REPORT NO. FRA

FRA/ORD 81/75.2

ENGINEERING DATA CHARACTERIZING THE FLEET OF U.S. RAILWAY ROLLING STOCK
Volume II Methodology and Data

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APRIL 1980

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ENGINEERING PARAMETRIC CHARACTERIZATION OF THE U.S. FLEET OF RAILWAY ROLLING STOCK		5. Report Date August 1979
		6. Performing Organization Code
7. Author(s) P.G. Przybylinski & G.B. Anderson		8. Performing Organization Report No.
9. Performing Organization Name and Address Pullman Standard Company 1414 Field Street Hammond IN 46320		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-TSC-1362
12. Sponsoring Agency Name and Address U.S. DEPARTMENT OF TRANSPORTATION Transportation Systems Center Kendall Square Cambridge MA 02142		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report contains engineering parameter descriptions of major and distinctive freight vehicle configurations covering approximately 96% of the U.S. freight vehicle fleet. This data has been developed primarily for use in analytical simulation modeling of rail vehicles to analyses of vehicle/track dynamic interaction dynamics. To characterize loaded freight vehicles, representative ladings and average load conditions were defined, and load-dependent characterizations were developed for each major vehicle/lading combination. Freight truck design data was assembled and correlated with carbody descriptions, and some typical freight vehicle wheel profiles were defined based on a field measurement survey. Population data and estimates of total annual mileage traveled by each vehicle and vehicle/lading combination are also provided.

Engineering parameter descriptions of major locomotive and passenger vehicle design groups are also provided.

The concept of generically similar railcar configurations is also introduced as a practical and cost effective approach to analyzing large numbers of vehicles in rail system dynamics studies.

Volume I - is user oriented containing (a) a summary description of data developed, (b) a detailed data directory to facilitate access to data contained in appendices of Volume II, and (c) supplemental comments on elements of the detailed methodology.

Volume II- contains the fleet characterization data and describes the detailed methodology used to generate the data.

17. Key Words	18. Distribution Statement
Engineering Parameters, Freight Vehicles, Locomotives, Passenger Vehicles, Characterization, Freight Wheel Profiles.	

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

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

PREFACE

The Federal Railroad Administration (FRA) is sponsoring research, development and demonstration programs to provide improved safety, performance, reliability and maintainability of the rail transportation system at reduced life-cycle costs. The Transportation Systems Center is supporting the FRA Office of Research and Development by developing engineering data sufficient for characterization of the vehicle/track system and conducting analytical and experimental studies under the Improved Track Structure Research Program to provide the technological base for meeting these objectives. These studies are aimed at developing relationships between track design, construction, and maintenance parameters and the safety and performance of the fleet of railcars operating over the nation's track system in order to:

(1) Quantify vehicle/track dynamic responses associated with variations in track geometry and structural compliance for the range of rolling stock including freight, locomotive and passenger vehicles in operation over the track system network, and

(2) Develop improved performance-based safety standards for track construction and maintenance which limit vehicle/track dynamic interactions to safe and tolerable levels at reduced life cycle costs.

Accomplishment of these goals requires development of a physical characterization of the fleet of U.S. railway rolling stock operating over the track system network. Engineering parameter descriptions of freight, locomotive and passenger vehicles are necessary in sufficient detail for use in analytical simulation modeling to predict vehicle/track dynamic response characteristics for the range of railcars and track conditions which characterize the U.S. railway system.

The successful completion of this program is in a large part due to the contribution of many individuals in the various areas of their expertise. Significant contributions were made by many members of the Pullman Standard Research and Development staff, especially Brad Johnstone who acted as Program Manager for the majority of this project. The assistance of Frank DiMasi of Transportation Systems Center was invaluable in determining the direction of this effort.

Further assistance was provided under subcontractural arrangement by R.D. Hunt of Arthur D. Little in the development of the basic lading data, information and analysis. Information for locomotive characterization was obtained from H.A. Marta of the Electro-Motive Division of General Motors. Information useful in the characterization of freight car trucks and in the development of the freight car wheel program was provided by F.J. Korpics of American Steel Foundry and W.J. Kucera of Griffin Wheel Company based on their respective areas of expertise.

ABSTRACT

This report contains engineering parameter descriptions of major and distinctive freight vehicle configurations covering approximately 96% of the U.S. freight vehicle fleet. This data has been developed primarily for use in analytic simulation modeling of rail vehicles in analyses of vehicle/track dynamic interaction. To characterize loaded freight vehicles, representative ladings and average load conditions were defined, and load-dependent characterizations were developed for each major vehicle/lading combination. Freight truck design data was assembled and correlated with carbody descriptions, and some typical freight vehicle wheel profiles were defined based on a field measurement survey. Population data and estimates of total annual mileage traveled by each vehicle and vehicle/lading combination are also provided.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Transportation Systems Center, in support of the FRA Office of Rail Safety Research, is conducting analytical and experimental studies of the interrelationship between track geometry variations and railcar safety related dynamic response under the Improved Track Structures Research Program. In order to conduct these studies, a physical characterization of the fleet of U.S. railway rolling stock, including locomotive, freight and passenger vehicles, is required for use in analytical simulation models which will be used to predict the dynamic performance of:

(a) Railcars typical of those having a high incidence and frequency of derailment in selected derailment scenarios.

(b) Railcars typical of a particular type of service (e.g., all bulk commodity cars), and/or

(c) The entire fleet of U.S. railway rolling stock described in terms of generically similar classes of railcars for more global analyses of the vehicle/track system network aimed at developing improved performance-based standards for track geometry.

The fleet characterization must envelop a wide range of vehicle configurations including approximately 1.7 million U.S. owned freight vehicles, 22,000 locomotives and 5,000 passenger vehicles. In particular, the large freight vehicle population exhibits wide variations in length, capacity, car function and other design-related features. Fleet characterization data must span this range of equipment variation and configuration and provide engineering parameter descriptions in sufficient detail for use in a wide range of rail vehicle dynamic simulation models. These models may be used for assessing railcar lateral stability, lateral/roll/yaw forced response (e.g., harmonic roll), vertical pitch/bounce forced response, longitudinal train action, and curving performance. Engineering parameter descriptions must include all principal carbody and truck dimensions, masses and inertias (including effects of representative loads carried), carbody flexibility characteristics, parameters describing carbody/truck interface, and truck suspension data.

The fleet characterization data in this report has been developed by Pullman Standard R&D of Hammond, Indiana, under Contract DOT-TSC-1362, entitled "Engineering Data for Characterization of Railway Rolling Stock and Representative Ladings and Wheel Profiles." Volume I is intended to serve as a user's guide and data directory to the fleet charaterization data contained in the appendices of Volume II and to facilitate organizing various data elements into "complete vehicle descriptions" for use in vehicle simulation modeling. Volume II also contains the detailed methodology used to generate the characterization data.

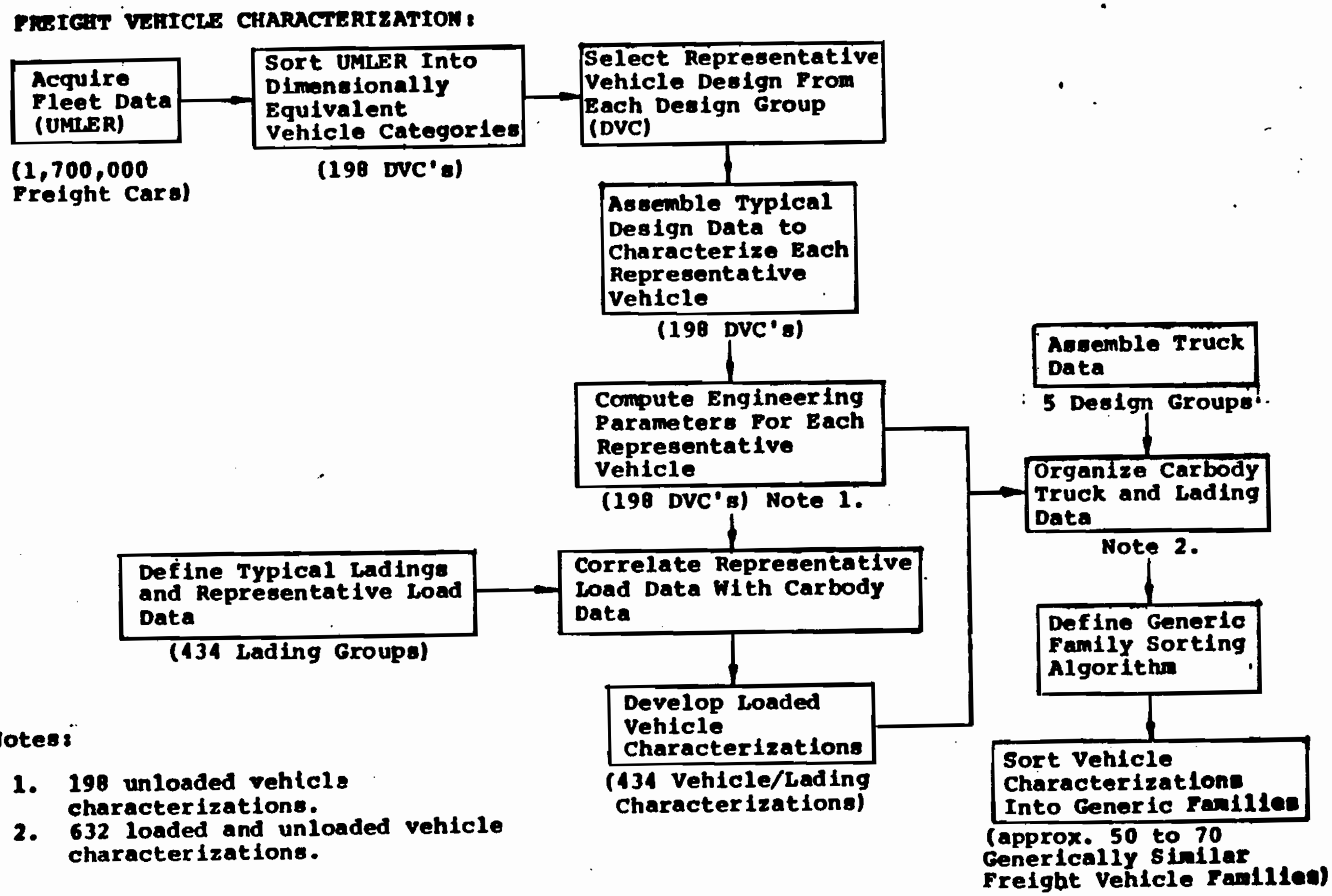
1.2 APPROACH

The fundamental problem associated with developing characterizing data for the fleet of 1.7 million U.S. freight vehicles at the desired level of detail, involves making reasonable tradeoffs between the extremes of detail and accurate representation. At one extreme, every vehicle can be considered distinctive in some way. However, characterization of the fleet in this manner would obviously result in a prohibitively expensive venture producing an unmanageable amount of information. At the opposite extreme one might consider characterizing the fleet in terms of just a few, representative vehicles. The large variations in equipment size, capacities, mechanical configurations and functions, however, are broad enough such that this approach would not produce information in adequate detail to accurately model a significant part of the fleet.

The amount of data available in the literature must also be considered. There are several detailed vehicle characterizations available in the published literature based on FRA and AAR/TTD sponsored test programs, but these characterizations are representative of a very small fraction of the fleet. On the other hand, there are two major fleet registers available for analysis (10,11), which cover the entire freight vehicle fleet and contain significant amounts of useful dimensional and design related data on individual vehicles.

Detailed individual vehicle characterization and the all-encompassing fleet register both include parts of what is really needed. The former characterizes a vehicle in the right depth and detail; the latter contains information sufficient to define major and distinctive categories of dimensionally similar railcar designs which in the aggregate describe the composition of the entire freight vehicle fleet. The fleet register file does not, however, contain enough data to provide a detailed characterization of these vehicle design groups.

The above considerations led to the approach of defining and developing detailed engineering parameter descriptions for major and distinctive vehicle design categories, as shown in Figure 1-1, each category being representative of a "standard" or "equivalent" vehicle design group having a significant population in the fleet. A total of 198 dimensionally similar freight vehicle design categories (or DVCs) were defined, based on analysis of fleet register data, to represent the range of freight vehicle equipment types and the variations in configuration. Figure 1-2 illustrates the number and relative populations of these design categories by cartype. A representative railcar was selected from each DVC and extended engineering parameter descriptions were developed for this vehicle, which in an approximate sense, are representative of the entire group pouplation. Representative ladings were defined for each DVC and an additional 434 loaded-vehicle characterizations were also developed. Major freight vehicle truck designs were identified, engineering parameter descriptions were assembled, and truck designs correlated with freight vehicle carbody descriptions. Representative freight vehicle in-service wheel profile descriptions were also developed based on a small field measurement survey.



Notes:

1. 198 unloaded vehicle characterizations.
2. 632 loaded and unloaded vehicle characterizations.

FIGURE 1-1. OVERVIEW OF METHODOLOGY USED IN FREIGHT VEHICLE CHARACTERIZATION

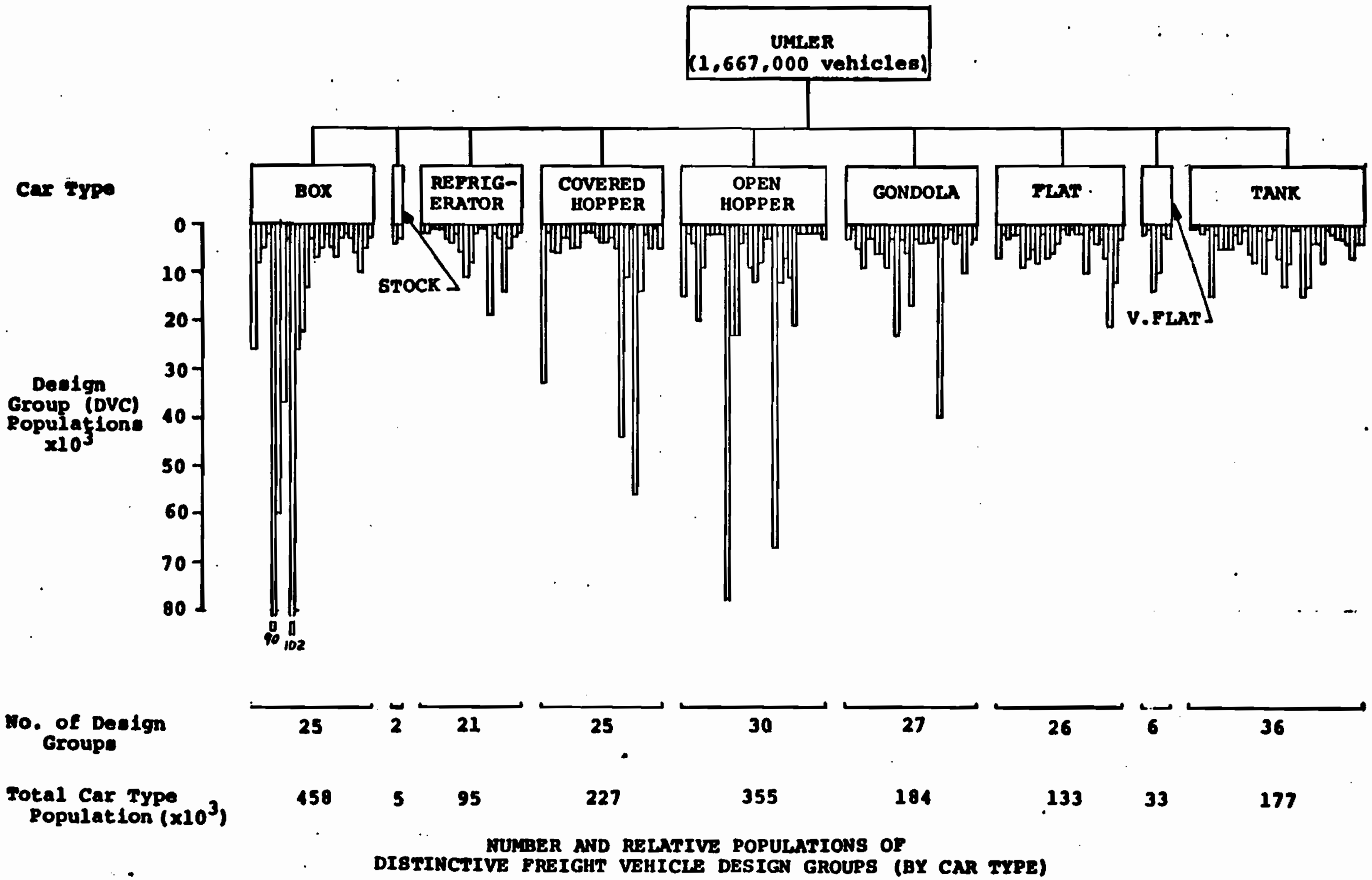


FIGURE 1-2. NUMBER AND RELATIVE POPULATIONS OF DISTINCTIVE FREIGHT VEHICLE DESIGN GROUPS (BY CAR TYPE)

The UMLER file used in these analyses was current as of December 1977. Since the overall composition of the fleet does not change rapidly from year to year the fleet characterization data developed should be representative of the current fleet. Lading data was developed based on waybill sample data and ICC annual carload statistics for CY1974, which was the latest available at the time of this study. Overall lading statistics such as carloads and freight car miles traveled for the year 1974 are also projected to be very similar to current statistics.

To provide a reduced number of freight vehicle characterizations for use in more global rail systems dynamics analyses, the 198 vehicle and 434 vehicle/lading characterizations have been consolidated into a smaller number of generically similar vehicle families and statistical engineering descriptions developed for each family. This step is also shown in Figure 1-1. These statistical descriptions will be useful in probabalistic analyses of each railcar family to predict the likelihood of dynamic response to statistically described track conditions.

Major and distinctive groups of locomotives and passenger vehicles have also been defined; however, the relatively small populations of these vehicles permits a more direct approach to developing engineering parameter descriptions. On the other hand, the relatively complex suspension systems typically used by these vehicles make these characterizations more difficult to complete in their entirety.

1.3 REPORT ORGANIZATION

Section 2 of this report describes the methodology used in the development of dimensional vehicle categories and lading characterizations leading, in conjunction with freight truck data, to the dimensional characterization of representative vehicles and the calculation and compilation of engineering parameters of loaded and unloaded freight vehicles. Section 2 also describes the methodology for further grouping of railcars to produce a smaller number of generically similar railcar designs based on key configurational features which have important effects on railcar dynamic response.

Section 3 describes the methodology used to characterize the passenger car fleet including the development of truck parameters.

In a similar manner, Section 4 describes the methodology used to characterize the locomotive fleet.

Section 5 outlines the work done under this study on wheel profile characterization and also describes the profilometer developed to accurately record wheel profiles.

The appendices in this volume contain the results of the work and cover the following subject areas: dimensional vehicle categories, lading data, parameter computation, freight car truck parameters, freight car generic families, freight car generic families basic data listings, passenger car generic families, locomotive generic families, locomotive truck parameters, wheel profile groups and a statement of new technology (wheel profilometer).

2.0 FREIGHT CAR FLEET CHARACTERIZATION

2.1 DEVELOPMENT OF DIMENSIONAL VEHICLE CATEGORIES

2.1.1 Parameter Search

The first step in developing the freight car fleet characterization was to determine the level of detail required for accurate vehicle modeling. This level has been set in conjunction with TSC personnel experienced with rail vehicle dynamics simulation models. Lists of desired engineering parameters were compiled and prioritized for both freight car bodies and trucks. A listing of these parameters and their principle sources is shown in Table 2-1.

Due to the vast amounts of information needed to characterize the railroad freight car fleet, a search for data was conducted through many different sources. Computer searches, using key word descriptors, were made through the Illinois Institute of Technology Research Institute (IITRI) and through the Arthur D. Little, Inc. Library Resource Center (ADL). The IITRI search centered on obtaining actual engineering parameters from any possible published literature while the ADL search was aimed at determining railroad operating data and manufacturer production information. The results of these two searches showed that available data fell into two categories. It either was extremely general in nature dealing with overview and summary information, or extremely specific, although detailed, dealing with parametric descriptions of an indivudual car under study. None of these sources covered the entire fleet in adequate detail to allow an encompassing characterization of the total fleet.

Further searches were made at the Interstate Commerce Commission (ICC), the Association of American Railroads (AAR) and the Department of Transportation (DOT) libraries, as well as the extensive transportation libraries at Massachusetts Institute of Technology and Northwestern University.

As a result, ICC, DOT and AAR publications and data were

TABLE 2-1. ENGINEERING PARAMETERS FOR FREIGHT VEHICLE CHARACTERIZATION AND PRINCIPAL DATA SOURCES

PARAMETER DESCRIPTION	PRINCIPAL SOURCES
Carbody Mass	Published Literature
Carbody Geometric Configurations	Published Literature
Loaded Car Mass	Published Literature
Length of Coupler	Published Literature
Carbody Center of Gravity	Computation
Lading Center of Gravity, Density, Stiffness, Mass	Published Literature
Carbody Moments of Inertia (roll, pitch, yaw)	Computation
Carbody Stiffness (vertical, lateral, torsional)	Computation
Carbody First Bending Mode Frequency (vertical, lateral, torsional)	Computation
Assembled Truck Mass	Manufacturers Data
Truck Geometric Configurations	Manufacturers Data
Assembled Truck Moments of Inertia (roll, pitch, yaw)	Published Literature
Assembled Truck Centerplate to Rail Stiffness (vertical, lateral, roll, pitch, yaw)	Manufacturers Data & Computation
Truck Bolster to Sideframe Stiffness (vertical, lateral, roll, pitch, yaw)	Manufacturers Data & Computation
Truck Sideframe to Wheelset Stiffness (vertical, lateral)	Manufacturers Data & Computation
Truck Bolster to Sideframe Damping	Manufacturers Data & Published Literature
Centerplate Yaw Friction	Published Literature
Truck Bolster to Sideframe Clearance (vertical, lateral, longitudinal)	Manufacturers Data & Computation
Truck Sideframe to Axle Yaw Clearance	Manufacturers Data & Computation
Side Bearing Distance from Centerline and Clearance	Published Literature
Bolster Bowl Diameter and Center Pin Height	Published Literature
Centerplate-Bolster Bowl Net Clearance	Manufacturers Data

accumulated which were referenced in previous dynamic studies and appeared appropriate. These included studies published by Martin Marietta, the Track/Train Dynamics program and many government funded studies. Additional information was requested from equipment manufacturers, such as American Steel Foundries, who have developed much data useful in this effort.

Basic data on the freight fleet was found to exist in two freight car registers as described later. These sources plus the experience of Pullman Standard in the carbuilding field have allowed identification of the railroad freight car fleet and their ultimate dynamic characterization.

2.1.2 Fleet Composition Search

A major effort of this contract was to describe the freight car fleet by a reasonable number of "standard" or representative vehicles which would allow computer simulation of the fleet to be feasibly performed. The representation of the fleet requires two basic areas of information. These are first, the composition of the fleet as to population percentages of each representative vehicle and second, the parametric description of each representative vehicle.

Due to the great variations in freight car configurations, it was found impossible to use the limited available individual car parameter data to realistically determine representative vehicles. Therefore, it was decided to first determine the physical composition of the fleet and select representative vehicles before addressing the issue of developing physical characterization in terms of engineering parameters. Only two possible sources of comprehensive fleet data were found to exist, both of which contain only gross configurational data. This gross data, however, could be used to determine typical vehicle configurations with sufficient detail to allow determination of appropriate engineering parameters.

One data source is the Official Railroad Equipment Register (ORER) published by the National Railway Publication Company. This is a proprietary publication listing the freight car fleet by owning railroad or company and by car number, along with specific overall car dimensions, capacity and population. This data is stored on computer tape and is available for sorting through the National Railway Publication Company in several standard formats. However, this company could not provide the detailed level of sorting (using a non-standard ORER format) that was required within the time restrictions imposed by the contract. The data tapes, being proprietary, were not available through purchasing to allow an independent sorting.

The second data source, the Association of American Railroads UMLER file, also could not be sorted by the AAR to meet the detailed requirements due to their schedule restrictions, but the data tapes were available for purchase to allow this project to perform the necessary data sorting. Certain data, however, which is considered proprietary by the railroads, was not included on the UMLER tapes finally purchased. This proprietary data consisted of such items as costs and car age, which do not measurably affect the information needed for the sorting analysis. Given, then, this large data bank (UMLER), containing approximately 2,000,000 entries, an analysis technique was formulated to allow efficient handling and sorting. A typical sample of data available in the UMLER is shown in the UMLER tape output format of Figure 2-1 for the more common cars. As can be seen from this list, much of the data pertains to operational features of car design with only an overall dimensional description of the car construction.

It was decided to use the UMLER tapes to determine the freight fleet configurational composition and then later determine additional necessary detail data for each freight car group representing a significant population. This approach was feasible due to the many standards used in the design and construction of freight cars. These standards are mainly set by the Association of American Railroads to assure adequate minimum structural requirements are met. In addition, many standard designs and practices exist in the railroad industry due to basic car designs which have historically been proven successful, and due to car configurations

UMLER FORMAT 1 - - REVISED

TAPE OUTPUT - - AAR UMLER MASTER & CHANGES

ALL CARS EXCEPT FLATS, REFRIGERATORS, CABOOSES, MAINT. OF WAY AND TANKS

CAR INITIALS	OWNER'S MARK	LESSEE'S MARK	CAR TYPE CODE	OWNERSHIP		CAR		INDICATOR	PER-DIEM RATE		MILEAGE RATE		INSIDE DIMENSIONS						OUTSIDE DIMENSIONS											
						Low Number	High Number						Length		Width		Height		Length		Extreme Width				UPPER EAVES			
																					Width		Height		Width		Height	
									$	¢	¢	Mills	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In
1	5	9	13	17	18	19	25	31	32		36		40		45		49		53		58		62		66		70	
A	A	A	A/N	A		N	N	N	N		N		N		N		N		N		N		N		N		N	

OUTSIDE DIMENSIONS				EXTREME HEIGHT		SIDE DOOR				END DOOR				BLANK	CAPACITY		TARE WGT (00)	BLANK	ROOF	LINING	RESTRICT	PASSENGER	BEARINGS	AXLES	OUTLETS	COMPARTMENTS	FLOOR		DRAFT GEAR	CLEARANCE	ARTICULATED	HEATER		DOOR		TRUCK CENTER		FITTING			AAR MECH DESIGN
LOWER EAVES						Width		Height		Width		Height			Cubic Feet Level Full (Actual)	Pounds Cap (000)											Type	Trough				Type	Fuel	Grain	Type			1	2	3	
Width		Height																																							
Ft	In	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In	Ft	In																							Ft	In				
N		N		N		N		N		N		N			N	N	N		N	A	A	A	A	N	N	N	A/N	A	N	A	N	A	A	A	N	N		A/N	A/N	A/N	A

INCENTIVE RATE		BLANK.	CU-FT. STRENGTH	CHANGE CODE	BODY TYPE	EFFECTIVE DATE		POOL CODE
$	¢					Mo	Yr	
N			N	N	A	N		N

FIGURE 2-1. UNIVERSAL MACHINE LANGUAGE EQUIPMENT REGISTER

which lend themselves to standard methods of construction. Armed with a knowledge of these common car configurations and practices, it is possible to determine detail information given only overall data from UMLER.

2.1.3 Initial Trial Groups of Freight Cars

Having decided on the methodology of characterizing the freight fleet by first determining the configurational or dimensional makeup of the fleet, the first step of this method is analysis of the UMLER file to determine fleet composition in terms of major and distinctive groups of freight vehicles.

However, rather than sort the UMLER file into an arbitrary matrix of combinations of vehicle configurational descriptors broad enough to cover the entire fleet, Pullman's knowledge of freight car construction plus manual inspection of the ORER publication was used to set up a list of initial trial groups of car types and physical descriptions into which the UMLER would be sorted. For example, in determining trial groups for box cars, common inside lengths are known to be 40 feet - 6 inches, 50 feet - 6 inches, 60 feet - 9 inches and 86 feet - 6 inches. Also, overall heights of 14 feet - 10 inches, 15 feet - 1 inch, 15 feet - 6 inches and 17 feet are usual and are related to other car features such as length. Similarly, other car types have common configurations which may be used to establish a rough approximation of the fleet makeup for each car type. These trial groups were chosen to represent car configurations which were believed to be common and would represent significant portions of the freight fleet. A typical vehicle could then be chosen from each significant group and used as the basis for extending the physical description of that group using procedures discussed in Section ___.

Additional groups (minor groups) were added to the list of trial (major) groups to act as "catch all" categories between the major groups to assure no car configuration would be omitted. By this method every freight car in UMLER would be assigned to or counted in one of the major or minor trial groups. The "catch all" groups generally, had wider sorting bandwidths, but if a significant population occurred in such a group, it would then be re-sorted.

The actual trial groups were divided by AAR mechanical car types to differentiate between boxcars, stock cars, refrigerator cars, open hopper cars, covered hopper cars, gondola cars, flatcars, tank cars and vehicular flatcars. Within each car type listing, trial groups were numbered, given a general physical description, and defined by two to four primary physical characteristics. Typically these characteristics were weight capacity, volume capacity, outside length, inside length, and/or tare weight as outlined in Table 2-2 for the various major car types. These characteristics should have a strong influence on vehicle parameters which must be computed or estimated in order to complete the necessary vehicle characterization. As an example, boxcars were divided by inside length, outside length, tare weight, and weight capacity as shown in Table 2-3. The ranges shown in Table 2-3 for each sorting dimension were selected to allow a limited variation about the expected "standard" car configuration and to allow a somewhat larger variation for "non-standard" cars. For example, boxcar group No. 34 represents a "catch all" category while groups such as No. 8 and No. 12 were expected to represent more standardized configurations. Depending on car type, final definitions incorporated secondary configurational attributes such as extreme height, door width, draft gear type, truck center distance, and platform height.

2.1.4 UMLER Sorting Considerations

Against this listing of trial groups, each representing a specific car configuration range, the UMLER data was sorted to determine the population in each trial group. Actually, rather than simply counting the population for each group, the complete data in each UMLER entry (for every individual car) was sorted into separate files representing each trial group. This procedure allowed further analysis of each group to determine additional characterizing features and dimensions.

TABLE 2-2. PHYSICAL CHARACTERISTICS USED IN DETERMINING TRIAL GROUPS FOR SORTING UMLER

CAR TYPE	INSIDE LENGTH	OUTSIDE LENGTH	WEIGHT CAPACITY	VOLUME CAPACITY	TARE WEIGHT
Box	X	X	X	-	X
Stock	X	X	X	-	X
Refrigerator	X	X	X	-	X
Covered Hopper	-	X	X	X	-
Open Hopper	-	-	X	X	-
Gondola	X	X	X	-	X
Flat	X	X	X	-	X
Vehicular Flat	X	X	X	-	X
Tank	-	X	X	X	X

X = Characteristic used

TABLE 2-3. BOXCAR INITIAL TRIAL GROUPS

Type	Car Description	Inside Length (feet)	Outside Length (feet)	Light Weight (1000 lbs)	Capacity (1000 lbs)
1	0 -40'	0-38	Any	Any	Any
2	40'-50T	38-42	40-47	45-60	0-115
3	40'-50T	38-42	>47	45-60	0-115
4	40'-50T	38-42	40-47	>60	0-115
5	40'-50T	38-42	>47	>60	0-115
6	40'-Others	38-42	Any	Any	Any
7	45'	42-48	Any	Any	Any
8	50'-50T	48-53	50-59	58-70	0-115
9	50'-50T	48-53	50-59	>70	0-115
10	50'-50T	48-53	>59	55-70	0-115
11	50'-50T	48-53	>59	>70	0-115
12	50'-70T	48-53	50-59	60-75	115-165
13	50'-70T	48-53	50-59	>75	115-165
14	50'-70T	48-53	>59	60-75	115-165
15	50'-70T	48-53	>59	>75	115-165
16	50'-Others	48-53	Any	Any	Any
17	55'	53-58	Any	Any	Any
18	60'-50T	58-63	Any	Any	0-115
19	60'-70T	58-63	62-70	65-80	115-165
20	60'-70T	58-63	62-70	>80	115-165
21	60'-70T	58-63	>70	65-80	115-165
22	60'-70T	58-63	>70	>80	115-165
23	60'-100T	58-63	62-70	65-80	>165
24	60'-100T	58-63	62-70	>80	>165
25	60'-100T	58-63	>70	65-80	>165
26	60'-100T	58-63	>70	>80	>165
27	60'-Others	58-63	Any	Any	Any
28	70'	63-83	Any	Any	Any
29	86'-70T	83-87	92-95	100-120	115-165
30	86'-70T	83-87	>95	100-120	115-165
31	86'-100T	83-87	92-95	100-120	>165
32	86'-100T	83-87	>95	100-120	>165
33	86'-Others	83-87	Any	Any	Any
34	All Others	Any	Any	Any	Any

After completion of the initial sorting, the populations were reviewed to determine if the expected major groups were correct and whether or not any minor groups or any of the intermediate groups had significant populations. When these minor groups were identified and found to lack sufficient descriptive detail due to the wide sorting bandwidth, a second sorting of just these groups was performed in order to provide the necessary descriptive detail. While this second sorting was useful, it was found that these groups could just as readily (in most cases) be separated and described by statistical analysis of the UMLER data performed on all trial groups. This procedure will be discussed later in the discussion of the final UMLER sorting and formulation of the dimensional vehicle categories.

Effectively, the sorting methodology separated and copied the entire UMLER data on rail vehicles into many discrete, physically identifiable groups (as described by the pre-set trial groups). Since a single entry in the UMLER file may represent one or more actual cars, the population of each UMLER entry was determined from the listing of car numbers for that entry. If more than one car number was indicated, that data entry was repeated in the copied file for the number of times equal to the entry's population. Thus, each data file representing a single car group would contain the number of entries equal to the car population of that group. This was done to obtain an accurate population count and also to allow use of a standard statistical package for later analysis.

The method of using the consecutive car numbering system assumed by the UMLER data collection system does lead to a practical error in population counting due to car renumbering or cars out of service. The UMLER input requires a single entry to list low number and high number of the group of cars described in that entry. However, later renumbering or destruction of a car contained in the series of car numbers may not be removed or accounted for immediately. Therefore, multiple counts may exist in each car group for renumbered cars and excess counts for destroyed cars that no longer exist. However, due to the relatively short history of the UMLER and the efforts of the AAR to maintain their records, these errors should be minimal and should have no significant effect on the statistics of each group or car type. Indeed, it may be assumed that this error is uniformly distributed across all car types and groups and, therefore, may raise the car count imperceptibly but should not affect the population ratios between various groups.

The UMLER data contains many freight cars which are foreign owned, but nevertheless registered in the UMLER to allow for their use in the United States. These cars were not included in this study since:

(a) The objective of this contract is a characterization of the fleet of U.S. railway rolling stock

(b) The population of foreign-owned vehicles operating in the U.S. is small, and

(c) The relative domestic and foreign usage of the foreign-owned vehicles registered for operation within the U.S. is unknown.

These cars were separated from the U.S. fleet, and their data collected in separate "foreign car" categories, which were stored but not analyzed. Some foreign cars are contained in the smaller population boxcar groups but these are not considered to be statistically significant.

The analysis of the UMLER file excluded certain cars which are not considered to be in normal interchange service. These include specialized cars such as high capacity flatcars, railroad-used maintenance of way cars, and cabooses. Further, certain cars, such as old 40 ft. - 50 ton box cars which may be in reserve storage are also not identified, but are considered to be active cars in the fleet. Also no attempt is made to adjust population ratios to account for a certain percentage of cars in repair or rework shops since this effect, while reducing the overall cars in service, is assumed to apply equally to all car groups and should not affect population ratios.

The purchased UMLER tapes, updated effective December 31, 1977, were the most recent available at the time the analysis was initiated. The overall fleet composition is not expected to significantly change before 1980. Indeed, new car designs and novel configurations may be introduced before 1980, but the production quantities possible still would not affect the large population overall fleet composition. This same logic also applies to several years before 1977 and therefore, the obtained fleet composition can be reasonably correlated to 1974 lading data as later discussed.

2.1.5 Final UMLER Sorting

After the UMLER data has been sorted into the final trial groups, the populations were reviewed to identify small population groups. Generally, groups with a population less than 1 percent of the total for each particular mechanical car type were considered to be statistically negligible and would receive no further analysis. All significant population groups were analyzed to obtain a better description of the cars in each group. Histograms and statistics of relevant data (i.e., door size, volumetric capacity, bearing type, etc.) were obtained to determine the percentage of each group having each characteristic range as shown in the sample worksheet in Table 2-4.

This worksheet (Table 2-4) provides a summary of the histogram and statistics for boxcar trial group No. 13 which is identified as a 70 ton capacity boxcar with approximately a 50 foot inside length. In order to efficiently use the histogram program, dimensional data was analyzed in one foot increments instead of smaller increments. This method does not effect the accuracy of the analysis since finer detail was considered unnecessary to determine a typical or representative dimension based on car construction knowledge.

The data shown in Table 2-4 indicates that 90 percent of the cars in boxcar group 13 are 50 foot inside length which actually are known (based on industry practices) to be a 50 foot, 6 inch

TABLE 2-4. UMLER ANALYSIS WORK SHEET

BOX CAR - 50 FT., 70 TON, POPULATION 16,667

BOX CAR DVC NO. 13

STATISTIC	DIMENSIONS	RELATIVE %	ADJUSTED %	REPRESENTATIVE DIM.	MEAN	MEDIAN
Inside Length	50'	90.4		50'-6"		
Outside Length	57' 58'	59.2 29.8		58'-0"		
Extreme Height	14' 15'	19.6 78.8		15'-1"		
Side Door Width	8' & 9' 10' 12' 15' 16'	7.6 55.8 10.4 6.1 11.1	73.8 17.2	10' 16'		
Bearings	Roller Plain	90.2 9.8				
Nominal Capacity	130k-145k 145k-174k	88.0 12.0		140k	142.7k	140.3k
Light Weight	75k-82k	90.0		78.0k	78.2k	77.4k
Draft Gear or Cushion Travel	Standard 10"-19" 20"-29"	9.0 18.6 71.9		Cushion Underframe 20"		
Door Type	Single Ctr'd. Single Stag'd.	49.7 21.3		Typ. for 10' Door		
	Double Ctr'd.	16.4		Typ. for 16' Door		
Truck Centers	40' Missing	19.0 65.5	55.2 —	40'-10"		

Side Door Width: 73.8 + 17.2 → 91.0% ⇒ 100%

100% = 16,667

81.1% = 13,517

18.9% = 3,150

AAR CODE:	MAIN CODES:
A - 81.1% B - 8.4% L - 10.4%	A230 A240 L047

1st No.: 0 - 10.4%, 1 - 3.5%, 2 - 86.1%

2nd & 3rd: 30 - 47.8%, 40 - 25.9%, 47 - 8.5%

Others - 0,4,7,8,9,10,13, 14,19,20,29,46, 47,50 inside length as shown as the representative value. This group is shown to have an outside length of 57 feet to 58 feet. The extreme height of these cars fall either into the 14 foot group or the 15 foot group. Typical boxcar heights of 14 feet - 10 inches and 15 feet - 1 inch represent these height groups with the 15 feet - 1 inch height taken as standard for all boxcar group 13 cars since this meets the standard AAR clearance requirements and also represents little variation from the 14 feet - 10 inch dimension. The truck center spacing of 40 feet - 10 inches is known to be typical for this boxcar group.

The next information to be analyzed is the width of the boxcar side door openings since this dimension will affect the value of carbody static stiffness and of vertical bending frequency. A preliminary sensitivity study showed that variation in the side door opening width from 6 feet to 10 feet had only minor influence on the carbody flexibility while a door width from 14 feet to 16 feet had a significant influence (compared to the smaller openings). These results were considered in grouping the various boxcar door widths. For the example group No. 13, two main door width groups were established with the 10-ft. door and the 16-ft. door chosen to represent their respective groups. Later analysis of door characteristics show that the 10-ft. doors are single centered doors and the 16-ft. doors are double centered doors (centered on the car sides). Had this analysis shown a staggered door configuration (doors on opposite sides of the car are offset in opposite directions from the centerline), this configuration would have been considered as another grouping since it will influence the determination of the carbody vertical bending stiffness and frequency.

Analysis of the draft gear or cushion travel data shows the large manjority of these cars are equipped with 20 inch travel cushioned underframes. (Indeed, the small percentage of standard draft gear cars would probably correlate with the small percentage of cars having 8 ft. and 9 ft. doorways, but such a group would represent a small population considered insignificant). The sizeable, but relatively small, percentage of cars having cushion travels of 10 inches to 19 inches are included with the longer travel cushion cars since the overall lengths of both groups are approximately equal (even though the shorter travel cushions are probably end-of-car designs).

Examination of the AAR car type code data shows both subgroups are listed as A230 and A240 by the AAR code definitions. The A230 code represents a standard boxcar which is loader equipped, while A240 represents the addition of insulation to the same car. Having identified two subgroups in the trial boxcar group 13, the population of each subgroup was determined from the percentage ratios of the distinguishing features (in this case door width). The resulting subgroups are then denoted as final groups 13a and 13b.

Similar analyses were performed on all boxcar trial groups and on all car type trial groups. When the available information could not be correlated to adequately identify a car group's or subgroup's features, a re-sort using narrower bandwidths or another sorting feature was used to provide the necessary data. All trial groups or subgroups with significant populations were considered final groups, the aggregate of which represents the entire freight car fleet. These final groups were used as a basis for determining the final step in dimensionally characterizing the freight car fleet, the dimensional vehicle category (DVC) which will describe a single car typical of each respective trial group. Engineering parameter descriptions were developed for each DVC using the procedures described in the following sections.

2.1.6 Dimensional Vehicle Categories

All data obtained from the foregoing UMLER sort provides a gross dimensional description of freight cars in each final group. Further, each final group represents cars with significant, but reasonable variation on the representative dimension or parameter. These variations generally range from 5 percent to 20 percent on the principal physical attributes describing major car populations to as much as 30 percent when smaller more diverse groups of vehicles have been lumped with larger population groups.

In order to assemble sufficient information to allow computation of engineering parameters, specific structural details are required such as principal dimensions and cross-sectional areas and area moments of inertia on principal structural members. Since construction details will vary from car to car, a true average car could only be determined by obtaining construction details on all cars and calculating averages for such items as structural member cross-sectional areas and inertias, etc. This approach would be impractical from a time and cost standpoint. However, it was felt that each trial car group could reasonably be represented by a single typical car design which could be studied to obtain the necessary construction details to extend the physical descriptions of freight vehicle carbodies in that group. This representative car, was carefully selected to conform very closely with the set of physical descriptors defining each final, sorted, freight car group. The assumption is made at this point that calculation of additional physical descriptors applies reasonably well not only to the representative car from which structural data was obtained, but to the entire population of vehicles included in the final grouping. The completed physical characterization of the representative car is therefore assumed to be representative of the entire group.

A typical listing of the dimensional vehicle categories (DVC) for boxcars, extracted from the total listing for all DVCs given in Appendix A, is shown in Table 2-5. In this listing, nominal dimensional data is given for the representative car selected to represent the entire group. The car height, weight, capacity and other data are carried over from the analysis of the trial group listing (UMLER analysis) as shown in Table 2-4 (except truck centers). In general, the total cars represented by the DVC's for any one mechanical car type represent over 90 percent of all cars of that type as summarized in Table 2-6. Taken together, the 198 DVCs represent over 95 percent of the total U.S. freight fleet.

Information is included on the percentage of each DVC which has trucks equipped with roller bearings or with plain journal bearings. The description of the DVC includes the truck capacity - car correlation which will be described in the discussion of truck parameters.

TABLE 2-5. BOXCAR DIMENSIONAL CATEGORIES

CORS NO.	DESCRIPTION	BEARINGS R-ROLLER P-PLAIN	INSIDE LENGTH	OUTSIDE LENGTH	EXTREME HEIGHT	DOOR WIDTH	DOOR TYPE	NOMINAL CAPACITY	LIGHT WEIGHT	DRAFT GEAR OR CUSHION	TRUCK CENTERS	POPU-LATION	% POPU-LATION
2a	40'-50T	R-.34 P-.66	40'-6"	44'-6"	15'-1"	8'	CENTERED	110k	52.0k	STD.	30'-10"	26,295	5.5
2b	40'-50T	R-.34 P-.66	40'-6"	44'-6"	15'-1"	14'	STAGGERED	110k	52.0k	STD.	30'-10"	8,343	1.8
3	40'-50T	R-.23* P-.77*	40'-6"	48-0"	15'-1"	6'	STAGGERED	100k	47.0k	STD.	30'-10"	5,560	1.2
4	40'-50T	R-.23* P-.77*	40'-6"	44'-6"	14'-10"	8'	CENTERED	110k	62.0k	STD	30'-10"	2,068	0.4
35	40'-50T	R-.13 P-.87	40'-6"	44'-6"	15'-1"	8'	CENTERED	110k	47.0k	STD.	30'-10"	90,450	19.0
8a	50'-50T	R-.24 P-.76	50'-6"	54'-6"	15'-1"	9'	CENTERED	110k	58.3k	STD.	40'-10"	60,077	12.6
8b	50'-50T	R-.24 P-.76	50'-6"	54'-6"	15'-1"	15'	STAGGERED	110k	58.3k	STD.	40'-10"	37,523	7.9
9	50'-50T	R-.24 P-.76	50'-6"	54'-6"	15'-1"	15'	STAGGERED	100k	73.0k	STD.	40'-10"	2,915	0.6
13a	50'-70T	R-.90 P-.10	50'-6"	58'-0"	15'-1"	10'	CENTERED	140k	78.0k	20" CTR. CAR	40'-10"	13,517	2.8
13b	50'-70T	R-.90 P-.10	50'-6"	58'-0"	15'-1"	16'	CENTERED	140k	78.0k	20" CTR. CAR	40'-10"	3,150	0.7
14	50'-70T	R-.90* P-.10*	50'-6"	60'-5"	15'-1"	10'	CENTERED	150k	69.0k	30" CTR. CAR	40'-10"	7,079	1.5
15	50'-70T	R-.90* P-.10*	52'-6"	60'-5"	15'-6"	12'	CENTERED	134k	81.0k	20" CTR. CAR	43'-0"	4,574	1.0
16a	50'-100T	R-.90* P-.10*	50'-6"	55'-5"	15'-1"	10'	CENTERED	188k	73.0k	STD.	40'-10"	1,801	0.4
16b	50'-100T	R-.90* P-.10*	50'-6"	58'-0"	15'-1"	16'	CENTERED	188k	73.0k	20" CTR.CAR.	40'-10"	4,568	1.0
12a	50'-70T	R-.93 P-.07	50'-6"	54'-6"	15'-1"	9'	CENTERED	149k	63.5k	STD.	40'-10"	102,171	21.5
12b	50'-70T	R-.93 P-.07	50'-6"	58'-0"	15'-1"	16'	CENTERED	149k	63.5k	20" CTR.CAR	39'-6"	25,758	5.4
12c	50'-70T	R-.93 P-.07	50'-6"	58'-0"	15'-1"	16'	STAGGERED	149k	63.5k	20" CTR.CAR	39'-6"	22,323	4.7

*Estimated

TABLE 2-5. BOXCAR DIMENSIONAL CATEGORIES (CONT)

CORS NO.	DESCRIPTION	BEARINGS R-ROLLER P-PLAIN	INSIDE LENGTH	OUTSIDE LENGTH	EXTREME HEIGHT	DOOR WIDTH	DOOR TYPE	NOMINAL CAPACITY	LIGHT WEIGHT	DRAFT GEAR OR CUSHION	TRUCK CENTERS	POPU-LATION	% POPU-LATION
20a	60'-70T	R-.90* P-.10*	60'-9"	68'-2"	15'-6"	10'	CENTERED	133^k	85^k	20" CTR.CAR	46'-3"	6,562	1.4
20b	60'-70T	R-.90* P-.10*	60'-9"	68'-2"	15'-6"	16'	CENTERED	133^k	85^k	20" CTR.CAR	46'-3"	3,094	0.6
23a	60'-100T	R-1.0*	60'-9"	68'-2"	15'-6"	10'	CENTERED	182^k	76^k	20" CTR.CAR	46'-3"	2,545	0.5
23b	60'-100T	R-1.0*	60'-9"	68'-2"	15'-6"	16'	CENTERED	182^k	76^k	20" CTR.CAR	46'-3"	2,972	0.6
24a	60'-100T	R-1.0*	60'-9"	68'-2"	15'-6"	10'	CENTERED	173^k	87.0^k	20" CTR.CAR	46'-3"	5,759	1.2
24b	60'-100T	R-1.0*	60'-9"	68'-2"	15'-6"	16'	CENTERED	173^k	87.0^k	20" CTR.CAR	46'-3"	10,264	2.2
37	86'-70T	R-1.0*	86'-6"	93'-7"	17'-0"	20'	CENTERED	102^k	113.0^k	20" CTR.CAR	64'-0"	5,313	1.1
38	86'-100T	R-1.0*	86'-6"	92'-10"	17'-0"	20'	CENTERED	142^k	114.0^k	15" END OF CAR	64'-0"	3,338	0.7
		*Estimated				TOTAL USA	BOX CAR	ENTRIES	476,179		TOTAL	458,019	96.2

TABLE 2-6. DIMENSIONAL VEHICLE CATEGORY POPULATION COMPARISON TO TOTAL UMLER POPULATION

CAR TYPE	TOTAL DVC POPULATION	TOTAL UMLER POPULATION	% POPULATION REPRESENTED BY DVC's
Box	458,019	476,179	96.2%
Stock	4,895	5,590	87.6%
Refrigerated	94,565	98,896	95.6%
Covered Hopper	226,957	241,112	94.1%
Open Hopper	355,450	366,769	96.9%
Gondola	183,911	189,495	97.1%
Flat	132,936	141,020	94.3%
Vehicular Flat	33,093	33,596	98.5%
Tank	177,072	187,539	94.4%
ALL CARS	1,666,898	1,740,196	95.8%

The DVC data of Table 2-5 also lists the types of draft gear or cushion typical for each category. The standard draft gear refers to the most common system used in the railroad industry. This standard system provides a friction or rubber shock absorber (draft gear) between the coupler and the carbody center sill. This absorber or draft gear cushions the carbody from buff and draft loads applied to the coupler. Travel of this standard draft gear falls in the range from 2-1/2 inch to 4-1/4 inch generally. A second method or isolating the carbody is through the use of an end of car hydraulic cushion unit. This cushion unit essentially replaces the standard draft gear on each end of the car but provides up to 15 inches of travel to absorb coupler loads in buff.

The third protection system is known as a sliding center sill cushion or a center of car cushion unit. In this system, a complete full length center sill with a standard draft gear arrangement on each end is connected to the carbody through a single hydraulic cushion unit located near the center of the car. One advantage of this system is in the longer travel of the cushion unit (typically 20 inches or 30 inches) permitting greater cushioning of the loads from the coupler.

The coupler length is not shown in the DVC listing but is included in the listing of computed parameters for each DVC (Refer to Section 2.2.2). The coupler length is closely related to the length of the carbody and its overhang (from the trucks to the end of the car). In order to provide required curving characteristics, longer cars are equipped with longer shank couplers with increased arc of movement. A review of past Pullman production was used to verify this correlation of coupler lengths to car length. Generally, cars shorter than approximately 55 feet use the most common "E" type coupler which has an effective length in buff of approximately 29.3 inches while longer cars use either a 43 inch length coupler or a 60 inch length coupler.

2.2 DEVELOPMENT OF ENGINEERING PARAMETERS

2.2.1 Lading Characterization

2.2.1.1 Overview - Work done up to this point has been devoted to identifying and dimensionally characterizing the basic vehicles in the freight car fleet. However, the actual cars in service are loaded for a majority of their mileage and this load must be considered in defining certain load dependent parameters such as center of gravity height, bending frequencies, etc., which are affected by the mass of the load. The methodology used to develop lading data has also provided a means for estimating the relative frequency of occurence (or usage) of each vehicle and lading combination in terms of total annual mileage traveled by specific vehicles (DVCs) carrying a specific load. This is an important feature of the data developed to describe typical freight car lading configurations. For the purpose of this contract, lading configurations are defined by lading density, car load weight, and loading geometry. With this data, adequate information is available for computing carbody parameters which are affected by typical loads. These parameters include mass, center of gravity height, mass moments of inertia and carbody flexibility characteristics.

Basic to the development of the lading data was the identification of basic carload commodity relationships describing the number of carloads and the tonnage and mileage distributions of commodities carried by the various design groups identified, i.e. the DVCs. This required a) defining commodity-density groups, b) estimating average mileage per carload for various car-commodity combinations and c) relating carload weight distributions with vehicle weight capacities within the various car types and d) compiling related data such as loading configurations, empty to loaded ratios, and the like.

Initial investigations were made to learn whether or not previous studies had integrated the aforementioned data in ways useful to this effort. Moreover, these studies were needed to identify the basic sources of reliable data for analyzing car-lading relationships. With this in mind, two computerized literature searches were made for applicable data. For thoroughness, one search focused on basic operating data in terms of car-loads and tonnages carried, while the second search was directed at dynamic aspects of freight cars. The two searches turned up a number of studies very general in nature as well as studies dealing with very specific details of limited car types but none directly applicable to the more global interests of this effort which required detail information on the entire freight vehicle fleet.

The absence of good previous study data that could be built on led to a detailed examination of what basic data was available for a "from the ground-up" analysis. With this in mind, all principal ICC, DOT and AAR data referenced in the bibliographies of previous related studies were accumulated. In addition, cognizant DOT, AAR and ICC personnel were contacted in order to discover other meaningful data resources. Literature searches were made at the ICC, AAR and DOT libraries, as well as the extensive transportation libraries at MIT and Northwestern University. After reviewing the available literature and data sources, a revised program plan was formulated for the identification of car/commodity relationships. A detailed outline of the methodology is shown in Figure 2-2.

In essence, the methodology consists of four principal tasks. They were:

Task 1 - Identify carload distributions of lading densities, carload tonnages, and mileage for each mechanical car type. These distributions, based on the FRA carload waybill statistics and adjusted to ICC annual statistics, form the basis for all lading analysis. With this data, it was possible to identify typical lading density groups carried by each car type and to determine related annual mileage and average load data.

As an example, box car ladings could be grouped into five density ranges, each corresponding to typical commodities carried

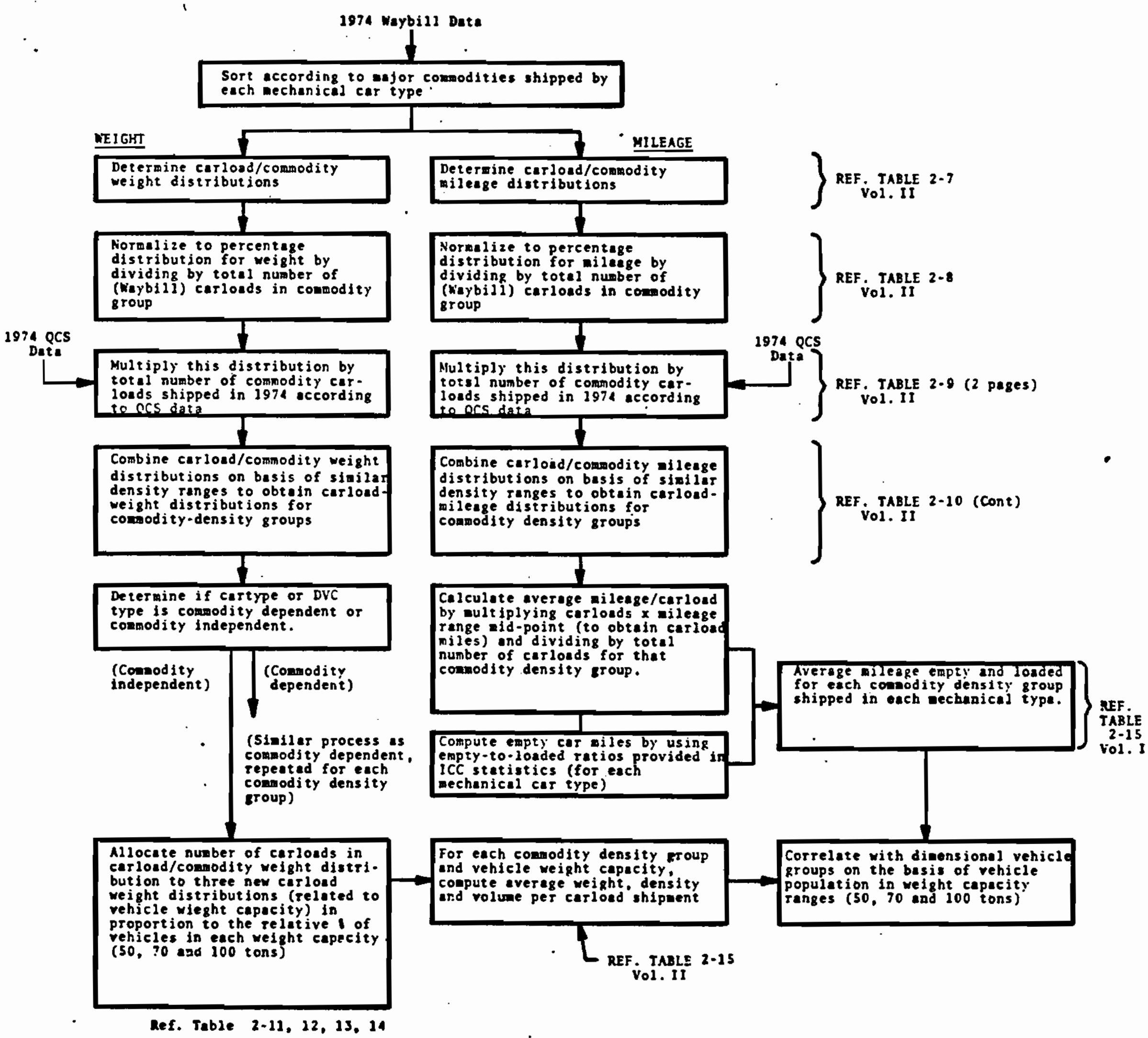


FIGURE 2-2. DETERMINATION OF LADING DATA AND CORRELATION TO DIMENSIONAL VEHICLE CATEGORIES

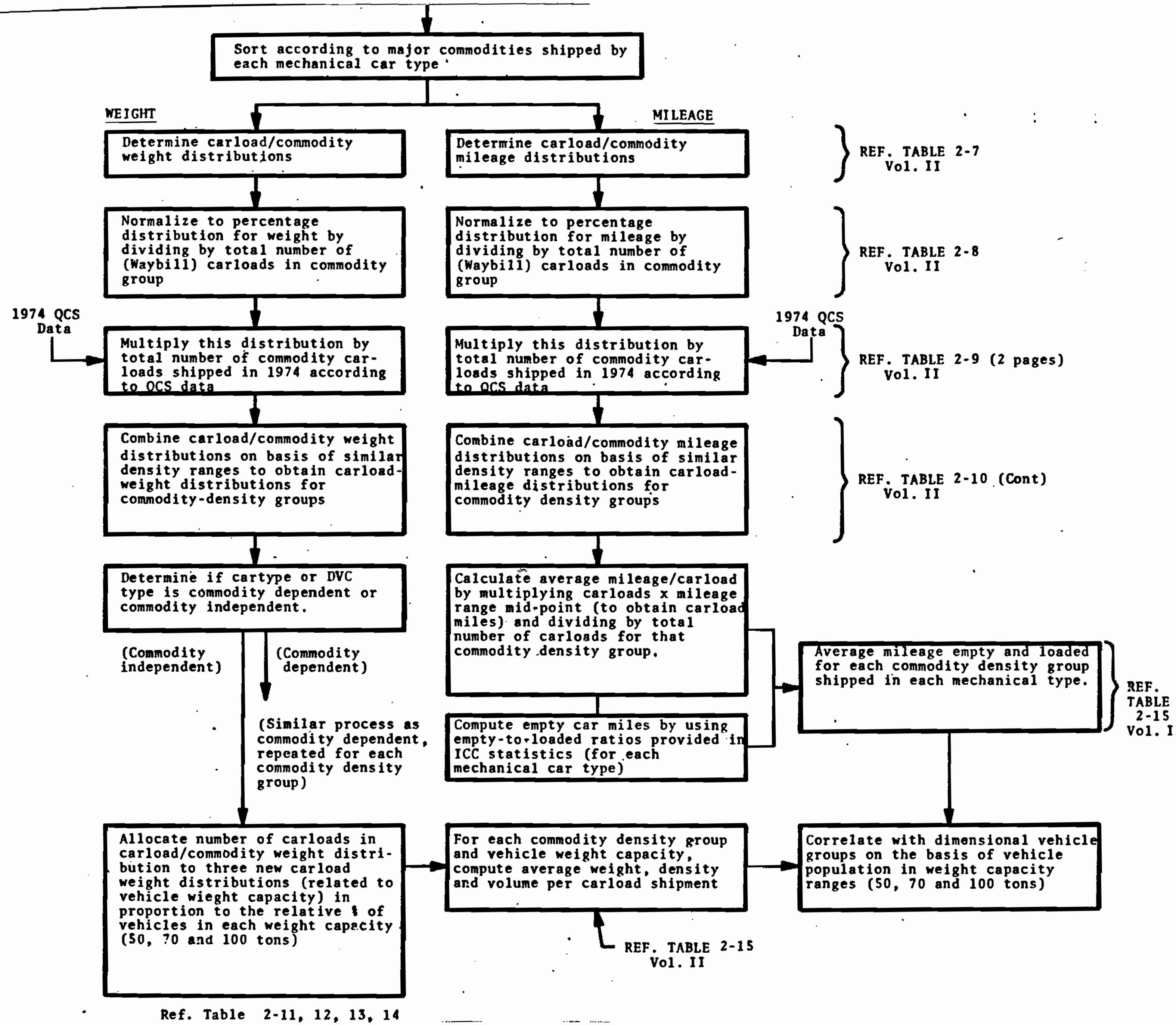


FIGURE 2-2. DETERMINATION OF LADING DATA AND CORRELATION TO DIMENSIONAL VEHICLE CATEGORIES

and representing over 80 percent of all boxcar loads. The carload tonnage distribution for each lading (density) group could then be determined along with average annual mileage for each group. It was then necessary to correlate this overall lading data for each car mechanical type to the individual car groups (dimensional vehicle categories) within each car type.

Task II - Determine a methodology to correlate overall carload data to specific car groups within each mechanical car type using Pullman's knowledge of freight car usage. All freight car types were classified either as general service cars or as commodity related cars. The general service cars are typified by the general service box cars and can be expected to carry widely varying commodities with varying carload weights. Basically, carload allocation for general service cars (within each car type) was done based on a combination of vehicle weight capacity and group population.

The commodity related cars, such as hopper cars or tank cars, are designed to haul a specific commodity (or commodities with a limited density range). Carload allocations for these cars are based on vehicle weight capacity, design lading density, design lading type and, finally, group population.

Task III - Develop and expand the car/lading relationships. This task develops the complete set of lading data which can be used to describe the typical loaded freight car fleet. The basic lading data sets for each car type typically represent over 80 percent of the carloads shipped in any particular mechanical car type. This data has been adjusted to represent the total carloads shipped in 1974 per ICC Freight Commodity Statistics. Using the average density and carload tonnage distribution for each commodity group, the average carload volume was determined to assure compatibility with assignment to specific car groups (DVCs). Extreme weight carload statistics were also determined to provide a basis for denoting extreme center of gravity conditions for each general service car group.

The lading data provides, for each car group, commodity density groups (with specific density ranges), number of annual carloads for each commodity-density group, average mileage for each carload by commodity density group, and by combination of the foregoing, the total annual mileage loaded for each DVC-lading combination. Empty car mileage for each DVC was determined using Empty-to-Loaded Mileage ratios provided in the ICC statistics for each mechanical car type.

Task IV - Project the above data to estimate car-lading relationships for cars in service prior to 1980. The basis for forecasting rail services to 1980 was the National Transportation Trends and Choices by the U.S. Department of Transportation. According to this source, the overall demand for rail services is expected to increase by 42 percent between 1975 and 1990. Based on this prediction, it was assumed that demand for rail service would increase by 14 percent between 1975 and 1980 (1/3 of 42 percent). This data also showed that the demand for rail services decreased by 11.3 percent between 1974 and 1975. Therefore, the overall change between 1974 and 1980 is a relatively small 2.6 percent (14-11.3 = 2.6) and the lading data used in this effort (based on 1974) can be used directly as indicative of rail service expected at the beginning of 1980. A further assumption made is that the relative percent distribution between various commodities will also remain constant between 1974 and 1980.

2.2.1.2 Methodology - The methodology used to correlate carload data to specific car groups (DVC) was based on a knowledge of railroad operations and car utilization. As a carbuilder, it is Pullman's experience that two car classes may be considered to describe the utilization of the freight fleet. These are the general service class and the commodity related class. Cars in the general service class are designed to haul a wide variety of commodities of differing densities and characteristics. These cars also are used to ship partial loads or drop-loads into more than one delivery point. In contrast, the commodity related cars are designed to haul various bulk commodities having relatively small variation in density. Typically, these cars are shipped fully loaded to their rail weight capacity.

The flow diagram in Figure 2-2 shows the methodology used to correlate ladings to car groups starting with the original data sources through classifying into general service or commodity related classes and finally yielding carload data for each car-group (loaded mileage for each density range, empty mileage, average and extreme weights per carload). The following discussion explains this process in detail using the boxcar as a typical general service car and the open top hopper car as a typical commodity related car:

A. Basic Carload Information

Basic carload information is obtained from a computer sort of the 1 percent waybill sample for 1974. This sample sort lists a breakdown in the number of carloads shipped in each mechanical car type for both weights and mileage. The weight sort lists the number of carloads shipped in carload weight ranges of 30,000 pound increments from 0 to over 300,000 pounds. The mileage sort similarly lists the number of carloads shipped by carload mileage ranges in various increments from 0 to over 3,000 miles. Each of these breakdowns is listed for specific commodities or commodity groups. A sample output of this data is shown in Table 2-7 for carload weight distributions.

B. Carload Data Organization

These basic waybill statistics are then organized into weight and mileage per carload distributions for 1974. Individual commodities are grouped into major classes using the ICC commodity codes as a guide. The first three numbers of the five number code establish a major class. The carload distributions for weight in each commodity class are added together for each mechanical car type. Example: Given boxcars in the chemical commodity class and a weight range of 0 to 30 kips, all the carloads in the boxcar 0 to 30 kip weight range that correspond to the ICC commodity code beginning with 281--would be added together.

The carload-commodity class distribution is then transformed

TABLE 2-7. 1974 CARLOAD WAYBILL STATISTICS

WEIGHT DISTRIBUTION OF CARS BY COMMODITY CLASS AND TYPE OF CAR

	COMMODITY CLASS AND TYPE OF CAR	TOTAL NO. OF TONS	TONS PER CAR	TOTAL NO. OF CARS	NUMBER OF CARLOADS BY TONNAGE RANGE INDICATED: 1-15 TONS	16-30 TONS	31-45 TONS	46-60 TONS	61-75 TONS	76-90 TONS	91-120 TONS	121-150 TONS	151 TONS & OVER
14213	DOLOMITE,BROKEN OR CRUSHED												
	GONDOLA	1977	79.1	25						25			
	HOPPER	14581	81.5	179				7	37	93	35		7
	OTHER	416	69.3	6				2		4			
	TOTAL	16974	80.8	210				9	37	122	35		7
14219	BROKEN OR CRUSHED STONE,NEC												
	BOX	4616	50.2	92		1	35	45	7	2	2		
	GONDOLA	104217	69.9	1491	3	2	20	461	425	171	179	15	215
	HOPPER	263001	78.4	3353	9	3	24	242	953	749	746	59	568
	SPECIAL	10393	73.2	142		1	2	20	61	41	9		8
	OTHER	20910	83.0	252	1		4	7	66	42	102		30
	TOTAL	403137	75.6	5330	13	7	85	775	1512	1005	1038	74	821
14411	SAND (AGGREGATE OR BALLAST)												
	BOX	2770	49.5	56			24	28	3		1		
	GONDOLA	20209	66.7	303	1		3	124	76	44	31	4	28
	HOPPER	99366	75.4	1318	5	5	5	100	289	227	258	14	415
	SPECIAL	7241	71.7	101		1	1	5	41	34	14		5
	OTHER	4528	80.9	56		1	3	3	11	8	26	4	
	TOTAL	134114	73.1	1834	6	7	36	260	420	313	330	22	440
14412	GRAVEL (AGGREGATE OR BALLAST)												
	BOX	689	53.0	13			3	7	3				
	GONDOLA	25236	66.4	380			2	178	76	42	38	2	42
	HOPPER	94098	78.5	1198	8	1	3	115	271	329	299	12	168
	SPECIAL	5999	72.3	83	1			2	66	7	4		3
	OTHER	736	73.6	10				2	3	4	1		
	TOTAL	126756	75.3	1684	9	1	8	304	419	382	342	14	205
14413	INDUSTRIAL SAND,CRUDE												
	BOX	11229	51.5	218	2		51	132	30	3			
	GONDOLA	2422	63.7	38				5	10	3	5		15
	HOPPER	3624	72.5	50				8	11	15	10	6	
	SPECIAL	96397	81.5	1183	7		6	42	257	410	347	5	109
	TOTAL	113845	76.3	1492	9		57	189	309	431	362	11	124
14519	CERAMIC OR CLAY MINERALS,NEC,CRUDE												
	TANK	7290	75.2	97					57	34	6		
	BOX	844	49.6	17			3	13	1				
	GONDOLA	5193	69.2	75	1	1		6	24	28	1		14
	HOPPER	10519	75.7	139				8	44	75	12		
	SPECIAL	882	73.5	12			1	3	3	1	4		
	TOTAL	24809	72.8	341	1	1	4	30	129	139	23		14

into a percentage distribution. The percentage distribution for each weight range is found by dividing the number of carloads in a commodity class, for an individual mechanical car type, by the total number of carloads shipped for that commodity in the waybill sample.

The total 1974 carload-commodity class distribution for weight is found by multiplying the percent distributions for each commodity class by the total number of carloads of that commodity shipped in 1974. The commodity carloads for 1974 comes from the ICC Freight Commodity Statistics, Class I Railroads.

This procedure is followed for both the carload tonnage distribution and the carload mileage distribution. A portion of this generated data is given in Table 2-8 for boxcars and open hopper cars.

C. Carload Data Analysis

Data for each mechanical car type is then analyzed to provide individual lading distribituions and the following information:

Carload Tonnage Distribution

Significant commodities consisting of approximately 80 percent or more of the aggregate shipped in each mechanical car type are chosen as the representative data. A typical summary of significant commodities for boxcars is shown in Table 2-9 (with the tonnage distribution). These commodities are then combined into groups of commodities with similar density ranges as shown in Table 2-10.

Average Density

Average density per carload is calculated for each commodity density range weighted by the number of carloads for each individual commodity.

Mileage Distribution

The mileage distribution is identical to the weight distribution except that mileage ranges and data are used.

TABLE 2-8. PERCENTAGE OF COMMODITY CLASSES LISTED IN 1974 WAYBILL SAMPLE BY CAR TYPE AND WEIGHT RANGES

PERCENTAGE OF COMMODITY CLASSES LISTED IN 1974 WAYBILL SAMPLE

BY CAR TYPE AND WEIGHT RANGES

				BOX CAR PERCENT OF TOTAL CARLOADS BY WEIGHT RANGE - 1000 LBS.								OPEN HOPPER CAR PERCENT OF TOTAL CARLOADS BY WEIGHT RANGE - 1000 LBS.							
ICC NO.	COMMODITY	TOTAL ANNUAL CARLOADS	COMMODITY DENSITY LBS/CU.FT.	2-30	30-60	60-90	90-120	120-150	150-180	180-240	240-300	2-30	30-60	60-90	90-120	120-150	150-180	180-240	240-300
011	Field Crops	1,929,302	44.8	0.5	2.2	2.0	14.7	11.9	0.1	0.1	—	—	1.4	1.5	—	—	—	—	—
012	Fresh Fruit & Nuts	61,577	32.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
013	Fresh Vegetables	106,681	26.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
100	Metallic Ores	1,575,538	100.0	—	—	0.2	0.1	—	—	—	—	0.1	—	0.1	0.4	3.8	12.8	5.9	0.2
110	Coal	4,690,717	70.0	—	—	—	—	0.1	0.1	0.1	—	0.2	0.1	0.2	7.6	25.4	25.0	24.0	0.4
201	Meat & Poultry	136,425	36.3	0.1	1.4	3.7	23.1	2.2	0.1	—	—	—	—	—	—	—	—	—	—
203	Canned Fruit, Etc.	230,081	41.6	0.2	2.8	4.2	7.3	1.9	0.1	—	—	—	—	—	—	—	—	—	—
240	Lumber & Wood Products	1,970,177	24.1	0.2	2.3	9.3	6.3	1.1	0.1	—	—	—	0.4	0.8	0.3	0.1	0.1	—	—
350	Mechanical Machinery	186,837	39.7	16.8	10.2	1.1	0.4	0.7	—	—	—	—	—	—	—	—	—	—	—

TABLE 2-9. PRINCIPAL BOXCAR COMMODITIES CARLOAD FREQUENCY DISTRIBUTION

CARLOAD FREQUENCY DISTRIBUTION

(CARLOADS x 1000)

COMMODITY	AVERAGE DENSITY (LBS/FT^3)	AVERAGE WEIGHT (TONS/CAR)	TONNAGE RANGES							
			1-15	16-30	31-45	46-60	61-75	76-90	91-120	TOTALS
Field Crops	44.8	70.7	9.65	42.44	38.59	283.61	229.59	1.93	1.93	607.74
Metallic Ores	100.0	80.3	—	—	3.15	1.58	—	—	—	4.73
Coal	70.0	83.3	—	—	—	—	4.69	4.69	4.69	14.07
Non-Metallic Minerals	100.0	77.6	—	2.20	17.63	44.07	8.81	2.20	2.20	77.11
Food & Kindred Products	37.5	44.9	31.64	301.69	263.30	208.79	41.39	2.29	1.0	850.10
Tobacco Products	18.0	30.8	0.19	11.62	7.75	—	—	—	—	19.56
Basic Textiles	17.8	19.8	44.85	4.04	0.40	—	—	—	—	49.29
Lumber	24.2	53.5	3.94	43.51	183.23	124.12	21.67	1.97	—	378.44
Furniture	11.5	8.9	210.81	2.54	0.23	0.23	0.46	0.69	—	214.96
Pulp & Paper	32.5	39.4	70.84	334.64	222.28	296.78	157.55	39.08	6.11	1127.28
Chemicals	56.7	66.7	3.35	23.97	56.15	109.02	41.13	8.65	0.44	242.71
Rubber & Plastic	17.0	16.9	83.61	117.06	5.35	0.89	—	—	—	206.91
Stone, Clay, Glass	59.9	60.3	13.52	52.95	87.87	144.28	29.29	10.14	2.25	340.30
Primary Metal Products	155.0	63.6	2.21	5.52	9.95	56.38	96.17	8.84	3.32	182.39
Fabricated Metal Prods.	95.2	33.6	74.50	2.69	1.01	1.68	0.34	0.34	0.34	80.90
Mechanical Machinery	39.7	22.7	31.37	19.06	2.06	0.75	1.31	—	—	54.57
Transportation Eqpt.	18.0	23.6	247.52	204.58	69.46	55.57	11.37	1.26	1.26	591.02
Misc. Mfg. Products	17.5	14.4	26.59	3.93	0.65	0.21	—	—	—	31.38
Waste & Scrap	125.0	50.7	3.79	85.37	79.68	34.15	6.64	0.95	—	210.58
Misc. Freight	17.5	20.6	19.35	6.65	0.17	—	—	—	—	26.17
Frt. Forwarder Traffic	17.5	19.4	22.47	7.70	6.87	4.37	3.95	—	0.42	45.78
TOTALS			900.22	1272.16	1055.78	1366.48	654.36	83.03	23.96	5356

Principal Box Car Commodities Represent 86% of Total Carloads

TABLE 2-10. CARLOAD FREQUENCY DISTRIBUTION ALL BOXCARS

(CARLOADS x 1000)

DENSITY RANGE (LBS/FT^3)	AVERAGE DENSITY (LBS/FT^3)	TONNAGE RANGE							
		1-15	16-30	31-45	46-60	*61-77	78-90	91-106	TOTALS
11-19	16.6	655.39	358.12	90.88	61.27	16.04	1.69	1.68	1185.07
24-40	33.1	137.81	698.90	670.87	630.44	227.70	37.56	7.11	2410.39
44-60	51.6	26.52	119.36	182.61	536.91	308.09	22.02	9.31	1190.70
61-100	97.6	74.50	4.89	21.79	47.33	9.49	2.20	2.54	176.81
101-155	138.9	6.00	90.89	89.63	90.53	104.12	8.48	3.32	392.97
TOTALS		900.22	1272.16	1055.78	1366.48	665.43	71.96	23.96	5356.00

*Tonnage range was changed from the computer printout range of 61-75 to 61-77. This was done by transferring 2/15% or 13.33% of the carloads in the 76-90 range into the 61-75 range. The change was made to allow 70-ton cars to have a maximum capacity of 77 tons.

Average Miles per Carload

The average miles per carload for each commodity density group is calculated by multiplying the carloads in each mileage range by the midpoint value of each range to determine carload-miles for each mileage range. These carload-miles are then summed together and divided by the total number of carloads in the commodity density group.

D. Car Type Usage Characterization

With detailed lading data compiled for each mechanical car type, each car type is then further classified as either a general service car or a commodity related car. General service cars, which haul an extreme variety of commodities with a wide range of load weights, include box cars and refrigerated cars. Commodity related cars include stock cars, open hoppers, covered hoppers, vehicular flats, and tank cars. Gondola and flat car types contain both general service and commodity related cars which were handled on an individual basis.

E. Correlation of Lading Data for General Usage Cars - Boxcar Example

The carload-density-weight distribution data, for cars which carry general commodities is related to car DVCs for each mechanical car type according to weight capacity. First the car types are placed into weight capacity groups. The carload-density-weight distribution data is divided among the weight capacity groups on a car population percentage basis. This is done assuming all cars carry loads of any weight, regardless of their maximum capacity, as long as their maximum capacity is not significantly exceeded. This assumption is based on the operating practices of the railroad industry and it's customers, the shippers. While the shipping rate structure intends to promote full load shipments, partial loads are shipped for many reasons such as multiple destinations of a single load, and configurations or load densities which preclude using the maximum weight capacity of the cars. Using this method, the original carload-density-weight distribution is divided into a number of new distributions, one for each weight capcity group. Example: Boxcars exist in three weight capacity groups with the following car population percentages:

Weight Capacity Range	Car Population Percentage
0-120 kips	50.92%
120-154 kips	42.26%
154-210 kips	6.82%

With these weight ranges, the original carload-density weight distribution (Table 2-10) is divided into three new distributions. The distributions are developed by multiplying the carloads shown in the three weight ranges by the population percentage factors shown in the Table 2-11. The outcome distributions as shown in Tables 2-12, 2-13 and 2-14 are for each weight capacity group with the following characteristics:

- The cars in the 0-120 kip weight capacity will carry their population share of the carloads within that range.
- The cars in the 120-154 kip weight capacity range will carry their population share of the carloads within that range along with their population share of the carloads in the 0-120 kip weight range.
- The cars in the 154-210 kip capacity range will carry all the carloads within that range along with their population share of the carloads in the 0-120 and 120-154 kip ranges.

Since the waybill statistics are approximately a 1 percent sampling and only 80 percent of its commodities were considered, the number of carloads in this analysis is not equivalent to the total number shipped in 1974. Therefore, to keep the proper usage ratios between mechanical car types, the carload total for each mechanical car type is adjusted to equal that of the ICC statistics.

The following average dondition data is computed for use in determining average condition parameters for car dimensional categories (DVCs):

Average weight per carload -- The average weight per carload for density ranges in each weight capacity group is

TABLE 2-11. POPULATION PERCENTAGE FACTORS

Car Weight Capacity Ranges	Weight Ranges			New Distributions
	0–120 kips	120–154 kips	154–210 kips	
0–120 kip	50.92%	–0–	–0–	50 Ton Distribution
120–154 kip	42.26%	$\frac{42.26}{42.26+6.82} = 86.1\%$	–0–	70 Ton Distribution
154–210 kip	6.82%	$\frac{6.82}{42.26+6.82} = 13.9\%$	100%	100 Ton Distribution

TABLE 2-12. CARLOAD FREQUENCY DISTRIBUTION 50 TON CAPACITY BOXCARS

(CARLOADS x 1000)

DENSITY RANGE (LBS/FT^3)	AVERAGE DENSITY (LBS/FT^3)	TONNAGE RANGES								ADJUSTED TOTALS (TO ANNUAL CARLOADS)
		1-15	16-30	31-50	46-60	61-77	78-90	91-105	TOTALS	
11-19	16.6	333.72	182.35	46.28	31.20	—	—	—	593.55	686.53
24-40	33.1	70.17	355.88	341.61	321.02	—	—	—	1088.68	1259.22
44-60	51.6	13.50	60.78	92.99	273.39	—	—	—	440.66	509.69
61-100	97.6	37.94	2.49	11.10	24.10	—	—	—	75.63	87.48
101-155	138.9	3.06	46.28	45.64	46.10	—	—	—	141.08	163.18
TOTALS		458.39	647.73	537.62	695.81	—	—	—	2339.00	2706.09

TABLE 2-13. CARLOAD FREQUENCY DISTRIBUTION 70 TON CAPACITY BOXCARS

(CARLOADS x 1000)

DENSITY RANGE (LBS/FT^3)	AVERAGE DENSITY (LBS/FT^3)	TONNAGE RANGES								ADJUSTED TOTALS (TO ANNUAL CARLOADS)
		1-15	16-30	31-45	46-60	61-77	78-90	91-105	TOTALS	
11-19	16.6	276.97	151.34	38.41	25.89	13.81	—	—	506.42	585.75
24-40	33.1	58.24	295.36	283.51	266.42	196.06	—	—	1099.59	1271.84
44-60	51.6	11.21	50.44	77.17	226.90	265.28	—	—	631.0	729.84
61-100	97.6	31.48	2.07	9.21	20.00	8.17	—	—	70.93	82.04
101-155	138.9	2.54	38.41	37.88	38.20	89.65	—	—	206.68	239.06
TOTALS		380.44	537.62	446.18	577.41	572.97	—	—	2514.62	2908.53

TABLE 2-14. CARLOAD FREQUENCY DISTRIBUTION 100 TON CAPACITY BOXCARS

(CARLOADS x 1000)

DENSITY RANGE (LBS/FT^3)	AVERAGE DENSITY (LBS/FT^3)	TONNAGE RANGES								ADJUSTED TOTALS (TO ANNUAL CARLOADS)
		1-15	16-30	31-45	46-60	61-77	78-90	91-105	TOTALS	
11-19	16.6	44.70	24.42	6.20	4.18	2.23	1.69	1.68	85.10	98.43
24-40	33.1	9.40	47.66	45.75	43.00	31.64	37.56	7.11	222.12	256.91
44-60	51.6	1.81	8.14	12.45	36.62	42.81	22.02	9.31	133.16	154.02
61-100	97.6	5.08	0.33	1.49	3.23	1.32	2.20	2.54	16.19	18.73
101-155	138.9	0.41	6.20	6.11	6.17	14.47	8.48	3.32	45.16	52.23
TOTALS		61.40	86.75	72.00	93.20	92.47	71.95	23.96	501.73	580.32

found by multiplying the carloads in each weight range by the range midpoint values (carload-kips). These carload-kips are then summed together and divided by the total number of carloads in that density range.

Average volume per carload -- The average volume per carload is found by dividing the average weight per carload by the average density of that commodity group. The average density for each density range was calculated previously and remains the same for each weight capacity group.

Loaded car miles -- The loaded car miles for each density range are found by multiplying the average miles per carload by the total number of carloads for the density ranges in each weight capacity group. The average miles per carload was calculated previously and remains the same for each weight capacity group.

Empty car miles -- The empty car miles are calculated by multiplying the total loaded car miles, in a weight capacity group, by an empty to loaded - factor. This factor is derived from the latest ratios of empty to loaded freight car miles found in the Interstate Commerce Commission Statement No. 152-72, December 1973, "Ratios of Loaded Freight Car-Miles by Type of Car and Performance Factors for Way, Through and All Trains Combined - 1972."

The extreme condition was chosen to be the load with the highest center of gravity, since the variations of this parameter would not be adequately represented in the average load conditions of the cars of that mechanical type. The following data is computed for use in determining the extreme condition parameters for car dimensional categories. This data has already been included in the derivation of average conditions data. Therefore, care must be taken not to confuse or combine the two sets of data.

Extreme weight per carload -- This value is the midpoint of the maximum weight range in each weight capacity group.

Extreme volume per carload -- The procedure for determining extreme volume per carload is identical to that of average volume per carload. the number of carloads in the maximum

Extreme loaded car miles -- The loaded car miles for each density range are found by multiplying the average miles per carload by the number of carloads in the maximum weight range. The average miles per carload was calculated previously and they remain the same for each weight capacity group.

The total miles traveled by each car type for the density ranges in each weight capacity group is estimated based on vehicle population. First, the total car population of each weight capacity group is determined (from UMLER) by summing appropriate DVC populations. Then, the population of each DVC is divided by the total car population in its weight capacity group to determine each car type's percentage of the weight capacity group. This percentage factor times the total mileage in each density range of the car's weight capacity group yields the individual DVC miles. The extreme condition mileage is also found in this manner. (Note: Extreme Carloads [and therefore mileage] are included in calculation of the average mileage values.) This method assumes the total fleet is in active use and, therefore, within any mechanical type, total annual mileage is simply a function of DVC populations. While this assumption is generally correct, certain cars, such as older cars, or dedicated cars may actually travel fewer or more miles per year than the averages indicate. However, this level of detail is generally not available and would only apply to relatively small groups of cars. A possible exception would be old 40 foot - 50 ton boxcar groups which as a total group may travel fewer miles than indicated. Determination of their usage would require a detailed survey which was not considered cost effective since the effect of such data would not significantly alter the overall data provided.

The final summary of this data is shown in Table 2-15 for average conditions and in Table 2-16 for extreme center of gravity conditions. Each load condition is assigned a lading code number which is later used in correlating specific lading conditions with appropriate DVCs. Each DVC was assigned from one to five average ladings (as specified by the lading code numbers) plus one extreme center of gravity lading condition. An example of this lading code assignment is indicated in Table 2-17 which is a sample of the computed data developed for boxcar DVCs. (A more complete discussion of the data contained in this table is provided in Section ? .)

F. Correlation of Lading Data for Commodity Dependent Cars -- Open Hopper Car Example

In certain cases, the carload-density-weight data can be correlated with specific car dimensional categories (DVC) using known car-commodity relationships. This distribution method is based on the fact that certain cars, such as open hoppers, are designed to carry specific density commodities at full weight capacity.

Identification of principal commodities was done as previously described, and accounts for more than 80 percent of the total carloads carried. This list for open hopper cars is shown in Table 2-18. These commodities are combined into similar density groups as shown in Table 2-19.

The designed density for each open hopper car dimensional category (DVC) is determined by dividing its weight capacity by its volume capacity. The specific DVC's are then paired with the commodity density range which most closely corresponds to their designed density and any identifiable special purpose car designs (such as wood chip cars in the case of open hopper cars). Their carload distribution is then calculated on a population basis. First, the total DVC group population are determined for each vehicle commodity density range. Then, the population of each DVC is divided by the total DVC group population having a particular design density to determine each DVC's percentage of total carloads

TABLE 2-15. BOXCAR LADING DATA SUMMARY - AVERAGE CONDITIONS

AVERAGE CONDITIONS (ANNUAL)

WEIGHT CAPACITY	LADING CODE	DENSITY RANGE (lbs/cu. ft.)	AVERAGE DENSITY (lbs/cu. ft.)	AVG. WT. /CARLOAD (kips)	AVG. VOL. /CARLOAD (cu. ft.)	NO. OF CARLOADS (x1000)	AVG. MILES /CARLOAD	TOTAL MILES (x1000)
0-120 k	1	Empty	—	—	—	—	—	1,325,183
	2	11-19	16.6	34.5	2078	686.53	780.82	536,056
	3	24-40	33.1	72.04	2176	1259.22	778.66	980,504
	4	44-60	51.6	89.58	1736	509.69	476.59	242,913
	5	61-100	97.6	54.47	558	87.48	500.58	43,791
	6	101-155	138.9	75.62	544	163.18	650.92	106,222
0-154 k	7	Empty	—	—	—	—	—	1,382,596
	8	11-19	16.6	37.32	2248	585.75	780.82	457,365
	9	24-40	33.1	91.86	2775	1271.84	778.66	990,331
	10	44-60	51.6	109.93	2130	729.84	476.59	347,834
	11	61-100	97.6	64.09	657	82.04	500.58	41,068
	12	101-155	138.9	102.67	739	239.06	650.95	155,616
0-210 k	13	Empty	—	—	—	—	—	273,215
	14	11-19	16.6	43.07	2595	98.43	780.82	76,856
	15	24-40	33.1	105.95	3201	256.91	778.66	200,046
	16	44-60	51.6	114.69	2223	154.02	476.59	73,704
	17	61-100	97.6	99.09	1015	18.73	500.58	9,376
	18	101-155	138.9	121.87	877	52.23	650.95	33,999

TABLE 2-16. BOXCAR LADING DATA SUMMARY - EXTREME CONDITIONS

MAXIMUM LOAD CONDITIONS (ANNUAL)

WEIGHT CAPACITY	LADING CODE	DENSITY RANGE (lbs/cu. ft.)	AVERAGE DENSITY (lbs/cu. ft.)	AVG. WT. /CARLOAD (kips)	AVG. VOL /CARLOAD (cu.ft.)	NO. OF CARLOADS (x1000)	AVG. MILES /CARLOAD	TOTAL MILES (x1000)
0-120 k	19	11-19	16.6	106	6386	36.09	780.82	28,178
	20	24-40	33.1		3202	371.31	778.66	289,124
	21	44-60	51.6		2054	316.22	476.59	150,707
	22	61-100	97.6		1086	27.88	500.58	13,956
	23	101-155	138.9		763	53.32	650.95	34,709
0-154 k	24	11-19	16.6	138	8313	15.97	780.82	12,470
	25	24-40	33.1		4169	226.77	778.66	176,577
	26	44-60	51.6		2674	306.84	476.59	146,237
	27	61-100	97.6		1414	9.45	500.58	4,731
	28	101-155	138.9		994	103.69	650.95	67,497
0-210 k	29	11-19	16.6	196	11807	1.94	780.82	1,515
	30	24-40	33.1		5921	8.22	778.66	6,401
	31	44-60	51.6		3798	10.77	476.59	5,133
	32	61-100	97.6		2008	2.94	500.58	1,472
	33	101-155	138.9		1411	3.84	650.95	2,500

TABLE 2-17. SAMPLE BOXCAR DIMENSIONAL VEHICLE CATEGORY OUTPUT

EMPTY CARBODY PARAMETERS - CODE 1-BOX CAR
THE UNITS USED ARE INCH-POUND-SECOND ORIENTED
ALL STIFFNESSES ARE CALCULATED STATICALLY

CAR I.D. AND NUMBER		EMPTY CAR MASS	MOMENT OF INERTIA -YAW-	MOMENT OF INERTIA -PITCH-	MOMENT OF INERTIA -ROLL-	C.G. HEIGHT	VERTICAL BENDING STIFFNESS	LATERAL BENDING STIFFNESS	TORSIONAL STIFFNESS *10**7	LENGTH B. TRUCK CENTERS.	LENGTH B. COUPLER PINS	LENGTH OF COUPLER
1	1 2A	98.8	2321984.0	2377617.0	378015.0	73.6	-7.4	1395167.0	171.0	370.0	476.0	29.3
2	1 2B	98.8	2328412.0	2380631.0	385172.2	73.6	677495.9	8602665.0	171.0	370.0	476.0	29.3
3	1 3	85.9	2052430.0	2094286.0	355817.9	75.7	6771571.0	5518701.0	171.0	370.0	518.0	29.3
4	1 4	124.7	2916070.0	2966871.0	471060.9	70.6	2520709.0	3793257.0	171.0	370.0	476.0	29.3
5	1 35	85.9	2006912.0	2091641.0	349617.9	75.7	2922898.0	3746426.0	41.0	370.0	476.0	29.3
6	1 8A	115.9	4079339.0	4141805.0	468418.2	73.9	3017228.0	1615689.0	41.0	490.0	596.0	29.3
7	1 8B	115.9	4074222.0	4105632.0	475676.5	73.9	755058.9	2944144.0	41.0	490.0	596.0	29.3
8	1 9	153.2	5342024.0	6425082.0	603897.6	71.3	676831.8	2944144.0	41.0	490.0	596.0	29.3
9	1 13A	159.7	5427321.0	5469763.0	547209.4	62.9	2075576.0	1598611.0	41.0	490.0	638.0	29.3
10	1 13B	159.7	5435355.0	5468751.0	547032.0	62.9	1893549.0	3100850.0	41.0	490.0	638.0	29.3
11	1 14	136.4	4633024.0	4692690.0	458302.9	64.4	3867399.0	2419055.0	41.0	490.0	667.0	29.3
12	1 15	167.4	6051969.0	6141482.0	539498.9	62.5	3531932.0	2007457.0	49.0	526.0	667.0	29.3
13	1 16A	141.0	4974720.0	5052457.0	589629.9	74.2	2579251.0	1905341.0	41.0	490.0	607.0	29.3
14	1 16B	141.0	4904827.0	5089912.0	650860.5	74.2	775871.0	3407625.0	41.0	490.0	638.0	29.3
15	1 12A	122.2	4242487.0	4309918.0	483674.1	69.6	4001214.0	1830621.0	41.0	490.0	596.0	29.3
16	1 12B	122.2	4244236.0	4298754.0	471012.4	69.6	983528.6	2050242.0	36.0	474.0	638.0	29.3
17	1 12C	122.2	4244236.0	4298754.0	471012.4	69.6	508202.4	3190061.0	36.0	474.0	638.0	29.3
18	1 20A	177.8	8518768.0	8566481.0	593598.0	62.0	2954296.0	1443067.0	21.0	555.0	760.0	29.3
19	1 20B	177.8	8518768.0	8566481.0	593598.0	62.0	1708607.0	2275605.0	21.0	555.0	760.0	29.3
20	1 23A	148.8	7397760.0	7514589.0	664575.5	76.1	3045523.0	1256116.0	21.0	555.0	760.0	29.3
21	1 23B	148.8	7385392.0	7505986.0	650482.7	76.1	1586668.0	2025843.0	21.0	555.0	760.0	29.3
22	1 24A	177.3	8743348.0	8866361.0	755579.8	72.9	3045523.0	1256116.0	21.0	555.0	760.0	29.3
23	1 24B	177.3	8729192.0	8858153.0	739962.2	72.9	1586668.0	2025843.0	21.0	555.0	760.0	29.3
24	1 37	244.6	23445392.0	23833248.0	1183209.0	75.0	733243.2	664863.9	20.0	768.0	1003.0	60.0
25	1 38	244.6	23445392.0	23833248.0	1183209.0	75.0	567471.2	627926.9	20.0	768.0	994.0	60.0

CAR I.D. AND NUMBER		VERTICAL FREQUENCY	LATERAL FREQUENCY	TORSIONAL FREQUENCY	POPULATION SIZE	ANNUAL MILEAGE -EMPTY-	TRUCK CODE	LADING CODES: CODES OF THE COMMODITIES HAULED IN THIS CAR TYPE					
1	1 2A	23.5	26.1	33.6	26295	146074	1	2	3	4	5	6	20
2	1 2B	58.2	64.7	33.3	8343	46347	1	2	3	4	5	6	20
3	1 3	57.7	55.6	34.7	5560	30887	1	2	3	4	5	6	20
4	1 4	21.7	38.3	30.1	2068	11988	1	2	3	4	5	6	20
5	1 35	26.1	45.8	17.1	90450	502468	1	2	3	4	5	6	20
6	1 8A	31.5	30.0	14.8	60077	333740	1	2	3	4	5	6	20
7	1 8B	23.1	40.5	14.7	37523	208448	1	2	3	4	5	6	20
8	1 9	20.1	35.3	13.0	2915	16193	1	2	3	4	5	6	20
9	1 13A	25.4	25.5	13.7	13517	97556	2	8	9	10	11	12	25
10	1 13B	28.9	35.5	13.7	3150	22738	2	8	9	10	11	12	25
11	1 14	28.6	33.9	15.0	7070	51091	2	8	9	10	11	12	25
12	1 15	29.8	30.3	15.1	4578	33012	2	8	9	10	11	12	25
13	1 16A	26.6	29.6	13.2	1801	17631	3	14	15	16	17	18	30
14	1 16B	36.5	39.6	12.5	4568	44718	3	14	15	16	17	18	30
15	1 12A	38.8	31.1	14.6	102171	737399	2	8	9	10	11	12	25
16	1 12B	27.9	30.4	13.8	25758	185903	2	8	9	10	11	12	25
17	1 12C	22.4	38.0	13.8	22323	161112	2	8	9	10	11	12	25
18	1 20A	11.7	19.8	9.4	6562	47366	2	8	9	10	11	12	25
19	1 20B	12.2	24.8	9.4	3099	22330	2	8	9	10	11	12	25
20	1 23A	12.8	26.2	8.9	2545	24010	3	14	15	16	17	18	30
21	1 23B	13.2	25.6	9.0	2972	29094	3	14	15	16	17	18	30
22	1 24A	11.7	18.5	8.3	5759	56377	3	14	15	16	17	18	30
23	1 24B	12.1	23.4	8.4	10264	100478	3	14	15	16	17	18	30
24	1 37	6.9	10.6	6.5	5313	29515	2	2	3	4	5	6	19
25	1 38	6.8	10.3	6.5	3338	24091	3	8	9	10	11	12	24

TABLE 2-18. PRINCIPAL OPEN HOPPER CAR COMMODITIES - CARLOAD FREQUENCY DISTRIBUTION

(CARLOADS x 1000)

COMMODITY	DENSITY (LBS/FT^3)	AVERAGE WT. PER CARLOAD (KIPS/CAR)	TONNAGE RANGES							TOTALS
			1-15	16-30	31-45	46-60	61-75	76-90	91-105	
Metallic Ores	100	160.6	1.84	—	1.84	7.34	69.76	234.99	108.32	424.09
Coal	55	166.6	10.93	5.46	10.93	415.39	1388.36	1366.36	1311.76	4509.11
Non-Metallic Minerals	100	155.2	5.14	2.56	5.14	82.16	308.08	331.19	251.60	985.87
Lumber (Wood Chips)	24.1	107.0	—	9.18	18.36	6.89	2.30	2.30	—	39.03
TOTALS			17.91	17.2	36.27	511.78	1768.42	1943.84	1671.68	5958.10

TABLE 2-19. CARLOAD FREQUENCY DISTRIBUTION OPEN TOP HOPPER CARS

(CARLOADS x 1000)

DENSITY RANGE (LBS/FT^3)	AVERAGE DENSITY (LBS/FT^3)	TONNAGE RANGES							TOTALS	ADJUSTMENT FACTOR	ADJUSTED TOTALS
		1-15	16-30	31-45	46-60	61-80*	81-90	91-105			
8-30	24.1	—	9.18	18.36	6.89	3.07	1.53	—	39.03	1.10	43.08
31-60	55.0	10.93	5.46	10.93	415.39	1843.73	910.91	1311,76	4509.11		4976.82
61-155	100.0	6.98	2.56	6.98	89.50	566.57	377.45	359.92	1409.96		1556.21
TOTALS		17.91	17.20	36.27	511.78	2413.37	1289.89	1671.68	5958.10		6576.00

*Tonnage range was changed from the computer printout range of 61-75 to 61-80. This was done by transferring 1/3 or 33% of the carloads in the 76-90 range into the 61-75 range. The change was made to allow 70-ton cars to have a maximum capacity of 160,000 lbs.

shipped in a particular, matching commodity density group. This percentage factor times the number of carloads in the commodity density range yields the individual DVC carload distribution and total carloads as shown in Table 2-20. Dimensional vehicle groups and corresponding "representative" loads are codified in Table 2-2(for open hopper cars, using DVC and lading code numbers or alpha numerics.

The total miles traveled by each DVC/lading combination is determined by multiplying the DVC carloads by the average miles per carload in the commodity density range previously calculated.

G. Methodology Verification

General Service Cars

To check the method of statistical analysis for each general service car, the total tons shipped according to the analysis is compared to the total net tonnage shipped in 1974 as determined by ICC annual statistics (apportioned to cartypes using ratios developed from waybill sample data). The total tons shipped according to the analysis is found by multiplying the number of carloads in each density range by their average weight per carload. For each cartype this aggregate tonnage is approximately 10 to 14 percent higher than the total tonnage indicated by the ratioed ICC totals.

Commodity Related Cars

To check the method of statistical analysis and the assumption that each car is filled to weight or volume capacity for commodity dependent cartypes, the total tons shipped according to the analysis is compared to the total net tonnage shipped in 1974 as determind from ICC annual statistics (apportioned to cartypes using ratios developed from waybill sample data). The procedure is similar to that for general usage cars. However, the tonnage shipped for the commodity dependent cars according to the analysis, is found by multiplying the number of carloads shipped in each car by its maximum weight capacity. For each cartype this aggregate tonnage is within 10 to 15

TABLE 2-20. OPEN HOPPER CAR LADING DATA SUMMARY

DVC No.	LADING CODE	AVERAGE DENSITY (LBS/FT^3)	WEIGHT CARLOAD (KIPS)	% POPU-LATION	TOTAL CARLOADS	NO. OF CARLOADS (1000's)	AVERAGE MILES/ CARLOAD	MILES LOADED (1000's)	MILES EMPTY (1000's)
16	34		96.4	15.79		6.80		1,158	1,054
17a	35		108.45	20.17		8.69		1,479	1,346
17b	36	24.1	130.14	19.44	43.08	8.37	170.22	1,425	1,297
18a	37		168.7	15.57		6.71		1,142	1,039
18b	38		168.7	29.03		12.51		2,129	1,937
4	39		110.0	6.69		332.95		90,476	82,333
5a	40		118.25	2.83		140.84		38,272	34,828
7a	41		148.0	25.46		1267.10		344,322	313,333
7b	42		148.0	7.74		385.21		104,677	95,256
7c	43		132.0	7.74		385.21		104,677	95,256
8a	44		110.0	1.29		64.20		17,446	15,876
9a	45		160.0	4.07		202.56		55,044	50,090
9b	46	55.0	160.0	2.73	4976.82	135.87	271.74	36,921	33,598
9c	47		176.0	0.83		41.31		11,226	10,216
11	48		166.0	0.94		46.78		12,712	11,568
12a	49		187.5	21.97		1093.41		297,123	270,382
12b	50		187.5	3.94		196.09		53,285	48,489
14a	51		197.0	2.37		117.95		32,052	29,167
14b	52		197.0	3.83		190.61		51,796	47,134
15a	53		199.0	6.87		341 91		92,911	84,549
15b	54		199.0	0.70		39.84		9,467	8,615
1a	55		100.0	37.55		584.36		83,727	76,191
1b	56		121.0	6.06		94.31		13,513	12,297
3	57		154.0	10.24		159.37		22,835	20,780
5b	58		154.0	4.03		62.72		8,987	8,178
6a	59	100.0	213.0	4.88	1556.21	75.94	143.28	10,881	9,902
6b	60		200.0	4.35		67.70		9,700	8,827
6c	61		200.0	5.99		93.22		13,357	12,155
8b	62		182.0	6.01		93.53		13,401	12,195
8c	63		182.0	20.88		324.94		46,557	42,367

percent of the total tonnage indicated by the ratioed ICC totals.

An additional check on this analysis was made based on the total annual mileage for all freight vehicles, both empty and loaded. Total mileage using ICC statistics (total annual carloads and an empty to loaded mileage ratio) and the DOT Waybill Summary data (average miles/carload) indicates a total mileage of approximtely 25.3×10^9 freight car miles while the total mileage accounted for in this analysis is approximately 23.8×10^9 miles indicating excellent correlation (within 5 percent).

H. Methodology Variations

The above methodologies were applied to all mechanical car types with some adjustments to suit each car type. A complete list of principle commodities carried by car type is given in Table 2-21. The following discussion describes methodology variation specific to each mechanical car type:

Covered Hoppers -- The majority of covered hoppers are grouped according to the commodity dependent car method. Cars with a capacity of less than 4000 ft^3 are used in metallic ore and mineral service. Grain is carried in cars with a cubic capacity between 4000 ft^3 and 5000 ft^3. The higher volume cars (those greater than 5000 ft^3) are used in plastic pellet service.

Tank Cars -- Since the density of commodities carried in tank cars is basically the same, the majority of cars are placed into one group. However, the density of chlorine is substantially higher than other commodities. Due to this and the fact that chlorine is a hazardous commodity, chlorine cars were grouped separately. Liquid Petroleum Gas (LPG) cars are also grouped separately since this commodity is carried in specific cars only -- those with a capacity of greater than 30,000 gallons.

TABLE 2-21. PRINCIPAL COMMODITIES CARRIED BY CAR TYPE

COMMODITY	BOX	STOCK	REFRIGERATOR	COVERED HOPPER	OPEN HOPPER	GONDOLA	FLAT	VEHICULAR FLAT	TANK
Field Crops	X		X	X					
Food & Kindred Products	X		X	X					X
Lumber	X						X		
Furniture	X								
Pulp & Paper	X		X						
Chemicals	X			X					X
Rubber & Plastic	X			X					
Stone, Clay & Glass	X			X					
Primary Metal Products	X					X			
Transportation Equipment	X						X		
Waste & Scrap	X					X			
Livestock		X							
Metallic Ores				X	X	X			
Non-Metallic Ores				X	X	X			
Woodchips						X			
Coal					X				
Shipper Assoc. or Similar							X		
Miscellaneous Mixed Shipments							X		
Automobiles								X	
Petroleum & Coal Products									X

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Instead of loading to weight capacity, tank cars are loaded to full volume capacity. This is done according to AAR regulations which specify that tank cars must be loaded to 98 percent volume capacity.

Gondola and Flat Cars -- Gondolas and flats are grouped using a combination of both methods. The majority of flat cars and gondolas can be classified as general usage cars. However, there are also some which are commodity dependent (coal and wood chips in gondolas, pulpwood and trailer carrying flat cars).

Vehicular Flats -- Vehicular flats are built to carry one commodity (assembled motor passenger vehicles). The method used to find the weight per carload differs from that used previously. It is based on the average tonnage carried and on the fact that bi-levels carry two-thirds the load of tri-levels. When average weights per carload are determined, the remaining calculations are carried out as in the commodity dependent car method.

Stock Cars -- Stock cars are also built to carry one commodity. The number of carloads and tonnages for commodities is not available from the waybill sampling data, and is taken from the ICC Freight Commodity Statistics for 1974. The average mileage is obtained from carload Waybill Statistics, U.S. Department of Transportation for 1974. The average weight per carload is calculated by taking a weighted average of the three major groups of livestock commodities (cattle, hogs, sheep).

Refrigerator -- Refrigerator cars are handled as general service cars, using only one density range which represents all carried products.

Appendix B contains summary data defining commodity or commodity-density groups and associated average and extreme load conditions characterizing representative loads for all mechnical car types. This load data is correlated to specific DVCs through lading code identifiers included in Appendix B.

2.2.2 Parameter Computation

The approach to characterizing the U.S. fleet of rail cars in terms of engineering parameters adequate to permit vehicle/track dynamic analyses began with a search of available literature. The result was that all parameter data uncovered was found to be for specific cars which were not representative of the wide variety of cars in the entire fleet. In order to complet the physical characterization of the 198 dimensional vehicle categories plus several hundred loaded car conditions, it was deemed necessary to compute more detailed vehicle physical descriptors such as mass moments of inertia, fundamental vertical lateral and torsional bending frequencies, carbody weights (or mass) and center of gravity heights, using appropriate computational algorithms.

The computer program, PARMS, used data directly from the dimensional vehicle category definitions plus information assembled from drawings, files and test data (as shown in Table 2-22 for a typical boxcar) to compute engineering parameters characterizing each of the dimensional vehicle categories. Some of the DVC data is simply transferred into the tabulations while other data is used in computation of additional parameters.

Carbody mass is computed from the vehicle lightweight, less the weight of a carset of trucks, plus lading weight. Truck centers, population, draft gear type, and truck capacity are direct DVC data. Other information such as center of gravity height, torsional stiffness and coupler length are determined for a typical car from each DVC, using drawings and files, and test data when available. Mass moments of inertia are computed based on structural data obtained from DVC dimensional drawings, such as length, height, and width, and a review of the mass distribution as detailed in representative design drawings. Vertical carbody stiffness and fundamental bending frequency are computed or estimated based on carbody stiffness and mass distributions determined from drawings of typical cars for each DVC. An example of the output data from the PARMS program for empty box cars is shown in Table 2-17.

TABLE 2-22. TYPICAL INPUT DATA FOR PARAMETER COMPUTATION PROGRAM (PARMS)

EXAMPLE - BOX CAR 24a

WC - Carbody Weight	-- 68,500 lbs.
XL - Carbody Length	-- 729 in.
XT - Length between Truck Centers	-- 555 in.
XP - Length between Coupler Pins	-- 760 in.
XC - Coupler Length	-- 29.3 in.
TS - Torsional Static Stiffness	-- 21.0 in-lb/rad.
CG - Center of Gravity Height above Rail	-- 72.9 in.
XB - Height from Rail to Bottom of Carbody	-- 42.0 in.
XW - Carbody Width	-- 122.0 in.
AP - Side Plate Area	-- 3.8 $in.^2$
AS - Side Sill Area	-- 8.7 $in.^2$
XH - Carbody Height	-- 137.0 in.
PM - Moment of Inertia--Side Plate in Doorway	-- 39.2 $in.^4$
SM - Moment of Inertia--Side Sill in Doorway	-- 387.3 $in.^4$
XD - Door Width	-- 120.0 in.
AT - Side Plate Area in Doorway	-- 6.8 $in.^2$
AB - Side Sill Area in Doorway	-- 11.4 $in.^2$
BX - Distance from Truck Center to Edge of Door	-- 217.5 in.
VF - Vertical Bending Frequency	-- 11.7 Hz.

Loaded car parameters such as annual mileage and lading codes are input directly to PARMS. Mass moments of inertia and frequencies, which are the parameters changed due to loading, are computed for the loaded car cases using several estimations depending on carload body type.

The accuracy of the computed parameters has been checked versus test results where available. The accuracy has been found to be reasonable for the purpose of this program (example comparisons are given later). Since the purpose of this program is to produce engineering parameters representative of grouped car configurations contained in each DVC, exact correlations of computed parameters with the actual parameters of any single car in that group cannot be expected. The computed parameters do, however, provide a good approximation of parameters for all cars contained in a single group (DVC). Depending upon a user's needs it may be necessary or desirable to supplement the data contained herein with additional information specific to a particular vehicle of interest

Accepting the fact that the engineering parameter descriptions of railcars developed herein, involve a degree of approximation these characterizations do provide sufficiently accurate data on which to base a characterization of the entire freight vehicle fleet.

The following sections describe the analytical methods used to compute engineering parameters for the various freight car dimensional vehicle categories (DVC):

2.2.2.1 Mass Moment of Inertia Calculations - The mass moments of inertia in roll, pitch, and yaw were calculated in PARMS by different procedures depending on carbody configurations. For empty cars, a single algorithm was applied to box, stock, refrigerator and covered hopper cars, and then to open top hopper and gondola cars, and individual algorithms were applied to flatcars with bulkheads, flatcars without bulkheads and tank cars.

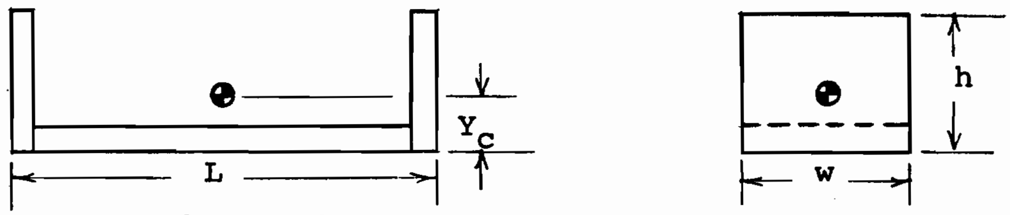
For loaded cars, mass moments of inertia were computed by one method for box, stock, and refrigerator cars, by a second method for covered and open hopper cars, a third for gondolas, and others for flatcars with bulkheads, flatcars without bulkheads, and tank cars individually.

The actual formulae for all cars are too lengthy to describe completely, but are based on standard engineering formulae. As an example, a flatcar with bulkheads is assumed to be three rectangular solids as shown in Figure 2-3. Mass moments are calculated (Figure 2-3) based on mass distribution between ends and floor as indicated by the center of gravity height.

For calculating loaded car parameters, the load is assumed to be evenly distributed between the bulkheads, full width, and from the deck to a height as indicated by the lading volume which is determined from lading density and total lading weight. The mass properties of this rectangular solid are calculated for each load type on this body type and added to the empty car data.

2.2.2.2 Carbody Static Stiffness Calculations - The stiffness of the carbodies was determined for the vertical, lateral, and torsional directions. The vertical and lateral stiffnesses were computed using the areas of the side sill and side plate, the height of the side girder, or the width of the car. The torsional stiffness values were input directly based on data from publications and tests and were extrapolated, based on car lengths and types, to provide estimated stiffness values for all DVCs.

A single algorithm was employed for vertical stiffness of box and refrigerator cars which took into account the door opening and location. A second algorithm was used for open top and covered hopper cars and gondolas. A third algorithm was used for all flatcars, and a fourth for tank cars. In general, there was only one algorithm used to compute lateral stiffness for all types, except for tank cars where the lateral stiffness was equal to the vertical stiffness. The lading was not considered to contribute any additional stiffness to the car and was, therefore, not considered in these calculations. These algorithms combine the



$$I_{roll} = \frac{Wf}{g}\left(Y_c^2 + \frac{w^2}{12}\right) + \frac{We}{12g}\left(h^2 + w^2\right) + \frac{We}{2g}\left(\frac{h}{2} - Y_c\right)^2$$

$$I_{yaw} = \frac{Wf}{12g}\left(L_2 + w^2\right) + \frac{We}{2g}\left(\frac{L^2}{2} + \frac{w^2}{12}\right)$$

$$I_{pitch} = \frac{Wf}{g}\left(Y_c^2 + \frac{L^2}{12}\right) + \frac{We}{g}\left(\frac{L^2}{2} + \frac{h^2}{6}\right) + \frac{We}{2g}\left(\frac{h}{2} - Y_c\right)^2$$

Where: W_c = car weight

W_f = flat weight = $W_c\left(\frac{h - Y_c}{h}\right)$

W_e = end weight = $W_c\left(\frac{Y_c}{h}\right)$

g = acceleration of gravity

L = car length

w = car width

h = car height

Y_c = center of gravity height

I_{roll} = mass moment of inertia - roll

I_{yaw} = mass moment of inertia - yaw

I_{pitch} = mass moment of inertia - pitch

FIGURE 2-3. MASS MOMENT OF INERTIA CALCULATION EXAMPLE - FLATCAR WITH END BULKHEADS basic vehicle descriptive data (dimensional and construction) with standard engineering formulae to provide the required stiffness data.

2.2.2.3 Natural Frequency Calculations - Natural frequency estimates were made for the various carbody types by two different approaches since the doorway in box-type cars is an important discontinuity in the structure not found in the construction of hopper cars, etc.

Box, stock and refrigerator cars were handled by using small finite element models in NASTRAN for each DVC to estimate the first mode vertical bending frequency. These results were input directly into the PARMS program.

Lateral and torsional frequencies for boxcars, and all three body frequencies for other cars were calculated in PARMS using the following formulae:

$$f_{vertical} = \frac{11.2}{\pi}\sqrt{\frac{EI_s}{ML^4}}$$

$$f_{lateral} = \frac{11.2}{\pi}\sqrt{\frac{EI_f}{ML^4}}$$

$$f_{torsional} = \frac{1}{2}\sqrt{\frac{Ts}{I_x}}$$

where:

M = car mass per unit length

L = car length

I_s = Area Moment of Inertia - Sides

I_f = Area Moment of Inertia - Floor

I_x = Mass Moment of Inertia - Roll

Ts = Torsional Stiffness

The PARMS output results have been compared with two cases where test data is available for carbody natural frequencies.

The 80-ton open hopper car tested by Martin-Marietta (NASA Report CR-144000) falls in open hopper DVC No. 9A, and the reported test results are compared in Table 2-23 versus the PARMS results.

TABLE 2-23. PARMS RESULTS VS MARTIN-MARIETTA TESTS RESULTS - DVC NUMBER 9A

		TEST	PARMS
Empty Car	$f_{vertical}$	29.6 Hz	34.7 Hz
	$f_{lateral}$	17.6 Hz	28.0 Hz
	$f_{torsional}$	5.3 Hz	2.9 Hz
Loaded Car	$f_{vertical}$	14.6 Hz	14.8 Hz
	$f_{lateral}$	8.3 Hz	11.9 Hz
	$f_{torsional}$	4.9 Hz	1.4 Hz

Comparison was also made for flatcar DVC No. 28A vs. the 89-foot flatcar reported in the Track Train Dynamics Demonstration Test and Analysis, Volume 1 - Free Vibration Study. The first vertical bending mode response from this test of 4.28 Hz compares well versus the PARMS output of 6.1 Hz. Generally, these comparisons show the vertical bending frequencies have the best correlation with test results while the torsional frequencies show the least correlation.

However, the computed values of vertical bending frequencies are reasonably accurate for the purpose of separating the carbodies into groups such as flexible or rigid based on carbody fundamental vertical bending frequencies.

The final tabulations of the computed freight carbody parameters (PARMS output) are given in Appendix C for both empty and loaded cars. These tabulations contain sufficient data to assemble complete engineering parameter and dimensional descriptions of the freight car population including population data, and estimated frequency of occurence for each loaded and unloaded vehicle configuration described in terms of total annual mileage traveled. This vehicle information uses "CORS" number, a truck code, and lading codes as a mechanism to allow cross referencing between various data elements. Freight vehicle truck characterizations are described in the following section.

2.3 FREIGHT TRUCK CHARACTERIZATION AND CORRELATIONS WITH DVC

The modern freight car truck, consisting of a three-piece frame and two wheel-axle sets, is a proven design evolving out of 100 years of railroading. The pair of trucks that comprise a car-set are designed to carry the freight car over widely varying track profiles and to sustain all the dynamic loads imposed by track related excitations.

The freight car truck is designed to four very distinct capacities due to the restraint of allowable wheel loads, standard wheel diameters, interchangeability of trucks of the same capacity, and other industry standards. These four nominal capacities are 50-ton, 70-ton, 100-ton, and 125-ton (although the 125-ton truck is, at present, only allowed to carry the 100-ton rail load limit).

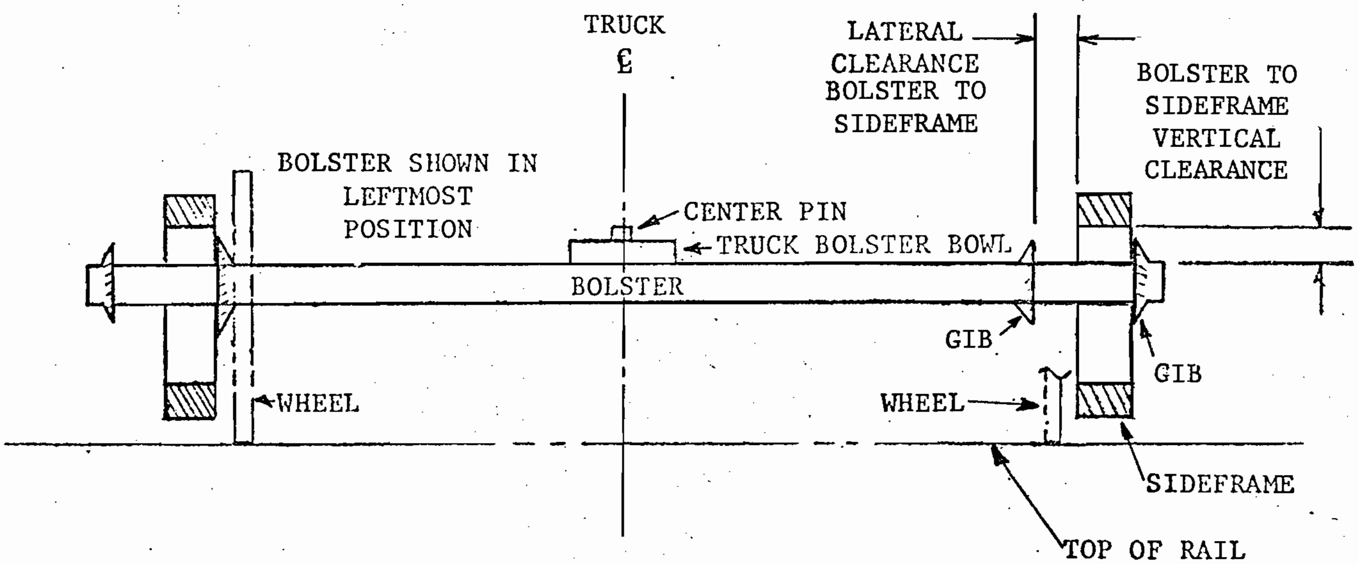
Freight car trucks were naturally, therefore, characterized by these four capacity distinctions. A fifth category was added to include those trucks designed to go under low level flat cars. These low level trucks have been designed to both 70-ton and 55-ton capacities. After discussion with truck manufacturers, it was decided that while the 55-ton capacity was originally used, the 70-ton truck has since become the more common truck for low level flatcars. Since either design used a 28 inch diameter wheel, the effective rail load limit for these low-level cars is approximately 179,000 lbs. These five categories, then constitute the basic freight car truck designs in service in the freight vehicle fleet.

As stated above, the freight car truck consists of a three-piece frame and two wheel-axle sets. The frame consists of the bolster, which spans the truck from side to side, and is supported on two sideframes. The sideframes in turn mount on the wheel-axle sets. A wheel-axle set is simply comprised of two flanged wheels mounted on the ends of a single axle. Two of these sets are used in an assembled truck. A schematic of the truck is shown in Figure 2-4.

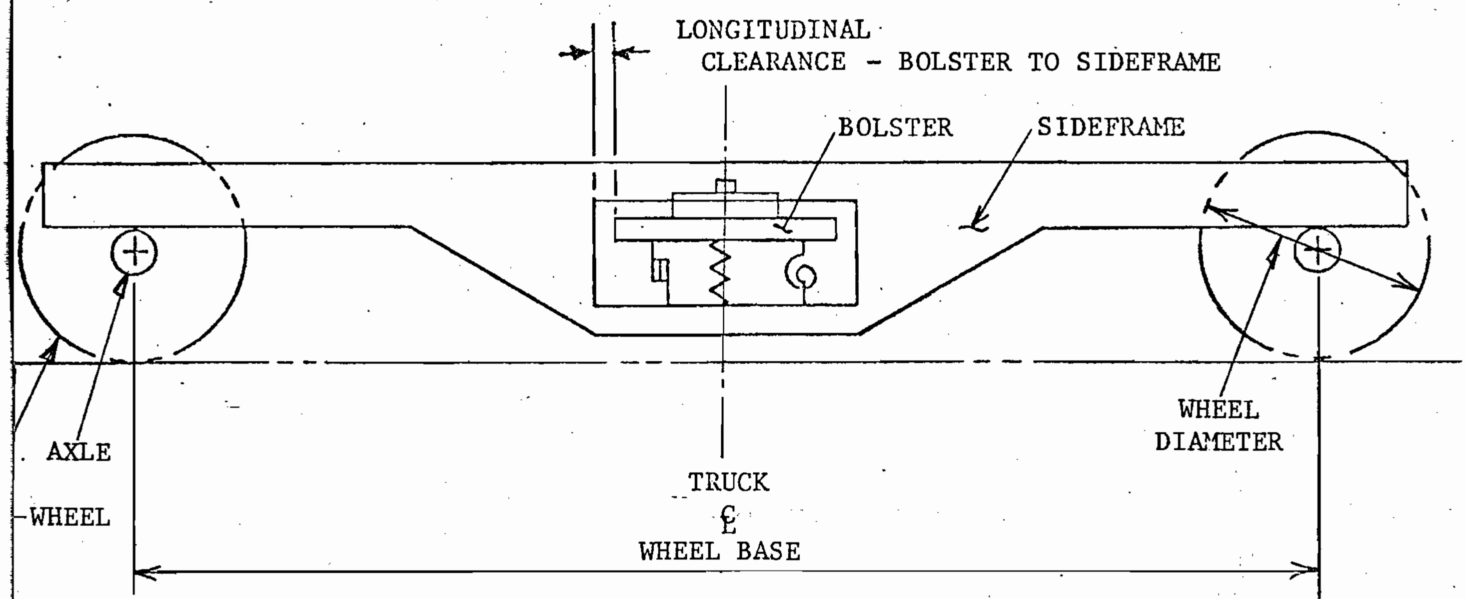
The bolster is made of high strength steel and is a one-piece casting. At its centerline is a circular bowl, known as the bolster bowl, with a nominal diameter varying from 12 to 16 inches. The bowl has a flat bottom and a 1-1/8 inch high rim around its perimeter. It is in this bowl that the matching diameter carbody centerplate supports the weight of the car. In addition, there is a center pin coming up through the bowl to a height of eight inches that fits into a matching hole in the center of the carbody centerplate. The carbody is free then to rotate in this bolster bowl, while forces in three directions (vertical, lateral and longitudinal) are transmitted through this interface. The truck bolster also has two roller side bearings in cages attached to its top surface, each being 25 inches from bolster centerline (towards the sideframe). These side bearings form a secondary carbody-truck interface in the event of car rocking. They are literally rollers, and transmit mainly vertical forces. Normally, however, there is clearance between the roller and the carbody.

Between the bolster and each sideframe is a group of coil springs which is the suspension of the truck. The groups vary according to car and truck capacity, while the basic patterns are determined by AAR standards. The truck suspension contains friction dampers that act in the vertical and lateral directions and are of two main types.

One damper system uses separate springs to supply a constant friction force irrespective of spring height while the second type using springs in the main spring group provides a varying force with varying spring heights. Estimations of population ratios of constant damping versus variable damping trucks in service vary



END VIEW



SIDE VIEW

FREIGHT CAR TRUCK - TYPICAL

widely. Based on Pullman's experience, a reasonable estimate would be equal percentages of the two types. If a car owner so desires, this suspension group could also contain auxiliary hydraulic or friction damping to control vertical motion.

The sideframe is a high strength steel casting designed to span between wheel-axle sets, while providing a seat for the suspension group at its centerline. At each of its ends the sideframe sits on a bearing which in turn is mounted directly to the axle.

There are two types of axle bearings, journal (bronze) and roller. Since the 1950s the roller bearing has been an industry standard, so only older trucks are still supplied with journal bearings, roughly 5 percent or less of the total truck population.

Having defined the aforementioned major categories of freight car trucks, the task of assembling parameters for a typical truck in each category was begun. Three principal sources were used to compile this data. These include published literature or manufacturers data, analytical computation, and parameters estimated from test data and experience. In some cases, more than one source was used in order to complete the data necessary to establish a given parameter. A list of the principal data requirements for freight car truck characterization and corresponding sources is given in Table 2-1. Since additional truck data was readily available in the literature, an expanded characterization has been provided in Appendix D.

Differences in truck frame design from one manufacturer to another have little effect on the value of most parameters since the standards of the Association of American Railroads are used by all manufacturers and govern dimensions, design loads, materials, and commonality of spring groups, resulting in great similarities between trucks in the areas of mass, stiffness, geometry, and tolerances. The differences between trucks occurs mainly in the area of lineal friction damping. Therefore, it was decided that characterization of one manufacturer's truck would adequately provide most parameters for all trucks.

Refering to the freight truck data tabulated in Table 2-24 the first item in this tabulation is truck mass which is given for an assembled truck as well as for certain individual components which contribute a significant proportion of the total. These values were gathered from manufacturers' data which was already in Pullman Standard Engineering files. The second item, cneter of mass, is given for a complete truck measured from the top of the rail. This number was calculated using mass values and dimensions from manufacturers' drawings. The next three items are the rotational intertias of an assembled truck about its center of mass. These values were calculated using the given mass values and the associated geometry from manufacturers' drawings. Secondary rotational inertias are given excluding the bolster inertia. These inertias are taken about the truck bolster bowl surface locations. Beginning with the bolster to sideframe vertical stiffness and continuing through the next 15 items to center-plate to rail pitch stiffness, are the translational and rotational stiffness values as a function of displacement. The bolster and sideframe stiffness in the vertical and lateral directions were provided by American Steel Foundries (ASF), a major truck manufacturer. Average vertical and lateral spring group stiffnesses were available in published literature of test results, as well as from AAR standards. The differences between AAR standard spring groups for a given capacity truck are small and were, therefore, neglected. It should be noted that the values for lateral spring group stiffness are given for two extreme spring heights (an empty car and a fully loaded car spring heights). The lateral stiffness with respect to spring height is non-linear, and is best established by test. The sixteen different stiffness parameters in the tabulation were calculated using appropriate combinations of component part stiffnesses, spring group stiffnesses, and truck geometry obtained from manufacturers drawings.

The next three parameters in the tabulation are lineal friction damping values between bolster and sideframe in the vertical and lateral directions, and centerplate yaw friction. The vertical and lateral coefficients of friction were obtained from the Track-

TABLE 2-24. FREIGHT CAR TRUCK PARAMETERS

I. GENERAL FAMILY DESCRIPTORS AND COMPOSITION

Family No.	1	2
Descripton (Classification)	50-ton	70-ton
Assembled Weight/Pair	13,830 lbs.	16,310 lbs.

II. ENGINEERING PARAMETER DESCRIPTION OF FAMILIES

	PARAMETER	VALUE	VALUE	NOTES
MASS & INERTIA	Mass: Complete Truck	17.9	21.1	mass units
	One Sideframe	1.7	2.1	lb-sec^2/in.
	Bolster	2.2	2.7	
	Wheelset (axle-2 wheels)	5.0	5.6	
	Center of Mass (in.)	17.1	17.5	complete truck-above of rail
	Yaw Moment of Inertia w/bolster	30,400	35,950	complete truck-about center of mass; lb-sec^2-in (typical)
	Yaw Moment of Inertia w/o bolster	29,400	34,740	
	Pitch Moment of Inertia w/bolster	14,590	18,050	
	Pitch Moment of Inertia w/o bolster	15,660	19,180	about centerplate
	Roll Moment of Inertia w/bolster	17,190	19,590	
	Roll Moment of Inertia w/o bolster	17,280	19,600	about centerplate
SPRING & MEMBER STIFFNESS	Bolster to Sideframe -Vertical Stiffness	(D-3,4) 48,730	(D-5) 47,130	2 spring groups lb/in. (typical)
	-Lateral Stiffness empty car	9,510	7,160	
	-Lateral Stiffness loaded car	24,030	18,810	
	Bolster to Sideframe -Roll Stiffness	72.2×10^6	71.7×10^6	springs only in-lb/rad. (typical)
	-Yaw Stiffness empty car	14.1×10^6	10.9×10^6	
	-Yaw Stiffness loaded car	35.6×10^6	28.6×10^6	
	-Pitch Stiffness	4.38×10^5	7.94×10^5	
	Sideframe to Wheelset -Vertical Stiffness	5.46×10^6	6.26×10^6	bending of two sideframes lb/in.
	-Lateral Stiffness	652,000	800,000	bending of one sideframe lb/in.
COMPLETE TRUCK STIFFNESS (INCL. STRUCTURAL COMPLIANCE)	Centerplate to Rail -Vertical Stiffness (springs, bolster, sideframes)	47,250	45,930	lb/in. (typical) prior to solid springs
	-Vertical Stiffness (bolster, sideframes)	1.558×10^6	1.797×10^6	solid springs
	-Lateral Stiffness (springs, sideframes)	9,440 23,600	7,130 18,590	-emtpy car -car loaded to capacity prior to gib contact
	-Lateral Stiffness (one sideframe only)	652,000	800,000	after gib contact
	Centerplate to Rail -Roll Stiffness (springs, bolster, sideframes)	70.0×10^6	69.5×10^6	in-lb/rad. (typical) prior to solid springs
	-Roll Stiffness (bolster, sideframes)	2.31×10^9	2.73×10^9	solid springs
	Centerplate to Rail -Yaw Stiffness	2.2×10^9	3.3×10^9	in-lb/rad. (typical) bolster, sideframes only
	-Pitch Stiffness	482.0×10^6	574.0×10^6	bolster, sideframes only
	Bolster Vertical Stiffness	2.18×10^6	2.52×10^6	lb/in.
FRICTION DAMPING	Lineal Damping/Friction Bolster to Sideframe -Vertical	0.5	0.5	average coefficient of sliding friction
	-Lateral	0.37	0.37	

TYPE

TABLE 2-24. FREIGHT CAR TRUCK PARAMETERS (CONT)

	Family No.	1	2	
	PARAMETER	VALUE	VALUE	NOTES
FRICTION DAMPING & COLUMN LOADS	Centerplate Yaw Friction -Dry Surface -Teflon Surface	 2.1 .41	 2.4 .41	torsional resistance/ vertical load in-lb/lb. (typical)
	Column Load - Constant (4/truck) lbs.	(D-3) 3130 (D-4) 2360	(D-5) 4040	nominal force acting on one sideframe column
	Column Load - Variable (4/truck) lbs.	N/A	(D-5) 1472 3430	-empty car) -loaded car) one column
CLEARANCES	Bolster to Sideframe -Vertical Clearance	5.69	5.75	solid springs in.
	-Lateral Clearance (average worn condition) (range) (standard deviation)	 0.75 .375 - 1.125 0.125	 1.10 0.70 - 1.5 0.135	in.
	-Longitudinal Clearance (average worn condition) (range) (standard deviation)	 ±0.19 .064 - .316 0.042	 ±0.22 .061 - .375 0.053	in.
	Sideframe to Axle Yaw Clearance	9.8/4.5	7.2/3.4	(max/min) degrees, roller bearings
	Centerplate-Bolster Bowl Net Clearance	0.5/0.25	0.5/0.25	(max./min.) in.
	Side Bearing Clearance (average worn condition) (range) (standard deviation)	 0.25 .125 - .375 0.042	 0.25 .125 - .375 0.042	in.
DIMENSIONS	Wheelbase Distance	66.0	68.0	in.
	Wheel Diameter	33.0	33.0	nominal at tape line (in.)
	Distance Between Outside Face of Wheels	64.19	64.19	average nominal condition (in.)
	Bolster Bowl Diameter	12.0	14.0	new nominal condition (in.)
	Center Pin Height	8.0	8.0	above bowls bottom surface (in.)
	Rail to Bolster Bowl Wear Surface Height	25.75	25.75	empty car on truck (in.)
	Side Bearing Distance from Longitudinal Centerline	25.0	25.0	(in.)

From Appendix D

WATCH

D TYPING

REDUCED TO 90% OF ORIGINAL

Train Dynamics (TTD) Harmonic Roll Series - Volume II Report on "70-ton Truck Component Data." The values taken from this report were obtained from tests conducted by ASF. The centerplate yaw friction values were also obtained from the TTD-Harmonic Roll Series Report and are given for dry steel and teflon contact surfaces. Centerplate-bolster bowl contact surfaces are normally lubricated, threfore the dry steel then would represent a high friction extreme, while the teflon would denote a low extreme, with maximum lubrication.

The next five items in the tabulation are clearances which are calculated from manufacturer or AAR standard tolerances between truck components. Wear is assumed to be a contributing factor on several of the items as clearances increase due to the motion of the truck. The clearances affected by wear are listed as average worn values with one standard deviation, calculated asssuming a normal or gaussian distribution between a new truck condition and the condemnable limit on wear as given in the AAR Interchange Rules.

In each case clearance values exclusive of wear were calculated from manufacturers' drawings for each truck type as outlined in the TTD-Harmonic Roll Series - Volume II Report on 70-ton Truck Component Data.

The next seven items in the tabulation cover truck geometry. These values were obtained from published standards of the AAR.

The last two items are the column loads which provide the suspension damping. These values, as given for the appropriate spring group in each category, were obtained from manufacturers data. The first column load given is constant with respect to spring height, while the other is variable and given for the two spring height extremes. These column loads act in a normal direction to the sideframe column. The damping friction force is equal to the column load times the coefficient of friction for the appropriate direction of motion. There are two columns per sideframe and four columns per truck.

Each truck category has an associated maximum allowable gross rail load (limit) for a carset of trucks. This rail limit allows a simple correlation between trucks and carbodys since the total of the light car weight plus the lading weight (or weight capacity) cannot exceed the specified rail limit for each truck group. The allowab allowable gross rail load for 50-ton trucks is 177,000 pounds per carset, 220,000 pounds for 70-ton cars, 263,000 pounds for 100-ton cars, and 315,000 pounds for 125-ton cars. Referring to the example UMLER worksheet in Table 2-4, the boxcar lading capacity shown there is 149,000 pounds while the light weight of the example car is 64,000 pounds. Therefore, the total gross rail load is 213,000 pounds, which is greater than the 50-ton truck allowable but less than the 70-ton truck allowable. Therefore, the example car would be equipped with 70-ton trucks. This method was employed to determine which truck type is under each DVC. This procedure was applied to all cars to correlate the DVC's with their appropriate truck.

2.4 SUMMARY OF FREIGHT VEHICLE CHARACTERIZATION DATA

At this point, the entire freight vehicle fleet has been represented by the 198 dimensional vehicle categories and 437 vehicle - lading combinations. Principle engineering parameters required for dynamic analysis have been tabulated (Table 2-25) for each vehicle and vehicle - lading combination and are given in Appendix C. Estimates of total annual mileage have been compiled which are indicative of the relative frequency of occurrence of each vehicle configuration in service and a detailed characterization of freight vehicle trucks and suspensions has also been provided in Appendix D which has been codified in order to correlate the appropriate truck data with each vehicle characterization.

These 635 vehicle and vehicle-lading configurations with associated mileages and truck data provide a detailed description of the composition of the in-service railway freight vehicle fleet. This data base provides an important and heretofore unavailable source of vehicle characterization data which may be used in vehicle dynamic modeling activities such as:

a) Comparative dynamic analysis of individual vehicle designs. Since approximately 95 percent of the freight vehicle fleet is characterized by the 635 vehicle and vehicle lading descriptions, virtually any vehicle in the fleet can be closely approximated by identification of that vehicle with the appropriate dimensional vehicle category.

b) Dynamic analysis of large population groups of freight vehicles: Since each dimensional vehicle category represents a significant percentage of the freight fleet, modeling of a single DVC, therefore, will approximate the response of a significant vehicle population.

c) Dynamic analysis of the entire freight fleet of U.S. rail vehicles: Using the data base provided, the entire freight fleet may be modeled as a group of 635 representative vehicles.

2.5 DEVELOPMENT OF GENERIC FREIGHT VEHICLE FAMILIES

While the last analysis described above may be impractical because of the large number (635) of vehicle and vehicle/lading characterizations developed, these characterizations provide a basis for further grouping of railcars to produce a smaller number of generically similar railcar designs. These groups have been established by grouping the 635 vehicle and vehicle/lading characterizations on the basis of key configurational features which are known to have an important effect of railcar dynamic response. Grouping vehicles in this manner results in a relatively small number of freight vehicle families which should exhibit generically similar dynamic response characteristics. The 635 vehicle and vehicle/lading characterizations (i.e. DVCs) have been grouped according to the following railcar physical attributes:

- o Suspension characteristics.
- o Truck center spacing.
- o Gross weight.(1)
- o C.g. height.(2)
- o Carbody vertical bending frequency.

The railcar's suspension characteristics have a major effect on dynamic response characteristics. Consequently, three separate groups were established in the initial sorting to correspond to 50, 70, and 100 ton truck designs since these are the dominant population groups. Since there are relatively small numbers of 125 tons and low-level truck design in service these were handled separately as special cases. Truck center spacing is included in the sorting algorithm because it acts as a chordal filter on important track geometry irregularities, (especially those associated with bolted construction.) Vehicle gross weight is especially important in predicting vertical wheel/rail forces; c.g. height is particularly important to harmonic roll analysis; and, vertical bending stiffness influences railcar stability and general response characteristics. To develop generic railcar families, a computer code incorporating histogramming features was developed and used to group vehicles into a matrix of families according to specified ranges on railcar physical characteristics described above. The historgramming feature was used to identify natural groupings of vehicles in the fleet. For a given sorting parameter, the range of possible values was first established. This range was then divided into 50 equal increments and a histogram was developed by grouping vehicles into this matrix according to the sorting parameter.

This histogram data was used to define the final sorting bandwidths on each sorting parameter. Using this approach the 635 DVCs have been combined into a total of 66 generically similar freight vehicle families, as discussed below. Because each family is composed of a number of DVCs, the generic family descriptions are necessarily statistical. In addition, to account for the relative in-service usage of vehicles composing each family, the statistical descriptions have been mileage weighted.*

(1) Weight of carbody, carset of trucks plus load weight (if applicable).

(2) Composite c.g. height of carbody and lading (if applicable). Does not include trucks.

Figures 2-5, 2-6, 2-7, and 2-8 present a summary of initial definitions of generically similar freight vehicles. These figures illustrate the order of sorting as well as the sorting bands used for each parameter. The final sorted groups are representative of how the DVCs can be handled in terms fo defining generically similar vehicle configurations and do not necessarily represent a final definition of generic vehicle families.

The first level of sorting was based on the nominal vehicle capacity and corresponding truck capacity. Since the truck characteristics (damping, spring constants, etc.) are inherently related to the dynamic response of a vehicle to track irregularities, it is natural to divide the entire freight car fleet characterization data into the five major capacity groups: 50-ton, 70-ton, 100-ton, 125-ton, and 70-ton low level as shown in Figure 2-5. In addition, three vehicle configurations were chosen

*Reference Section 4.3 of Volume I for supplemental discussion.

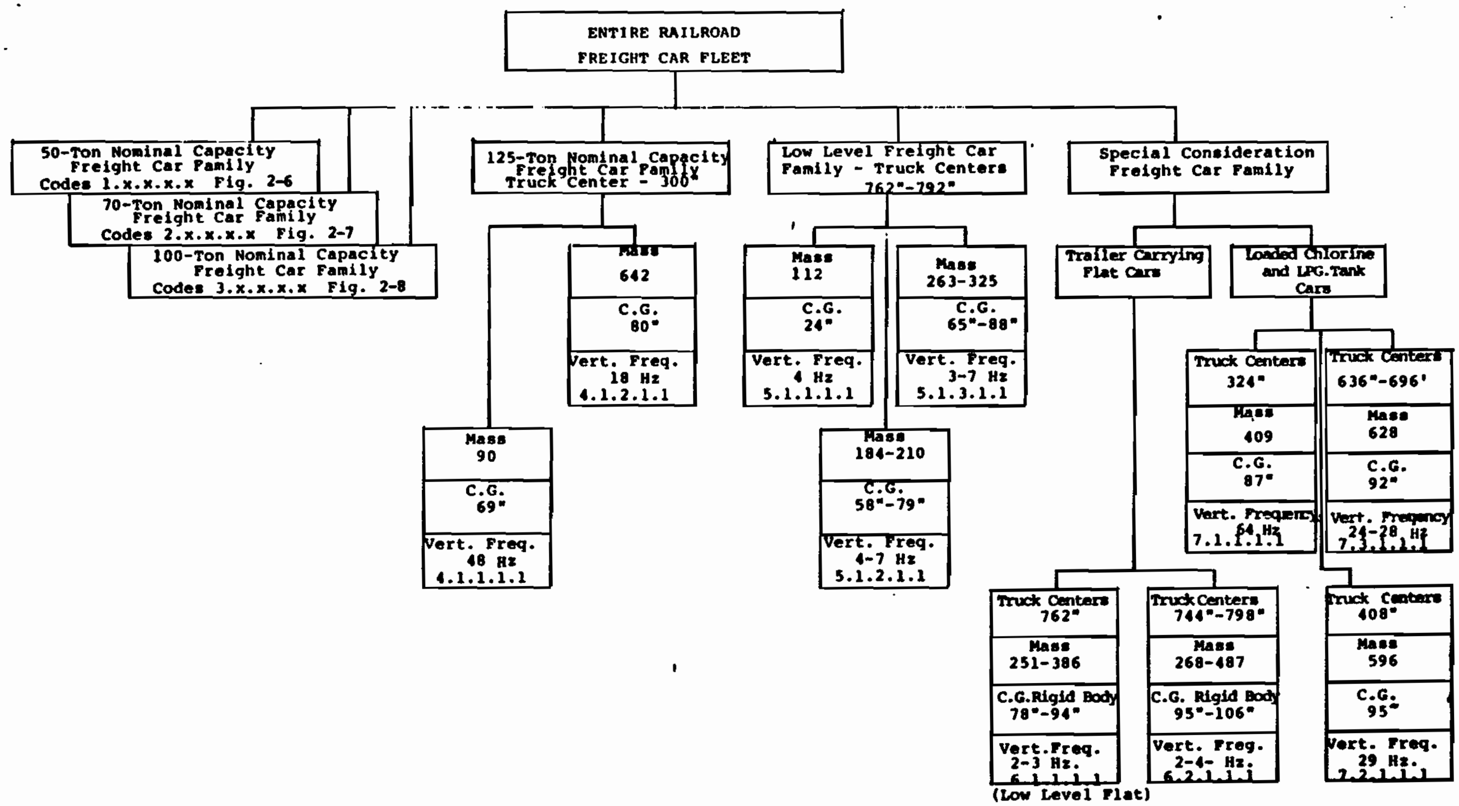


FIGURE 2-5. ENTIRE RAILROAD FREIGHT CAR FLEET SORT

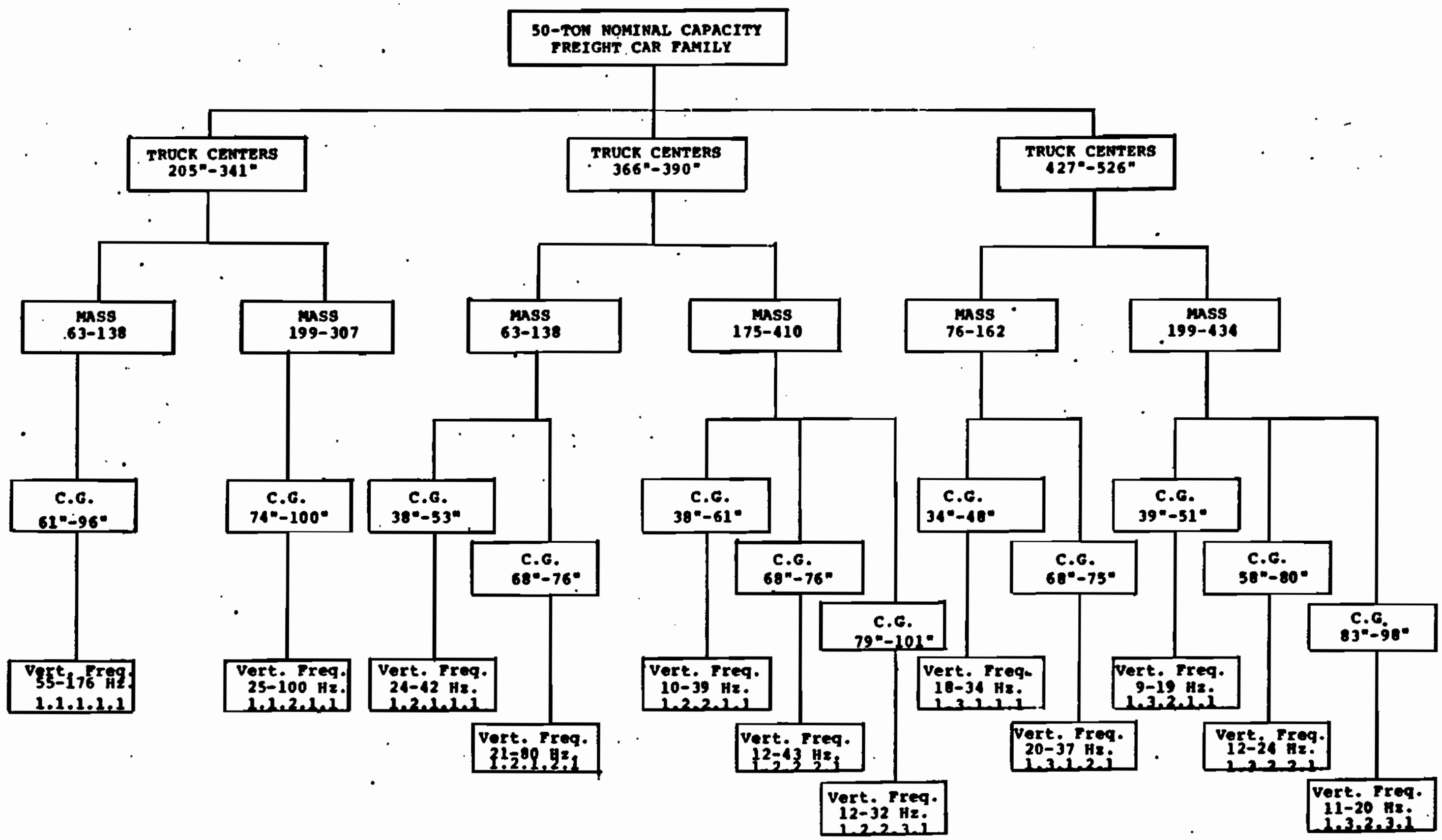


FIGURE 2-6. 50-TON FREIGHT CAR FAMILY SORT

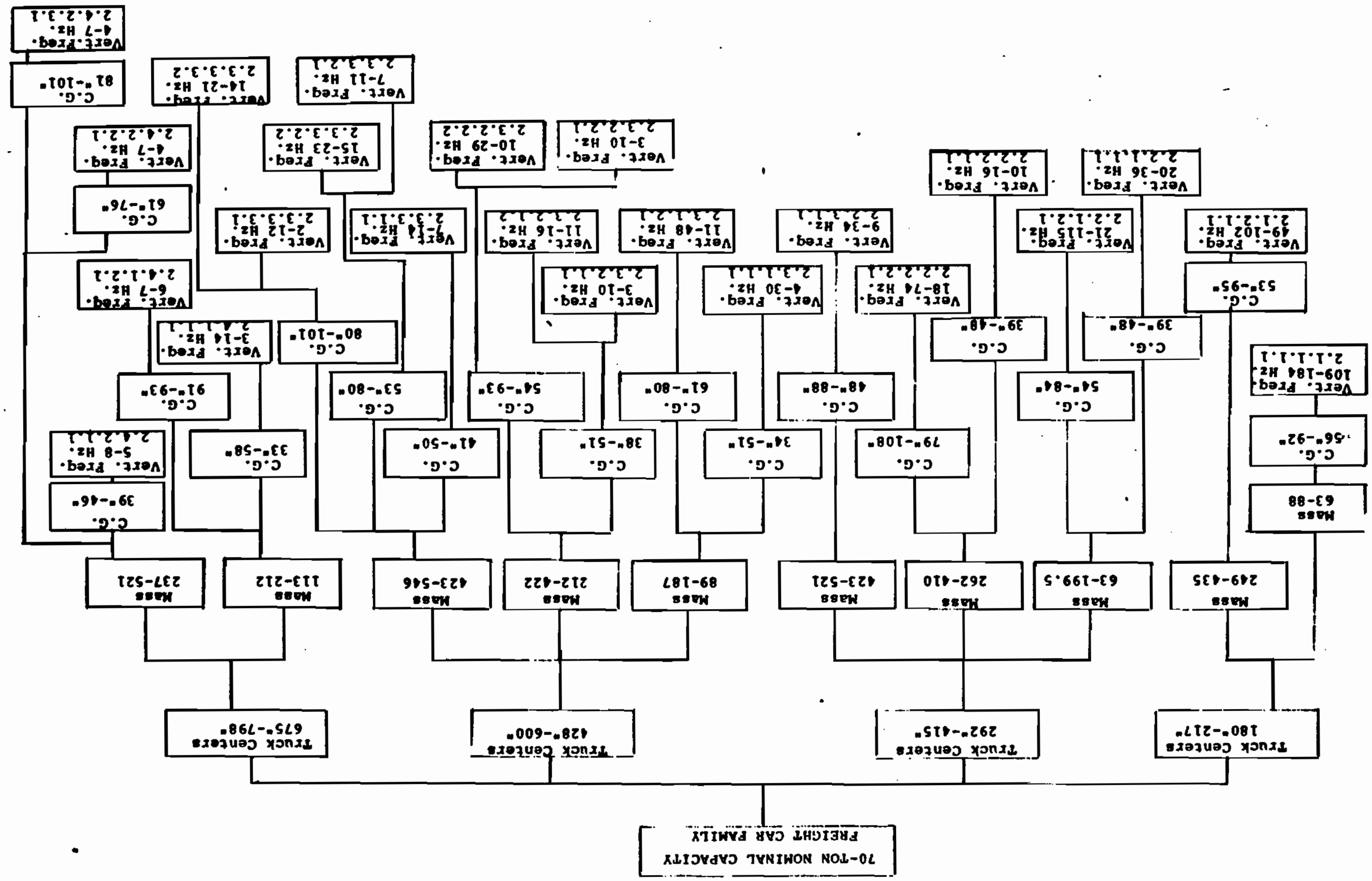


FIGURE 2-7. 70-TON FREIGHT CAR FAMILY SORT

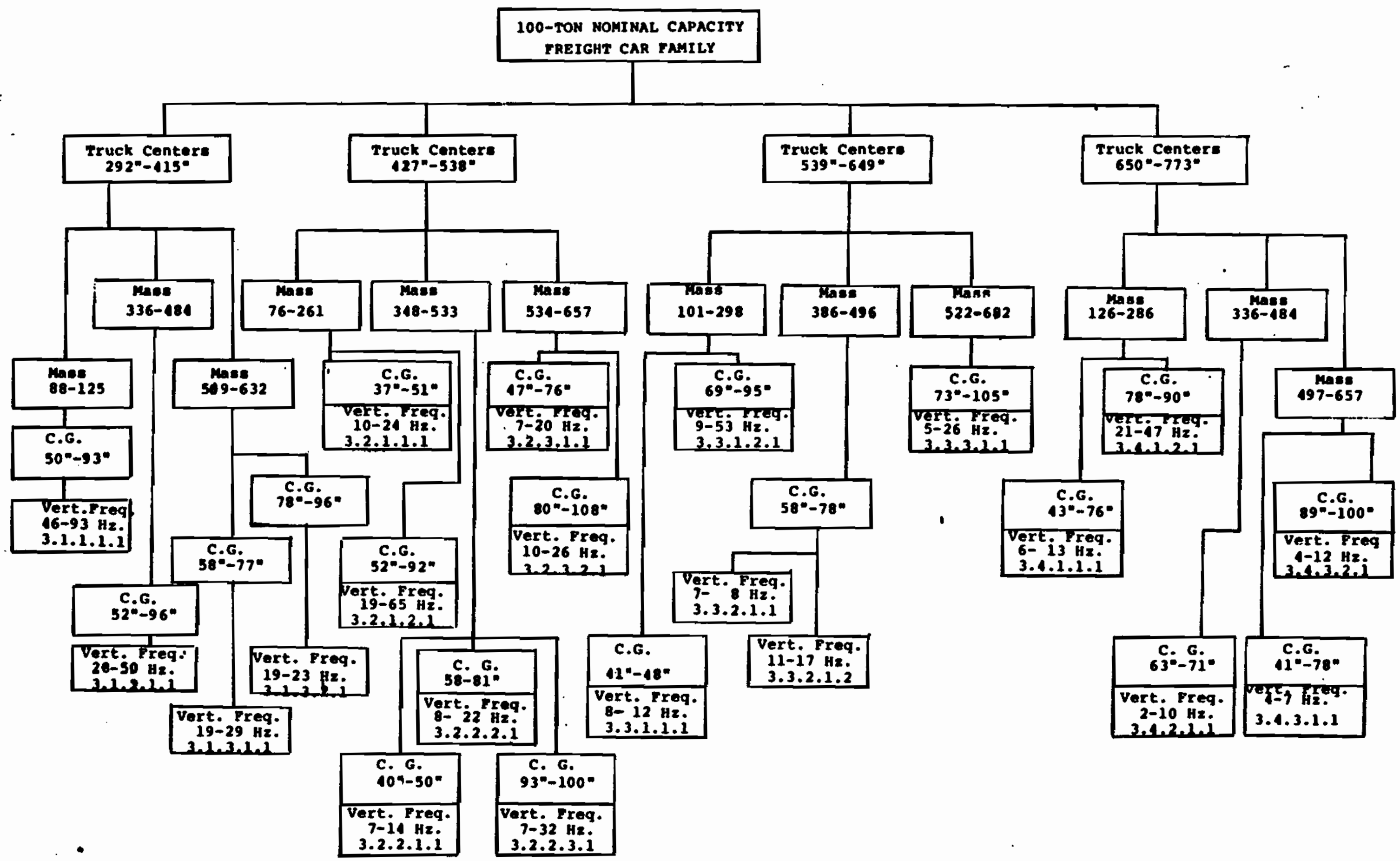


FIGURE 2-8. 100-TON FREIGHT CAR FAMILY SORT

to receive special consideration. These are the trailer carrying flatcars (TOFC), chlorine tank cars, and LPG tank cars. The TOFC cars require separate characterization due to the influence of the trailer's suspension on the dynamic response of the overall vehicle-lading configuration. Additional data has been generated to characterize the trailer suspension. These same vehicles when empty, do not have this unique influence and are, therefore, included as empty vehicles in the overall sorting of the freight fleet characterizations. The chlorine and the LPG tank car characterizations received special handling due to the hazardous nature of their commodities. For the purposes of this program, only chlorine and LPG were defined as hazardous commodities even though lists of published "hazardous commodities" are far more extensive. Again, empty chlorine and empty LPG tank cars are not considered hazardous and were included in the overall sorting of the freight fleet characterizations.

Returning to the first level of sorting by truck capacity, the entire set of fleet characterizations were sorted into five nominal capacity groups, except for the special consideration cars just discussed. Each capacity group was then divided into truck center spacing groups. Groups were basically established by reviewing histogram data which described the number of total annual miles traveled by freight vehicles as a function of various values of the sorting parameter. (For example, the range of truck center spacings existing in the fleet, as described by the DVCs, is divided into a total of 50 equal intervals, and mileage histograms are developed as a function of these 50 increments on truck center spacing.) This data is used to define distinctive ranges of truck center spacing. Similar histograms are used for vehicle gross weight (using mass units), center of gravity height and vertical bending frequency as described below.

As an example, three truck center spacing groups as used for 50-ton vehicles (Figure 2-6) were: 205 inches to 341 inches, 366 inches to 390 inches, and 427 inches to 526 inches. These bands are not continuous since the histogram analysis, made to determine possible sorting bands, showed all 50-ton vehicles exist in the three bands selected. The selection of truck center spacing groups was tempered by the desire to maintain at least one group near the 39 foot (468 inches) spacing of staggered rail joints. This group would then be expected to exhibit the most significant response to the harmonic irregularities provided by this standard track construction. Thus, all nominal capacity groups, were divided into truck center spacings of which one group is "closest" to the 39 foot spacing of rail joints.

Each truck center spacing group was then further subdivided into mass groups as a third level of sorting. Again, a histogram analysis allowed determination of natural groupings and possible bandwidths. As an example, the 50-ton capacity vehicles (Figure 2-6) with a truck center spacing of 366 inches to 390 inches, were found to have vehicle or vehicle-lading mass in two groups: 63 to 138 lb.-sec.^{2}/in. and 175 to 410 lb.-sec.^{2}/in. Further analysis of each of these mass groups was used to provide a fourth level of sorting using the center of gravity height parameter. Thus it was found, as shown in Figure 2-6, that all 50 ton capacity vehicles, with a truck center spacing of 366 inches to 390 inches, and with a mass between 175 and 410, have center of gravity heights which may be grouped as: 38 inches to 61 inches, 68 inches to 76 inches, and 79 inches to 101 inches.

The final (fifth) sorting parameter considered was the first mode carbody vertical bending frequency. This parameter was used to approximate carbody flexibility as either flexible (less than 10 Hz) or rigid (greater than 10 Hz). Again, a histogram was generated to analyze the distribution of bending frequencies in each capacity - truck center spacing - mass - center of gravity height groups. In the example discussed above, no vehicle or vehicle-lading condigurations exhibited a vertical frequency under 10 Hz and therefore, are all considered as having rigid carbodies.

Having divided all vehicle and vehicle-lading characterizations through the five levels of sorting, the final 66 groups are denoted as final generic families. Each family is codified by a cumulative sorting number indicating its subgroups in each level of sorting. Thus, the three final families used as an example above, are noted as 1.2.2.1.1, 1.2.2.2.1, and 1.2.2.3.1 (See Figure 2-6). These families are assigned a final generic family number in ascending order (See Appendix E) as well as retaining their cumulative sorting number. In the final listing families 1.2.2.1.1, 1.2.2.2.1 and 1.2.2.3.1 become families 5, 6, and 7 respectively.

3.0 PASSENGER CAR FLEET CHARACTERIZATION

The passenger car fleet in the United States today is a mixture of the very old and the very new. Historically, after 1950 there was a steady decline in acquisition of new equipment. Throughout the 1960s most new cars were built for short haul commuter service only. New acquisitions in the area of long haul rail passenger cars has come in recent years with the nationalization of most interstate passenger traffic under the auspices of Amtrak. This, then, is the situation which has led to the existence of a fleet of passenger cars 25 years old or older combined with cars 10 years old and younger, with the exception of some commuter cars.

3.1 DEVELOPMENT OF GENERIC FAMILIES

3.1.1 Fleet Composition Literature Search

The Railway Passenger Car Annual - Volume III, published in 1976 gives a complete list of intercity mainline and commuter rosters of passenger cars. This publication gives car owner, car number, car type, and date of construction. It also includes information on new passenger equipment on order from various carbuilders. Car information was recorded from this publication and cars were grouped according to car type, such as coach, baggage, sleeper, diner, observation, etc. Analysis of this information resulted in the formation of fourteen categories encompassing single level cars, bi-level cars, and self-powered cars. Car type description and population data were provided for each category; thus establishing an initial fleet characterization.

3.1.2 Fleet Physical Description

A literature search was made for passenger car data needed to fill in details on the fourteen categories of the fleet consist. The sources for average weights and lengths of the vehicles were the 1953 edition of Statistics of Railways in the United States published by the Interstate Commerce Commission; various editions of Car Builder's Cyclopedia, and trade magazines. The data gathered from these sources showed that few cars in existence had lengths other than 85 feet, or truck center spacings other than 59-1/2 feet. This was confirmed by information from Pullman Standard Engineering files, and it was therefore possible to disregard the non-standard cars as insignificant in the overall fleet.

The fleet consist tabulation in Table 3-1 shows the fourteen distinct passenger car categories, eleven of which are single level car categories and three are bi-level car categories. Of the total of 5181 cars, almost half belong to Amtrak while the remainder are under the ownership of numerous railroads and transit authorities. All cars are 85 feet in length with a truck center spacing of 59-1/2 feet. The values for average weight are calculated for each category based on car populations in the category.

This fleet of cars, as previously described, includes some cars which are on order and have not as yet been placed in service. As of now, this entails approximately 270 bi-level cars on order for Amtrak. These cars were included in the passenger vehicle characterization effort in order to provide the most current fleet description possible. The principal exceptions include a small number of commuter cars, now on order.

In developing the passenger vehicle characterization data, typical passenger loads were not included in establishing typical vehicle weights. This approximation was made because passenger loads were not considered significant in terms of gross vehicle weight or vehicle dynamic characteristics. The total weight of passengers, assuming every seat filled, is in general, less than 10 percent of the average weight of the car.

3.1.3 Manual Sort to Generic Families

Having identified the range of passenger vehicle configurations in terms of fourteen principal design categories according to car type, average weight, overall length, and truck center spacing, it was then desirable to group these cars into a reduced number of

TABLE 3-1. PASSENGER CAR FLEET COMPOSITION

	GROUP	TYPE CAR	POPULATION	TOTAL AVERAGE WEIGHT (KIPS)*	LENGTH (FT-IN)	TRUCK CENTER SPACING
SINGLE LEVEL	1	Coach	2187	129.84	85-0	59-6
	2	Combination Coach	236	125.36	85-0	59-6
	3	Sleeper	455	162.05	85-0	59-6
	4	Club, Lounge Observation	387	146.44	85-0	59-6
	5	Diner	136	160.06	85-0	59-6
	6	Baggage	202	104.94	85-0	59-6
	7	Parlor	9	139.68	85-0	59-6
	8	Steam Generator	18	182	85-0	59-6
	9	Self-Powered Coach	272	115	85-0	59-6
	10	Rail Diesel Cars (RDC)	174	114.9	85-0	59-6
	11	Metroliner	61	152.5	85-0	59-6
BI-LEVEL	12	Coach	640	129	85-0	59-6
	13	Self-Powered Coach	120	134.84	85-0	59-6
	14	New Amtrak Cars	284	151.87	85-0	59-6
		TOTAL	5181	134.11		

*Including trucks.

generically similar passenger groups if possible.

The approach taken in sorting the passenger cars was a manual method, unlike the freight vehicle sorting method, due to the limited number of design groups, small population sizes, and similarities in average weight, height, length, and truck center spacing. There are only two heights associated with the cars, single level and bi-level. It is known from dimensional similarities of railroad equipment and AAR standard clearance requirements that all single level cars are approximately the same height. Similarly all bi-level cars have a common height.

Three parameters were considered of major importance in completing the manual grouping into generic families. These were average weight, single level or bi-level car, and self-powered or non-self-powered truck design. It was assumed that the self-powered cars would exhibit different dynamic characteristics due to position and weight of auxiliary equipment, differences in suspension characteristics, unsprung masses, etc. The table in Table 3-2 shows the relationship of the fourteen design group caterories to the four final generic families which may be described as: single level light cars, single level heavy cars, single level self-powered cars, and bi-level cars.

3.1.4 Passenger Vehicle Carbody Characterization

A list of the engineering parameters necessary to characterize the passenger car fleet was determined and is shown in Table 3-3, below. The search for carbody parameters and data to calculate parameters centered about two areas: published literature and Pullman Standard engineering files. Of the total population of about 5181 cars, approximately 37 percent have been built by Pullman Standard.

A passenger car must be built to meet industry standards as set by the Association of American Railroads (AAR) and federal standards set by the Department of Transportation (DOT). These standards result in similarities between cars regardless of manufacturer. Therefore, appropriate data could be taken from Pullman

TABLE 3-2. PASSENGER CAR SORT

	DIMENSIONAL CATEGORIES			FINAL GENERIC FAMILIES		
	NO.	DESCRIPTION	POPULATION	NO.	DESCRIPTION	POPULATION
SINGLE LEVEL	1	Coach	2187	1	Single Level-Light Car	2187
	2	Combination Coach	236	1	Single Level-Light Car	236
	3	Sleeper	455	4	Single Level-Heavy Car	455
	4	Club, Lounge Observation	387	4	Single Level-Heavy Car	387
	5	Diner	136	4	Single Level-Heavy Car	136
	6	Baggage	202	1	Single Level-Light Car	202
	7	Parlor	9	4	Single Level-Heavy Car	9
	8	Steam Generator	18	-	—	0
	9	Self-Powered Coach	272	3	Single Level-Self-Powered	272
	10	Rail Diesel Cars (RDC)	174	3	Single Level-Self-Powered	174
	11	Metroliner (Amtrak)	61	3	Single Level-Self-Powered	61
BI-LEVEL	12	Coach	640	2	Bi-Level	640
	13	Self-Powered Coach	170	-	—	0
	14	New Amtrak Cars	284	2	Bi-Level	284
TOTAL			5181	TOTAL		5043 (97%)

TABLE 3-3. PRIMARY ENGINEERING DATA FOR CHARACTERIZATION OF PASSENGER CARBODIES

A. Carbody Mass

B. Carbody Rotational Inertias
   1. Roll
   2. Pitch
   3. Yaw

C. Location of the Center of Mass

D. Carbody Stiffness
   1. Vertical
   2. Lateral
   3. Torsional

E. Carbody Fundamental Bending Mode Frequencies
   1. Vertical
   2. Lateral
   3. Torsional

Standard files and used in the calculation or estimation of some parameters. Few published sources, however, were found for obtaining necessary carbody parameters, but one valuable source was a DOT report entitled "Engineering Data on Selected High Speed Passenger Trucks".

The completed passenger carbody generic family parameter tabulation is presented in Appendix G, and the following generally details the methods used to obtain each parameter. The carbody mass values were calculated by taking the population weighted total mass for each generic family and subtracting the appropriate mass of the trucks which belong to that family. The whole problem of using average values for carbody and truck masses is addressed in the topic of carbody-truck correlation. (The major difficulty, however, was in establishing any definitive car truck correlation for the older passenger equipment.)

The center of mass was calculated for older equipment based on drawings from Pullman Standard engineering files, while other values came from the above referenced DOT report. The rotational inertias in yaw, pitch, and roll were taken from the DOT report for similar vehicles and adjusted for the appropriate mass. The values for stiffness were calculated based on structural data taken from drawings in Pullman Standard's engineering files.

The vertical, lateral, and torsional frequency parameters were generated from either past test data in Pullman Standard engineering files or calculated using the stiffness values already known.

3.2 DEVELOPMENT OF TRUCK PARAMETERS

3.2.1 Carbody - Truck Correlation

The task of establishing correlation between a given carbody and truck presented problems which were due to the nature of the passenger car fleet. The fleet, as discussed previously, is made up of some relatively new equipment and much relatively old equipment. The correlation task for the new equipment is easier because more information is available from both published literature and truck manufacturers. On the other hand, there is little information available on the old equipment due to lack of published data, the retiring of some manufacturers from the industry, and the rehabilitation of and swapping of some trucks and cars. Also, much of the older equipment has undergone a change in ownership which complicated the task further.

The correlation of trucks and cars was accomplished by making two assumptions regarding the passenger car fleet. The first assumption was that the older Amtrak owned cars are representative of all older cars. The second assumption was that the General Steel Industries (GSI) - Commonwealth truck is typical of all older trucks.

The first assumption was based on the fact that Amtrak owns roughly 50 percent of all older equipment exclusive of self-powered cars. Also, their equipment was inherited from many railroads nationwide and was, therefore, a broad sampling of the typical cars of the past four decades.

The second assumption was based upon the Amtrak "Passenger Car Truck Directory" by the Engineering Division of General Steel Industries (GSI). This directory covers 1616 cars, of which 1552 have GSI - Commonwealth trucks. Also, a search through past "Car and Locomotive Cyclopedia" issues showed GSI - Commonwealth to have been the major passenger car truck manufacturer.

The fleet of Amtrak GSI - Commonwealth trucks was categorized using information from the "Passenger Car Truck Directory." The Amtrak population of the various truck types from that categorization were used on a percentage basis to cover the entire fleet of old trucks.

3.2.2 Passenger Car Truck Parameters

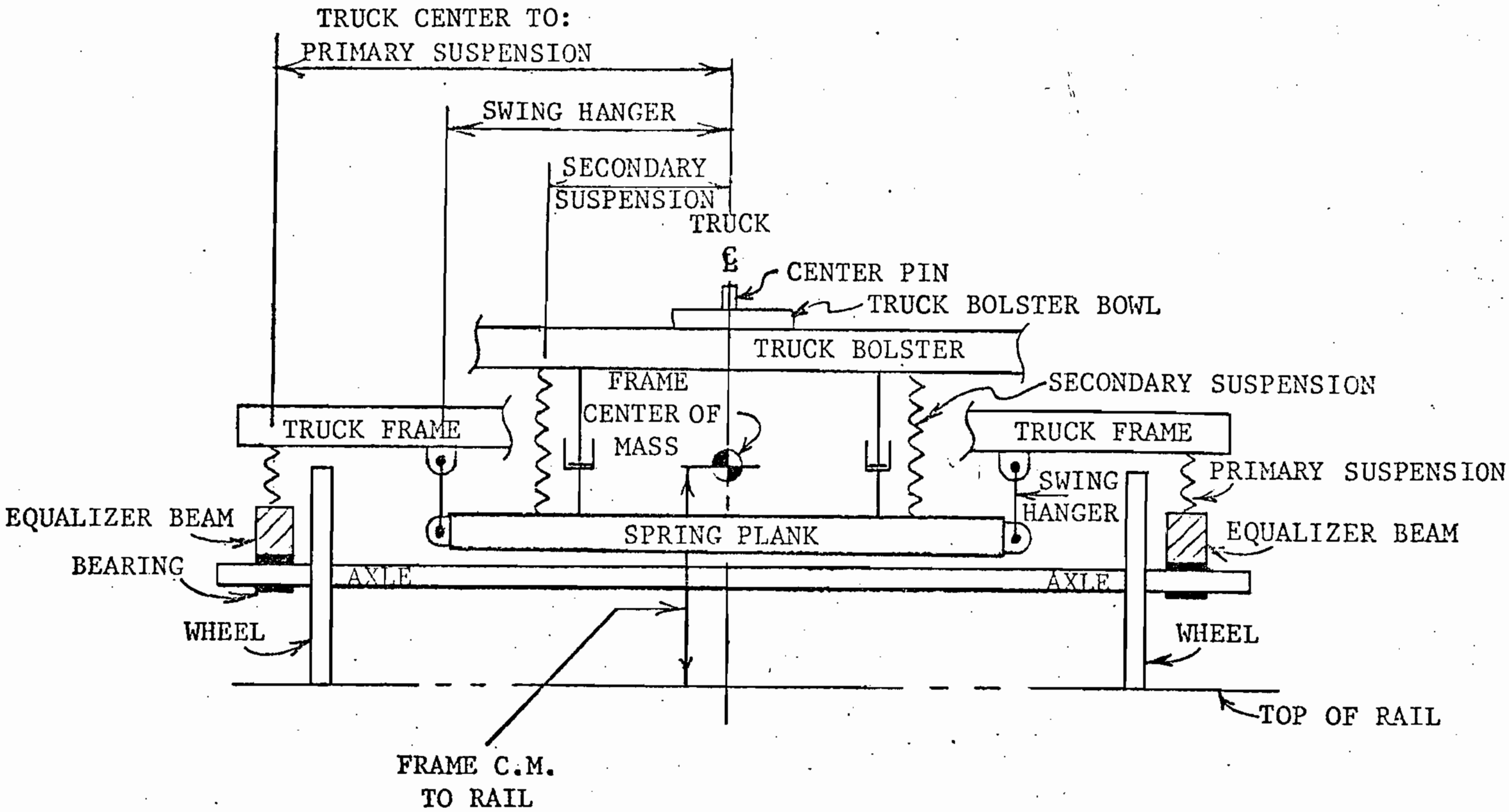
Passenger car trucks, like the carbodies that ride on them, consist of much older equipment and some newer equipment. The old truck equipment is best represented by GSI - Commonwealth trucks, while the newer equipment, more technologically diverse, requires broader representation. The first truck design category represents the older style GSI - Commonwealth trucks which have some variation in swing-hanger spring plank design configuration (i.e., inside vs outside swing hanger arrangement) resulting in variations in lateral suspension. The newer trucks have been classified into three (3) other categories to represent self-powered car trucks, single level car trucks, and bi-level car trucks. These four (4) categories are used to represent the entire fleet of passenger car trucks. The correlation of these four truck categories with the four carbody generic families is listed in Appendix G, denoted by the truck code. Also listed with each truck code is the percentage of population of that particular carbody having that truck code. All the truck groups represent 2-axle, 4-wheel trucks. There are at least 32 older cars owned by Amtrak, that have 3-axle, 6-wheel trucks. The characteristics of this truck are sufficiently different to exclude them from the other four truck groups, but too small in population to warrant characterization as a fifth truck group and, therefore, they have been omitted.

The tabulation of passenger truck parameters is given in Appendix H. The first group is the GSI - Commonwealth truck which incorporates a one-piece cast steel frame, equalizer beams and swing hangers. The primary and secondary suspension uses coil springs with friction damping in the secondary suspension only. A schematic of this truck is given in Figure 3-1.

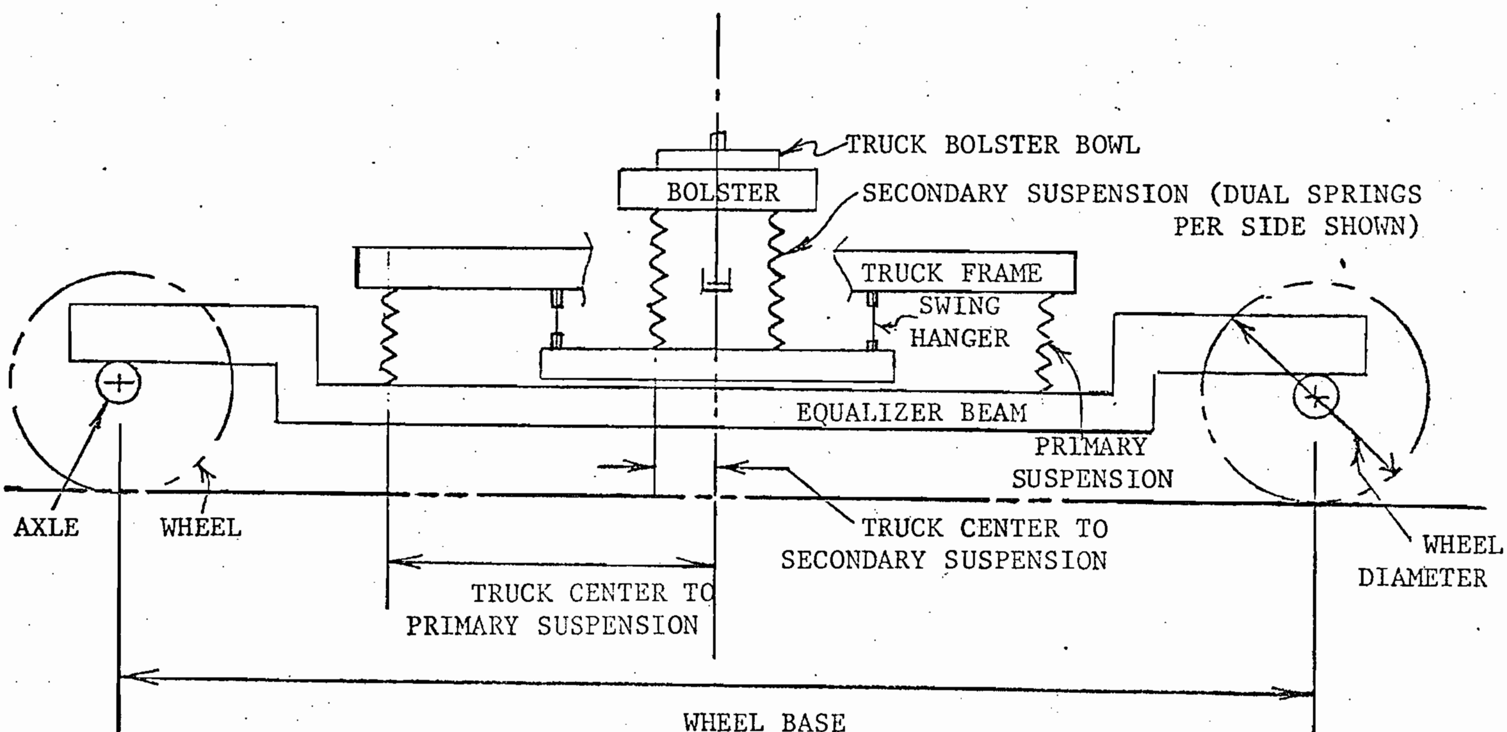
The second group is the Minden Deutz - USA truck, which has a one-piece, fabricated steel frame and no equalizer beams. It is represented by the schematic in Figure 3-2. The primary suspension uses coil springs and hydraulic dampers, while the secondary suspension is composed of air springs and hydraulic dampers.

The third group is the Budd-Pioneer III truck, shown in schematic form in Figure 3-3 which incorporates an articulated cast steel frame and no equalizer beams. The primary suspension is composed of rubber rings and no dampers, while the secondary suspension has air and coil springs in series and hydraulic dampers.

The fourth groups is the Metroliner truck, shown in schematic

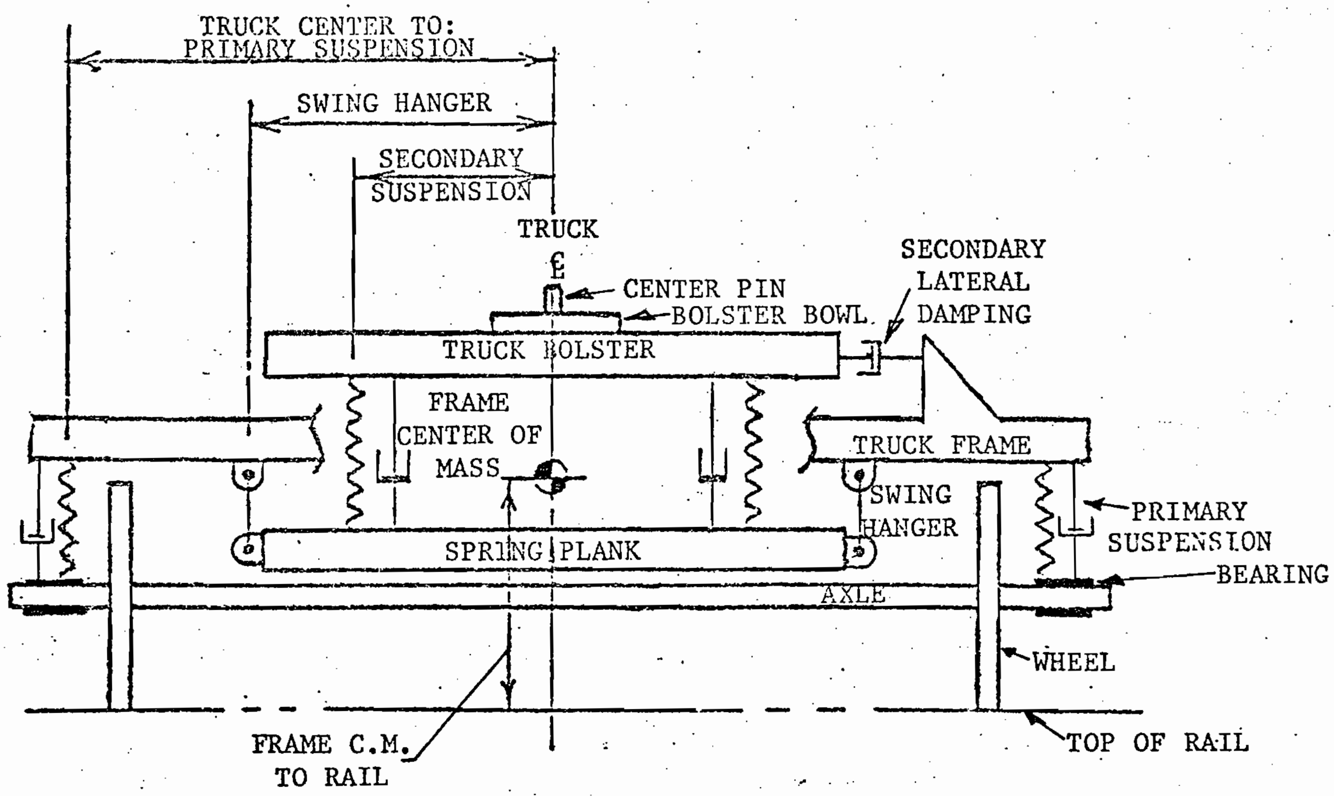


END VIEW



SIDE VIEW

PASSENGER CAR TRUCK SCHEMATIC
TRUCK GROUP 1



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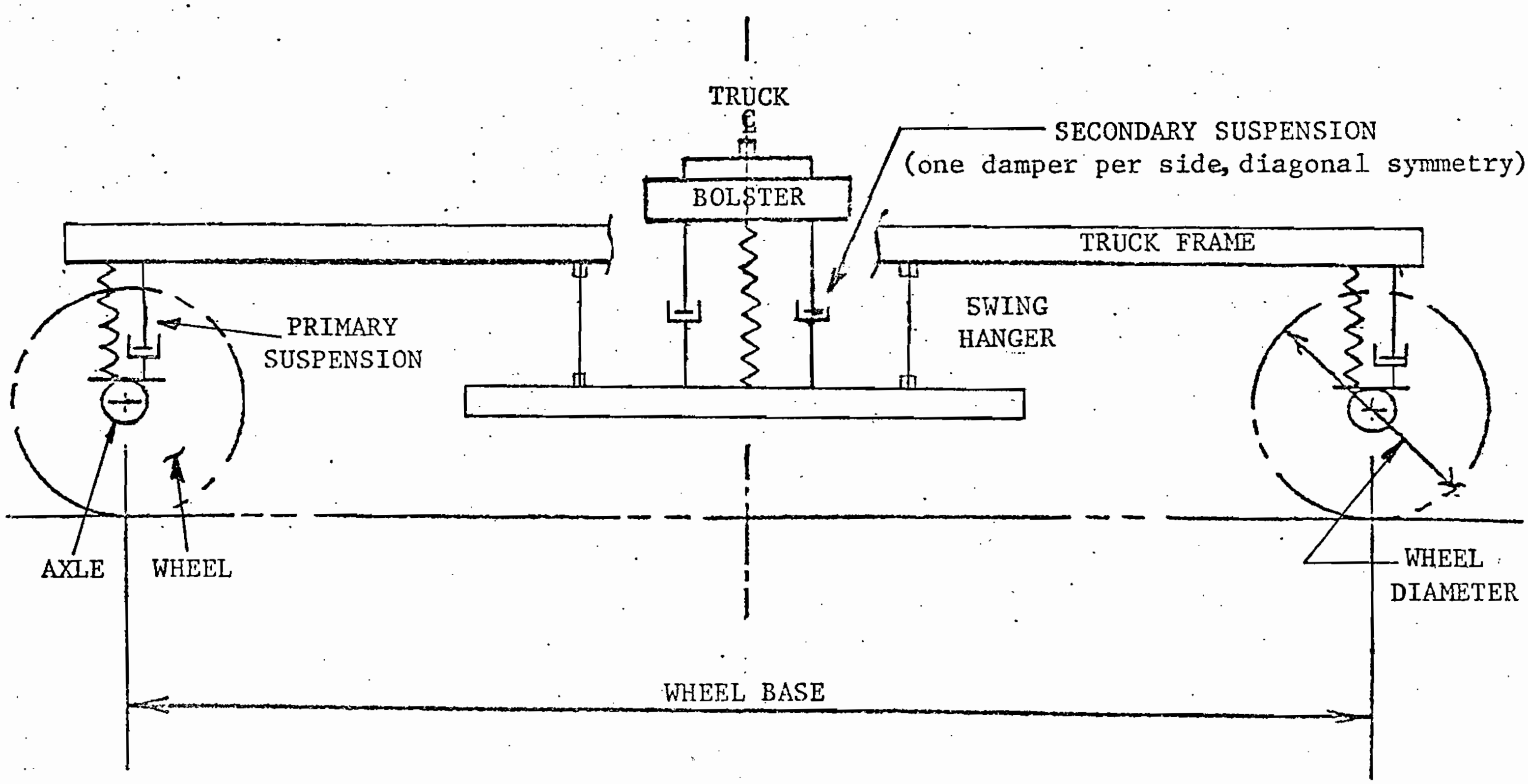
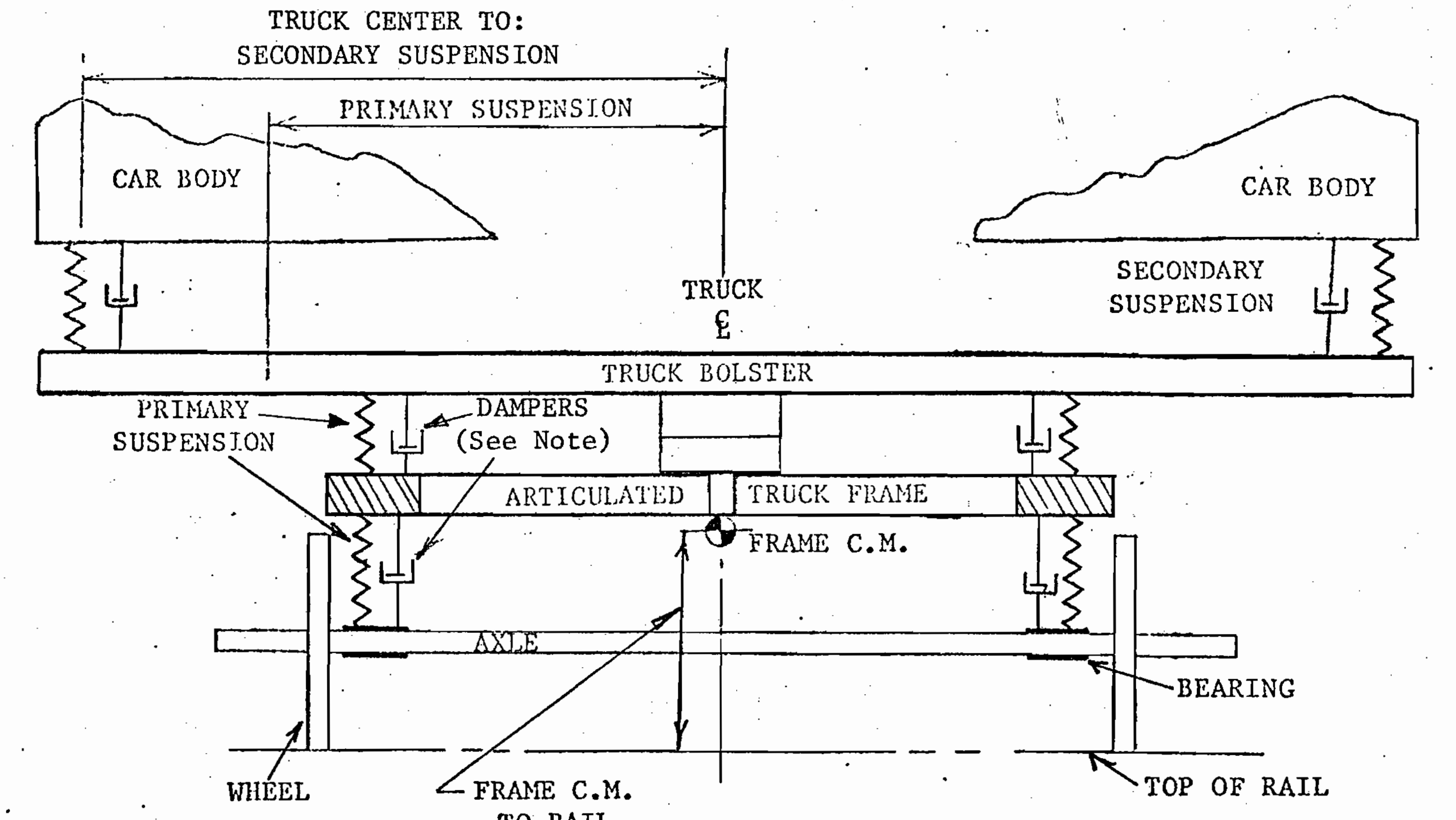


SIDE VIEW

PASSENGER CAR TRUCK SCHEMATIC
TRUCK GROUP 2



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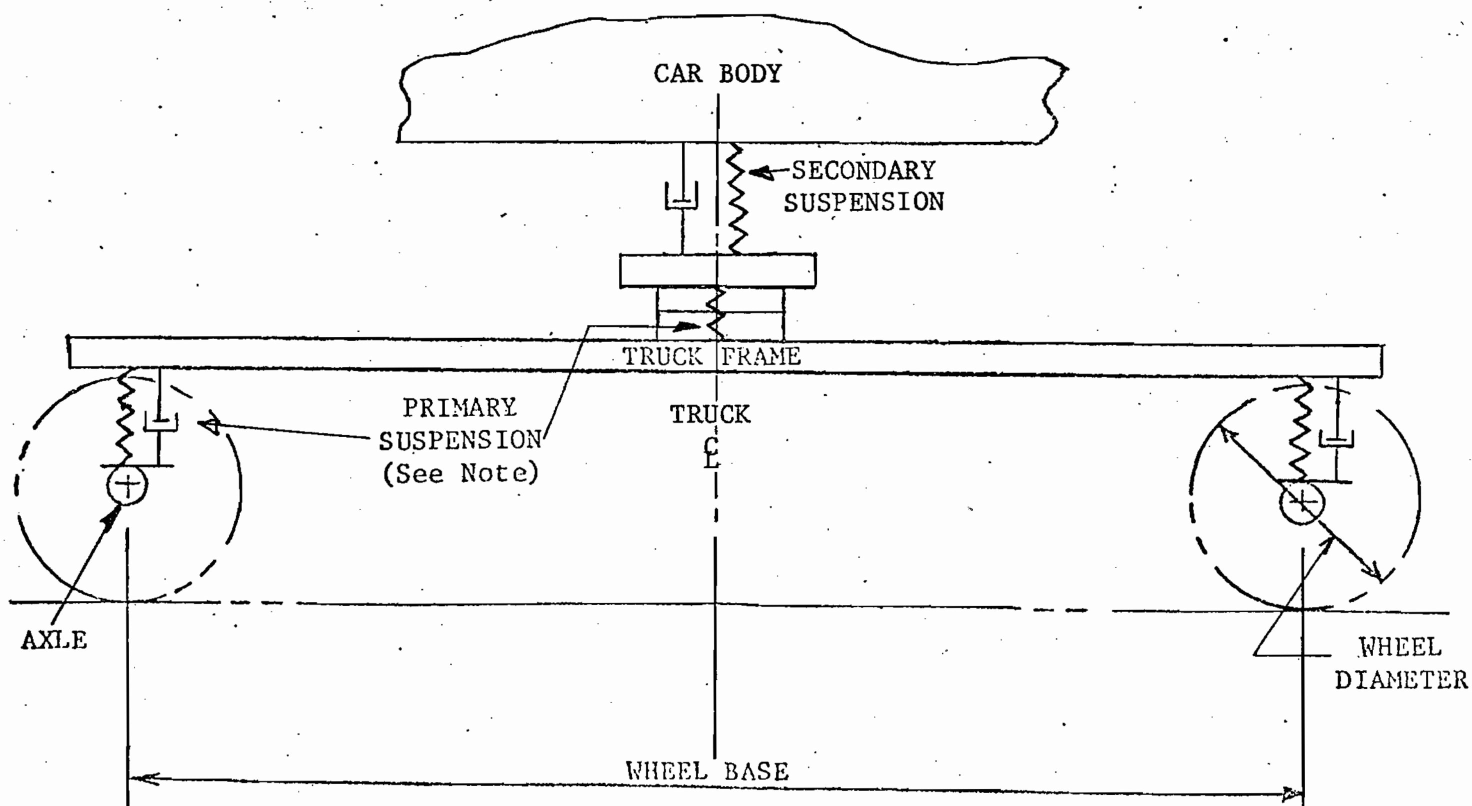
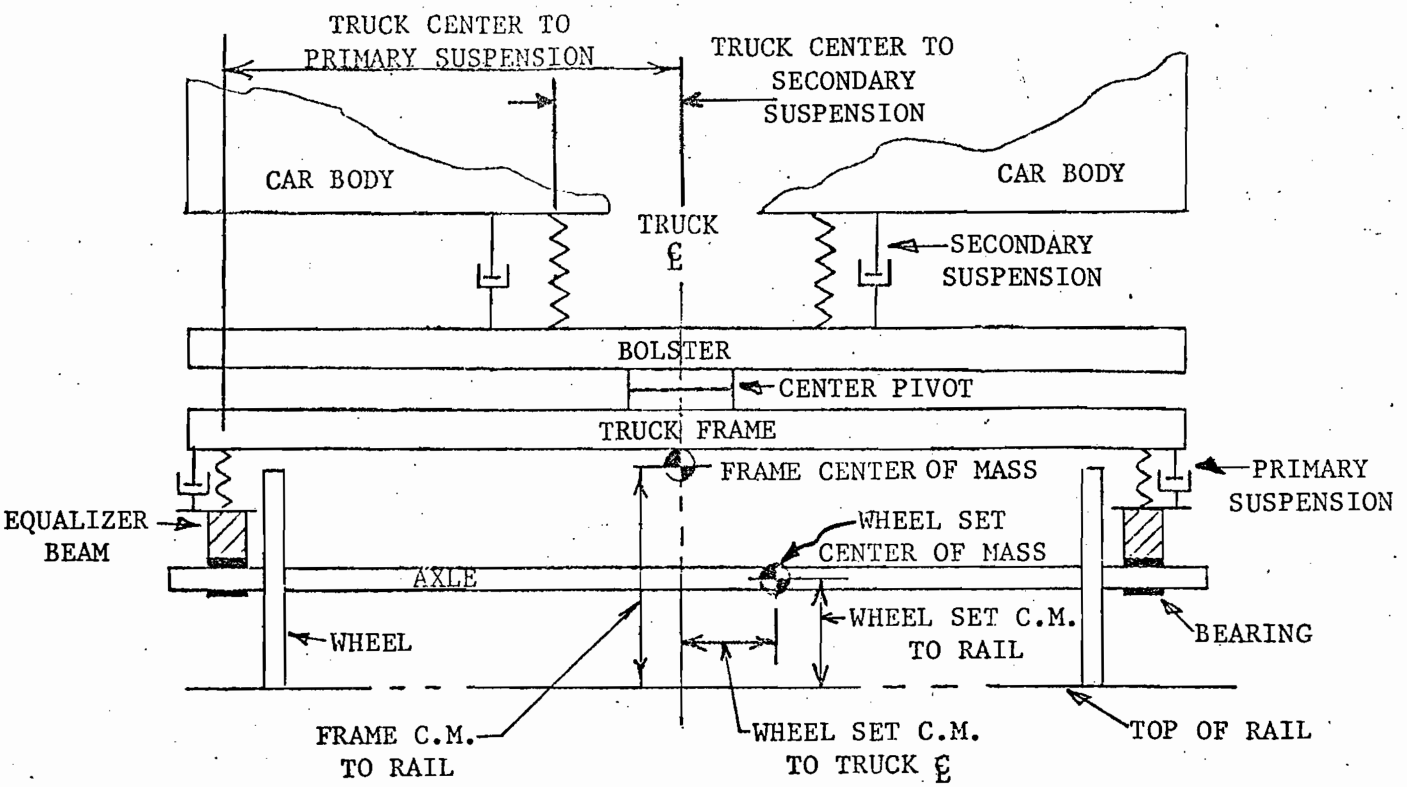


NOTE: The damping is inherent
in the rubber primary springs.

SIDE VIEW

PASSENGER CAR TRUCK SCHEMATIC
TRUCK GROUP 3



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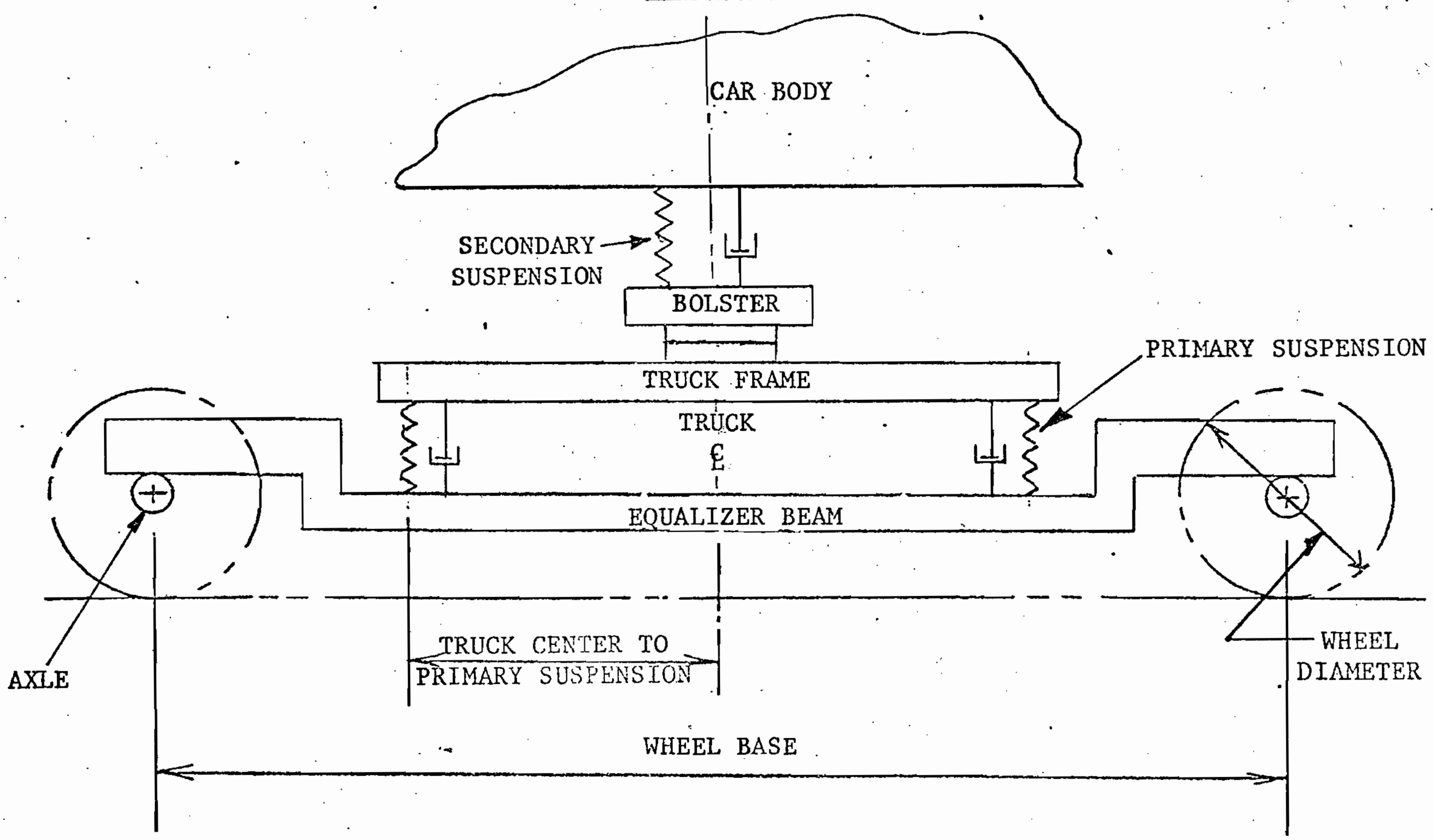


SIDE VIEW

PASSENGER CAR TRUCK SCHEMATIC
TRUCK GROUP 4

form in Figure 3-4, which has a rigid cast steel frame and equalizer beams. The primary suspension is composed of coil springs alone, while the secondary suspension has coil and air springs in series and hydraulic dampers.

The parameters for the GSI - Commonwealth truck came from Pullman Standard engineering files, GSI files, or were calculated using GSI drawings for needed dimensions and part sizes. The parameters for the M.D. - USA truck were provided by the New York Air Brake Company, licensed supplier for the German built truck in the United States, or were calculated from drawings supplied by the manufacturer. The parameters for the Budd-Pioneer III and Metroliner trucks came from the DOT report entitled "Engineering Data on Selected High Speed Passenger Trucks".

The first three items in the tabulation are concerned with the masses of the major components. The first is the wheelset mass, i.e., the mass of two 36 inch diameter flanged wheels pressed onto a single axle. Two wheelsets are used in a truck. The second mass is that of the frame. This is referred to as an intermediate or "sprung" mass, since it is suspended between the primary and secondary suspension. The third mass is that of the equalizer beam, where applicable. For the Metroliner truck, traction motor masses are lumped with wheelset and frame masses.

The suspension stiffness values are either given per wheel, meaning four per truck, or per side meaning two per truck. Truck groups 3 and 4 have no centerplates and therefore "none" is listed under bolster bowl diameter heading. The centerplate yaw friction listed for those groups is the yaw frictional constraint at the carbody-truck interface.

4.0 LOCOMOTIVE FLEET CHARACTERIZATION

4.1 DEVELOPMENT OF GENERIC FAMILIES

4.1.1 Fleet Composition Literature Search

The fleet of locomotives today is almost totally comprised of diesel-electric units of which there are some 27,000. The remainder of the fleet consists of approximately 200 electric units. Population data on the locomotive fleet was available from the 1977 "Yearbook of Railroad Facts," a roster from the AAR and originally assembled by Electro-Motive Division of General Motors Corporation (EMD) and "The Second Diesel Spotters Guide" by J. Pinkepank. A preliminary fleet consist, categorized by a manufacturers designation with population, was assembled from this roster. The roster included data from the largest 25 railroads, showing a total of 25,658 road locomotives and switchers for the first quarter of 1977. This preliminary fleet description listed 50 model categories. It was both necessary and desirable to reduce the number of listed categories to provide a managable characterization of the locomotive fleet. The approach used was to gather basic dimensional parameters such as overall length and truck center spacing and locomotive weights and group the fleet according to this data to characterize similar locomotive design groups.

Of the 25,658 locomotives in the listed categories, 3,904 were switching or transfer locomotives. Since these locomotives are in captive service in railroad yards and generally do not freely move in interchange service, they were eliminated from the fleet consist. Also not included in the fleet consist were 5 locomotives built by Fairbanks-Morse and 24 built by Baldwin Locomotive Works, neither of which are currently manufactured locomotives. The number of these locomotives is too few to warrant consideration.

4.1.2 Locomotive Design Groups

Before the locomotive fleet could be grouped according to weight, length, and truck center spacing, one more physical distinction had to be accounted for, and that was truck design. Standard class designations exist to describe various locomotive truck configurations as specified by the Association of American Railroads (AAR). If a locomotive has 2-axle, 4-wheel trucks with both axles powered, it is designated a B-B locomotive. The locomotive with 3-axle, 6-wheel trucks and all 3-axles powered is termed a C-C locomotive. A D-D locomotive has 4-axle, 8-wheel trucks with all axles powered. The most common types are the B-B and the C-C locomotives. Of the 21,725 locomotives remaining in the survey after the initial deletions above, only 137 had trucks which were not designated B-B or C-C.

The grouping of the various locomotive models into design groups is shown in Table 4-1. Figure 4-1 histograms locomotive populations by groups. The wheel arrangements of the locomotives were included as a primary grouping parameter in addition to weight, length, and truck center spacing. The population of the locomotive models built by ALCO were estimated, since specific model population data was not available from the EMD roster. A table showing the estimation method and approximate ALCO populations is given in Table 4-2.

Inspection of the design groups in Table 4-1 shows that 5 of the 14 total categories contain over 90 percent of the total population, those 5 categories being 1, 2, 4, 6 and 9. Since the bulk of the locomotives fall into these limited number of categories, these categories were chosen to represent final generic families. The five generic families represent distinctive design groups based on weight, length, truck center spacing and wheel arrangement.

A look at design groups numbers 1, 2, 4, 6 and 9 shows that by population Electro-Motive Division General Motors (EMD) has built 82 percent of the total, while General Electric (GE) has built 14 percent and ALCO the remaining 4 percent. Since EMD is by far the largest manufacturer, it was assumed that the parameters des-

TABLE 4-1. LOCOMOTIVE DESIGN GROUP CATEGORIES

GROUP	TOTAL WEIGHT (KIPS)	LENGTH	MODEL'S % OF GROUP	TRUCK CENTERS	MODELS	BUILDER	POPULATION
1	228	54-8	13%	30-8	U18B	GE	105
	230	50-8	87%	30-0	F7, F9	EMD	692
2	240	54-11-3/4	1.4%	31-0	RS-1	ALCO	120
	240	56-5-3/4	4.8%	30-0	RS-3	ALCO	428
	240	56-11-3/4		31-0	RS-11	ALCO	111
	240	53-7-1/2		28-0	C415	ALCO	9
	240	55-9	62.5%	31-0	GP7, GP9	EMD	5517
	240	56-2	6.1%	31-0	GP18, GP20	EMD	538
	240	54-11		29-9	GP-15	EMD	60
	242	56-2	10.0%	32-0	GP-30	EMD	885
	244.8	56-2		32-0	GP-28	EMD	15
	244.8	56-2	13.0%	32-0	GP-35	EMD	1147
3	248	47-8	100%	24-2	MP15	EMD	203
4	244.8	59-2	39.1%	34-0	GP38	EMD	1909
	244.8	59-2	26.9%	34-0	GP40	EMD	1313
	246	60-2	5.7%	36-2	U23B	GE	280
	252	60-2	9.0%	36-2	U25B	GE	438
	252	60-2	2.8%	32-2	U28B	GE	139
	254.8	60-2	5.3%	36-2	U30B	GE	261
	256	59-2		34-0	GP39	EMD	89
	256	59-2		34-0	SD39	EMD	56
	256	60-2	2.7%	36-2	U33B	GE	133
	257	59-2		34-0	F40PH	EMD	30
	257.2	60-2	2.8%	36-2	U36B	GE	138
	240	60-3		34-5	C420	ALCO	44
	256	59-4		32-6	C424, 425	ALCO	49
5	272	63-1		36-9	C430	ALCO	5
6	300	60-8	70.0%	35-0	SD7, SD9	EMD	548
	328	60-8-1/2	27.6%	35-0	SD24	EMD	216
	328	60-8-1/2		35-0	SD18	EMD	19
7	324.8	70-3	72.2%	43-0	E9	EMD	187
	343	69-6	17.8%	46-5	C-628	ALCO	46
	350	69-6		46-5	C-630	ALCO	26
8	344	60-8		35-0	SD28	EMD	2
	360	60-8	82.6%	35-0	SD35-SDP35	EMD	389
	360	56-5-3/4	12.1%	29-9	RSD-5	ALCO	57
		58-1-3/4		30-5	RSD-12	ALCO	23
9	356	65-8		40-0	SD38	EMD	56
	360	65-8	71.0%	40-0	SD40-SDP40	EMD	3743
					SD45-SDP45	EMD	
	363	67-3	10.6%	40-11	U30C	GE	560
	363.6	67-3	6.8%	40-11	U33C	GE	359
	364.8	67-3	2.4%	40-11	U36C	GE	124
	366	67-3		40-11	C30-7	GE	10
	366	64-6	2%	42-0	U25C	GE	104
	366	64-6		42-0	U28C	GE	67
	368	67-5-1/2		41-8	F45	EMD	86
	335	66-7		38-6	RSD-15	ALCO	30
	348	67-3	2.5%	40-11	U23C	GE	133
10	386	72-4	51.0%	46-0	P30CH	GE	25
	390	70-8	28.6%	45-0	F(P)45	EMD	14
	380	69-6	20.4%	43-4-1/2	C-636	ALCO	10
11	417	79-0	100%	50-2	U50C	GE	40
12	488	87-11	100%	55-0	DD35	EMD	45
13	536	83-6-1/2	100%	41-6	U50	GE	46
14	540	98-5	100%		DD-A40K	EMD	46
						TOTAL	21725

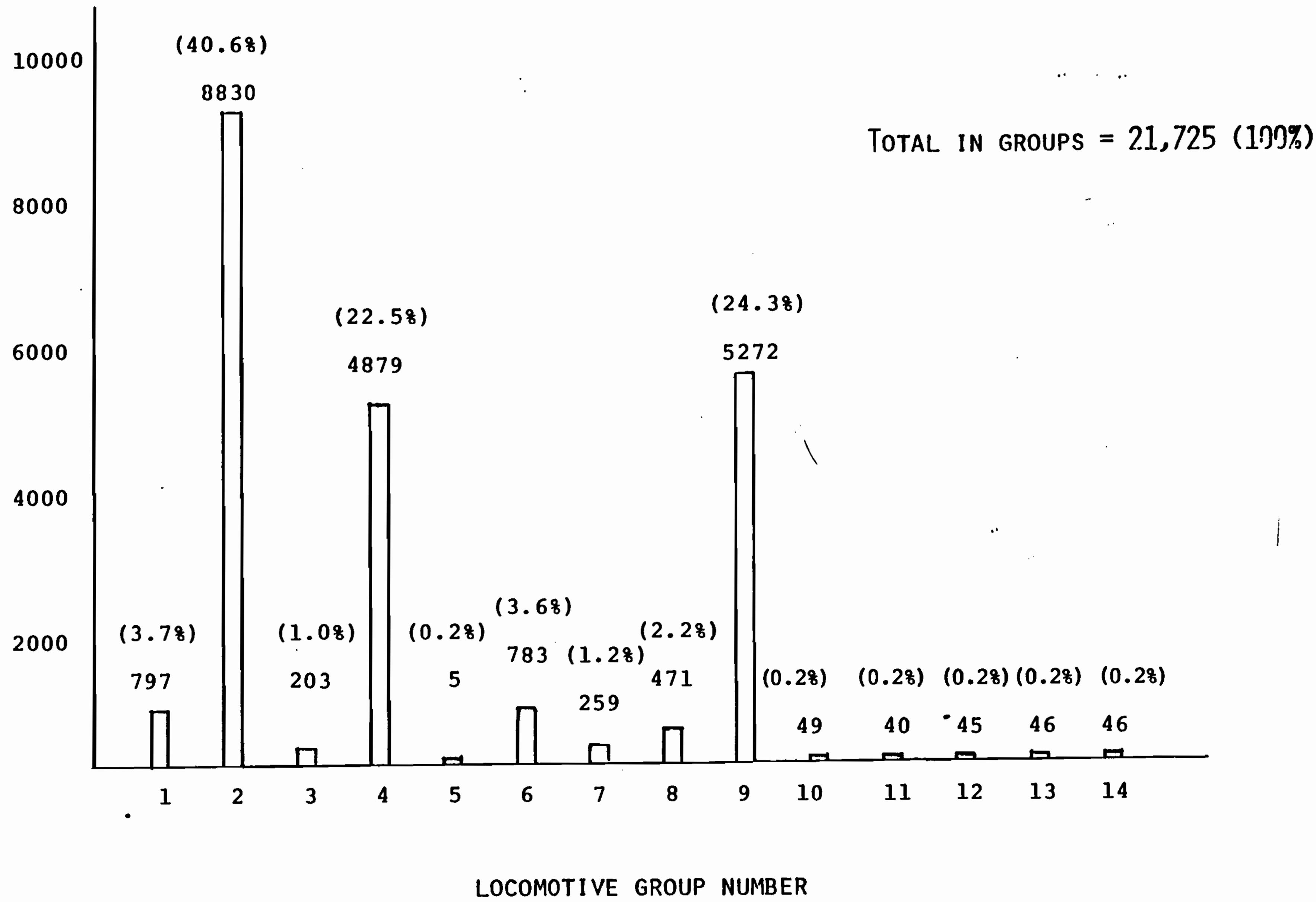


FIGURE 4-1. LOCOMOTIVE POPULATION BY GROUP

TABLE 4-2. ALCO LOCOMOTIVE POPULATIONS

MODEL	OLD POPULATION	FRACTION OF TOTAL	ESTIMATED CURRENT POPULATION*
RS-1	353	0.125	120
C-415	26	0.0092	9
RS-3	1265	0.447	428
RSD-5	167	0.059	57
RS-11	327	0.116	111
C-420	129	0.046	44
C-424	53	0.019	18
C-425	91	0.032	31
C-430	16	0.0057	5
C-628	135	0.048	46
C-630	77	0.027	26
C-636	34	0.012	10
RSD-12	69	0.024	23
RSD-15	87	0.031	30
TOTAL	2829	1	958

*Total Alco locomotives in EMD survey = 958. Estimated current population was found by multiplying each model's fraction of old population by 958. For example, RS-1's population = 0.125 x 958 = 119.75 = 120. Old population data taken from The Second Diesel Spotters Guide by J. Pinbepank.

cribing appropriate EMD locomotives would be typical for all locomotives within the five final generic families. This assumption was also based on the fact that the locomotives contain similar equipment located in the same general areas on the body frame. These facts are supported by general locomotive layouts in the "Car and Locomotive Cyclopedia" and manufacturer specifications. Therefore, EMD was approached for specific engineering parameters on certain models of their locomotives contained in the generic families.

4.1.3 Locomotive Parameters

Pullman Standard contracted with EMD to provide the data listed in Table 4-3 to characterize the major locomotive design groups Engineering data was provided by EMD under purchase order for the following EMD locomotive models: E8/9, F7/9, SD9, GP7/9, GP35, GP38, GP40 and SD40/45.

The parameter tabulations for locomotive generic families are given in Appendix I. All of the parameters contained in the tabulation came from EMD with the exception of some dimensional data contained in the design groups. The values obtained from EMD were either gathered from actual test data, or were computed from data obtained in test, or were estimated from experience. Locomotive mass, length over center plates, and length over end plates have been listed as a typical values and a mean value with one standard deviation to indicate variations associated with these parameters. The typical value is taken from the EMD data while the mean value is taken from the data listed in the design groups, taking into account percentage of population. These three parameters were the only parameters where complete data on all locomotive models was available and the mean and standard deviation could be computed. The remaining values were based on specific locomotive design data from EMD. It should be noted that the locomotive weights are given without weight of water and/or fuel. The fuel is typically carried in 800-1000 gallon tanks in smaller locomotives and 3000-4000 gallon tanks in larger locomotives, which figures to be around

TABLE 4-3. LOCOMOTIVE BODY PARAMETERS

PRIMARY ENGINEERING DATA FOR CHARACTERIZATION OF LOCOMOTIVE BODY PARAMETERS (FOR EMD MODELS F9, SD9, GP9, GP35, GP38, GP40, and SD45)

A. Locomotive body weight

B. Center of mass (C.M.) location

C. Mass moment of inertias about the C.M.
   1. Yaw
   2. Roll
   3. Pitch

D. Side bearings
   1. Are they constant contact? If not, what is the clearance?
   2. No. of side bearings
   3. Spring rate of each
   4. Preload, if any

E. Geometry
   1. Length over end sills
   2. Width over side sills
   3. Length between coupler pins
   4. Length of couplers (free pivot to face)
   5. Center plates distance

3000 to 15,000 pounds total weight assuming a half full tank. This weight is less than 2 percent of the average body weight of a locomotive and the effect of the fuel was therefore neglected.

4.2 DEVELOPMENT OF TRUCK PARAMETERS

4.2.1 Locomotive Truck Correlation

As was stated previously, the most common wheel arrangements are designated as B-B, and C-C. In the final generic families of locomotives only these two wheel arrangements are used. Of the five generic families, groups 1, 2 and 4 have B-B wheel arrangements, while groups 6 and 9 have C-C arrangements. The task of developing truck parameters and correlating them with the generic families centered about the B-B and C-C wheel arrangements. Information on diesel locomotive trucks are available in "The Second Diesel Spotters Guide," from published data of the AAR, from "Extra 2200 South" a locomotive newsmagazine, "The Car and Locomotive Cyclopedia," and from locomotive manufacturers.

Preliminary information on locomotive trucks pointed up the fact that the three major locomotive manufacturers Elector-Motive Division (EMD), General Electric (GE) and ALCO were responsible for the design, specifications for, or manufacturer of the locomotive trucks for their bodies. Also, the facts were clear that EMD locomotives had EMD trucks, GE locomotives had new GE or older GE-ALCO trucks, and ALCO locomotives had GE-ALCO trucks. Since EMD is by far the largest locomotive manufacturer, it follows that their trucks are in like proportion. The truck information sources also showed that EMD has produced three major truck designs, two for C-C wheel arrangement, and one for B-B arrangements. Their B-B truck has been put under new EMD road locomotives since 1939, and is called the four wheel Blomberg design. It is the most populous truck in the locomotive fleet. This truck was assumed to be under every EMD B-B locomotive contained in the final generic families.

The two type C-C trucks from EMD are referred to as the Flexicoil and as the HT-C, or high traction truck. The Flexicoil design was the standard for all EMD C-C road locomotives prior to 1972. Since 1972, the C-C road locomotives have had either the Flexicoil or the new HT-C design.

The General Electric Company and ALCO shared a common B-B truck design for many years. This GE-ALCO design is assumed, based on the data sources, to be under all ALCO B-B road locomotives and under all GE locomotives up to 1972. Beginning in 1972, GE began to put their new B-B "floating bolster" design truck under their new locomotive orders that specified new trucks. In 1966, GE introduced their C-C "floating bolster" design, and it is assumed to be standard on all C-C road locomotives, since all were built in 1966 or after according to the AAR roster of locomotives.

In order to develop a set of complete parameters on locomotive trucks, Pullman Standard first contracted with EMD to supply the list of truck parameters, given in Table 4-4, for their B-B Blomberg design, their Flexicoil design, and their HT-C design. Next, information on the GE B-B and C-C "floating bolster" designs was approximated from data contained in published literature.

Information necessary to include the GE-ALCO B-B truck parameters was not available. Further search for data on this truck was terminated since the total population is small (9 percent of locomotives in generic families) and the model is out of production. ALCO is not making any new locomotives and GE is now using its own "floating bolster" design; therefore, the GE-ALCO truck population will be decreasing with locomotive retirements in future years. The only other locomotive truck which could possibly be included is the ALCO trimount C-C truck, but the population of that truck is only 0.2 percent of the fleet in generic families and out of current production. Therefore, it has not been characterized.

4.2.2 Locomotive Truck Parameters

Engineering data characterizing locomotive truck designs is

TABLE 4-4. LOCOMOTIVE TRUCK PARAMETERS

PRIMARY ENGINEERING DATA FOR CHARACTERIZATION OF LOCOMOTIVE TRUCK DESIGNS

A. Weights
   1. Assembled truck
   2. Per wheelset
   3. Truck frame

B. Center of mass location
   1. Assembled truck
   2. Truck frame

C. Mass moment inertias
   1. Per wheelset - yaw
   2. Truck frame - pitch, roll and yaw

D. Primary suspension stiffnesses
   1. Vertical per truck
   2. Lateral per axle
   3. Longitudinal per axle

E. Secondary suspension stiffnesses
   1. Vertical per truck
   2. Lateral per truck
   3. Yaw per truck

F. Damping
   1. Lateral, vertical, and longitudinal per axle
   2. Secondary vertical and lateral per truck

G. Geometry
   1. Wheel diameter
   2. Locations of wheel/rail contacts
   3. Location of wheelsets/truck frame attachment points
   4. Location of truck frame/bolster attachment points
   5. Centerplate diameter and location
   6. Describe if suspension links, equalizers, or swing hangers are part of truck
   7. Spring bottoming deflection from nominal static position

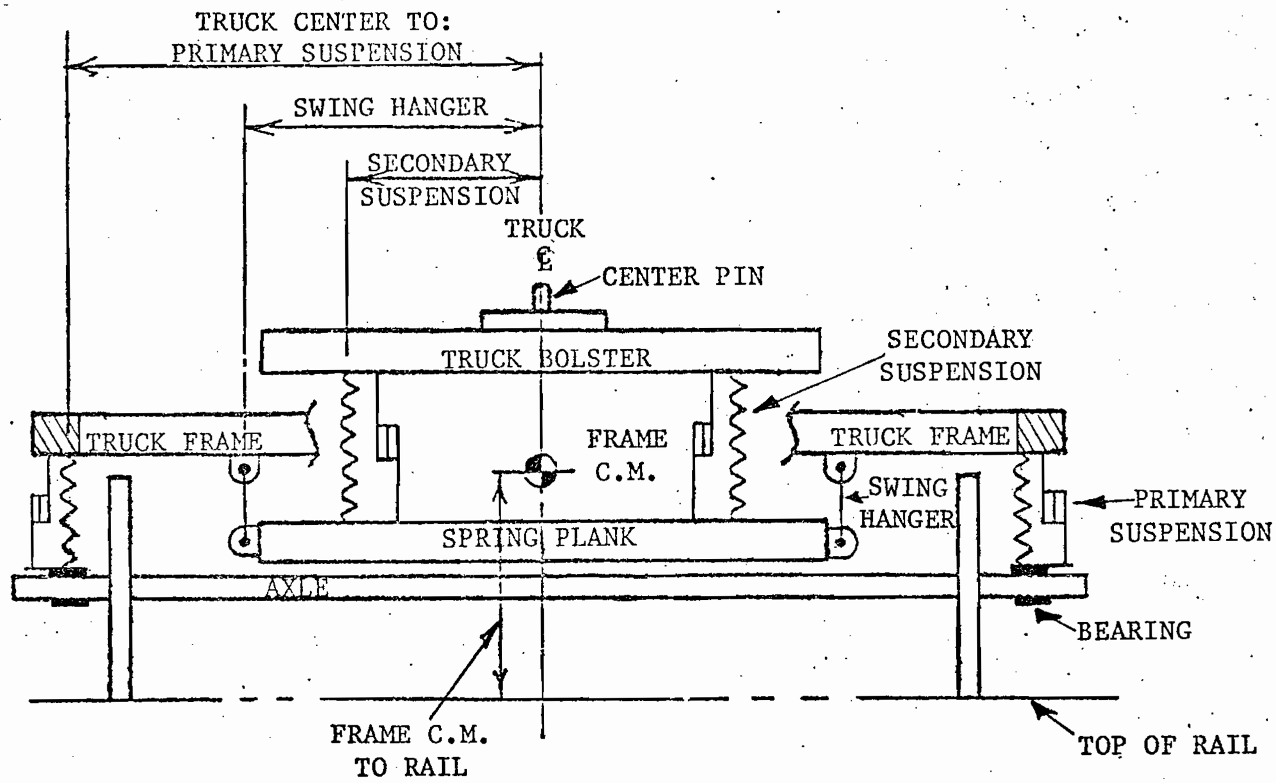
tabulated in Appendix J. The principal locomotive truck characterization data outlined in Table 4-4 is given in Appendix J for the following truck design; the EMD "Blomberg design: the EMD Flexicoil, the two GE "Floating bolster" designs, and the EMD HT-C design.

The EMD Blomberg design is a 2-axle, 4-wheel truck with coil spring primary suspension located at the journal areas. The truck is shown in schematic form in Figure 4-2. The secondary suspension is provided by a pair of elliptical springs between the bolster and a spring plank. The spring plank is attached to the truck frame by a pair of swing hangers which provide for lateral motions only. Friction damping is used in both suspensions.

The EMD Flexicoil truck is a 3-axle design with a primary suspension similar to that of the Blomberg truck. The secondary suspension is provided by helical coil springs, and the damping for both suspensions is friction damping. The schematic diagram for this design is given in Figure 4-3.

The GE "floating bolster" trucks, both 2 and 3 axle models have coil springs and friction damping at the journals serving as the primary suspension. The secondary suspension is composed of four rubber springs that transmit loads between the bolsters and the truck frame. The trucks are shown in schematic form in Figures 4-3 and 4-4 for 3-and 2-axle models, respectively.

The EMD HT-C truck also has coil springs at the journals serving as the primary suspension with two hydraulic dampers located one on each side of the center axle between the journal box and truck frame. There is also friction damping at each journal. The secondary suspension is provided by four rubber springs. The schematic for this truck is the same as the GE 3-axle "floating bolster" model shown in Figure 4-3.



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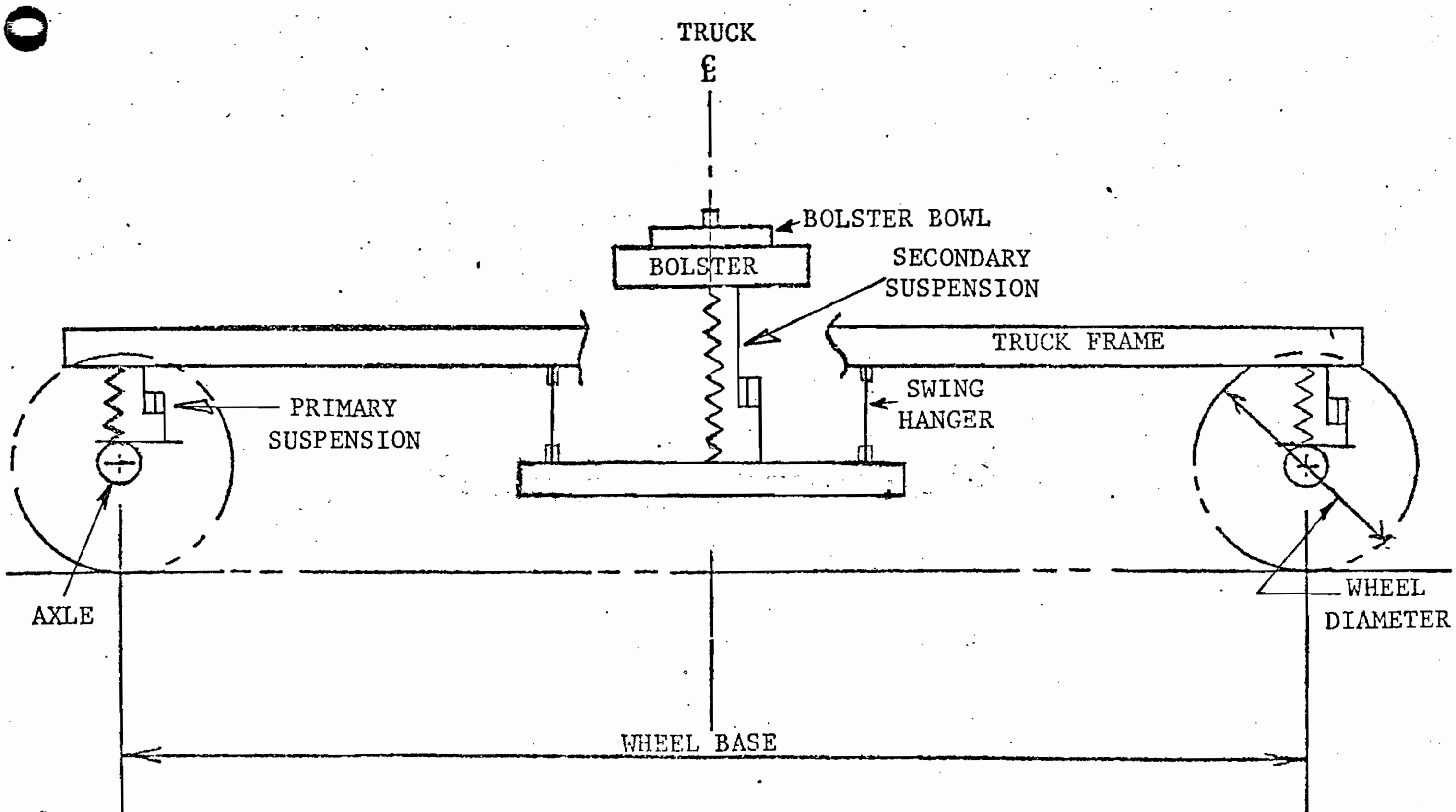
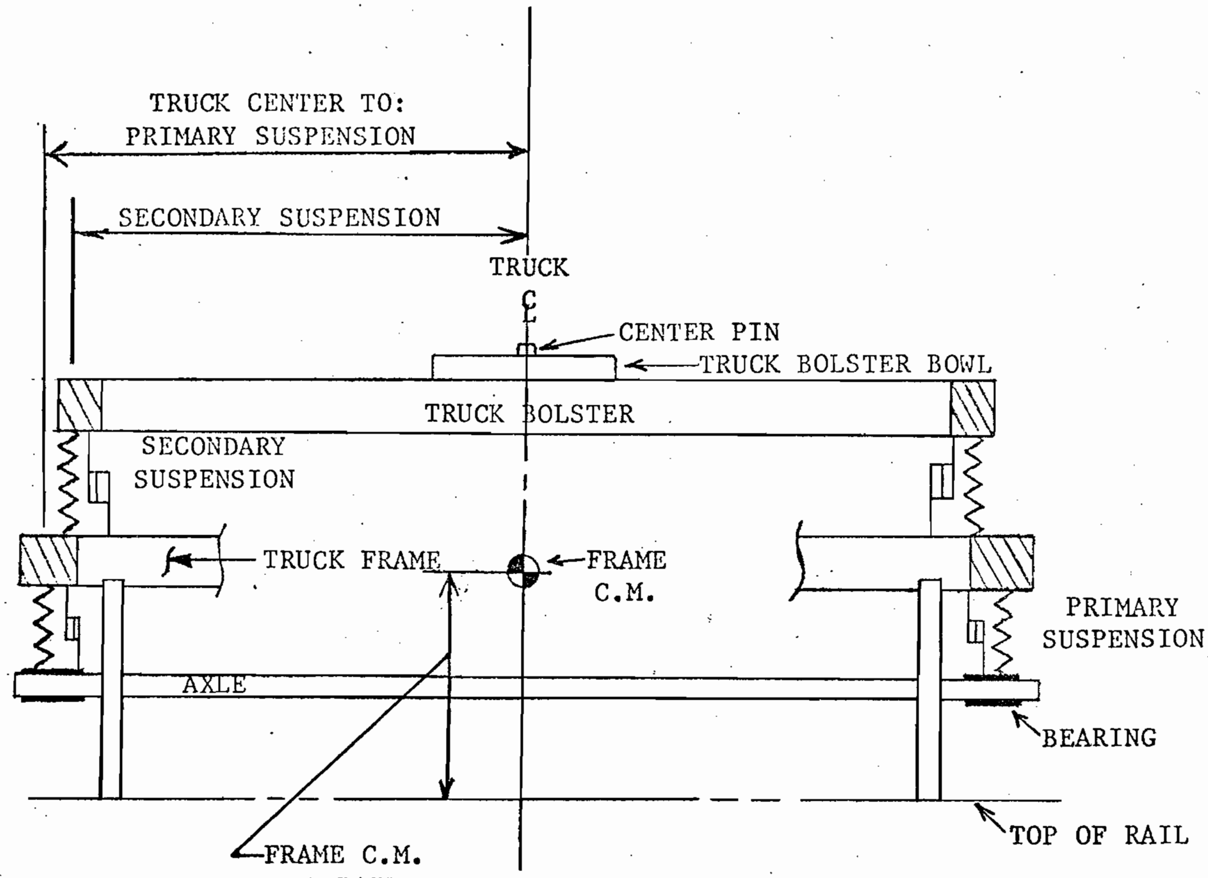


SIDE VIEW

LOCOMOTIVE TRUCK SCHEMATIC
TRUCK GROUP 1



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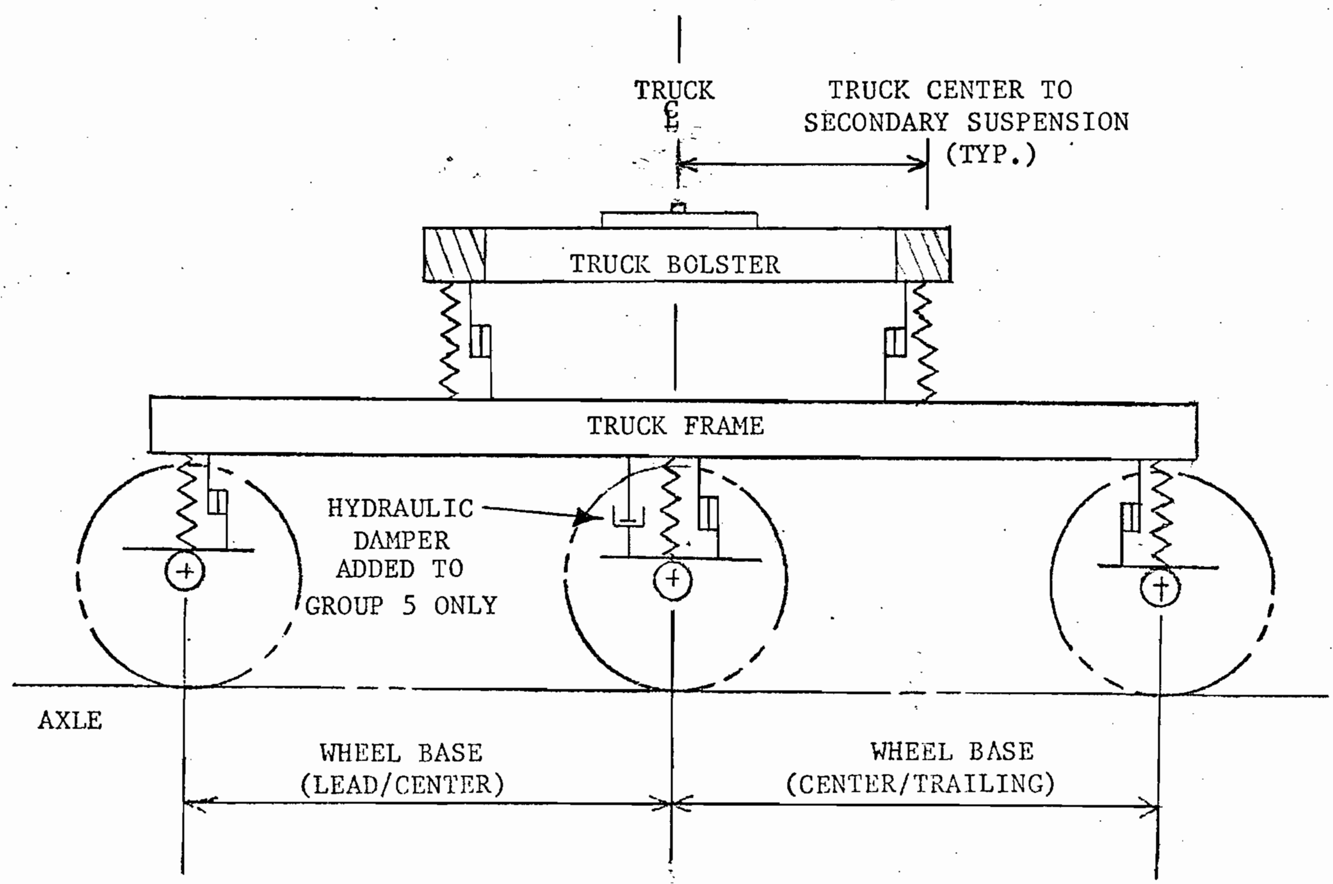
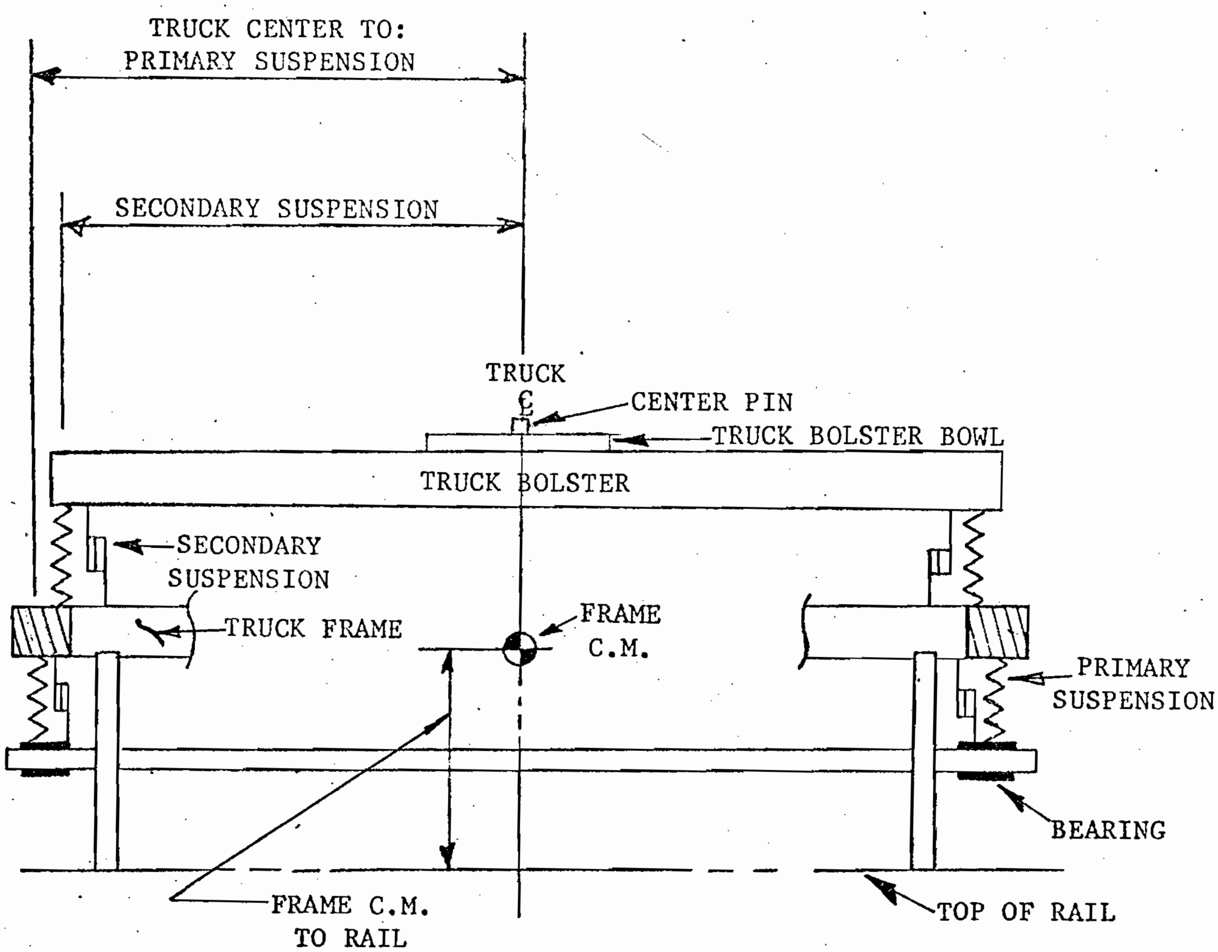


SIDE VIEW

LOCOMOTIVE TRUCK SCHEMATIC
TRUCK GROUPS 2, 4, 5



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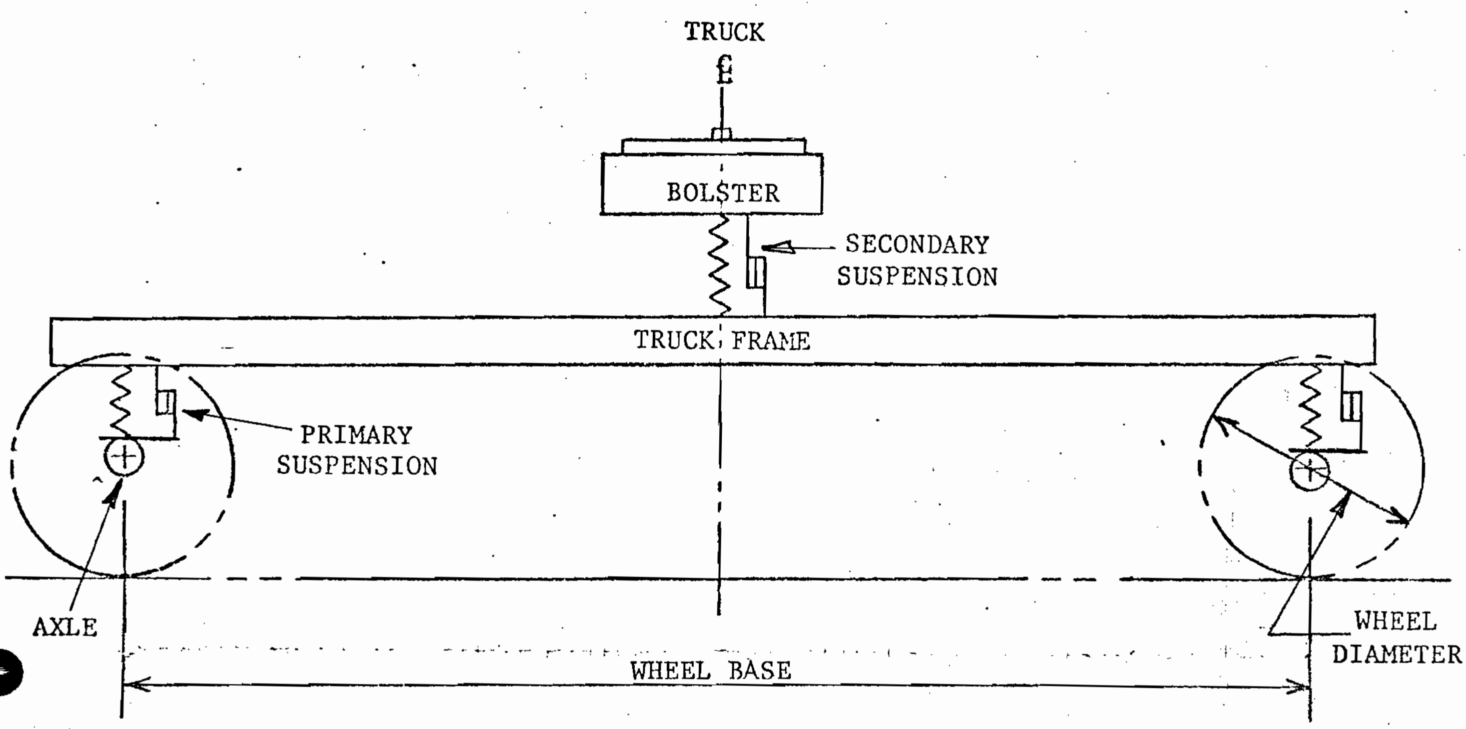

SIDE VIEW

LOCOMOTIVE TRUCK SCHEMATIC
TRUCK GROUP 3

5.0 WHEEL PROFILE CHARACTERIZATION

5.1 BACKGROUND

In analyzing a railcar's lateral dynamics, the vehicle's wheel profile characteristics may have an important effect on forces generated from wheel/rail interaction and on vehicle stability. For this reason, wheel profile characteristics may be required as a part of an overall vehicle characterization for certain analyses. The wheel profile characterization effort described below is intended to define representative wheel profiles found on in-service freight vehicles.

The task of characterizing wheel profiles, as existing on the in-service freight fleet, and of associating the profiles with specific vehicle configurations is extremely difficult. Many factors may influence the profile developed by a worn wheel, including vehicle characteristics such as truck center spacing, gross weight, truck type, etc. Further, operating conditions may exert an even greater influence on wheel profiles due to variations in loading patterns, typical operating speeds (empty and loaded), unit train service and other factors. There has not been sufficient study to provide positive identification of the influences of all factors or the influence of the possible combinations of these factors. This program has, therefore, addressed the identification of actual profiles existing in service as an initial effort in the overall characterization of wheel profiles.

A search for available data sources revealed that no study has been performed to typify the wheelset tread profile as present in the entire fleet. Generally, previous studies concentrated on the wheel profile wear characteristics over the life of a wheel but not on what profiles could be representative of the complete fleet. Other studies performed at the High Speed Test Facility in Pueblo, Colorado under the AAR - FRA RPI Track Train Dynamics (TTD) program have also addressed wear rates of wheels under simulated service conditions. However, these studies of wear rates and specific wear factors do not provide data useable in an effort to characterize in-service wheel profiles. In general, all possible sources of data were investigated. In addition to the above programs, inquiries were made to the AAR Technical Center, to a major wheel manufacturer, and to the Norfolk and Western Railway Company. The Norfolk and Western had completed a 1976 wheel profile study and provided profiles of 44 wheelsets which were awaiting wheel turning. These profile represent wheels worn severely enough to require turning (reprofiling) and do not provide data on average profiles to be expected on cars in service.

5.2 WHEEL SURVEY PROGRAM

A field survey program was developed to provide necessary wheel data for freight cars. The scope of a program to statistically sample the entire 1.7 million cars (or the 13.6 million wheels) including consideration of factors which could influence profiles far exceeds the resources of this effort. However, in order to provide some limited profile data, a small field sampling program was taken to provide representative profiles. A sampling methodology was formulated to obtain wheel profiles from cars which represent some extreme variations in car size and configuration. The car sample from which wheel profiles were taken include:

A. 50-ton, 40-foot inside length box cars, with plain or journal bearing trucks,

B. 50-ton, 50-foot inside length box cars, with plain or journal bearing trucks,

C. 70-ton, 50-foot inside length box cars, with roller bearing trucks,

D. 100-ton, 60-foot inside length box cars, with roller bearing trucks,

E. 70-ton and 100-ton, 86-foot inside length box cars with roller bearing trucks,

F. 50-ton, 11,000-gallon (short length) tank cars with plain bearing trucks,

G. 100-ton, 21,000-gallon tank cars with roller bearing trucks,

H. 70-ton, 89-foot long flat cars with roller bearing trucks,

I. 70-ton, 2930-cubic foot capacity (short length) open hopper cars with roller bearing trucks,

J. 70-ton, 2750-cubic foot capacity (short length) open hopper cars with plain bearing trucks,

K. 100-ton, 3410-cubic foot capacity open hopper cars with roller bearing trucks.

This range of vehicles was large enough so that variations between short and long cars, low and high weight capacities, flexible and rigid carbody constructions, plain and roller bearing trucks, would be sampled. Additionally, each car type was also sampled when equipped with cast wheels and wrought wheels. These variations in vehicle configurations, truck characteristics, and wheel manufacturing are likely factors in the mechanics of wheel wear. Wheel profiles were taken for a complete truck set at one end of a car which also allows for comparison of inboard and outboard axlesets. In all, a minimum of three samples of each car-type/wheel-combination were obtained, resulting in a final acceptable data set of 250 profiles from which representative profile groups were identified.

5.3 PROFILOMETER DEVELOPMENT

The aquisition of wheel profiles required the use of a field portable device capable of recording accurate profiles. Wheel profile measurements suitable for use in analytical modeling require accurate tracings of both wheels on an axle. Thus, not only must each profile be accurately recorded, but the spatial relation of both profiles on a single axle must be retained. It was not possible to use or adapt an existing profile measuring device. No one device combined portability (necessary for use on cars in railroad yards without detrucking) with the ability to accurately record both wheel profiles on an axle with a commom reference to the axle.

It was therefore necessary to design and construct a profilometer to meet the specific needs of this program. The device is shown in Figures 5-1 and 5-2. The profilometer uses a stylus and pen to trace the wheel profile on a 4 inch x 6 inch card. The profilometer attaches to the tread of the wheel and is radially positioned by reference stops at the tape line of the tread and is laterally poistioned by reference stops on the outside rim face of the wheel. Since this face is perpendicular to the axle centerline (within AAR specified tolerance), the profilometer is constructed to hold the bottom edge of the profile card perpendicular to the rim face or parallel to the axle axis. Thus, the angular relation of a wheelset's profiles is maintained on the recorded cards. A second gage is used to record the distance between the outside rims of both wheels of a wheelset. This distance is recorded on a wheel profile data card thereby providing a lateral reference for both wheels on the sample wheelset and completing the necessary spatial reference needed to describe the wheelset profiles.

In addition to the above measurements, a dial gage is mounted on the profilometer to record the height of a reference chord of the wheel rim. Using this height and appropriate calibration, the actual wheel diameter at the tape line was determined using common geometric relations. This measurement was also recorded on each wheel profile data card. Additional information recorded on each profile card included wheel age, manufacturer (and therefore whether cast or wrought construction), truck data (bearing type, brake shoe type, etc.), and car data (car type, capacity, etc.). An example of the profile card format is shown in Figure 5-3.

5.4 PROFILE GROUP IDENTIFICATION

Since no standard method of grouping or characterizing groups of wheel profiles exists, a methodology was developed based on distinctive physical characteristics observed in the samples.

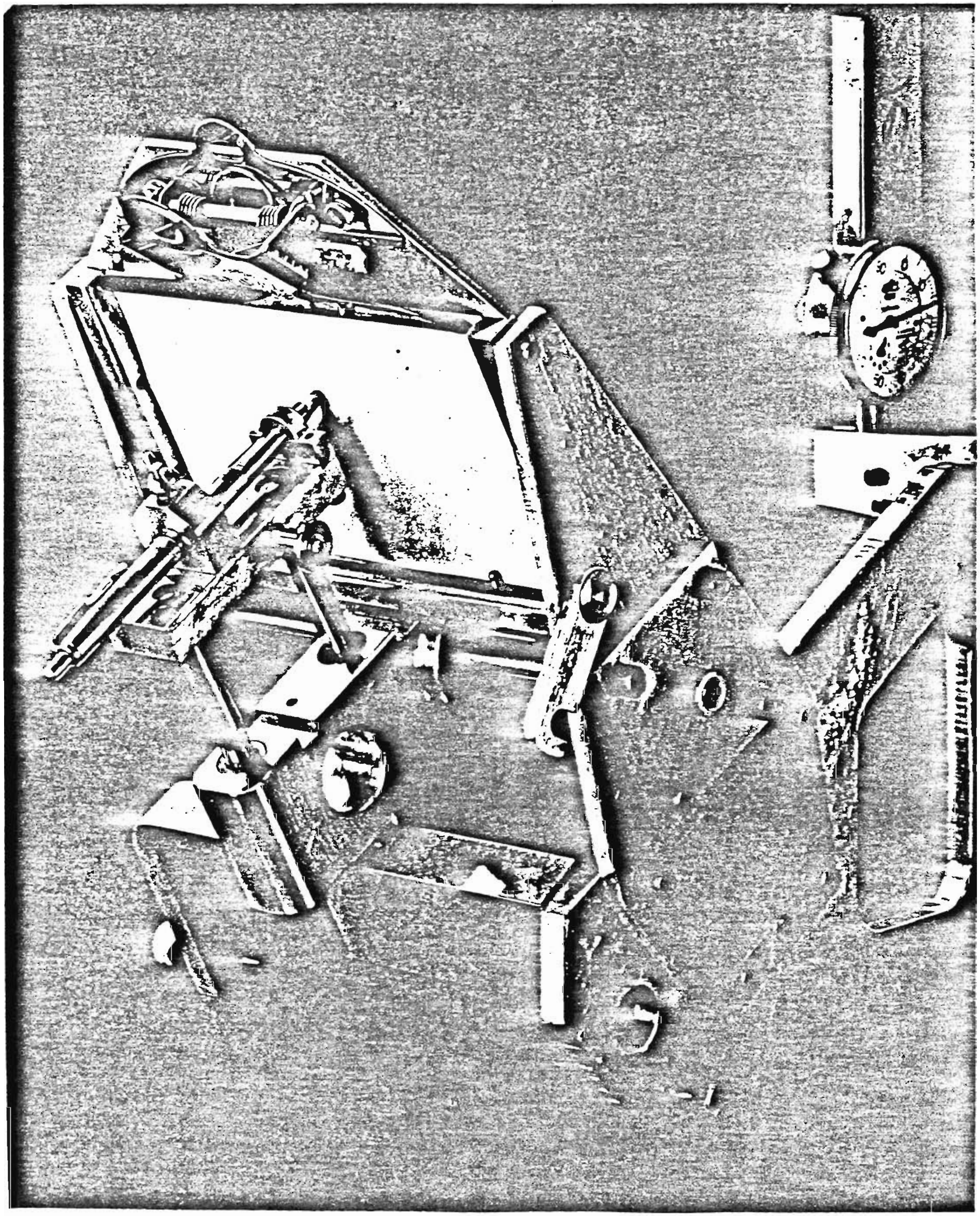

FIGURE 5-1. WHEEL PROFILOMETER

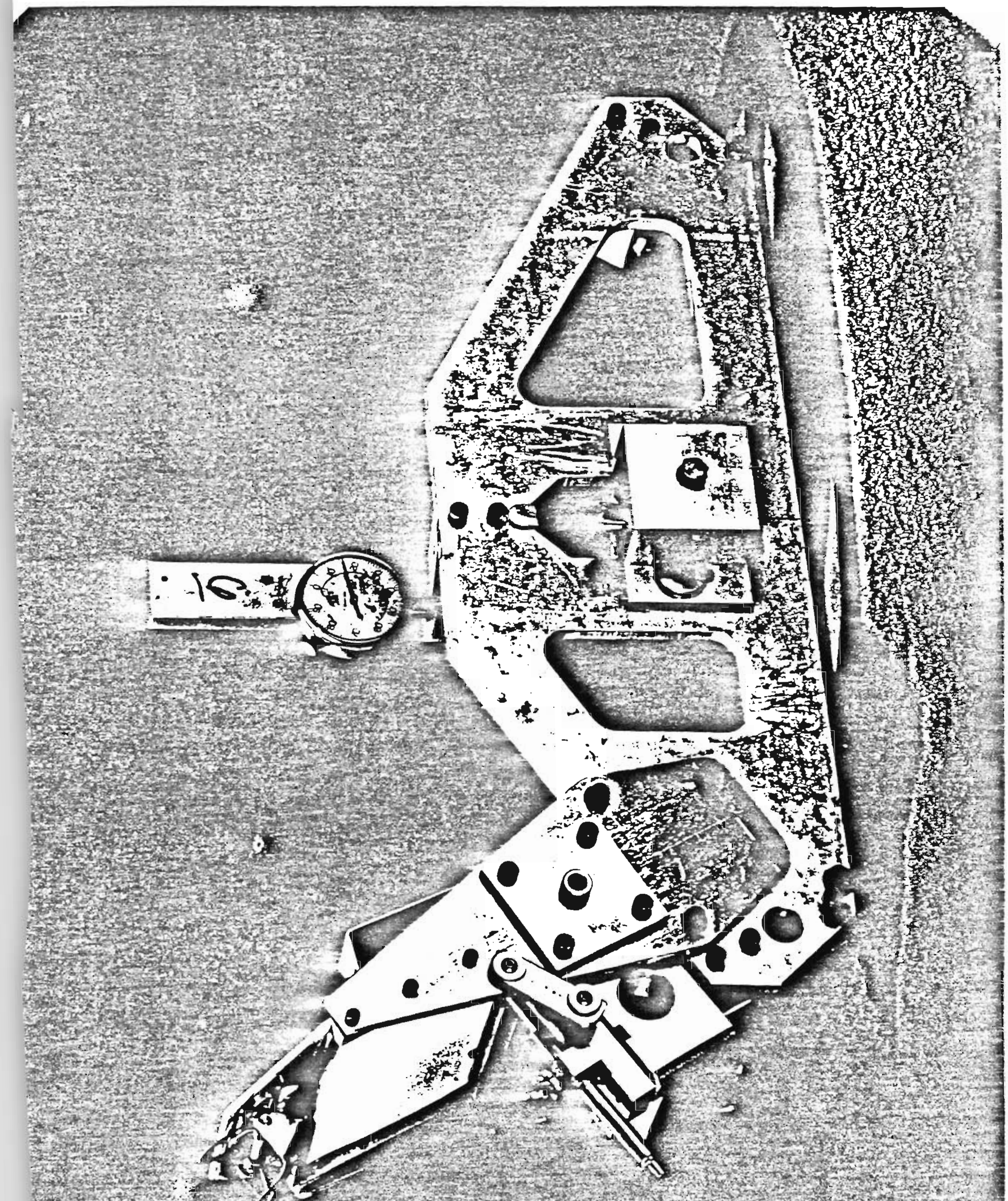

FIGURE 5-2. WHEEL PROFILOMETER

Pullman Standard

Passenger Engineering
1414 Field Street
Hammond, IN 46320

Bottom Gage Edge → Index Side →

Profile No.________ Gage_________ Dial Gage Reading _______

Railroad Yard_____________________________ Date__________

Car No. & Status____

Mech. Car Type & Code ___________________________________

Lightweight-lbs.________________ Capacity-lbs.___________

Inside Length___________________ Volume-cu.in.___________

Std. Draft Gear or Cushion Travel-in. & type________

Built Date ______________________ Truck Centers__________

Special Features (side bearings, etc.)___________________

____

____

Truck Manuf. & Type__________________ Brakes: Iron

Bearings: Roller Friction

Plain Wheel Date__________

Wheel Manuf.____________ Location R1 R2 R3 R4 L1 L2 L3 L4

Auxiliary Snubbing Devices_______________________________

Special Conditions-Comments______________________________

____

Observers____

____

FIGURE 5-3. SAMPLE PROFILOMETER DATA CARD FORMAT

These characteristics, which were selected after several iterations, using different sorting criteria, include:

a. Symmetric or non-symmetric wheelset assessment

b. Tread contour

c. Flange location with respect to the tape line

d. Flange root curvature and flange slope.

Assessment of wheelset (or axleset) symmetry was the first criteria applied and considered only two wheels on a common axle. Thus, the symmetric grouping includes profiles from a common axle which are a mirror image of each other. The non-symmetric profiles obviously do not have this feature but differ (side to side on an axleset) in flange slope, tread contour, flange position or any combination of these characteristics. After sorting according to symmetry, further analyses of the profile groups were performed on each wheel profile independently of the other wheel on the same axle.

The tread contours were basically separated as either tapered (similar to a new wheel profile), non-tapered (or with only slight taper), or hollow worn (tread surface is concave for some portion). Considering non-symmetrical wheelsets and the necessity of retaining matched pairs of wheel profiles from a single wheelset, the following categories were defined according to observed trends:

a. Both wheels in the axleset had much the same shape as a new wheel profile and were almost symmetric

b. Both wheels were tapered on the end (outboard) of the tread

c. One wheel showed taper on the end of the tread, while the other wheel was hollow worn

d. Both wheels were hollow worn.

The flange location as used for all profiles in this program was arbitrarily chosen as the distance from the tape line of a profile to a point on the flange 0.55" above the tape line location on the tread. Several bands were selected to provide a range of flange locations for grouping purposes. After an initial sorting, these bands were adjusted to better fit and separate the distribution of flange locations found on the actual profiles.

The flange root curvature and flange slope characteristics were the most subjective features used to analyze the wheel profile data. Again, the initial classification system was adjusted, after review of the data, to provide improved sorting criteria to better define the profile features. Generally the lower sloped flange was related to a larger flange root radius and probably corresponds to minimum flange wear. The steeper sloped flange is accompanied by a smaller radius at the flange root and relates to greater flange wear. An illustration of the criteria used in sorting by flange location and by flange slope is shown in Figure 5-4.

These characterizing methods resulted in the identification of ten wheel profile groups as described in Table 5-1. Six groups (1 through 6) are symmetric wheelset profiles and are represented by a single typical profile. The remaining four groups are nonsymmetrical and are represented by a typical profile for each wheel of a wheelset.

The fourteen representative profiles (6 symmetric and 8 nonsymmetric) were digitized and stored on computer tape to facilitate future use or analysis. The representative profiles are shown in Appendix K. Statistics on wheel tread wear and axleset gage (defined for this program as distance from tape line to tape line) were also calculated for each profile group. The wheel tread wear values are the difference in radii between the measured wheel and a new wheel measured at the tape line. Use of the tread wear measurement was selected since the identified wheel profile groups contain wheels of different diameters (from various capacity trucks) and the need to provide an average group wheel radius. The wheel diameter and truck capacity do not appear to be factors in determining wheel profile characteristics. This wheel wear statistic (mean and standard deviation) was determined from the difference, for each wheel, between the measured worn wheel diameter and its assumed new wheel diameter. The new wheel diameters are specified

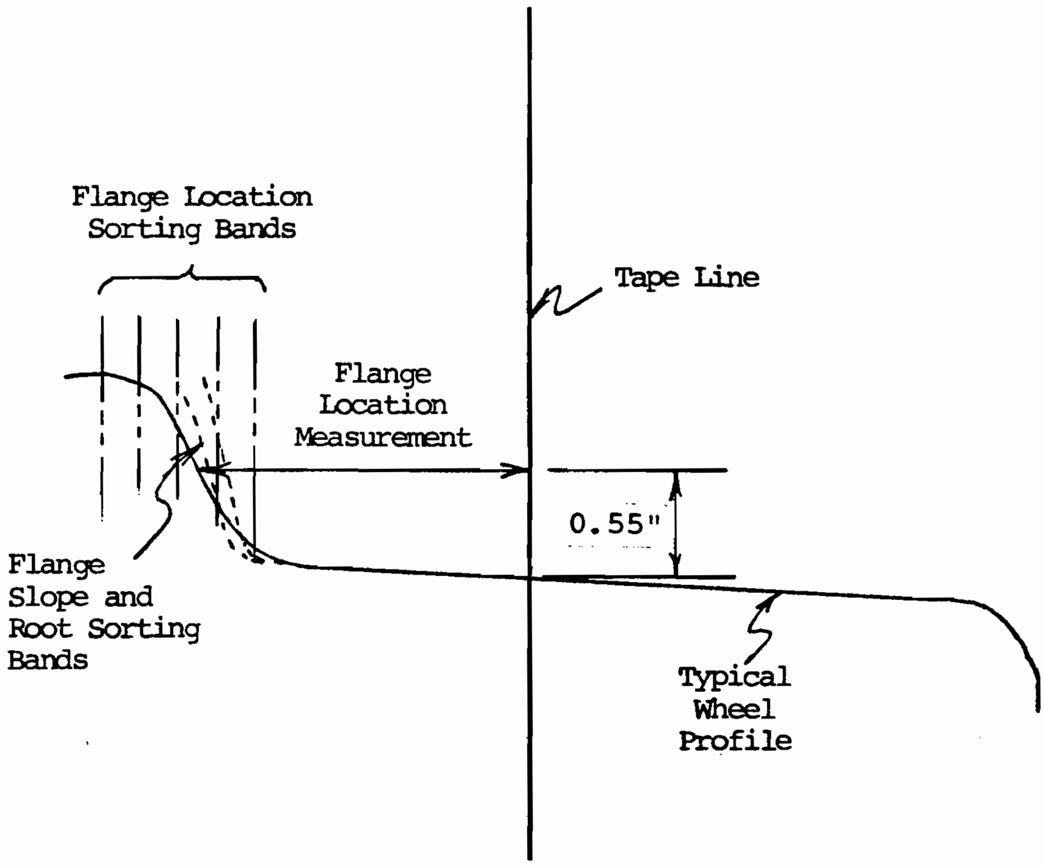

FIGURE 5-4. ILLUSTRATION OF WHEEL PROFILE SORTING CRITERIA FOR FLANGE LOCATION AND SLOPE

TABLE 5-1. FREIGHT CAR WHEEL PROFILE GROUP DESCRIPTION

GROUP NO.	DESCRIPTION	GROUP PROFILE POPULATION
1	Symmetric Axleset Profiles - Moderate flange wear, medium flange root radius, tread evenly tapered.	78
2	Symmetric Axleset Profiles - Small amount of flange wear, medium flange root radius, tread evenly tapered.	34
3	Symmetric Axleset Profiles - Large amount of flange wear, medium flange root radius, tread evenly tapered.	16
4	Symmetric Axleset Profiles - Moderate flange wear, medium flange root radius, tread hollow worn.	24
5	Symmetric Axleset Profiles - Large amount of flange wear, medium flange root radius, tread hollow worn.	9
6	Symmetric Axleset Profiles - Small amount of flange wear, large flange root radius, tread evenly tapered.	9
7	Non-Symmetric Axleset Profiles - (Profiles almost symmetric) - "A" Profile has slightly greater flange slope than Profile "B" - mixed tread differences and flange wear.	22
8	Non-Symmetric Axleset Profiles - "A" Profile has greater flange slope than "B", tread profiles tapered.	14
9	Non-Symmetric Axleset Profiles - "B" Profile flange slope much greater than "A" flange, generally hollow worn tread.	12
10	Non-Symmetric Axleset Profile - "B" Profile flange slope much greater than "A" flange, "B" flange more worn, treads hollow worn.	32

Total Profiles in Sample - 250
Total Symmetrical - 170 Profiles -- 85 Axlesets
Total Non-Symmetrical - 80 Profiles -- 40 Axlesets

by the AAR with tolerances for each standard wheel (or truck) capacity. The mean new wheel diameter is taken as the average between the allowable extremes of manufacturing tolerances. The actual wheel radius for any profile group and for a selected wheel capacity is determined by subtracting the given radius wear from a chosen mean new wheel radius as listed in Table 5-2.

TABLE 5-2. FREIGHT CAR NEW WHEEL DIAMETERS AND CAPACITIES

TRUCK CAPACITY	NOMINAL WHEEL DIAMETER	MEAN NEW WHEEL RADIUS
50-Ton	30"	15.189"
50-Ton 70-Ton	33"	16.689"
100-Ton	36"	18.189"
125-Ton	38"	19.189"
70-Ton Low Level	28"	14.189"

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