaching over couplers while making up and handling cars."
2. "Better grab-irons and foot steps on flat cars--autoracks--tanks. Low handbrakes. Walk ramps on each end of cars for moving between cars."
3. "The only way to reduce injuries is to decrease the length of trains to cut down on the excessive amount of slack action from the cushioned drawbars."
4. "A train consisting of 85 cars or less is much safer for operating employees to handle."
5. "Keep couplers and long drawbars oiled so thay can be moved easily when aligning them; also keep pin lifters for said cars in good order so as to make it easier to uncouple cars."
6. "Well maintained track--we had over 500 derailments at [Southwestern town] in 1974 and 1975. Since they rebuilt tracks and road bed, we have three or four a month now."
7. "Larger cars do not handle curves well. Heavier cars are harder to stop and start, and cause additional strain on bad track. This additional strain can sometimes cause rail to turn over."

8. I have noticed that the newer S00 Line cars have high sill steps, and it is hard to get on to these cars. Also, the handbrakes on most piggyback flats are hard to apply, placing one in a bad position."

9. "Newer cars--you can not change the air hose with one wrench and one man. Most newer cars have a rubber hose running into train line and an air hose which will turn if not held with another wrench--in most cases, you need two men and two wrenches.

10. "Employees whose work is inspection--maintenance of cars could be increased. Forces have been decreasing in our area--rules have been broken with no penalties."

11. "Ladders should be positioned for easy access and low enough to step on."

12. I think that the cars are safe if properly maintained and frequently inspected. I work every day with freight cars that haven't been maintained."

Question 11: In your opinion, which of the following conditions best describe each type of railcar with regard to personal injury?

The respondents had a choice of four answers for each car type: likely to be involved when unloaded, loaded, whether loaded or unloaded, and not likely to be involved in a personal injury accident. Very few chose any of the cars unloaded as likely to be involved in personal injury accidents. More respondents felt the cars were likely to be involved in personal injury accidents when loaded; however, the percentage was still less than choosing either of the remaining two possibilities. The only exception was flat-other cars, which by a 9.1% to 6.2% ratio was chosen as more dangerous. Other car types showing high loaded to unloaded rations were:

Gondola - Plain	10.7% - 4.0%
Gondola - Other	9.8% - 3.4%
Hopper - Open	10.8% - 5.5%
Hopper - Unit Train	10.1% - 2.6%
Hopper - Covered	10.0% - 1.2%
Tank - Jumbo	13.5% - 2.6%

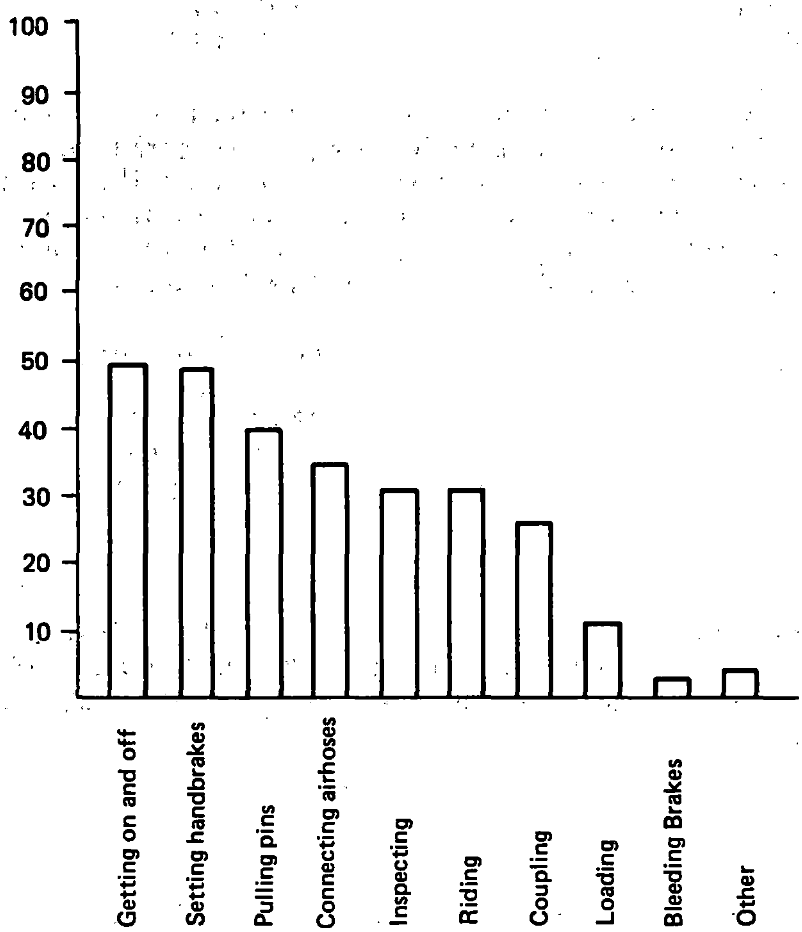
The majority of the answers were in the last two columns when loading made little difference in a car's likelihood of being involved in a personal injury accident; and for most of the cars, the answers were split evenly between the two choices. The most salient feature of the responses was the five cars for which a majority of the answers indicated that the cars were likely to be involved in personal injury accidents. The percentage of respondents selecting the cars as likely and not likely to be involved are listed below:

	Likely	Not Likely
Tank-Jumbo	46.1%	9.7%
Tank - Other	32.9%	13.7%
Flat-Auto	44.0%	13.1%
Flat - TOFC	50.9%	7.9%
Flat - Other	48.2%	8.5%

Note: The percentage of responses for all four categories did not add to 100% as some respondents did not answer the question for all cars. The effect of adjusting would have been to raise the percentages shown. However, only unadjusted percentages have been used.

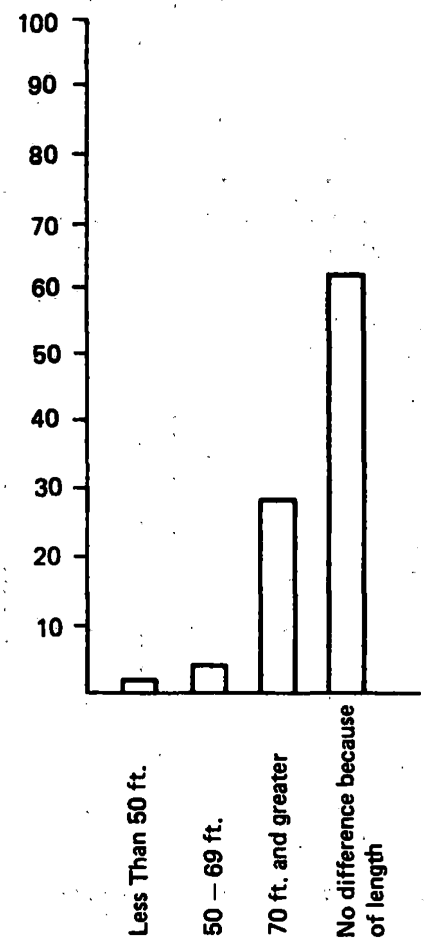
Question 12: What operating practices which affect the size, weight, and length of rail-cars could be improved to reduce the risk of personal injuries?

A sizable proportion of respondents selected most of the options listed for this question. Only bleeding brakes (3.9%) and loading (11.3%) were not selected, with a rather high frequency. The remaining ranged from a low of 26.2% for coupling to a high of 49.6% for getting on and off cars.



Question 13: Which of the cars are hardest to get on and off? (Length)

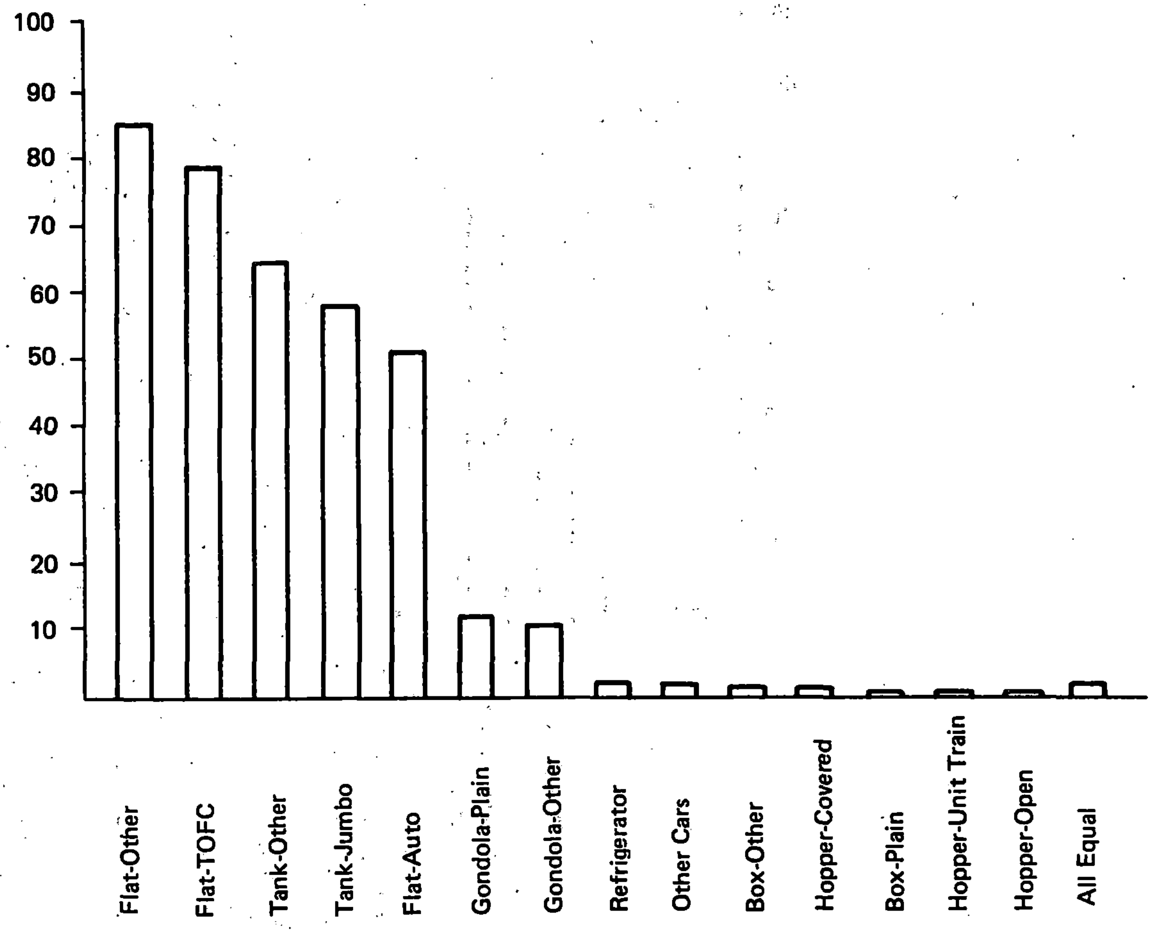
The majority of respondents, 61.4%, felt that there was very little difficulty caused by the varying lengths. Of those respondents specifying one size car as difficult to get on and off, 27.8% chose 70 foot and longer cars, 4.4% chose 50-67 foot cars and 2.3% chose less than 50 foot cars.



Question 14: Which car types are hardest to get on and off?

The car types were broken into two distinct groups: one for which relatively few respondents thought it was hard to get on and off, and a second, for which approximately 50% or more of the respondents felt were hard to get on and off. 1.7% of the respondents felt that all cars were equally hard to board and exit. The five car types that were difficult to board and the percentage of respondents selecting them were:

Flat - Other	83.8%
Flat - TOFC	77.0%
Tank - Other	63.4%
Tank - Jumbo	56.9%
Flat - Auto	49.9%



Question 15: Which features of larger cars (over 70 feet) do you feel increase the chance of personal injury in yards?

These categories show the features of long cars which increase the probability of personal injury in yards.

Coupler and draft gear	38%
Overhang	30%
Safety appliances	24%
Brake system	8%

Representative responses include the following:

1. "Most of the larger cars have anti-shock couplers and some very strange cutting-lever devices. If the couplers miss and a man is required to straighten them out in order to match them up again, many things can happen. The car can lunge forward or the coupler can move without warning from a jammed position back to its normal extended position, striking the individual."
2. "The hard stirrups and grab-irons make getting one off these cars very difficult because of the positioning of the grab-irons."
3. "The hand brakes on piggyback flats are hard to set and release-yaw are usually in an awkward position while applying these brakes."
4. "Long cars swing out more on curves. Most long cars have a long drawbar that will by-pass easy."
5. "When ladder tracks and switch frogs are poorly maintained, these extra length cars do not readily slew."
6. "So many are top heavy when loaded, and when empty are too rigid."
7. "There is not enough ladder on the TOFC car to afford a safe boarding while in motion."
8. "The length of these cars in turnouts causes them to derail, and the drawbars are very hard to align."

Question 16: Explain any hazards or risks associated with the size, weight, or length of railcars that have important influences on safety.

These categories indicate areas of hazard or risk associated with the size, weight, or length of railcars:

Track maintenance more important	26%
Consist makeup and handling	21%
Car inspection and maintenance	12%
Safety appliances	10%
Coupler and draft gear	9%
Dynamic response to track irregularities	9%
Long and light cars more likely to derail on curves	8%
Brake system	5%

Representative responses include the following:

1. "Covered hoppers loaded over 100 ton — in succession of 5 cars or more." "Series of heavy loads next to caboose with empties in middle of train." "High or wide cars placed next to caboose. Open loads placed next to caboose."
2. "Ore cars are extremely dangerous because of the small diameter of the draw-bar and yoke assembly. They break easily which increases the chances of derailment from running over the broken assembly."
3. "Long cars in yard service require more room for clearance of cars on adjacent tracks."
4. "Not enough braking power to stop and have control when riding cars by oneself."
5. "Normally, industrial tracks are poorly maintained. And, as extra weight and extra length cars do have a greater tendency to derail, I believe the spotting and taking off spot from industrial tracks is extra hazardous. Also, on an industry servicing track that is incapable of 15 mph, employees should not be allowed to ride extra dimension cars."
6. "Tank cars don't have the right kind of grab-irons to afford a safe boarding while in motion."
7. "Shiftable loads can and do cause problems. Better standards for proper loading may help reduce damage and possibly injury."
8. "Cars over 70 feet long create a greater risk, but design rather than length is a greater factor. Even more important is a thorough inspection program to eliminate safety appliance defects, which probably cause more injuries than car type, length, weight."
9. "Long trains with mixed freight tend to sway."

APPENDIX D

SURVEY OF RAILROAD MANAGEMENT

This appendix lists the three questions which the Association of American Railroads posed to the management personnel of several U.S. railroads to assist in this study. The specific responses are not shown, but the results are incorporated into the report.

Question 1: If the average capacity of freight cars was increased by 15% with no change in car lengths, what would be the likely impact associated with the safety and economics of operating your company?

Question 2: If the average capacity of freight cars decreased by 15% with no change in car lengths, what would be the likely impact on the safety and economics of operating your company?
a. Bulk Commodities
b. Merchandise Commodities

Question 3: List any significant steps that railroad industry or your company has taken with regard to equipment, track, operation, inspection, and maintenance to compensate for increases in size, weight, or length of rail cars. (Where possible, indicate 10-year trends.)

APPENDIX E

INVESTIGATIONS OF CONTACT STRESSES AND PLASTIC FLOW FROM HIGH WHEEL LOADS*

WHEEL-RAIL CONTACT STRESSES

Introduction

The stresses in the contact zone between wheel and rail arise as a result of the various loads imposed on the wheel-rail during the operation of a rail car. We thus have:

- Compressive normal stress in the wheel tread and rail crown as a result of the imposed normal load.
- Lateral shear in the crown (rail) and wheel tread from the lateral loads encountered during curve negotiation.
- Longitudinal shear stresses in the wheel and rail surface from driving and braking torques.
- Stresses resulting from the dynamic loads along all three component directions.

In the study of the behavior of rail-wheel contacts, the problem is further complicated by the fact that the contact zone shifts on the rail from the crown to the gage side as a result of lateral wheel movement.

It should be pointed out that these braking, driving, lateral, and dynamic loads are all directly or indirectly related to the normal load. Thus, the contact stresses produced by the normal loads are a good starting point for comparative analysis of different design choices.

It is generally recognized that the contact stresses between wheel and rail, for current U.S. industry practice, are higher than the simple tension yield stress of the rail steel. However, for the purpose of relative comparisons, it is still valuable to determine the contact stresses using available elastic solution. Many such investigations have been made.

The following observations can be made from these studies:

- Contact stress increases as load to the 1/3 power for a given wheel and rail.
- Stress decreases with increasing wheel diameter as well as increasing rail profile radius.

*Prepared by the Illinois Institute of Technology

- The stress reduction is larger with an increase in rail crown radius than an increase in wheel radius. For example, an increase in wheel diameter from 30 to 42 inches gives a stress reduction from 138 ksi to 124 ksi, whereas an increase in rail crown radius from 10 to 20 inches gives a stress reduction from 138 ksi to 98 ksi.
- The radius of the crown of the rail currently used seems too low.
- Best gains in stress reduction should be possible by a suitable combination of increasing wheel diameter, the radius of the crown of the rail, and changes in wheel tread profile.

Measured Contract Stresses in Laboratory Simulation

The IIT-GMEMD wheel-rail simulation facility was utilized for determination of contact stresses for the different tonnage cars. The 8-inch diameter Hertz simulation wheels were used on a 36-inch diameter wheel which simulated the rail. The metallurgy and hardnesses of the two were also kept close to those in the field. A friction coefficient of $\mu \sim 0.02$ was used for all experiments. The IIT replica tape contact measuring technique was used to measure the areas of contact between wheel and rail. The contact areas for tests simulating 55-, 70-, 95-, and 125-ton cars are plotted together in Figure E-1 for comparison purposes. The curves are corrected using the IIT contact area measurement technique. They are not expected to be the best fit for the shown data points. The following observations can be made:

- The area of contact increases faster for the heavier tonnage cars. This is due to combined effect of both plastic flow and wear of the two steels.
- The area of contact stabilizes for 55- and 70-ton cars much sooner than for the 95- and 125-ton cars. In fact, the plastic flow of the track for these higher tonnage cars continues for a long period. It is clear from the plot that the stabilized area of contact has still not been reached in 45,000 cycles.
- For the current industry design practice, the areas of contact predicted by Hertz theory (point marked H at 0 cycles) is a true area of contact for only a short time. The actual area of contact is always larger than that predicted by the Hertz Theory.

Contact stress for all the four tonnage cars have been replotted in Figure E-2. Several interesting observations can be made from this plot. The contact stress decreases to a stable value for all cars. For higher tonnage cars, the contact stress stabilizes at smaller stress values, showing the effect of continued plastic flow. This seems to indicate that the degree of work hardening developed by smaller tonnage cars is more than that developed by higher tonnage cars. This should be further investigated. It can also be observed from this figure that in all cases, the stress level at which all car wheels stabilize are in a relatively narrow stress range of approximately 88 to 103 ksi. This is probably due to mechanical-metallurgical characteristics of the rail steel.

Comparison of Theory, Laboratory Simulation, and Field Measurements

The contact stresses can be estimated theoretically for brand new wheel and rail by assuming elastic behavior and using the Hertz solution. Stresses were computed in this manner for the wheels of the freight cars operating at the Facility for Accelerated Service

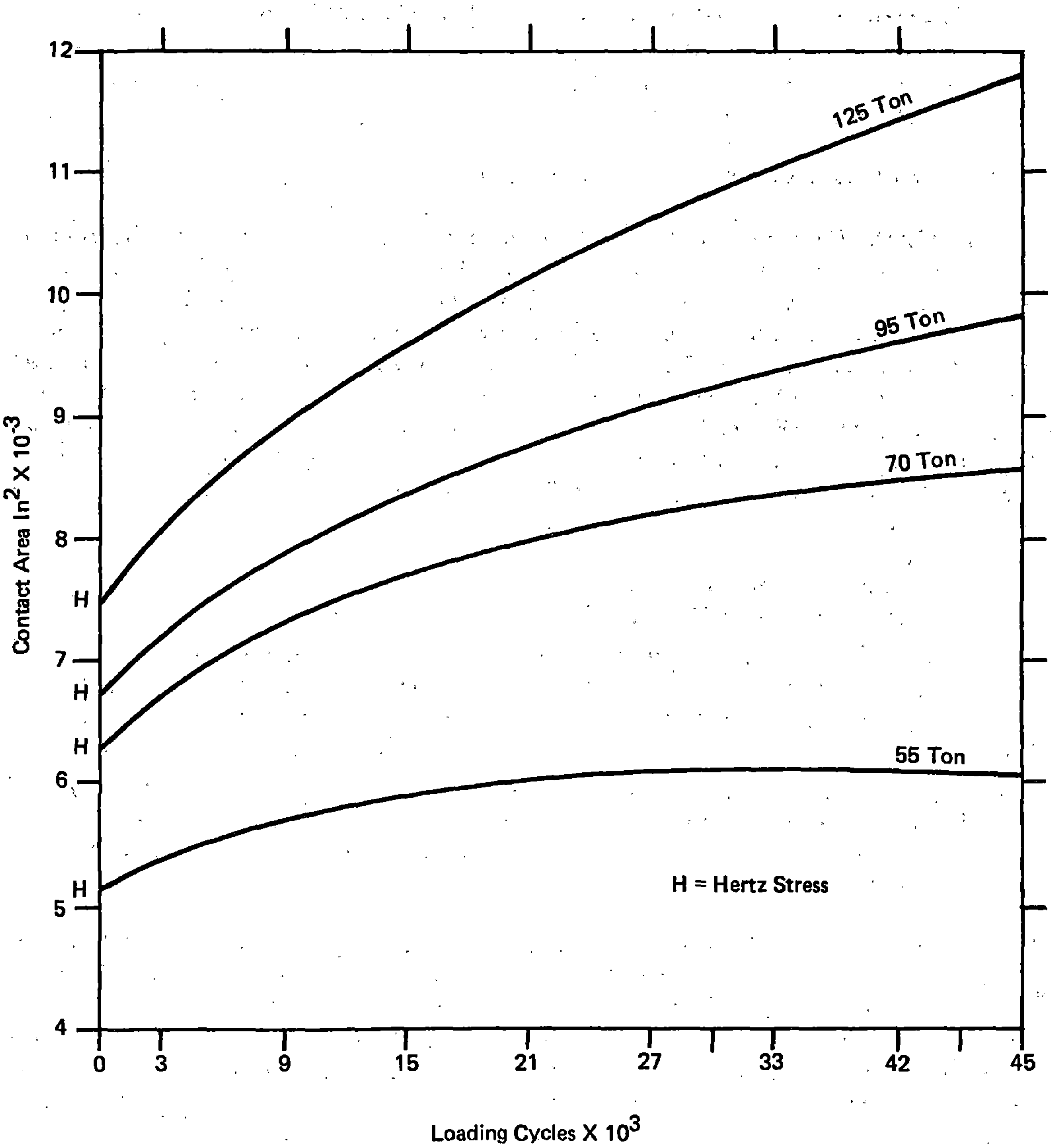


FIGURE E-1 GROWTH OF AREA OF CONTACT FOR WHEEL AND RAIL IN DIFFERENT TONNAGE CARS IN LABORATORY SIMULATION

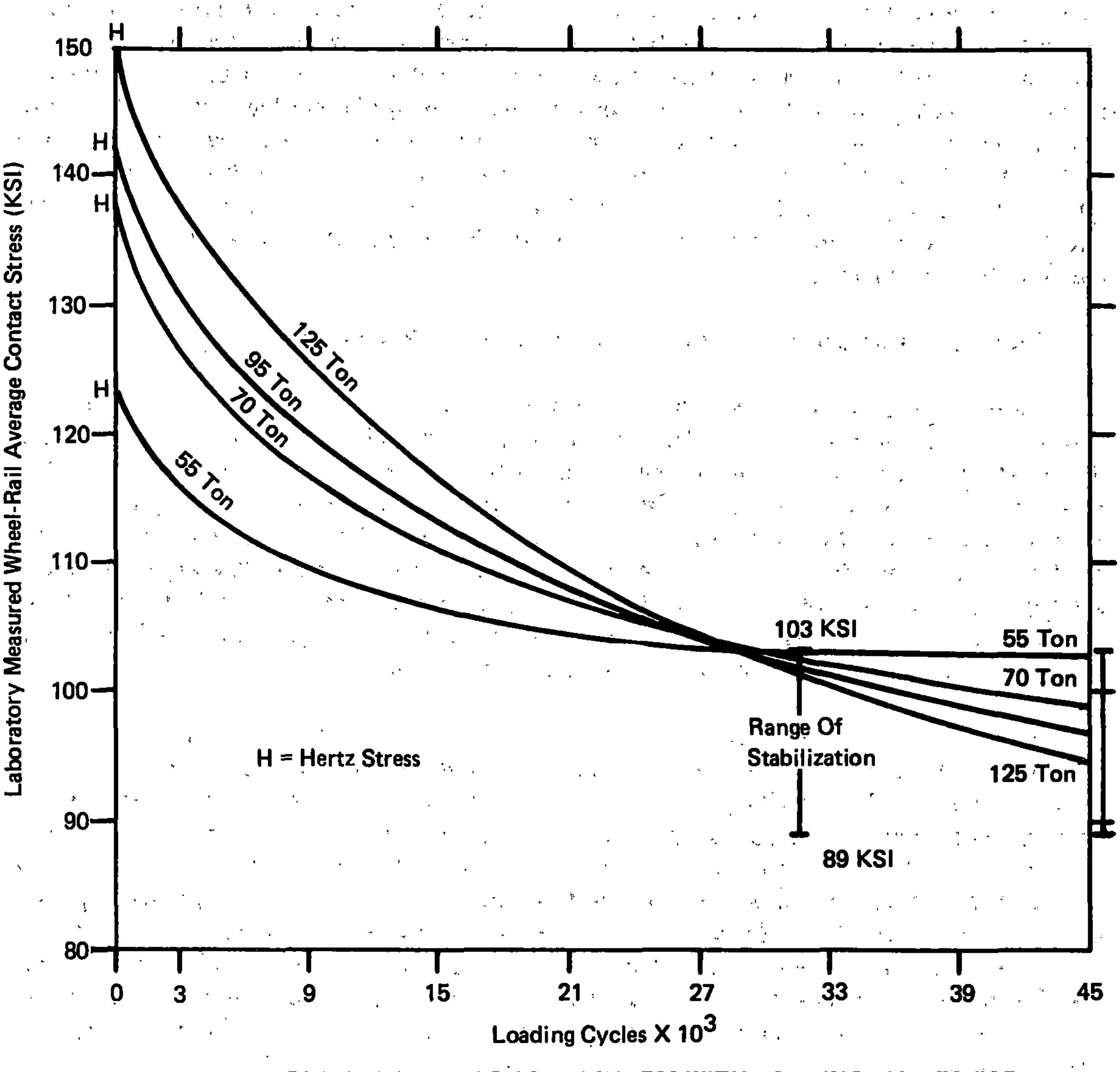


FIGURE E-2 REDUCTION OF CONTACT STRESS WITH LOADING CYCLES FOR VARIOUS TONNAGE CARS IN LABORATORY SIMULATION

and Testing (FAST) at Pueblo, Colorado. Field measurements of average contact stresses were also made at FAST for the 100-ton cars.

The stress values obtained from theory, laboratory simulation, and field measurements are combined in Figure E-3 for comparison purposes. As was expected, the measured contact stresses for 100-ton cars at FAST were always lower than the theoretical Hertz contact stress for which the new wheel and rail were designed. Further, it is interesting to observe that the field contact stresses fell in the same range as the laboratory simulation contact stresses. Several field data points fell in the stabilized contact stress band determined by laboratory experiments. Only one field contact stress measurement gave a value of approximately 70 ksi, which is much below the stabilized stress value band. This measurement was taken on a highly worn wheel profile with a two-point contact between the wheel rim and the rail crown and is not considered a relevant reading. In fact, the wheel was going to be taken off, and the car was brought in the maintenance shop for this purpose. On the whole, the agreement of the field data with the laboratory data for the 100-ton cars was excellent. It is therefore felt that the laboratory simulations of the 55-, 70-, and 125-ton cars should be valid also.

Implications of Contact Stresses and Investigations Needed

As discussed, the wheel-rail contact stresses are considered to be directly or indirectly responsible for various kinds of degradation of the rail and wheel. These include plastic deformation, wear, and fatigue of the rail and wheel. Even the effect of dynamic loads is proportionately reduced if the design contact stresses are lowered as compared to the current industry practice. Figure E-3 shows that the stabilized contact stress band is located at stress values considerably below the current industry design values. The gap is the largest for the 125- and the 100-ton cars. If the design standards were changed such that the design contact stresses fell below the stabilized stress band, the wheel and rail profiles will be stable, resulting in less deterioration, longer life, and lower costs.

For this, it is necessary to investigate, in the laboratory, approaches to reducing design contact stresses, keeping in mind that the vehicles cannot be allowed to become dynamically unstable. Actual scaled down wheels and rails should be used for testing. Plastic flow, wear, and profile changes, all of which affect contact stresses, should be investigated. Other theoretical and experimental analysis techniques should be utilized for improved wheel rail profile designs. It should be mentioned that the worn profile approach used in Europe and Japan for wheels is not suitable for U.S. conditions. The U.S. designs should be made with a positive incorporation of U.S. conditions of tonnage, size of trains, metallurgy of wheels and rails, and operational, economic, and labor considerations. The Illinois Institute of Technology wheel-rail laboratory has capabilities to investigate many of these factors.

After laboratory investigations, the designs and concepts should be tested at FAST and, later, on an actual railroad.

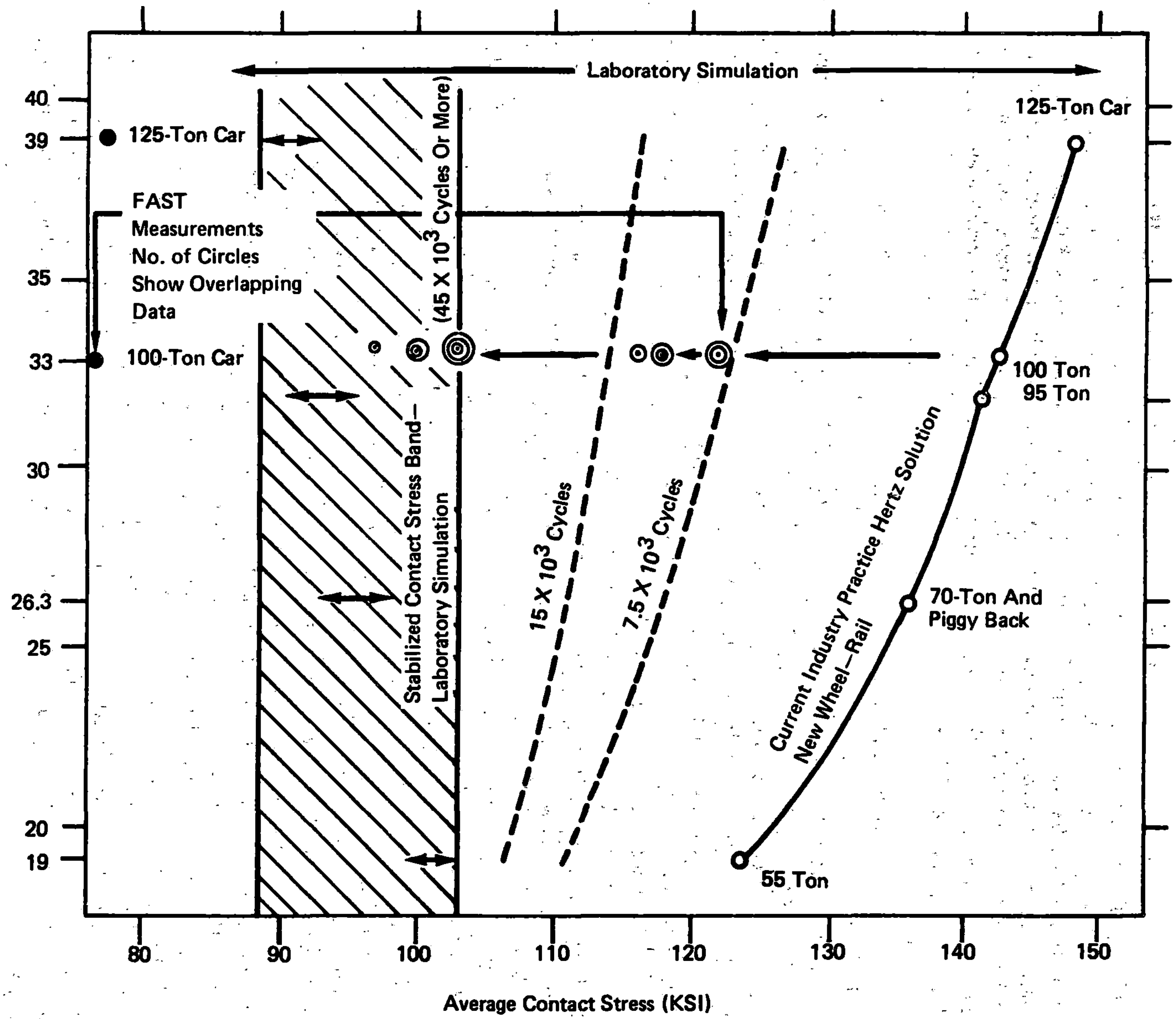


FIGURE E-3 LABORATORY AND FIELD MEASUREMENTS OF WHEEL RAIL CONTACT STRESSES FOR NEW, INTERMEDIATE, AND STABILIZED CONDITIONS

PLASTIC FLOW IN WHEEL-RAIL CONTACT

Introduction

Plastic flow of rail head is being investigated in the laboratory at IIT with Hertzian simulation for various tonnage freight cars and for both tangent and curved track. Plastic deformation affects wheel rail surfaces significantly. The depth to which plastic deformation develops can be of the order of the width of the contact area. The largest amount of plastic deformation takes place in the initial loading cycles, with a resulting residual compressive stress underneath the surface. The material seems to flow forward and sideways on tangent and curved tracks, the degree and rate being dependent on the tonnage and angle of attack between wheel and rail.

Plastic Flow Investigation of Tangent Track for Various Tonnage Cars

Investigations were conducted on the IIT-GMEMD wheel-rail facility using Hertzian simulation wheels (with a hardness of the small wheel equal to 40-43 Shore and the hardness of the large wheel equal to 30-32 Shore). After bringing the wheels into contact and loading with a prescribed load ranging up to 968 pounds, the wheels were rotated for a certain number of revolutions of the large wheel and stopped. The plastic flow is related to the penetration depth "h" of the large and small wheels (Figure E-4). This parameter "h" was therefore used as a measure of plastic flow for these experiments. To measure the above parameter, relative plastic flow, acrylic castings for both small and large wheels are obtained using the IIT acrylic replica technique. The maximum number of revolutions used for these tests was 40. The acrylic castings were obtained at regular intervals.

The acrylic castings showing the plastic deformation in the rolling contact were analyzed using Talysurf profilometer with vertical magnification up to 5000. Figure E-4 represents the maximum plastic flow depth "h" for various normal loads up to 968 pounds, at the end of 40 revolutions of the large wheel. Figure E-5 represents the growth of plastic flow in terms of parameter "h" with the number of revolutions of the large wheel for various normal loads. The rate of plastic flow of the large wheel (simulating the rail) is quite large in the beginning, and it decreases thereafter with increasing number of revolutions, finally stabilizing to a nearly constant value after about 15 revolutions. The magnitude and rate of plastic flow depend on the number of revolutions and applied load. It can be seen that the plastic flow seems to stabilize to a small constant rate (as indicated by angle "θ") after a certain number of cycles. This angle, θ, when plotted against the normal load (Figure E-6) shows that it increases with load and seems to be stabilized slightly above 3 degrees for normal loads up to 968 pounds. By defining the number of revolutions at which the rate of plastic flow stabilizes as a "critical large wheel revolutions number — N," and plotting N against the normal load, as in Figure E-7, it can be seen that N also increases as the normal load is increased. There was little plastic flow on the small wheel in all of the above tests.

From the above investigation, it is evident that plastic flow is a major factor in the degradation of the standard rail. The majority of plastic flow develops in the early stages of use. Its magnitude is dependent on the tonnage of the cars being used. However, the plastic flow continues at a small constant rate during subsequent loading cycles, and this

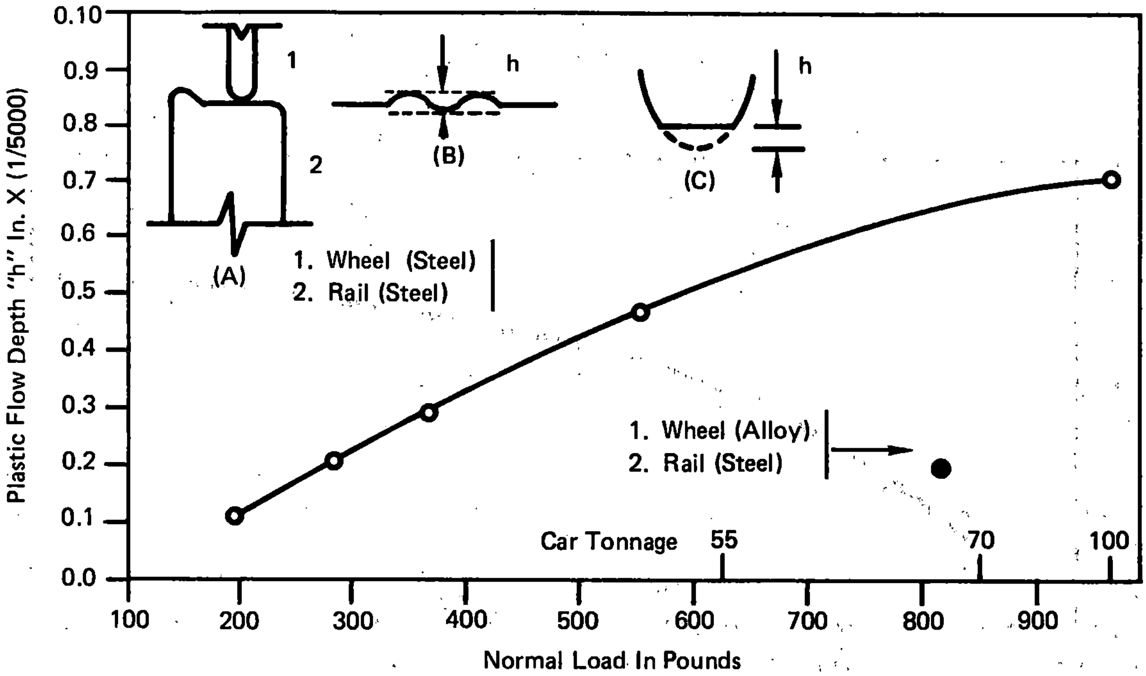


FIGURE E-4 PLASTIC FLOW VS NORMAL LOAD

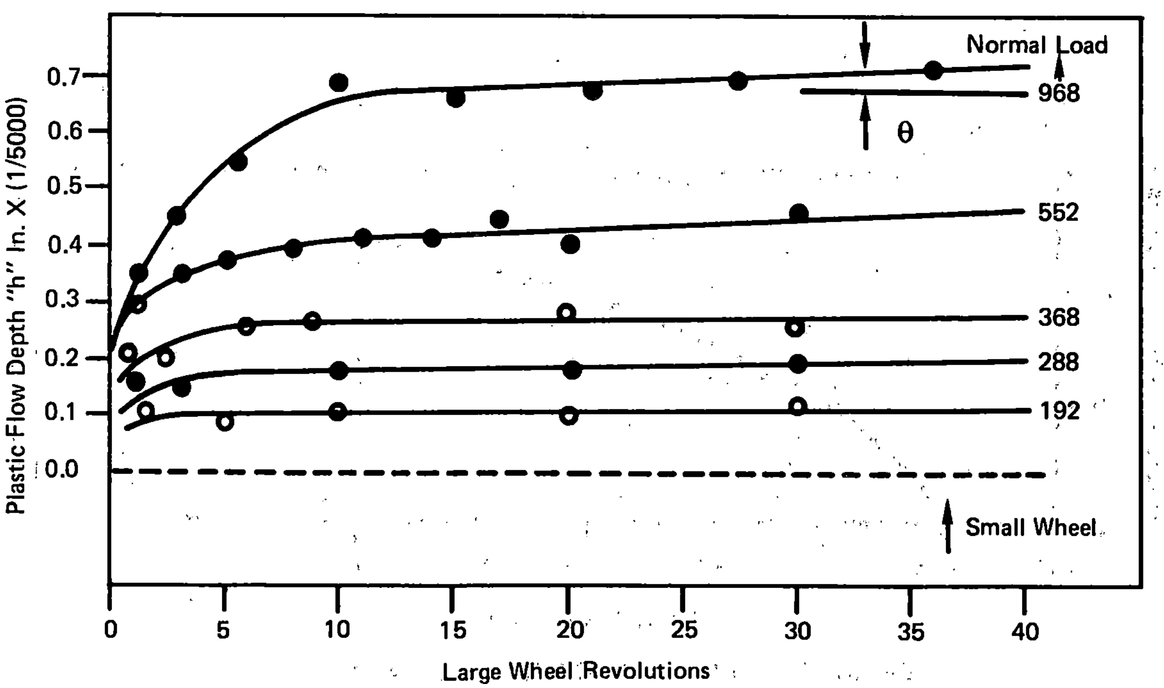


FIGURE E-5 PLASTIC FLOW GROWTH WITH RUNNING IN

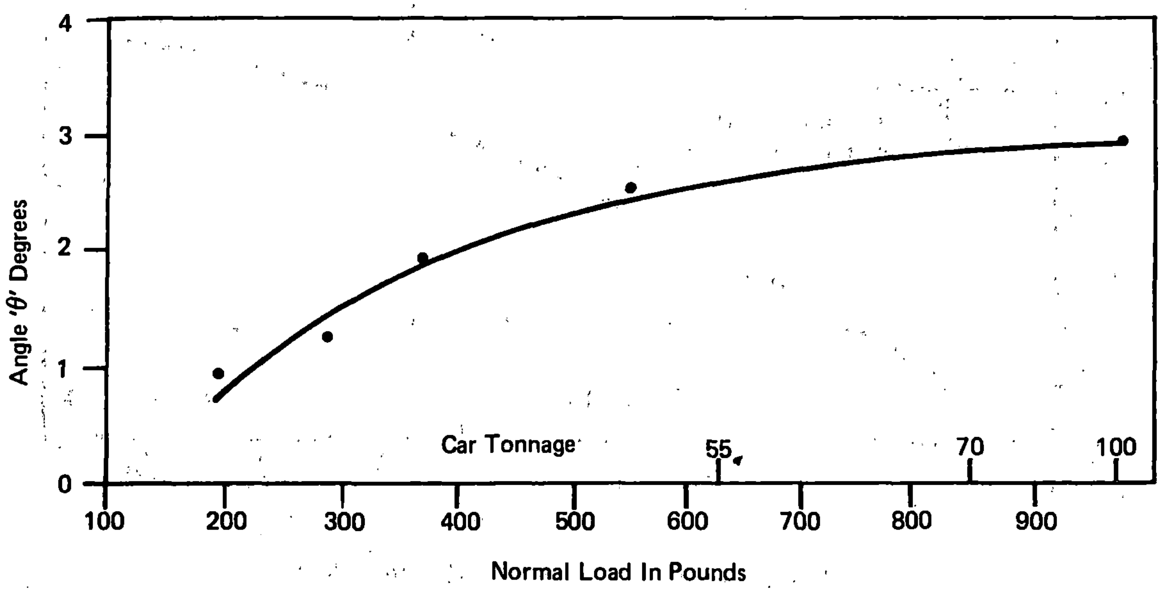


FIGURE E-6 STABILIZED θ VS. NORMAL LOAD

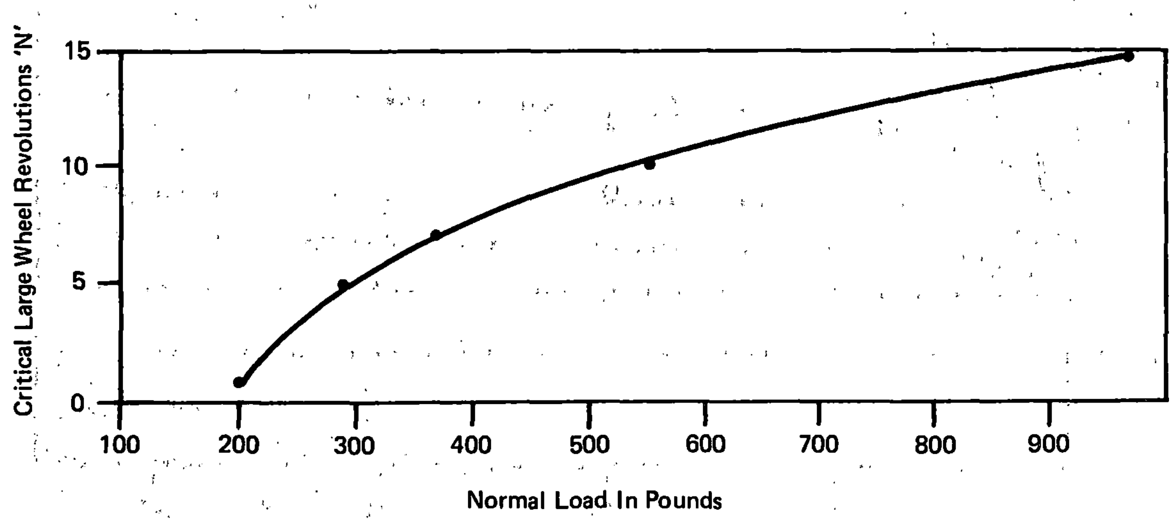


FIGURE E-7 CRITICAL DISTANCE VS NORMAL LOAD

aspect needs further investigation and validation. The above data do not apply directly in a quantitative way to the plastic flow of rails in the field because the geometry and the side constraints of the total rail are not fully simulated; also non-linearity of material behavior is involved. However, it can still be used to gain a qualitative indication of the effects of higher tonnage cars.

It is expected that plastic flow will be considerably less in the laboratory Hertz simulation as compared to full-scale field results. Therefore, it would seem that the initial plastic flow and rates of flow developing in the field should be higher than those predicted by Hertz simulation. The flow rates are expected to continue during the shakedown process, which is expected to be completed sooner for the lighter tonnage cars. The work hardening of the rail and the reduction of the contact stresses are contributing factors. For high tonnage cars (100 tons or more), it seems that the flow rate continues for a very much longer period as compared to the 55- or 70-ton cars. In fact, this rate for the higher tonnage cars may never reach zero values. In other words, the shakedown process for the high tonnage cars may never be fully implemented. All of these plastic phenomena need to be investigated further.

From the laboratory tests conducted above, recognizing their limitations as stated, the following observations can be made:

- Higher tonnage cars produce more initial plastic flow. The depth "h" in the experiments was 29% more for 70-ton cars as compared to 55-ton cars and 6% more for the 100-ton cars as compared to the 70-ton cars. In terms of the volume of steel displaced, the 100-ton cars displaced, in the initial loadings, 10% more than the 70-ton cars.
- The rate of plastic flow of the rail steel before shakedown is higher for the higher tonnage cars. In this experiment, the difference in the rates of the 100-ton and 70-ton cars was almost twice the difference in the rates of the 70-ton and 55-ton cars.

Plastic Flow Investigation of Curved Track for Various Tonnage Cars

The above investigation was conducted on the IIT-GMEMD Wheel-Rail facility using Hertzian simulation wheels (with a hardness of small wheel equal to 40-41 Shore, and the hardness of the large wheel equal to 30-32 Shore).

Plastic flow investigation of curved track for 95-ton and 70-ton cars was conducted with angles of attack 0.1°, 0.3°, and 0.5°

Accurate (within 0.01° error) angles of attack between the wheel and rail were obtained by rotating the frame of the big wheel on the base of the rig by precalculated increments. Hertzian simulation of 95-ton and 70-ton cars was obtained with normal loads of 950 pounds and 852 pounds respectively.

After bringing the wheel in contact and loading with a prescribed load, the wheels were rotated at a very low speed for a certain number of revolutions of the large wheel and stopped at predetermined intervals.

For direct measurement of the profile of the large wheel under cyclic loading, a Talysurf 10 profilometer was mounted on the rig with suitable brackets. After each interval, the profile of the large wheel, across its width, was measured at a fixed location with the Talysurf unit. The maximum number of revolutions used for these tests was 100, and successive Talysurf measurements were taken with vertical magnifications of 1000, 2000, and 5000.

With an angle of attack between wheel and rail, the material flows to one side only (characteristic of the plastic flow of the outer rail in the field).

Figure E-8 represents the growth of plastic flow in the rail with cycles of loading for a 95-ton car Hertz simulation, with 0.3° angles of attack, as measured by the Talysurf unit with magnifications of 2000 and 20 in the vertical and horizontal directions respectively. This figure shows that the plastic flow depth increases, resulting in an increase in metal flow to one side, with increasing loading cycles.

To quantify the extent of plastic deformation in the rolling contact, we decided to measure the area of cross-section of plastic flow depth around the rolling contact (A_1) for 70- and 95-ton cars with various angles of attack. The variation of plastic flow area (A_1) for 95- and 70-ton cars with 0.1°, 0.3°, and 0.5° angle of attack is shown in Figure E-9. It can be seen that the plastic deformation is larger for heavier tonnage cars with the same angle of attack. From the trend of the curves, it can be surmised that there is a small rate of plastic flow which continues with successive loading cycles, the rate being higher for the heavier car.

The comments made earlier regarding the tangent track simulation tests and their applicability to field conditions apply here also. The present tests should not be interpreted as direct quantitative comparisons with full-scale field conditions. They, however, do serve as indicators of trends. The laboratory tests show, in Figure E-9, that the lateral flow of metal for the 95-ton car and 0.1° angle of attack was nearly twice that produced by the 70-ton car simulation. It may also be seen from this data that increases in the angle of attack may more strongly influence the extent of plastic flow than increases in tonnage.

CONCLUDING REMARKS

High-tonnage cars cause significantly more deterioration because of plastic flow on the rails than low-tonnage cars, for the current wheel-rail designs. The deterioration per MGT increases with increased car tonnage.

Contact stresses between wheel and rail are of critical importance in contributing to the degree of deterioration. Actual contact stresses are too high for the rail steels used. This is so, even though the actual stresses are lower than the theoretical Hertz contact stresses, due to plastic flow and wear. Contact stresses for 55-ton cars stabilize at higher value (102 ksi) than the contact stresses for a 100-ton car (92 ksi). This fact is caused by continued plastic flow of the rail for a long duration under higher tonnage cars. In fact, there seems to be a degree of work softening of the rail steel under the higher stresses as a result of higher tonnage and current wheel-rail design practice of the industry. For the current car rolling stock and rails, there is a band of contact stresses (approximately 88-103 ksi) at which the stresses stabilize. If the current industry design standards were changed to

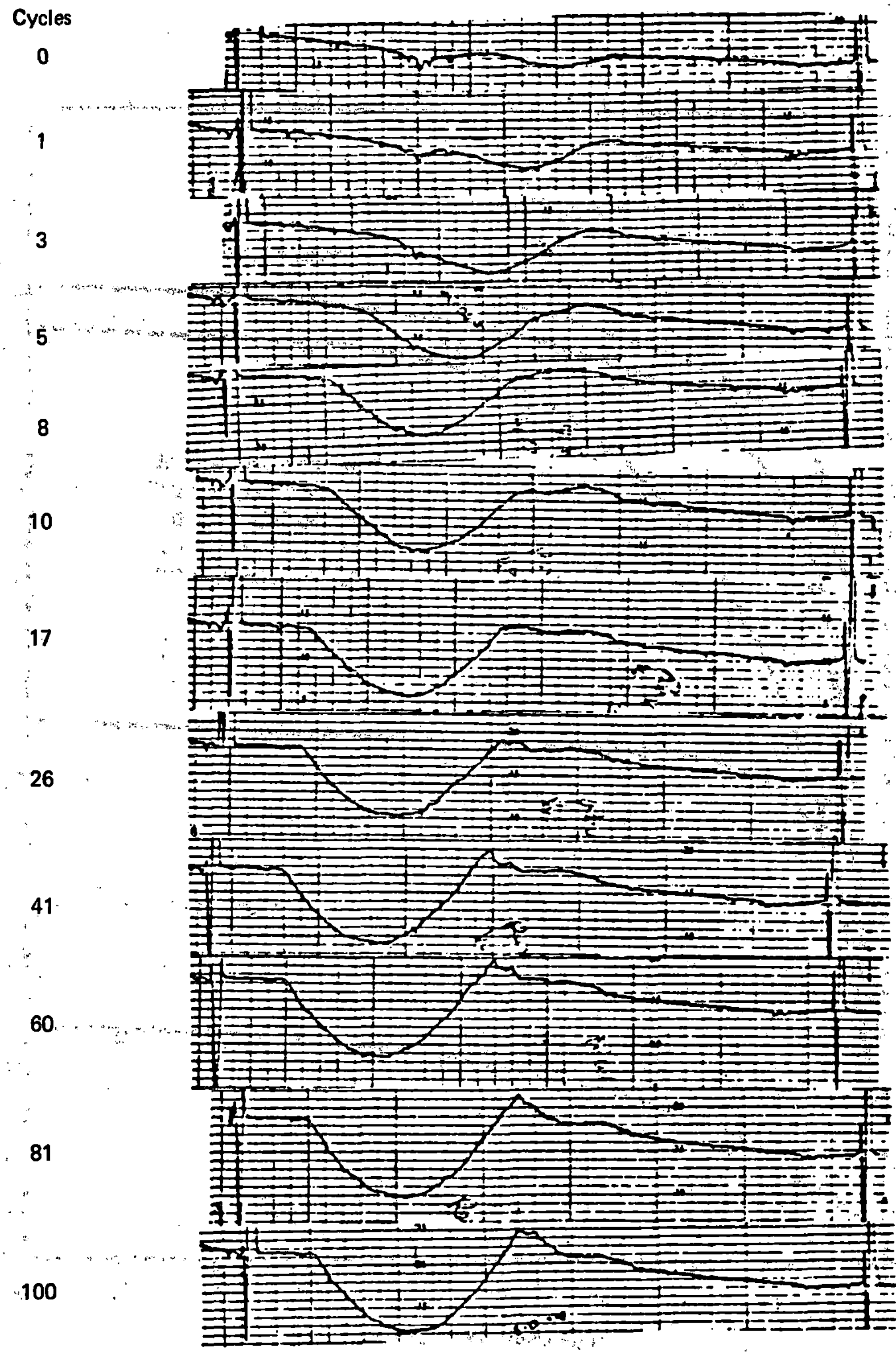


FIGURE E-8 GROWTH OF PLASTIC FLOW IN RAIL WITH CYCLES OF LOADING FOR A 95-TON CAR HERTZ LABORATORY SIMULATION WITH ANGLE OF ATTACK = 0.3°; ORIGINAL TALYSURF MAGNIFICATIONS: VERTICAL - 2000 HORIZONTAL - 20

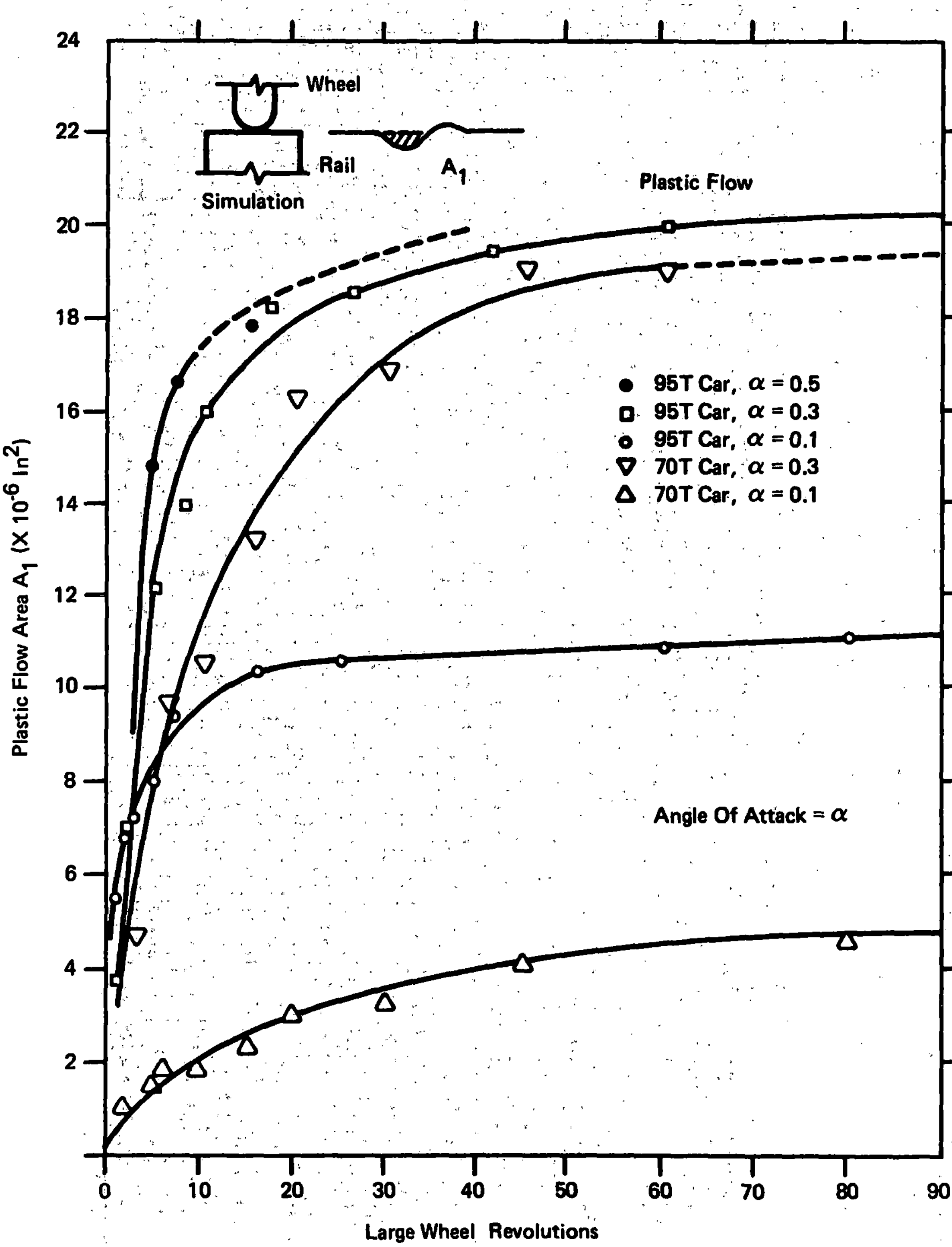


FIGURE E-9 GROWTH OF PLASTIC FLOW FOR 95-TON AND 70-TON CARS AT VARIOUS ANGLES OF ATTACK those which will enable reduction of contact stresses below this range, considerable reduction in track degradation could be achieved. These statements are based on laboratory simulation tests. The laboratory data for the 100-ton cars was validated by measurements made at FAST. It is now necessary to investigate approaches to reduce design contact stresses, keeping in mind that the vehicle should remain dynamically stable. Such stress reduction will help reduce plastic flow, wear, and fatigue-related rail deterioration.

Higher tonnage cars cause higher rate of plastic flow of the rail. In the laboratory simulation for tangent track, the plastic-flow-related surface height change was 29% more for the 70-ton cars as compared to 55-ton cars and 6% more for the 100-ton cars as compared to the 70-ton cars. In terms of volume of steel displaced, the laboratory simulation showed that the 100-ton cars displaced, in the initial loadings, 10% more than the 70-ton cars. The rate of plastic flow of the rail steel before shakedown is higher for the higher tonnage cars. In the experiments, the rate increase for the 100-ton car as compared to the 70-ton car was almost twice that of the 70-ton car as compared to the 55-ton car. For tests simulating curve negotiation with $L/V = 0.1$ and angle of attack = 0.1°, the lateral flow of steel produced by the 95-ton car was nearly twice that produced by the 70-ton car simulation. It is concluded from the tests that plastic flow of rail steel produced by the 100-ton car should be more than twice as much as that produced by the 70-ton car.

APPENDIX F

STUDY AND EVALUATION CONCERNING THE SAFETY AND EFFICIENCY OF RAIL TRANSPORTATION*

The following was received from a member railroad of the Association of American Railroads (AAR). It provides valuable information concerning the worth of many countermeasures that are presently available.

FIELD TESTS

Many tests were conducted that were designed to find methods of improving the ride quality of various types of cars. These tests were made both over-the-road and on a special test track. Tests included those made on 100-ton unit coal cars and clearly demonstrated the effectiveness of supplementary stabilizers. Hydraulic stabilizers reduced car rocking in these tests by 58% (Figure F-1). Tests were made on both bi-level and tri-level 89-foot autoveyor cars and demonstrated the effectiveness of hydraulic stabilizers (Figure F-2) and resilient constant contact side bearings in controlling car rocking and truck hunting (69% reduction) thereby reducing damage to both lading and the rail car. Tests were made on 70-ton box cars and TOFC cars to measure effectiveness of resilient side bearings in reducing truck hunting at high train speeds (over 69% reduction). Many tests on large covered hoppers were made on the test track to examine the effectiveness of hydraulic stabilizers in controlling car rocking at low speeds. See Figure F-3 for sample results. Tests were also made to reduce the vertical bounce resulting in the derailment of short (25-ft truck centers) covered hoppers. In all tests the use of hydraulic supplemental snubbing was shown to control low speed car rocking. The use of resilient, constant contact side bearings is effective in controlling self-excited truck hunting.

SIMULATED CAR DYNAMICS

A computer study was designed to show "worst case" freight car suspension performance comparison between 70 and 100-ton cars, with and without auxiliary hydraulic stabilizers, with actual service load conditions on track surface variations, and at speeds allowable under Class 2, 3 and 4 FRA Track Safety Standards. Computer solutions from a mathematical freight car vehicle model show maximum response with 3/4", Class 3 and 1", Class 2, track cross-level changes, half staggered rail joints at resonant speeds from 13 to 19 miles

*Prepared by a member railroad of the Association of American Railroads

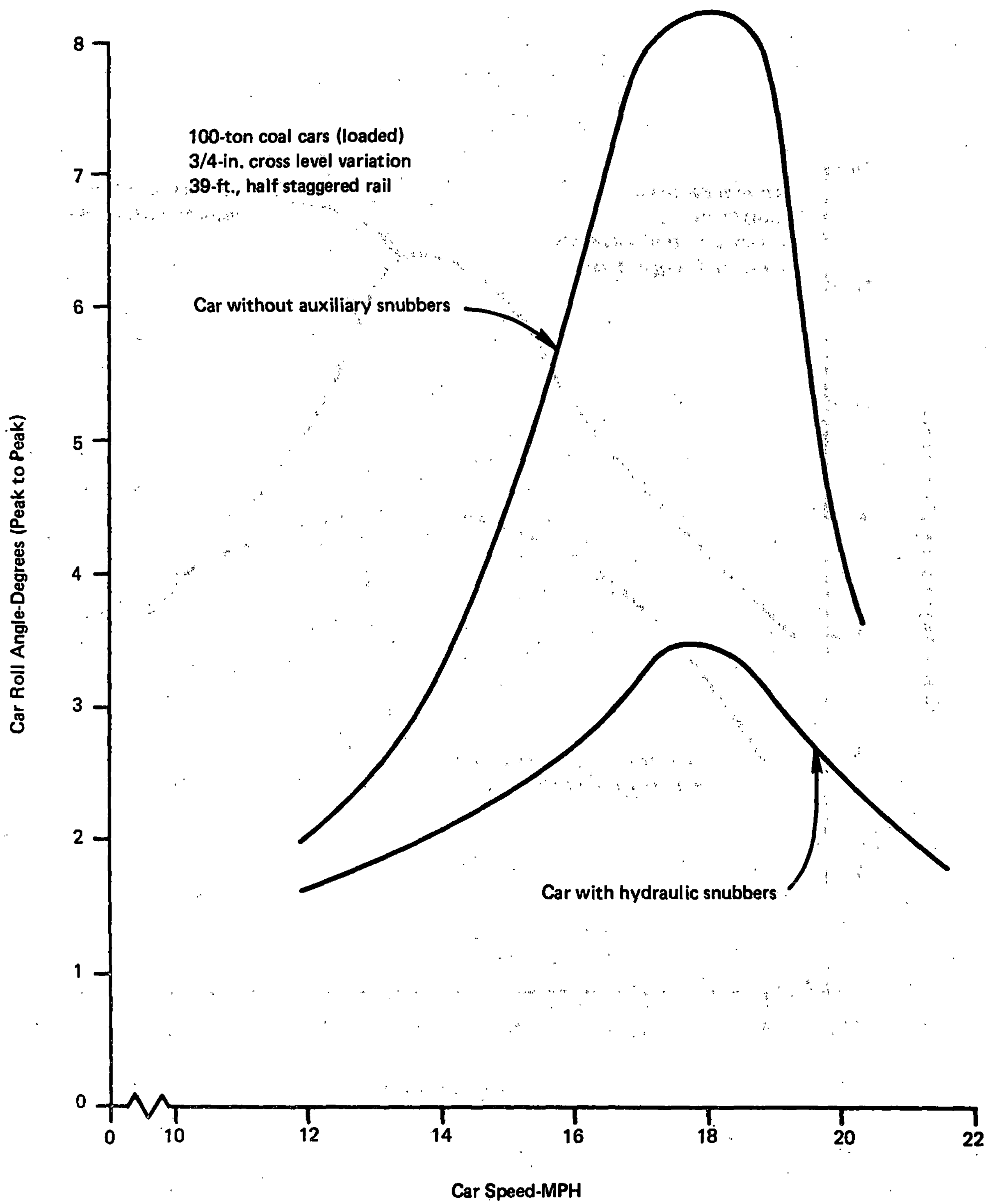


FIGURE F-1 EFFECT OF HYDRAULIC SNUBBING ON MAXIMUM CAR ROLL ANGLE

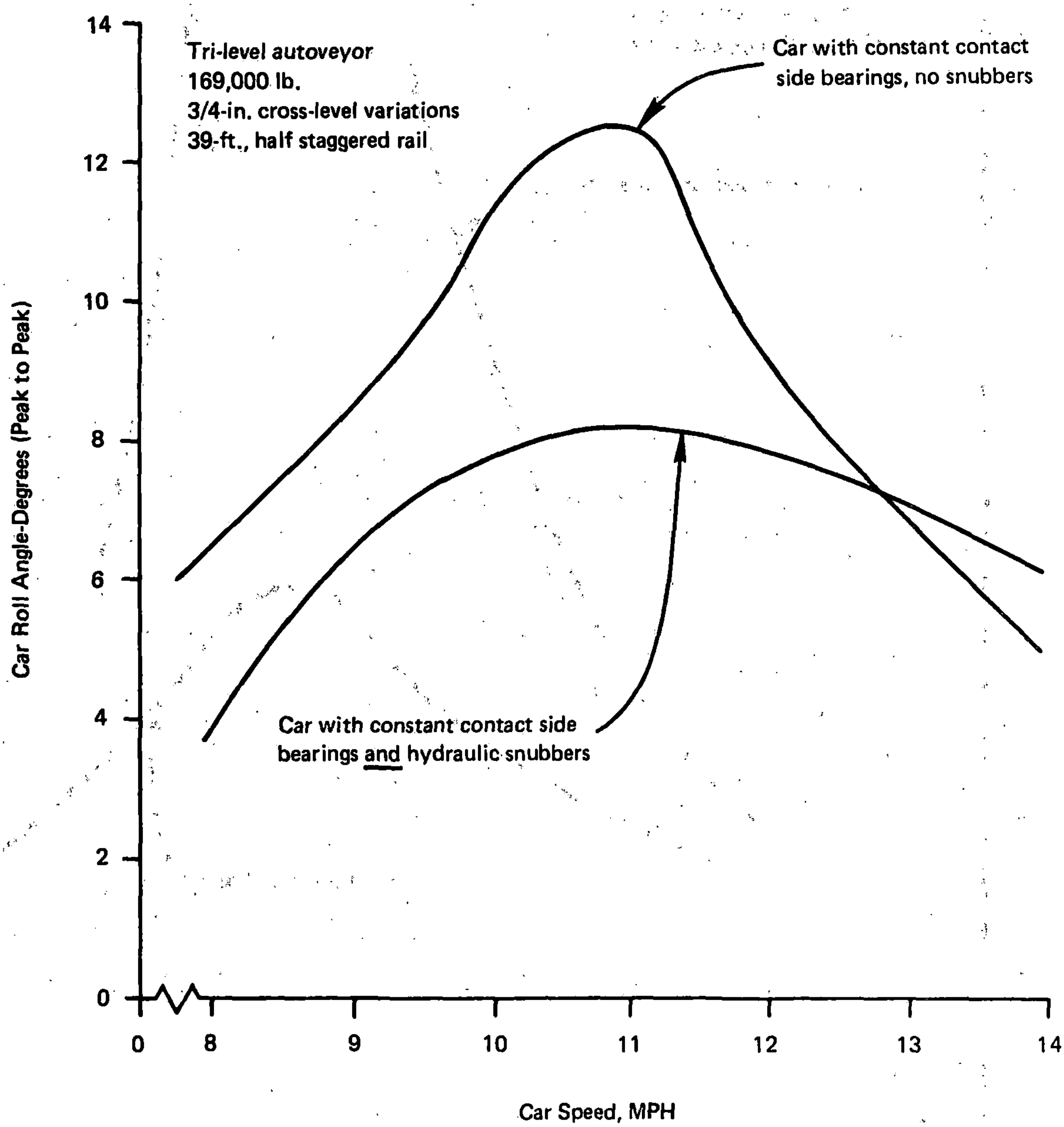


FIGURE F-2 EFFECT OF CONSTANT CONTACT SIDE BEARINGS AND HYDRAULIC SNUBBING ON MAXIMUM CAR ROLL ANGLE

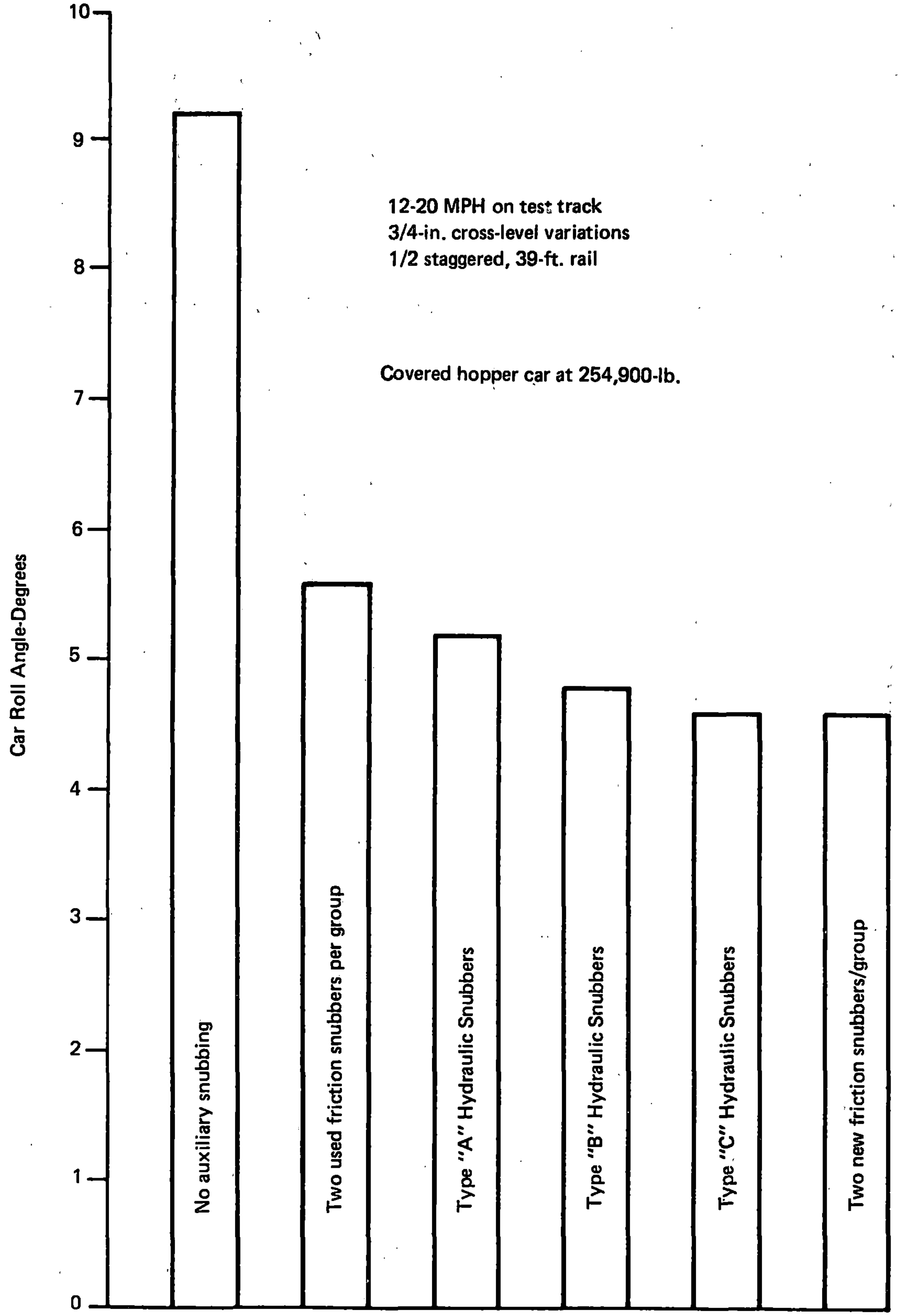


FIGURE F-3 EFFECT OF SNUBBING ON MAXIMUM CAR ROLL ANGLE per hour. Bounce and pitch resonant response was determined for 1-1/2" and 2" simultaneous depressions, Class 4 track. Base line results for two typical 70-ton box cars, Cases I and II, can be compared to two of the largest 100-ton box cars in modern service, Cases III and IV:

Case I — A 70-ton box car loaded to maximum rail weight, with high center of gravity and resulting high inertia.

Case II — A 70-ton box car lightly loaded but with slightly higher cube than Case I.

Case III — A 100-ton box car with a high roof, loaded to less than maximum rail weight but to an extremely high center of gravity.

Case IV — A 100-ton box car loaded to maximum rail weight and an extremely high center of gravity. It has the highest inertia moments about all three axes of any 100-ton car in service in the continental United States.

The graphs in Figures F-5 through F-9 show the resonant response of the 70-ton and 100-ton base line cars with conventional column guide friction damping only compared to the response resulting from additional spring group damping applied in the form of a commercially available hydraulic stabilizer that has been approved by the Association of American Railroads for the rocking control of sensitive high center of gravity cars. Surface wear and adverse environmental conditions such as moisture, hydrocarbons and other friction surface contaminants all tend to reduce the level of damping force available so that the response shown with column friction damping only is at the most effective friction damping level available over the life of the car. The column friction damping levels used are consistent with published values for one of the most common forms of column friction supplied to the industry over the past 20 years. The friction force levels, ±4500 pounds, are the same for both the 70 and 100-ton trucks. The hydraulic damper characteristics, applied as a countermeasure, is not the same for the 70-ton and the 100-ton equipment as shown in the attached hydraulic stabilizer characteristic curves (Figure F-4).

The vehicle model used for this study has been validated on various rocking test facilities as well as instrumented road tests where the dynamic rail profile was measured along with the resulting response of the freight car. Track surface variations may occur in any combination on either rail. However, the half-staggered 39 ft. incidence is doubtless most typical as is the occasional simultaneous depression or butted joint effect that occurs wherever rail joints are not staggered or wherever track maintenance conditions are abruptly changed at bridges, grade crossings, switches, etc. Although response from simple vertical inputs used in this study are special cases, they can be readily compared and related. The smooth, modified sine wave used to describe the vertical profile of the undeflected rail results in maximum rocking or vertical energy input at resonance for a given depth of depression or cross-level change.

The computer study compares the responses of typical 70-ton loaded cars with currently available state-of-the-art suspension on the largest and heaviest freight cars in modern use. Results show the inadequate damping generally supplied with conventional column guide friction groups on track surface which can be encountered with regularity. The FRA

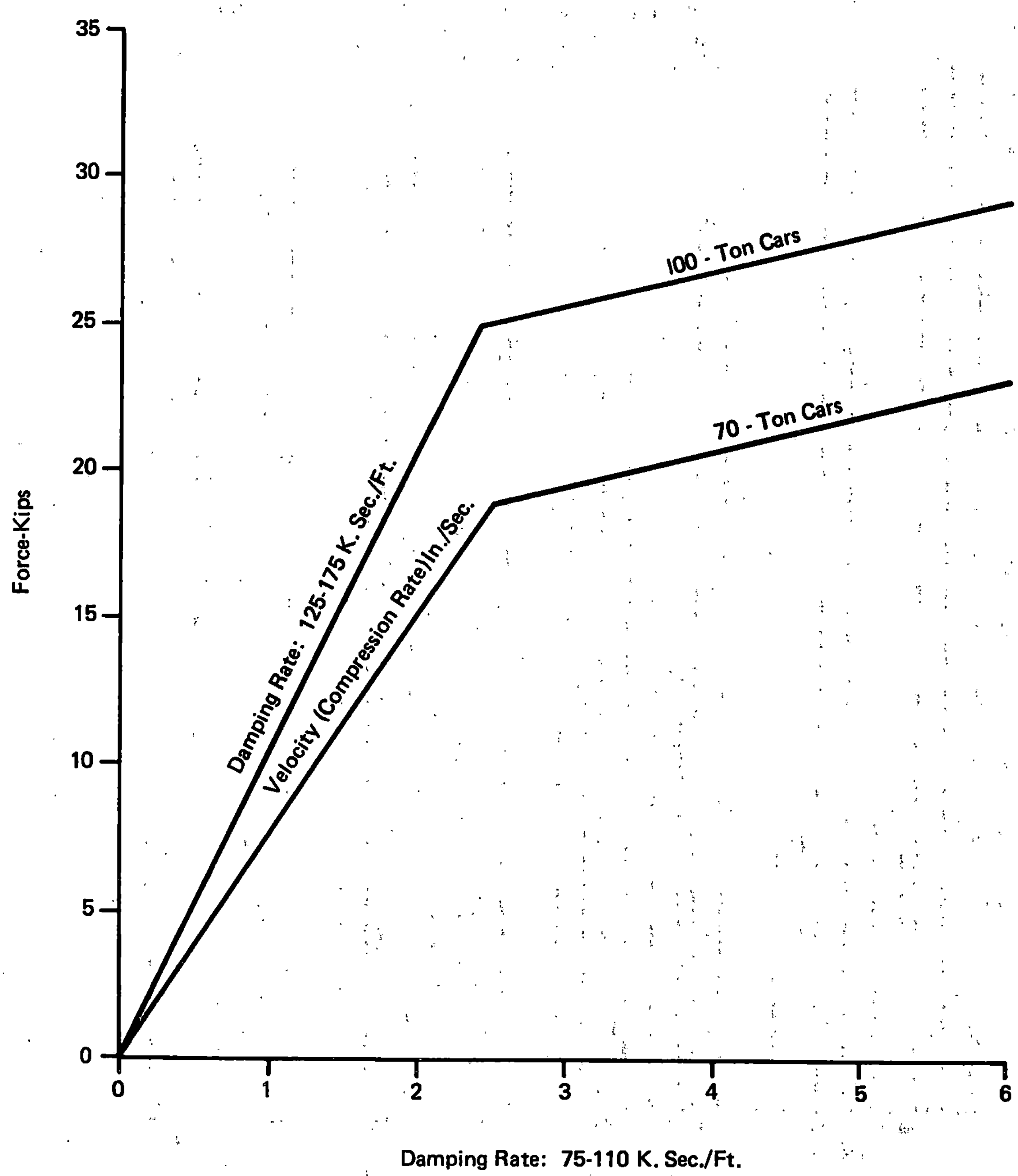


FIGURE F-4 DAMPING CHARACTERISTICS OF HYDRAULIC STABILIZERS FOR 70 AND 100-TON CARS

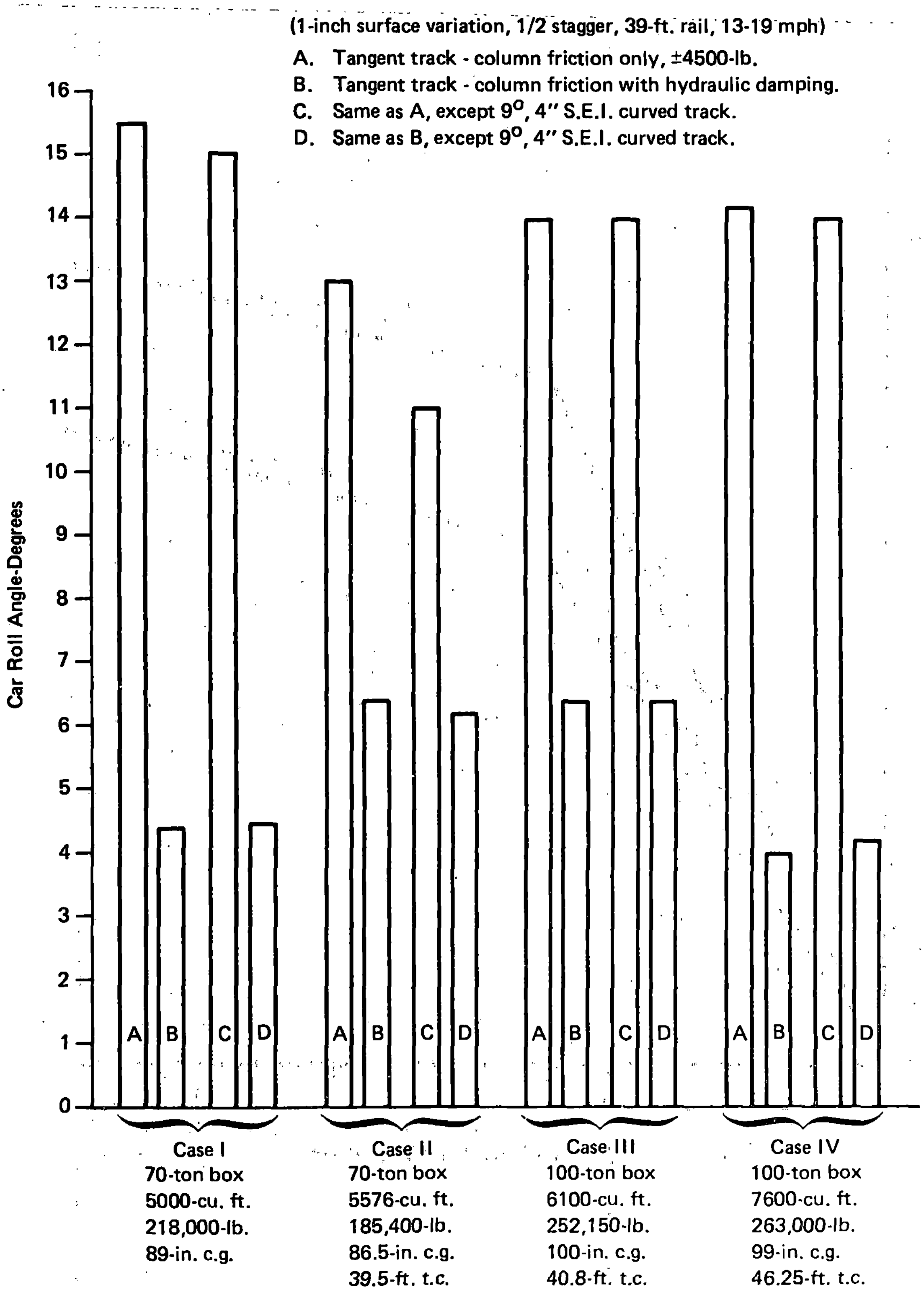


FIGURE F-5 EFFECT OF SNUBBING ON CAR BODY ROLL ANGLE ON TANGENT AND CURVED TRACK

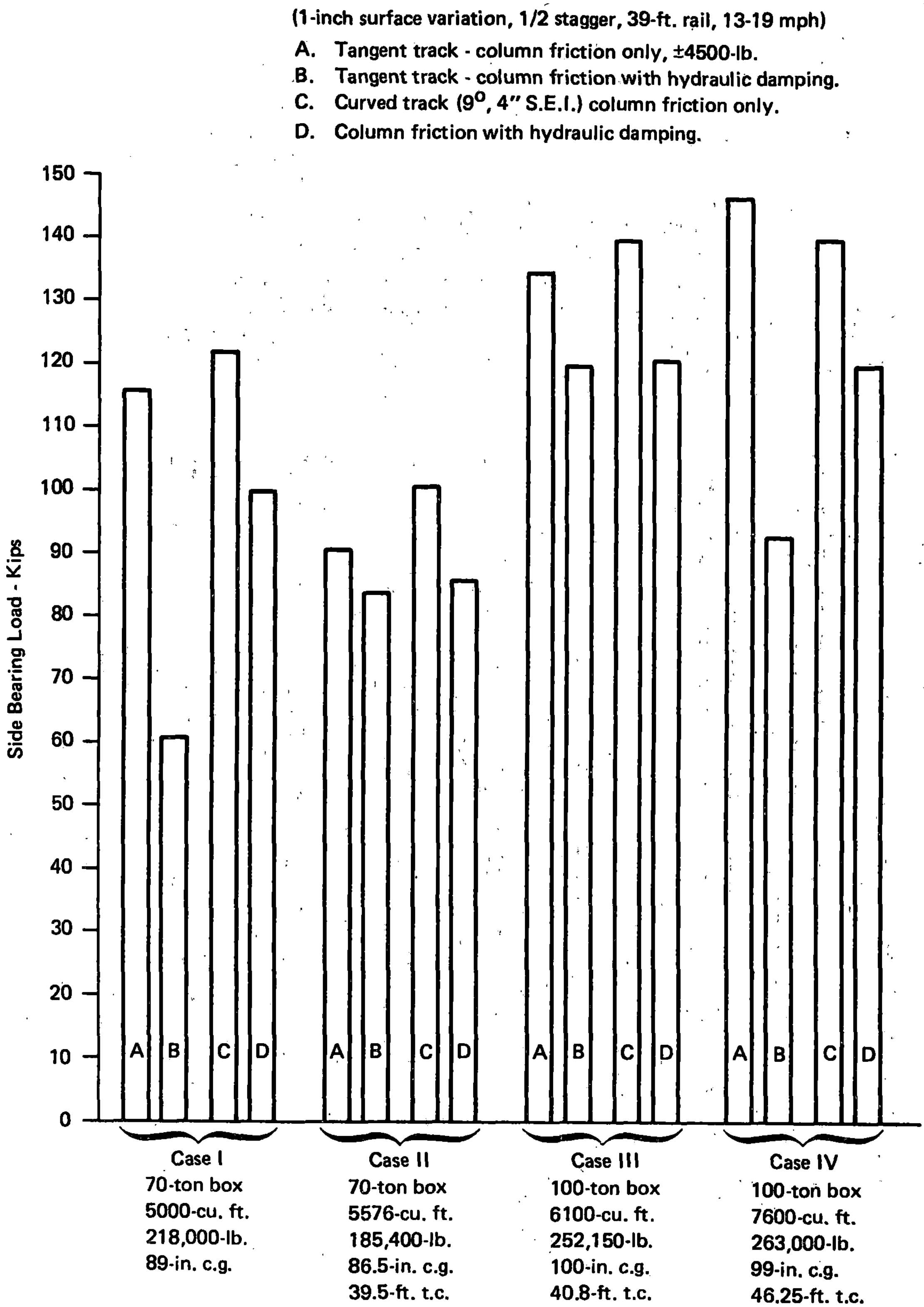


FIGURE F-6 EFFECT OF SNUBBING ON SIDE BEARING LOAD

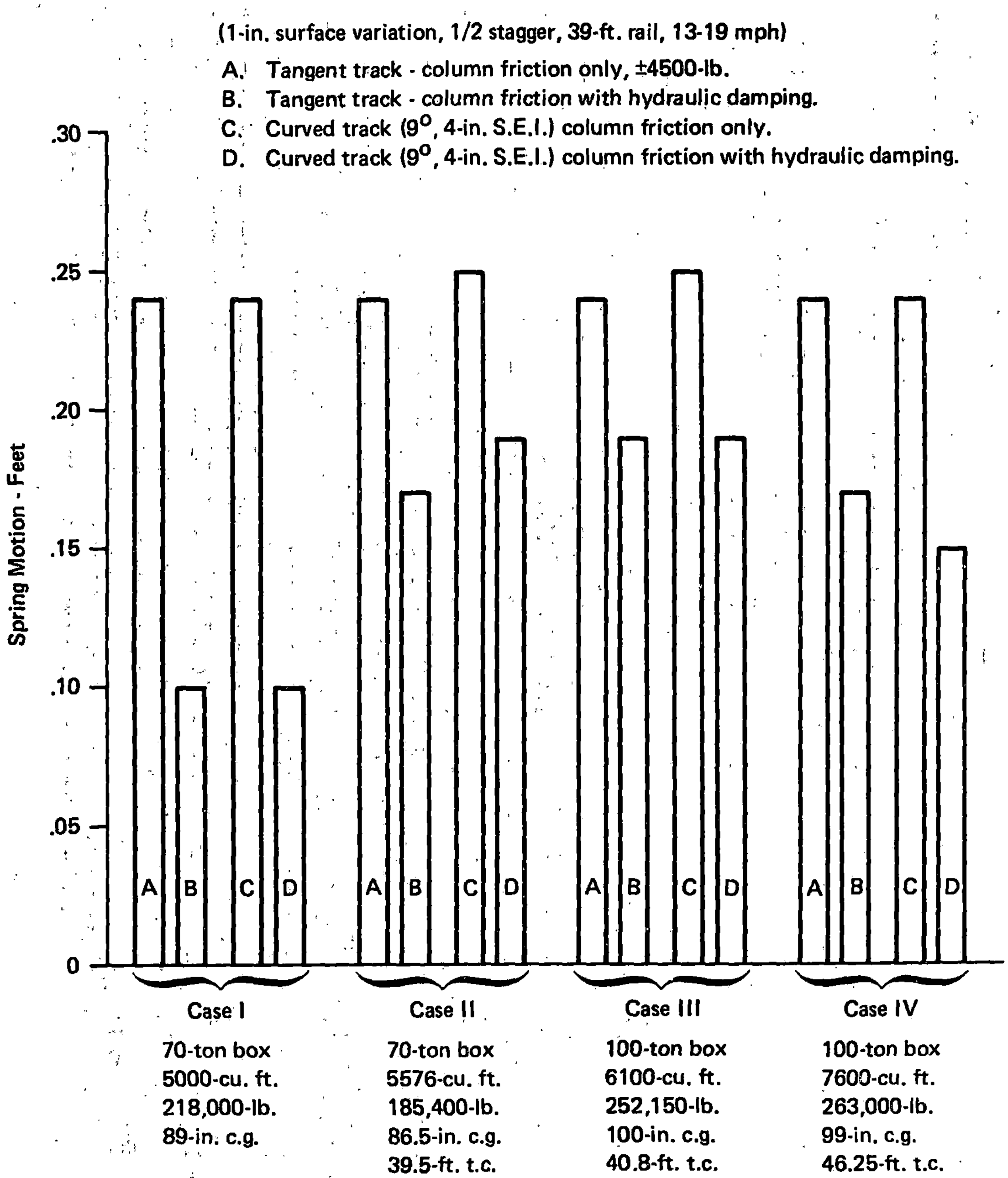


FIGURE F-7 EFFECT OF SNUBBING ON SPRING MOTION

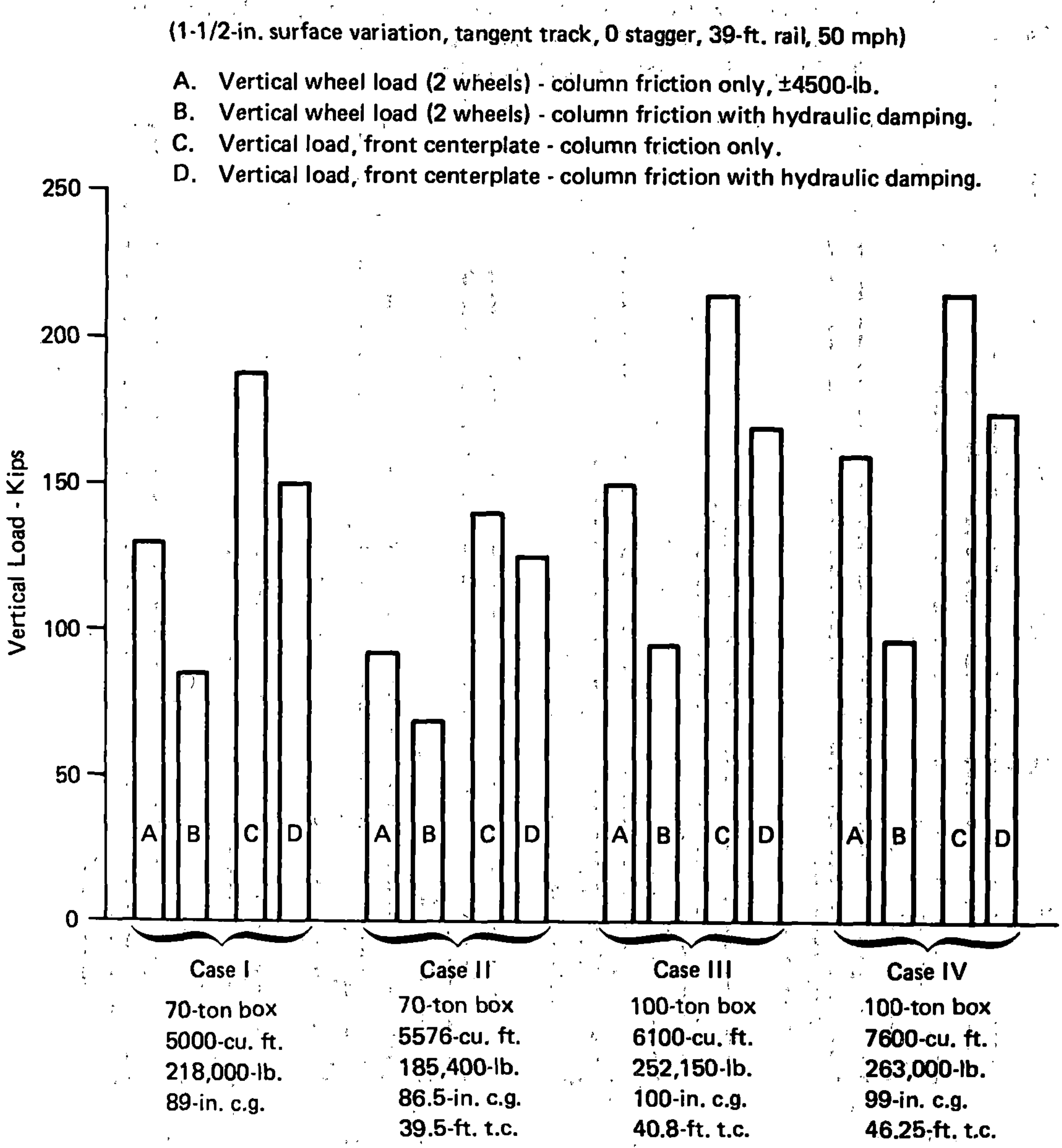


FIGURE F-8 EFFECT OF SNUBBING ON VERTICAL WHEEL LOADS

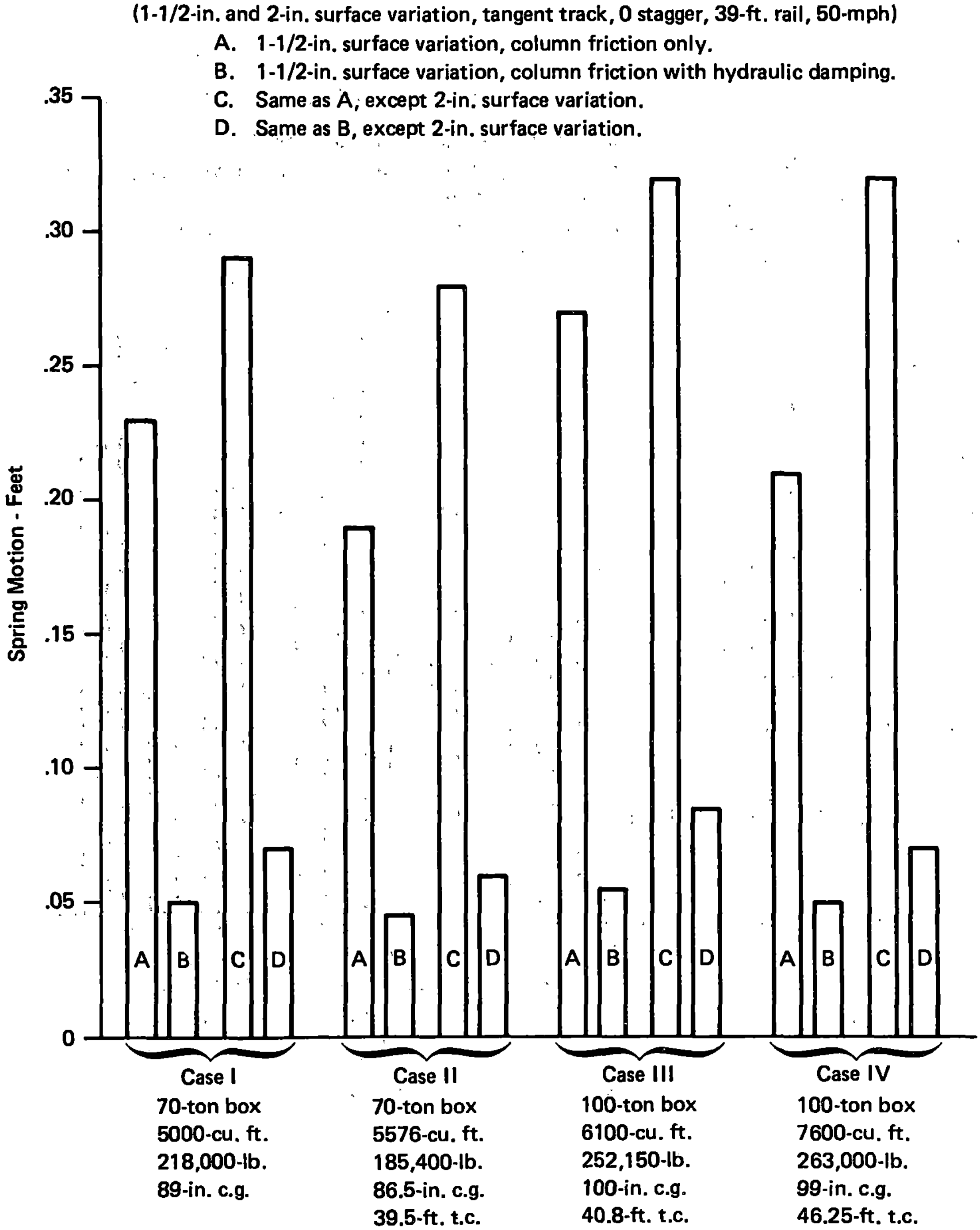


FIGURE F-9 EFFECT OF SNUBBING AND TRACK GEOMETRY ON SPRING MOTION

track safety standards do not limit the number of successive profile variations of a given allowable depth and the number required to produce the results given in this study are not unusual secondary track conditions. The addition of hydraulic snubbers, with characteristics shown in Figure 4, improves motion response levels (i.e., car body roll angle, car body to bolster angle and spring motion) for the worst case 100-ton response compared to the base line response of either 70-ton car by a factor of at least two and in many cases three. The addition of hydraulic damping units limits the car body motion, and wheel lifts and center plate separations are largely eliminated, thereby reducing the prospect of derailment on curved track which can occur at either slow speed rocking or a combination of higher speed rocking and vertical response mode. A series of simultaneous depressions in both rails, encountered at speeds around 50 mph, produce extreme center plate and wheel-rail load cycles. The same stabilizer applied for rocking control improves both the 100-ton suspension cases compared to the 70-ton base line cases, with regard to extreme load variations, by at least 30 to 40 percent. Addition of resilient side bearings in continuous contact make hydraulic dampers more effective and also stabilize empty car truck hunting.

A computer simulation was made to show the severe resonant rocking response of a conventional unsnubbed open hopper car for cross-level changes at the rail joints of 1/2-inch or more, and compare the unsnubbed car response to that of the same car equipped with hydraulic snubbers. The simulated traces obtained showed that zero wheel load occurs in all of the unsnubbed runs, often after only four successive low joints. Figure 10, a graph plotting the distance traveled with zero wheel load versus cross-level difference, shows the distance the car will actually travel with zero wheel load on one side of a truck. The graph is divided into three distinct zones generally indicating the likelihood of a derailment for a given condition described in that zone.

1. A safe zone includes all cases under the line drawn across the graph at the 10-foot level.
2. A moderately safe zone between 10 and 15 feet where a large radius of curvature would be on the safe side, a short radius curve more dangerous.
3. A dangerous zone for all distances over 15 feet with a manifold degree of danger increase with an increase in distance.

Without supplementary snubbing, dangerous wheel load distances are experienced for all profile variations of 3/4 inch or more on tangent or curved track. With superelevation of 4 inches or more and profile difference of 3/4 inch and higher, the car body almost leans far enough to the low side to fall off the trucks. It is during this most severe cycle after four to six low joints, that the car body hangs at an extreme angle with the vertical over to the low side. At this extreme position the center of gravity has moved over to a point almost directly over the side bearing location and the car body restoring force is relatively small, resulting in the long "zero load" distance traveled by the wheels on the high rail.

With supplementary hydraulic snubbing, the extreme weight shift does not generally occur (zero wheel loads), except at the large profile difference changes of 1-inch or more. Where zero wheel loads do occur, the distance traveled is relatively short, less than 13 feet for all cases. The car body motion is reduced 60 to 65 percent with the application of the hydraulic snubbing units. The most extreme wheel lift for the hydraulically snubbed car is

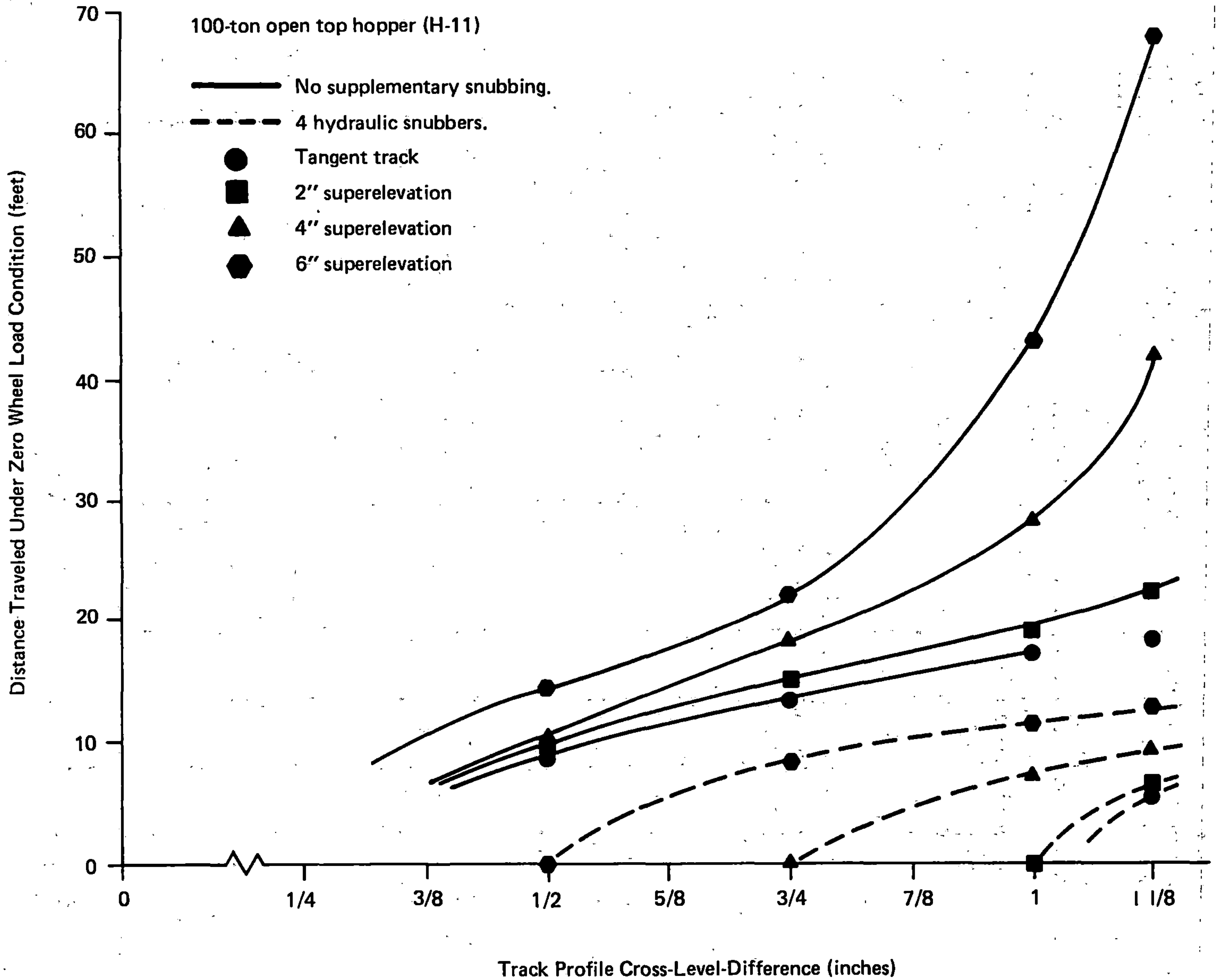


FIGURE F-10 DISTANCE TRAVELED UNDER ZERO WHEEL LOAD CONDITION AT RESONANT SPEED FOR VARIOUS TRACK CONDITIONS

3/4 inch with 1-1/8 inch profile difference on 6 inches of superelevation; for the unsnubbed car the wheel lifts for this same profile and superelevation are in excess of 4 inches.

TECHNOLOGICAL IMPROVEMENTS

The railroad industry is of a rather peculiar nature due to its great interdependence. This has led to many good effects such as the setting of standards and the keeping of statistics related to reliability of components, Ref. AAR Manual of Standards and Recommended Practices - AAR Billing Procedures. However, many times in the past, as new materials were introduced or reliability of a component increased there was a tendency to change operating conditions. In recent years freight car design has reached a plateau with 100-ton net (131.5 tons on rail) and 89-foot length being the accepted weight and length maximums.

Railroads routinely operate 8,000 — 16,000 ton unit coal trains with up to 120 cars, as well as TOFC/COFC trains made up entirely of 89-foot flat cars. As a result of running unit trains and TOFC-COFC trains where car mileages approach 200,000 miles per annum some improvements to operations which have been made are listed below:

1. The use of radio controlled equipment — "Locotrol" manufactured by Radiation Incorporated and New York Air Brake Co., or "RMU" manufactured by Westinghouse Air Brake Co., commonly referred to as RCE-1. From a train handling aspect, the use of RCE-1 can provide improved operation in trains of high gross tonnage. The specific advantages are:
   a. Faster initial charging times — about one-fourth the time of a regular train.
   b. Shorter stopping distances due to faster brake responses throughout the train.
   c. Increased store energy for brake response in trains due to higher charge in reservoir pressure.
   d. Reduced train shocks due to faster and more uniform brake response. Release time is approximately 4 times faster.
   e. Reduced drawbar stresses allowing heavier trains on heavy grade territory.
   f. Increased energy available for brake control in stopping and grade braking due to faster recharge.
2. The general improvement of freight car braking systems, reducing train stopping distance and release time, through evolution to AB, ABD and ABDW braking valves. Also a brake shoe force specification requiring all new car brake systems to conform within certain limits, thus insuring uniform deceleration within the train.
3. The use of stronger, heat treated, Class C, rim quenched wheels to improve fracture toughness and residual stress patterns.
4. The development and use of high performance draft gears to reduce in-train longitudinal forces.
5. The development and use of high strength alloy railroad castings:
   A. Bolsters — Grade C AAR Spec. M-201
   B. Couplers — Grade E AAR Spec. M-201

6. The use of 5160 alloy railway suspension springs with improved fatigue life over old C-109 carbon steel springs.
7. Heat treated body center plates to improve fracture toughness and wear surfaces flame hardened to reduce wear. An increased diameter center plate resulting in reduced centerplate stresses. Beveled center plates to reduce stresses from point contact during rock and roll.
8. Constant contact side bearings and hydraulic snubbers to reduce truck hunting and rock and roll tendencies.
9. The redesign of the 28-in. wheel used on many autoveyors by the AAR in 1974 to improve plate strength "D-28".
10. Special heat treated trailer hitches on TOFC cars to reduce wear.
11. Fuel savings due to lower rolling resistance per ton of 100-ton cars compared with lighter cars.
12. The development of locomotive simulators manufactured by Freight-Master and Singer-Link to train locomotive engineers in handling heavy trains.
13. Improved rail sections and metallurgy. These factors are considered in every track maintenance plan.

The above technological improvements are not applied indiscriminately to all cars but rather are applied on an "as needed" basis based on such factors as terrain over which operated, type of service, climate, etc. It should be pointed out that the derailment rate on new 100-ton cars with improved suspension is very low compared to the older cars. These improvements permit the extensive use of the larger 100-ton cars and longer trains. The resulting greater efficiency including lower fuel and maintenance costs translates into greater profitability for the railroads and lower transportation costs for the consumer.

CONCLUSIONS

The greatest pressure within the railroad industry has been the critical necessity to overcome the effect of continually rising labor, material and fuel costs through increased transportation productivity. This pressure has been met largely through the technological improvements in car, locomotive and track components. The product of these improvements is the heavier, longer, faster and more efficient modern freight train. Much of the potential benefit from the modern freight train would not have been realized had there been no recognition of the need for changes in the railroad's physical plant. Much additional resource has gone into the rebuilding and rearrangement of yard and passing track and related facilities to enable the efficient make-up and over-the-road movement of the large trains.

Issues and Dimensions of Freight Car Size: A Compendium (Final Report), 1980
US DOT, FRA