REPORT NO. FRA-OPPD-78-17
VOLUME I of II

A COSTING METHODOLOGY FOR FREIGHT CARS

THE TEST OF INCURRENCE/CONSUMPTION RELATIONSHIPS

An Interim Report
JUNE 1978

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
Federal Railroad Administration
Office of Policy & Program Development
Washington, D.C. 20590

NOTICE

NOTICE

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/OPPD-78-17		

4. Title and Subtitle	5. Report Date
A Costing Methodology for Freight Cars The Test of Incurrence/Consumption Relationships	June 1978
	6. Performing Organization Code 289-51868-40-60
7. Author(s) D. Hill, V. deSostoa, F. Dopfel, L.M. Vass	8. Performing Organization Report No.
9. Performing Organization Name and Address Peat, Marwick, Mitchell & Co. 1025 Connecticut Avenue, N.W. Washington, D.C. 20036	10. Work Unit No.
	11. Contract or Grant No. DOT-FR-55055
12. Sponsoring Agency Name and Address Federal Railroad Administration 400 Seventh Street, S.W. Washington, D.C. 20036	13. Type of Report and Period Covered Interim Report
	14. Sponsoring Agency Code FRA

15. Supplementary Notes

Volume 1 of 2

16. Abstract

This report explores the incurrence/consumption relationship for freight cars and applications of the information developed. Incurrence is the accrual of expense dollars for freight car repairs. Costs are incurred directly for labor and material, while overhead costs are applied for specific facilities. Consumption has been defined as the use of specific components or assets in company service. The concept of consumption was examined using actual data from a railroad and a car leasing company. To develop consumption information raw data from the two sources was extracted, compiled, edited, and a comprehensive data base was developed for analysis of consumption. Having examined the concept of incurrence/consumption, the study team explored some uses of the information developed. The incurrence/consumption information and procedures developed may be used for a variety of activities, from costing of potential traffic to budgeting shop activities. The intent was to demonstrate possible approaches to the costing of a commodity trip using incurrence/consumption relationships researched, not to develop an exhaustive list of applications.

Volume 2, the Conceptual Design of a Cost Information System, provides financial cost information for pricing input is catalogued under DOT Reference FRA-OPPD-78-16.

17. Key Words	18. Distribution Statement
Incurrence Freight cars Consumption Costing/Costing Statistical analysis Methodology Mathematical analysis Accounting, Cost Accounting	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	372	

Form DOT F 1700.7 (8-69)

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I. INTRODUCTION

This report presents the results of research performed under contract by Peat, Marwick, Mitchell & Co. (PMM&Co.). The study represents one of six parts of the Federal Railroad Administration's (FRA's) cost research program. The goal of this research is to develop procedures and methodologies defined by the FRA which can be used by any railroad, within the framework of its existing accounting system, to determine the costs associated with the movement of goods between two points. Each of the six parts of FRA's program focuses on a different function of railroad operations. The part presented here concerns what shipments are moved in: freight cars.

BACKGROUND

Compared to other industries, the railroad industry is underdeveloped in its ability to determine the cost of providing specific services. This underdevelopment has several causes. First, the task of determining, allocating, and assigning rail costs is extremely complex, particularly from a marketing and pricing viewpoint; second, railroads are extremely interdependent in providing "through" service, including the sharing of equipment and facilities (over 60 percent of all traffic is carried by two or more lines); third, there are a multitude of approaches to and interpretations of cost concepts and their applications; and fourth, past research has been inadequate for determining cause-effect relationships between services and the costs of providing those services on both a short-run and long-run basis. This underdevelopment, and the associated underdevelopment in cost control, budgeting, profit analysis, and investment decision making, have become partially solvable in recent years with the aid of the computer.

The need for accurate cost data permeates all aspects of railroading, from rates and regulation to operations, marketing, and maintenance policies. One costing system commonly used in the industry has been the Rail Form A formula developed by the ICC. Railroads have generally been dissatisfied with Rail Form A because the formula was designed to use aggregate dollar amounts as inputs and produces average cost factors as output. Rail Form A is being replaced by the Uniform Rail Costing System (URCS) for ICC costing. While URCS provides more specificity in developing costs because it relies on aggregated cost data, it also produces average cost factors.

The development of costing systems by individual railroads has helped alleviate the need for better information. But, while a road's own system may serve the needs of that road, no industrywide conclusions can necessarily be based on information from one road. What is needed is a universally accepted costing methodology and associated cost collection procedures. The goal of FRA's cost research program is the development of such a methodology and procedures.

RESEARCH FRAMEWORK

The movement of goods between two points involves a number of functional activities. The six studies included in the program focus on these different functions of railroad operation. The studies cover the following areas:

- right-of-way;
- yards and terminals;
- train operations and control;
- accessorial services;
- general and administrative services; and
- cars and power.

Each of the study areas addresses one aspect of moving goods between two points: what goods are moved in (cars) and by (locomotives); how cars are classified and reclassified into trains; what the trains move over and how they are dispatched and controlled; and the activities which assist in the handling of goods and support all railroad operations.

This report deals with the freight car portion of the cars and power study. Equipment ownership and maintenance costs make up a large portion of the total cost of an average rail movement. Equipment costs have become even more important as a result of the dramatic effects of inflation on both equipment prices and maintenance labor rates, but costing techniques have not evolved concurrently. Armed with more accurate equipment costs, railroad management would be better able to justify actions and costs to improve car utilization, equipment acquisition, and maintenance practices.

SCOPE AND OBJECTIVES

The study of freight cars, like the other five studies, is divided into three distinct phases. The first phase consists of a state-of-the-art review. This phase of the cars and power study was submitted in March 1976. The report contains the results of interviews conducted with railroad personnel, representatives of the Interstate Commerce Commission, and other knowledgeable individuals, as well as a review of relevant literature. The Phase I report details the experience of the interviewed railroads in developing their own financial/costing systems, including a summary of information and data collection systems. Phase II consists of developing improved costing methodologies and procedures, and Phase III is devoted to testing and verifying those methodologies and procedures.

The scope of this report is Phase II of the freight car study. The report addresses both the examination and selection of appropriate costing techniques and an exploration of the concepts of incurrence and consumption.

Generally, incurrence relates to the expenditure of funds and consumption to the use of the assets purchased by those funds. For freight cars, these concepts are easily illustrated. Incurrence deals with the expense of repairing the cars. How and in what kind of facilities repairs are made, how and by what are costs affected, how labor and material expenses vary, and how decisions are made are some of the issues relating to incurrence. Consumption deals with the activity that causes an asset, a freight car, to be used up. Identification of the causal factors and appropriate output units for measuring component wear, what factors cause the wear rate to vary, and how the costs vary with those factors are issues addressed on the consumption side. Cost variability, the portions of total costs which vary and are fixed, is an additional issue that the FRA program addresses. This cost research differs from previous research because it does not analyze the dollar expenses directly or attempt to associate dollars of expense directly with output units. Instead, it examines incurrence and consumption in light of the actual activities being performed.

The FRA cost research program is not intended to develop a universally applicable financial/costing system. Its objective is to provide information and methodologies usable by railroads with their existing systems. The research is aimed toward developing results which can be applied by a railroad's management to ascertain relevant costs and to direct cost control and data gathering efforts. The research is also aimed toward developing results which can be applied at differing levels of detail. This flexibility in the developed procedures and methodologies will facilitate their application at a level of detail consistent with the supporting information systems, and appropriate to specific costing applications and railroad management's needs.

STUDY APPROACH

This report explores the incurrence/consumption relationship for freight cars and discusses applications of the information developed. For freight cars, incurrence is the accrual of expense dollars for car repair. Throughout the useful life of a freight car, expenses are incurred by car repair shops for periodic repair of defective components and the inspections and servicing required by regulation. Costs are incurred directly for the labor and materials used in repairing a car. Indirectly, overhead costs are incurred for the operation and administration of the car repair shops. The policies of a shop and the accounting methods used impact the cost of repairing a car and, therefore, incurrence.

The purpose of developing incurrence factors is to examine the behavioral characteristics of cost in relation to the volume of repair activity. This task also involves examining how costs (or indices) vary. Costs may vary between shops due to differences in size, productivity, facilities, and equipment. With the assistance of a participating railroad, the study team selected and visited five repair shops to study the car repair process.

As mentioned above, car repair incurrence may be separated into three components: labor incurrence, materials incurrence, and overhead incurrence. Previous studies of this type have shown that three basic methods of analysis provide meaningful results. Thus, statistical methods, an audit of the chart of accounts, and review of contractual obligations were used. One or more of these techniques was applied to each of the components of shop operation. To be responsive to management and costing needs, reporting systems and accounting procedures should be consistent with costing applications and the way cost incurrence varies.

This Phase II report examines the concept of consumption using actual data on the car fleet of a railroad and a car leasing company. To develop consumption relationships, a data base was constructed utilizing car repair records and operating statistics collected by the two firms. The raw information from the two sources was extracted, compiled, and edited, and a comprehensive data base was then constructed for each source. In addition, the universe of freight cars was segregated into appropriate groups for analysis. Freight cars were categorized by type to create groups with similar characteristics and components. Repair categories were established to segregate incurrence into repairs related to specific components and component groups. Segregation of the freight cars and repairs into these elements facilitates analysis and provides convenient levels of detail from which railroads can choose the level appropriate for their needs and compatible with their information systems.

The service life of a freight car is influenced by a variety of situations to which the car is exposed. This is also true of the individual components and component groups which make up a car's construction. This research examines these components, component groups, and cars to determine what factors cause them to wear out. Engineering studies may be used to determine what causes such physical wear; however, the intent of this research was not to conduct extensive engineering studies. The actual analysis of causal relationships was performed using econometric techniques. Regression analysis, correlation analysis, and various other techniques were used to explain component wear in terms of activity and usage. Engineering studies can easily be adapted to and combined with the procedures developed in this study, but the procedures are not dependent on engineering results.

Having examined the concepts of cost incurrence and consumption, the PMM&Co. study team explored some uses of the information developed. The incurrence/consumption information and procedures developed may be used for a variety of activities, from costing of potential traffic to budgeting shop activities. The intent was to demonstrate possible approaches to the costing of a commodity trip using the consumption relationships researched, not to develop an exhaustive list. The actual use of the procedures and information developed in this study will be dictated by the needs and resources of the users.

ORGANIZATION OF THE REPORT

There are many different research results presented in this report. While all relate to the incurrence and consumption of freight car repair costs, some areas and applications may be of more interest to some readers. For this reason, the report is organized in the following manner:

- Section I - Introduction;
- Section II - Description of the data base used for the development of consumption relationships and the reporting system from which the information derives;
- Section III - Discussion of the analysis performed to identify how activities and situations affect asset life and thus to determine the appropriate measures of output for costing purposes;
- Section IV - Overview of the car repair process, including descriptions of the car shops visited and a discussion of the reporting systems used;
- Section V - Description of the accounting systems and procedures used to record and monitor labor and material usage in car repair shops;
- Section VI - Discussion of factors affecting a railroad's ability to adjust labor hours incurred in the car repair process;

- Section VII - Review of the information collected on the amounts and kinds of materials used to repair freight cars;

- Section VIII - Description of components, accounting procedures, and methods of distributing overhead (indirect) costs;

- Section IX - Discussion of two approaches to costing commodity trips based on consumption relationships;

- Section X - Description of possible applications of incurrence/consumption information, including cost control, budgeting, profit analysis, and pricing;

- Appendix A - Tabulations of the estimated nonparametric survival curves for total repair groups;

- Appendix B - Discussion of the sampling strategy used to select the data base described in Section II;

- Appendix C - Description of the procedure used to compute and tabulate nonparametric survival curves; and

- Appendix D - Review of the adaptability of current data processing tools to data collection in the car repair environment.

II. DATA BASE FOR DEVELOPMENT OF CONSUMPTION RELATIONSHIPS

Construction of a data base for use in developing consumption relationships will be described in three subsections: the derivation, the compilation, and the nature of the data base. The first subsection, derivation of the data base, describes the information systems from which equipment characteristics, repair records, and operating histories were extracted and the completeness and sufficiency of the available information. Sample selection, editing efforts, and the process of merging the several sources are described in the second subsection, compilation of the data base. The nature of the data base, including a summary of the information it contains and the implications for its use, is described in the third subsection.

Information from two sources, a major northeastern railroad and a large car leasing company, was used to construct the data base. These sources were used because of the availability of complete maintenance records and operating histories which could be matched for individual cars.

The information obtained from these two sources, although topically similar, differed significantly with respect to the details of the car, repair, and operating characteristics. These differences are attributable to the mix and service characteristics of the respective fleets; the kind of repairs performed; the reporting systems used; the number and accuracy of the operating statistics available; and the time period for which car histories could be obtained. Comparison of results based on the individual sources permitted analysis of these differences and their impact on the results.

DERIVATION OF THE DATA BASE

The inclusion of information in the data base is dependent on the availability and accuracy of such information. It is not feasible to include data that is not collected on an ongoing basis for a certain time period or that is not in a format compatible with the other data. Neither is it practical to include information which requires a large effort to extract, edit, or supplement in order to make it usable. Indeed, the very nature of correlation and regression analysis makes it worthless to construct new data based on existing information. If this were done, the analysis would merely show a perfect correlation between the two sets of statistics (the constructed set and the source set) and the coefficient for both would be identical. If inaccurate information is included in the data base, care must be taken to ensure that the results of the analysis are interpreted in a way accounts for the inaccuracy.

The data base was assembled from information covering three basic areas:

- car characteristics;
- car repairs; and
- operating histories.

Both the railroad and the car leasing company maintain this information as separate files derived from different information sources and gathering systems. Some of the sources and systems used to collect and maintain these three types of information are common to all U.S. railroads and private car owners. Others, however, are unique to the individual railroad or company which developed and uses them. Constructing a data base which could be used for analytical purposes necessitated combining information from all sources and systems on a common basis, one which could serve as the framework for relating and comparing the three types of information. The common basis used was the individual car. Data covering the three areas were matched using car identification (car initial and number) to permit maintenance incidents to be associated with car descriptive and usage factors.

Car characteristics (the data describing a car) are contained in standardized Universal Machine Language Equipment Register (UMLER) files maintained for all freight cars owned by railroads and private car companies in the United States, Canada, and Mexico. UMLER provided a listing, by car initial and number, of the cars in the railroad's and leasing company's fleets. The railroad's fleet totals approximately 97,000 freight cars. While over half of these are of a single car type (open-top hoppers), the population includes a wide variety of car types. By comparison, the leasing company's fleet of approximately 77,000 cars is composed entirely of one type (flat cars).

For the two car populations, the UMLER files provided considerable descriptive data pertaining to each car. The following information was extracted:

- car type;
- age (year built and rebuilt);
- type of bearings (friction or roller);

- tare weight; and

- pool assignment.

In addition to this information, UMLER files contained supplemental data on the car's construction, history, and use, including inside and outside dimensions, owner and lessee marks, original cost, year acquired secondhand, capacity, and per diem and mileage rates. None of these additional items were included in the data base since they were not considered either necessary or relevant for the analysis.

UMLER records were ideal in terms of the completeness and accuracy of the data they contained. Because the records are standardized, each record contains the same data in an identical format and can be readily used without modification or manipulation. Editing was required only where the fleets included unusual or unrepresentative cars which, if involved in the analysis, could bias the results.

The sources of car characteristic data were basically the same for both fleets: both sources were UMLER files modified slightly to fit the individual requirements of the two companies, but utilizing similar formats. Similar sources of car characteristic data are available, in the form of an UMLER file, for all railroads and private car owners. This information is thus available for use in developing consumption relationships for any fleet. This commonality is not the same for repair or operating data, however. There are common sources of limited information in both of these areas, but such information has to be supplemented to create complete maintenance and operating histories for the fleets. Several railroads and private car owners have developed systems for recording and maintaining supplemental data, but a majority do not have such systems. This lack of complete information will be a major problem in assembling a data base for additional companies.

Records of repairs performed by other than the car owner (and billed to the owner) are available from Car Repair Billing (CRB) records maintained by all railroads in accordance with the Association of American Railroads (AAR) Code of Interchange Rules (CIR). These rules do not require that owner-performed repairs be recorded, however, so these repairs must be entered and maintained in systems unique to the owners. Because all car owners do not have such systems, information on owner-performed repairs is often lacking in car maintenance records.

The CRB records of off-line repairs are transferred monthly from the railroad making the repair to the owner of the car. These monthly "bills," identified by car initial and number, contain information about where and when the car was repaired and what specific repair was performed. Repair information is coded according to CIR requirements as published in the AAR Field Manual. Both the railroad and the car leasing company input these monthly bills to computerized car repair history files which are maintained for all their cars.

Off-line repair records are supplemented by the railroad through the use of "system" CRB records which supply an account of on-line repairs to the company's own cars. The railroad requires each of its car repair shops to prepare a bill for owned or "system," as well as foreign, cars. The system bills capture repairs performed on each car in the same detail and format as repairs made to foreign cars. As with the bills for foreign cars, the system bills are coded in accordance with CIR. These bills are input to the same car repair history files as are the CRB bills received from other railroads.

Data on one other type of maintenance performed on the railroad's cars are required to complete the car repair histories. This maintenance involves the program repairs performed on owned cars from time to time. When a component(s) on a specific type of car is found to wear out or fail frequently, the railroad will start a repair program for that particular car type. All railroad personnel are notified to route cars of that type to a specific shop where the program is being performed. Each car that goes through the program receives a bill coded in the same format as CRB bills but with special codes. These codes refer to a "standard bill of repairs," listing the minimum maintenance performed on each car participating in the program. Any additional maintenance is recorded on a second bill, a regular system CRB bill. Both bills are entered into the car repair history files, thus completing the repair histories.

Although the car repair histories are complete from the aspect of all types of repairs being recorded, there are limitations to the accuracy of the records. These limitations are imposed by the information system used to collect the records and by the repair process itself.

The CRB bills (foreign, system, and program) go through a mechanized editing routine when they are input to the computerized files. This editing is not foolproof, however, since car initial and number are not edited. A larger number of problems concerning the accuracy and reliability of the records lie with the car repair process. Cars are bad ordered when inspected, but the inspection procedures may fail to reveal a problem. Cars are normally inspected on switching tracks or in yards while trains are being made up. A car is in a yard an average of once every 200 miles but it may be yarded less frequently and, therefore, inspected less frequently. In addition, an inspection in a yard cannot be thorough enough to uncover every mechanical problem--many defects can only be observed when a car is jacked up. Further limitations occur because the workload and car repair process make it impossible for shop personnel to audit car repair bills for correct and complete coding of repairs.

The system used by the participating railroad for collecting and recording repair information is primarily mechanized after the manual coding of the repair report forms is performed at the shop locations. Repair forms are forwarded daily to a central location where they are processed. The data on the forms are entered on data processing media (tape, disc, punch cards, etc.) at this location. Until mid-1977, the entries were made by keypunchers, but now they are made through optical scan techniques which eliminate some of the errors resulting from the manual data entry procedures. The data processing medium is then forwarded to the computer where, as previously mentioned, a series of edits is performed. This system for recording car repair records is very sophisticated when compared with the state-of-the-art in the industry, especially the inclusion of the optical scan data entry. The system is relatively young however, with records dating back only as far as February 1975. Complete and reliable data are available from the system beginning with the January 1976 records.

CRB records of repairs performed on the leasing company's cars are reported monthly and entered into the firm's computer files. These records comprise all repairs made by railroads and since the sources are the same, the data they contain are subject to the same limitations. Repairs other than those performed by railroads are made to the leasing company's cars in the company's own shops and by contract shops. The company has developed a shop billing system to capture records of these repairs. As with the CRB system, bills are submitted for each car being repaired, identified by car initial and number. Repairs are recorded using codes based on CIR but modified to reflect the specific types of repairs performed. These records are maintained in a separate file from the CRB records since they are not completely compatible.

Repairs recorded by the leasing company are program repairs. The cars are designed and built to function for a certain service period before they must be overhauled. After this period has expired, the cars are taken out of service and reconditioned. Therefore, the repairs performed in contract or company shops reflect the service life of cars' components, since the periods between reconditionings are based on estimates of the service life and wear of various components determined through experience. These repairs do not, however, accurately reflect the time-to-failure of components or the actual service life of a car, because components are not run to failure to determine the appropriate repair interval.

The car leasing company has collected car repair histories for a considerably longer period than has the railroad. CRB repairs (those performed by railroads) have been recorded since 1972, although all the records are not on data processing medium. Company and contract shop repairs have been recorded since 1973. Reliable combined repair records are available beginning with the data for 1974.

The longer time frame of available data (3 years versus 7 months) makes the car leasing company's records more valuable for analytical purposes than the railroad's; yet both are far shorter than would be ideal. An ideal time period is one that is as long as or longer than the service life of the longest-lived component--approximately seven to ten years. It is difficult to determine the causes of wear for a particular component while using records encompassing only a fraction of that component's life. Information for these short time periods may include all the events occurring during the service life of some components (such as brake shoes), but the majority of the service lives of longer-lived components (such as wheels) are excluded from the analysis by the short time frame.

Operating histories, like repair histories, are not completely collected by any one information system or the leasing company. Total days and mileage on foreign roads are reported to the owner in accordance with the AAR Code of Car Hire Rules (circular No. OT-10). However, additional off-line statistics and on-line statistics are not available from any standardized source. Systems to capture this more detailed data must be developed independently by those who want to use such information.

The railroad collects on-line operating statistics including time, mileage, load, tonnage, bad order classification, and utilization information (see Exhibit II-1). These data are maintained in five files: two car movement files, a waybill extract file, and two files pertaining to special traffic movements. The two car movement files, one of which is a spin-off of the other, contain the bulk of the operating data. Additional information concerning the specific tonnage and commodity types by Standard Transportation Commodity Code (STCC) are only available from the waybill extract and special traffic files.

The two car movement files contain considerable data, but the information is not always complete or accurate. In terms of completeness, two problems exist: duplicate records and "holes" (missing records). The duplication problem is more easily solved than is the problem of missing records. Duplicate records can be matched and merged. However, before a "hole" can be filled, it must first be determined that something is missing (and exactly what it is). Missing records can be the result of any number of circumstances, but they are usually attributable to one of the following:

- moves were not reported (this is especially true of empty movements);

EXHIBIT II-1

SOURCES OF ON-LINE OPERATING STATISTICS — RAILROAD

SOURCE	STATISTIC						
	TIME	MILEAGE	COMMODITY	TONNAGE	BAD ORDER	CLASSIFICATION	UTILIZATION
Two Car Movement Files	• Month, day, and time of move	• Origin and destination and miles by move	• Contents of car (alpha name)	• Net tons	• When bad order occurred in terminal	• Calculated from train number changes and length of stay in a terminal	• Load or empty information by move
Waybill Extract Information			• Commodity for general merchandise traffic only	• Net weight			
Two Special Traffic Files	• Month and day car was loaded and unloaded	• Origin and destination of loaded car only	• Commodity for coal and ore traffic	• Net tons for coal and ore traffic			

- car initial and number were recorded incorrectly, so the move cannot be associated with the car; or

- information on the record was miscoded so it cannot be integrated with other records.

Use of data with missing records will result in understated activity levels for the railroad's cars.

Additional problems are caused by questionable accuracy and incompleteness of reporting. As shown in Exhibit II-1, net tons are available from all three sources. The tonnage for a particular shipment may vary from source, to source, however, because of the different reporting procedures. Tonnage from the two special traffic files is more accurate than the car movement file tonnage, but the car movement file is the only source of the tonnage for general merchandise shipments. Commodity reporting is reliable only when the STCC is reported. A report of a car's "contents" is unreliable because it is generally a railroad employee's "best guess" as to what is in the car. There are also no standard abbreviations for the various commodity types. Bad order reporting is incomplete because the reporting system is used only in certain terminal areas and, therefore, captures only approximately 85 percent of the bad orders and 65 percent of the storage incidents.

For costing purposes, data should be collected in a consistent manner and maintained in a centralized location for easy retrieval. Detail is not as important as the manner in which the data are collected since the most detailed information is of no value if it cannot be extracted from the sources in a usable form. Most important, the data used to develop consumption relationships should not be more detailed than the data used for costing. For example, number of classifications need not be collected or used to develop freight car maintenance consumption relationships if costs will not be applied to specific movements by the number of classifications.

Off-line operating statistics are reported to the railroad monthly and are maintained in a per diem file. The per diem report contains only total car days and total mileage, with no detail about the route (other than the name of the railroad), loading, or handling of the car. Commodity, tonnage, and utilization data for off-line moves can be assumed to match the data for the car when it moved off-and on-line, but such data ignore additional loadings off line. Bad order information can be inferred from repair records, but cars are not always bad ordered at the same location where they are repaired. Finally, per diem contains no information about the location or frequency of switching activity.

The lack of detailed off-line reporting impacts the on-line statistics, as well as off-line activity records. Because the off-line reporting is incomplete by comparison with the on-line records, there are, in effect, "holes" in the data whenever a car moves off-line. As with the problem of missing on-line movement records, the lack of complete information results in understated total activity.

Because the car leasing company's equipment is always technically off-line, there is no source for operating statistics other than the per diem records. This limits the available activity measures to total car days and total mileage. A further limitation is placed on these data by inaccuracies occurring in the reporting of time (car days) by the railroads. When a car moves over two or more railroads during a month, the car days (which are reported on a monthly basis) can often be duplicative. The car days, reported separately by each railroad over which the car travelled during a particular month, can occasionally total more than 30 or 31 car days for a single month

While such overlapping is eventually resolved, the resolution may take a long time, perhaps as much as a year or more. Therefore, car day statistics, particularly for current periods, cannot automatically be assumed to be correct.

COMPILATION OF THE DATA BASE

Although car characteristic, repair, and operating data are available, the information is scattered and must be condensed to form a workable data base. The problem of working with the sources as they stand involves not only the physical separation of complete data about a single car but also the volume of some of the source materials. Information about car type and age are available from one source, repair records from another, off-line operating statistics (car days and car miles) from another, and on-line operating statistics (car days, car miles, tonnage, routing, etc.) from still another. The data sources for the railroad's on-line operating statistics alone were difficult to compile. The operating statistics are contained in five files, each of which provides a piece of a car's total operating history (see Exhibit II-1). The data sources are not designed or prepared for the analysis of car repair consumption relationships. They are, therefore, unwieldy to process, requiring considerable manipulation before they can be used for such analysis.

The processing of data for the entire populations of the two fleets (a total of almost 174,000 cars) would not be practical because the volume of data is so large. The amount of information needed for a data base covering 174,000 cars would not only be difficult to collect, but would be even more difficult to manipulate. Data processing time requirements alone for the several hundred tapes would be impractical. Because of the time involved in making one pass through the data for 174,000 cars, only a limited number of analyses could be performed on a "complete" data base. Therefore, using such a data base would require restricting the relations tested to minimize the number of analyses.

For these reasons, sampling techniques were necessary to select a data base of a practical size. The sampling strategy was based on the analysis objectives: to determine relations which are predictive of the incidence of maintenance and to achieve an acceptable level of precision on the parameters of those relations. To meet these objectives, a two-round sampling strategy was adopted. First, a modest random sample of cars was selected. With this sample base, predictive relations could be postulated. At this point, the relations were analyzed for degree of prediction, and alternate forms were tried until the objective of predictability was either achieved or deemed unattainable. To achieve an acceptable level of precision, an additional sample (again selected randomly) could be employed. These additional cars would be used, if necessary, to augment the initial sample until it was determined that the precision requirements had been met.

Sampling permitted ease in developing and testing data processing techniques and allowed more freedom in examining causal relationships. An initial 1 percent random sample (approximately 1,000 cars) was selected from the railroad fleet and a 2 percent random sample (2,000 cars) was selected from the car leasing company fleet. It was determined that additional samples were not necessary. For the purpose of this study, which was to develop and test a methodology but not necessarily an exact measure, the level of precision obtained was judged adequate.

The process of compiling the information and creating a data base is illustrated in Exhibits II-2 and II-3. Exhibit II-2 depicts the compilation of the railroad data base, while Exhibit II-3 depicts the car leasing company's data. Because of the differences in the sources and detail of the available information, the compilation processes differ somewhat. Essentially, they achieve an identical result, however--a data base which contains car characteristic repair and operating data by individual car for the sample equipment. The data base, when complete, was organized so to create a single record for each car which contains all the facts and records of activities pertaining to that car.

Prior to the selection of a sample, the railroad's UMLER file was edited to eliminate cars which would add "noise" to the data base without contributing to the analysis results. Cars which are no longer used in interchange service were deleted since they receive only a minimum amount of maintenance and are thus not representative of the entire fleet. Also eliminated were minor car type populations, which would not provide enough data to

EXHIBIT II-2

COMPILATION OF THE DATA BASE – RAILROAD

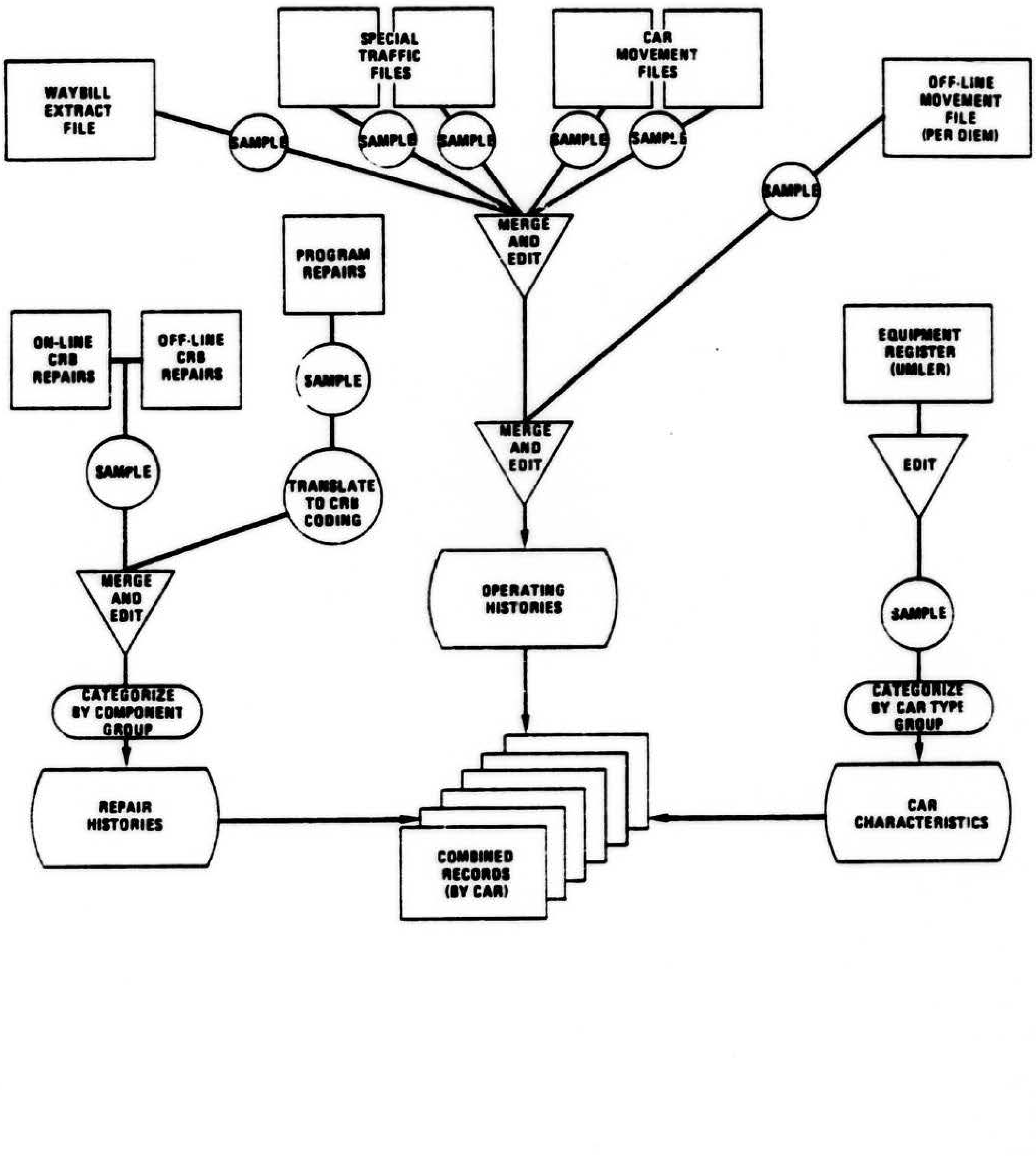
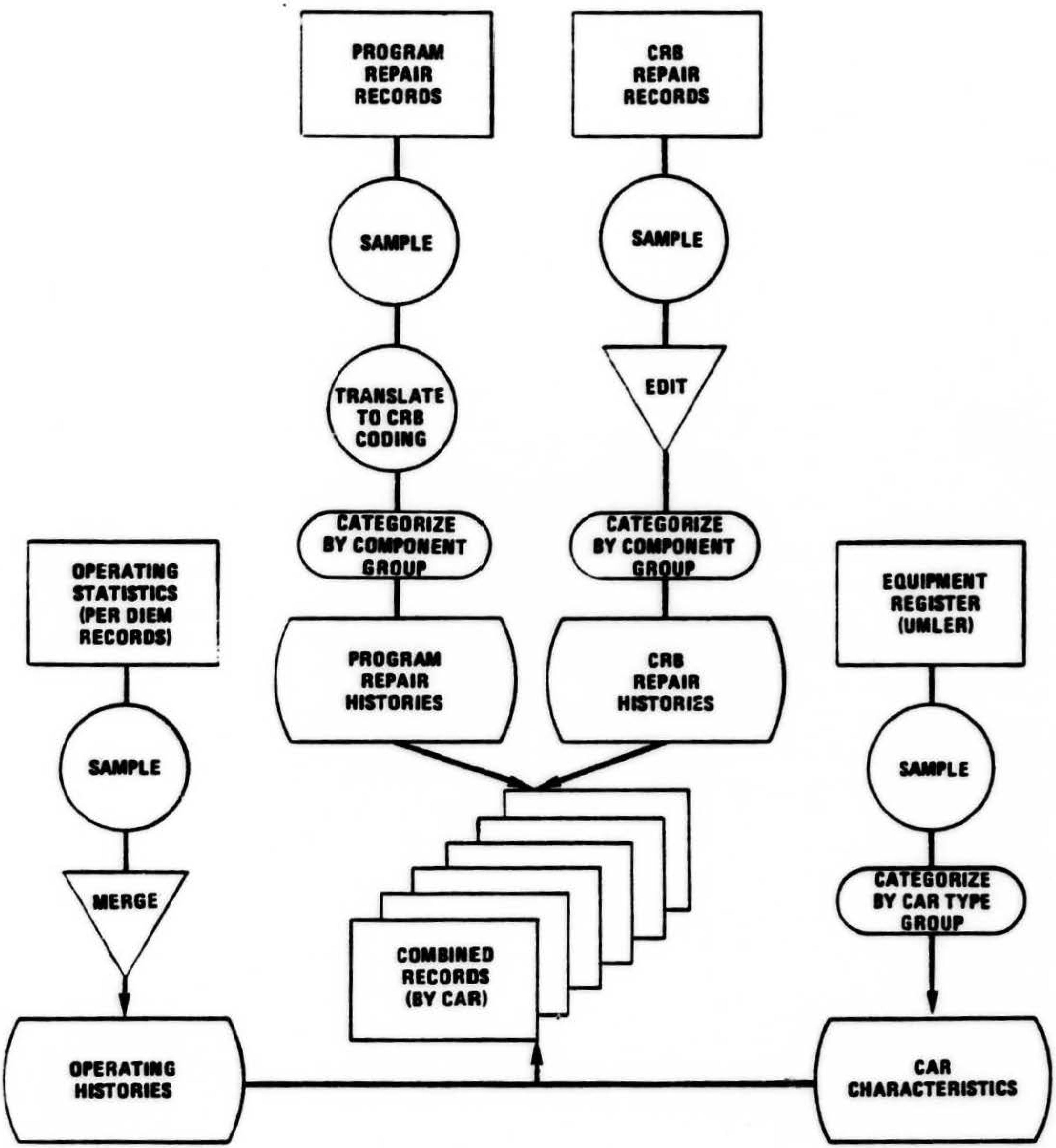


EXHIBIT II-3

COMPILATION OF THE DATA BASE– CAR LEASING COMPANY



support any conclusions about that particular car type. It was not necessary to edit the car leasing company's UMLER, since no unusual or unrepresentative groups of cars were identifiable in the fleet.

Repair data also had to be modified prior to analysis. Since the objective of the analysis is to draw conclusions about what makes a freight car or one of its components wear out, it is desirable to include in the data base only those repairs attributable to wear. The repair data were modified to this end in two successive steps.

First, records of repairs attributable solely to damage were eliminated from the files. These include repairs made because of an unusual situation (such as a derailment) which does not reflect a components's normal service life. Although repairs which were solely attributable to damage could be deleted from the records, those which could have resulted from either damage or wear remain in the data base. Many of the CRB "why made" codes are not specific enough to allow identification of the cause of repair and determination of whether or not they are wear-related.

Secondly, program repair records had to be incorporated with the other repair records. Because of the different repair philosophies, this was handled differently for the railroad and the car leasing company. Railroad-performed program repairs reflect the service life of particular components, since programs are generally instituted when a particular component or assembly on a specific car type has begun to fail or has proved weak or defective. Therefore, railroad program repairs were considered to be of the same nature as the modified CRB repair records, generally referring to wear rather than damage. The railroad's program repair coding was translated to CRB coding and integrated with the CRB repairs to form one data file.

The car leasing company's program repairs, on the other hand, are performed at specified time intervals during a car's life. While the intervals are based on experience and knowledge of the car's service life, the timing of program repairs does not actually indicate that a particular component has worn out. Thus, these program repairs would be more highly correlated to time than to wear. As a result, program repair coding was translated to CRB coding but was maintained in a separate data file. The two can be combined (if time intervals between repairs are being studied) or can be analyzed individually.

Compiling operating histories for the railroad was a more difficult task than compiling the repair histories because the data were scattered, most source files were not edited, and much of the data overlapped. The first step in completing this task entailed merging the six (five on-line and one off-line) operating statistic files. "Chaining" was then performed to create a continuous record and permit identification of the "holes." Editing procedures, which attempted to fill in the missing movements and eliminate duplicate ones, composed the second step. The third and final step involved extracting the relevant statistics from the merged files.

The six files were organized by sorting the data by car initial and number and sequencing the records by date. Merging was then attempted by arranging the records in date and time order. This method was successful for linking the two car movement files. However, the waybill extract, special traffic, and per diem files would not match up with the car movement record(s) because the dates were different. The car movement files record the date (month and day) the car moved; the waybill extract file records the manifest date; the special traffic files record the dates the car was loaded/unloaded; and the per diem file records the month the car moved. It was found that an extensive manual effort would be required to merge all six files, because of this lack of common information. Therefore, the two car movement files were merged and the other four files were held separately. It was then necessary to determine whether the information contained in the remaining four files could be extracted for use and whether it was indispensable to the study.

The per diem file contains information vital to the study because it is the only source of off-line statistics. Since the off-line days and mileage are recorded at an aggregate (monthly level), it was decided to combine the per diem records and the on-line statistics on an aggregate (total history) rather than a record-by-record basis. Railroad personnel were consulted about what value the waybill extract and special traffic files might have for the study. Based on these discussions, it was determined that the three files would provide more accurate tonnage figures for special shipments and detailed commodity information for all shipments. Commodity information cannot be practically used in the analysis because repair incidents cannot be related to a particular load and commodity; inclusion of that information is not essential to the results of the study. The other information the three files provide (tonnage of special traffic) merely adds accuracy to an already inaccurate data base. Since this additional detail does not warrant the time or effort required to merge these files, the special traffic and waybill extract files were not included in the data base.

Car movement records, which were merged and sorted by date, were then chained by matching the "to" station in one record with the "from" station in the following record. The computer could rearrange records with the same date to facilitate a match; however, it could not put the records out of date sequence. When as much chaining had been achieved as possible with the data in their original form, editing procedures were developed and implemented to identify and close any holes. First, moves were linked if the "to" and "from" stations were a short distance from one another in the same switching district or terminal area, where the move may not have been reported.

Next, records were skipped if, by skipping them, the other records would chain. This was done on the assumption that cars might have been reconsigned after a movement record had been entered into the reporting system or that the recorded movement might apply to another car (since the railroad does not check car initial and number). As a final step, movement records were generated to fill the remaining gaps.

In general, the gaps were due to missing records of empty movements. Many empty movements are not reported, including portions of most empty moves and almost the entire empty move of cars in dedicated service (primarily open-top hoppers). While small gaps in the movement records could be patched fairly accurately, this was not the case with open-top hoppers. As a result, total mileage for hoppers is lower than it should be, partially because the circuity of their empty moves is not accounted for completely.

Operating data were extracted from the edited records and seven operating statistics were derived from them (see Exhibit II-4). Some of these statistics could be extracted directly from the merged and edited records; however, others had to be calculated or extrapolated. Information from other than the edited car movement files was used in these calculations, including the car's tare weight from the UMLER file, off-line miles and days from the per diem files, and utilization (loaded versus empty) statistics from railroad records.

On-line car days and car miles were developed by adding the days and miles (loaded and empty separately) from each movement record for each car. Off-line total days and miles were added for each car and multiplied by loaded/empty time and mileage ratios (calculated by the railroad) to separate loaded from empty statistics. On-line and off-line statistics were then simply added together. Gross ton miles were also initially collected separately for on-line and off-line moves. On-line gross ton miles were calculated on a move-by-move basis, using the car's tare weight from the UMLER and the net weight from the car movement file. To this were added off-line statistics calculated by multiplying loaded off-line miles by the average gross weight of the car and the empty off-line miles by the tare. These statistics (car miles, car days, and gross ton miles) are slightly lower than they should be because of missing movement records but, aside from empty hopper records, they correspond reasonably closely with railroad-supplied statistics.

The number of classifications were extrapolated based on the logic that, if a car left a terminal more than four hours after it arrived and was then on

EXHIBIT II-4

OPERATING STATISTICS–RAILROAD

CAR DAYS

- Loaded
- Total (loaded plus empty)

CAR MILES

- Loaded
- Total (loaded plus empty)

GROSS TON MILES

NUMBER OF CLASSIFICATIONS

- Hump
- Total (hump and flat switches)

NUMBER OF LOADS

BAD ORDER LOCATION

COMMODITY BEFORE BAD ORDER

a different train, it had been classified at that terminal. Incidents which qualified as classifications were counted; however, the resulting total was far lower than railroad-supplied statistics indicated it should be. Although some of the error is due to the lack of a count of off-line classifications, the magnitude of the error indicates there is also an error in the on-line account. The number of loads counted is also far lower than it should be, reflecting the absence of off-line data and the inability of the computer to differentiate between a single load and a reload when there is no empty movement between loads. Although these statistics were included in the analysis, error can be assumed in any results based on these counts.

Bad order location and the commodity being hauled prior to or when the car was bad ordered could be extracted directly from the files for some movements. Bad order location was only available when the car was bad ordered on-line and was in a terminal which has a terminal reporting system that collects such data. The availability of this information was so limited that what little was extracted from the car movement files was not usable for analysis. Similarly, commodity information was scarce but could also be misleading, since the damage-causing load could have been carried several loads before the car was bad ordered. This commodity information was collected for each car in the sample, although it (like the location) was not used in any analyses.

Compilation of the car leasing company operating statistics required merely totalling the days and miles reported monthly for each car. As previously mentioned, when more than one railroad is involved, car days for a particular month may total more than 31 days. These figures were not adjusted since some of the reporting could be overlapping from prior or following months and the adjustment of these larger totals might bias equally imprecise reporting during other months for which total days look reasonable (equal to or less than 31 days).

Overpayment (and underpayment) of per diem car hire charges is frequent and not at all unusual. Over or underpayment is usually the result of a transposition, wrong car number, or missed interchange, and these problems are eventually straightened out in the course of the leasing company's claims cycles. The first claims cycle begins seven to eight months after a transaction. At that time, the car leasing company will list exceptions from their per diem records and contact the railroads involved. If the problem is not resolved, a second claims cycle is begun after two years and can continue well into or beyond a third or fourth year. A major reason for this extended claims adjustment period is that the car leasing company's cars are not subject to the penalty specified in Rule 1 of the AAR Code of Car Hire Rules (circular No. OT-10-E). Rule 1 specifies that a 15 percent increase in per diem and mileage (per car day and mile operated) rates will be charged if a car hire is not reported and paid within one month and 10 days of the last day of the month and claims are not settled within two months and 10 days. Some leasing company cars have recently become subject to this rule. However, until the penalty can be levied on all cars, car hire claims can be expected to remain unresolved for extended periods.

Before the final process of combining the data sources was performed, one additional conversion was necessary to prepare the data for use in analysis. This step entailed categorizing both the car type and repair information to allow for the analysis of the maintenance of specific components in appropriate subsets.

Car type categories were based on AAR car types and were grouped or broken down further by mechanical designation, capacity, or special equipment (see Exhibit II-5). This permitted aggregation or disaggregation to a detail consistent with the size of the population being studied and the level of analysis being performed. Repairs, identified by CRB job codes, were categorized into nine major component groups and 43 subgroups within those groups (see Exhibit II-6). Although repairs were grouped, the specific CRB job codes were maintained in the files to permit analysis on a more detailed level, if practical and desirable. Too disaggregate a level, manifested by too many groups of cars or repairs, often precludes the drawing of relevant conclusions since the data sets (groups) are too small (few members).

The final step in creating the data base involved combining the individual merged and edited sources to create records in a format suitable for analysis. Since not all the information from the sources is needed, data processing and analysis requirements could be simplified by combining the pertinent information from each. The combined records incorporate descriptive as well operating and repair data and centralize all information pertaining to a particular car. Analysis needs were met by organizing the data in two kinds of records--car repair summary records and interval records.

A car repair summary record was created for each car in the study sample. The record contains descriptive, operating, and repair data relating to that particular car. Descriptive data includes information extracted directly from the equipment register (UMLER) pertaining to the car's type, age, and other characteristics. The operating data contained in the summary record consist of available operating statistics which reflect the use of the car for the entire study period. Repair data also comprise the entire history of the car for the study period. The number of individual repairs are summed by repair category for each car. Organization of the data in this manner permits them to be easily used and manipulated in computer programs and also permits comparison of variables with one another.

EXHIBIT II-5

CAR TYPE CATEGORIES

	CAR TYPE	AAR CAR TYPE	NO. OF CATEGORIES	CRITERIA FOR CATEGORIZATION
RAILROAD	UNEQUIPPED BOX CARS	B	2	• Length
RAILROAD	UNEQUIPPED GONDOLAS	G	7	• Length • Type of Floor • Type of Ends
RAILROAD	UNEQUIPPED HOPPERS	H	4	• Number of Hoppers • Type of Dumping Mechanism • Capacity
RAILROAD	EQUIPPED BOX CARS	A	7	• Length • Special Equipment (Commodity Related)
RAILROAD	EQUIPPED GONDOLAS	E	5	• Roof • Length • Special Equipment
RAILROAD	EQUIPPED HOPPERS	K	2	• Capacity
RAILROAD	FLAT CARS	F	6	• Capacity • Special Equipment
RAILROAD	REFRIGERATOR CARS	R	3	• Length • Special Equipment
RAILROAD	SPECIAL TYPE CARS	L	18	• Car Type • Capacity • Special Equipment
CAR LEASING COMPANY	FLAT CARS	F	2	• Special Equipment • Use
CAR LEASING COMPANY	FLAT CARS EQUIPPED WITH SUPERSTRUCTURES	V	1	• Special Equipment

EXHIBIT II-6

REPAIR CATEGORIES

MAJOR COMPONENT GROUP	1.0 BRAKES	2.0 DRAFT GEAR	3.0 TRUCKS	4.0 BEARINGS AND AXLES	5.0 WHEELS	6.0 DOORS	CAR BODY 7.0 INTERIOR	CAR BODY 8.0 EXTERIOR	9.0 SPECIAL EQUIPMENT
SUBGROUPS	1.1 COT&S and IDT&S	2.1 Knuckles	3.1 Bolsters	4.1 Lubrication -journal bearings	5.1 Single wear	6.1 Plug or Sliding	7.1 Wooden or Steel floors	8.1 Crossovers brake steps, hand holds, ladders, etc.	9.1 Mechanical refrigeration equipment
	1.2 AB valves	2.2 Couplers	3.2 Side frames	4.2 Lubrication -roller bearings	5.2 Double wear	6.3 Misc.	7.3 Lining - sides or ends	8.2 Painting stenciling, ACI, etc.	9.2 TOFC equipment
	1.3 Retainer valves	2.3 Yokes	3.3 Springs	4.3 Bearings -journal type	5.3 Multiple wear		7.5 Misc.	8.3 Side sheets	9.3 Automobile equipment (racks)
	1.4 Release valves	2.4 Draft gear or end of car hydraulics	3.4 Side bearings and snubbers	4.4 Bearings -roller type			7.6 Lading Equipment	8.4 End sheets	9.4 Misc.
	1.5 Cylinder			4.5 Axles -journals bearings				8.5 Roof sheets	
	1.6 Slack adjuster			4.6 Axles -roller bearings				8.6 Hopper out -lets & roof hatches	
	1.7 Brake shoes and keys							8.7 Under frame	
	1.8 Hand brakes							8.8 Misc.	
	1.9 Misc. items (hoses, beams, etc.)							8.9 Slope sheets	

The other record, the interval record, is somewhat different from the summary record, since it was designed to serve a different purpose. The organization and contents of the interval record provide information about the existence and size of intervals between repair occurrences. For every repair performed on each car, a record was created specifying the car type, age, repair category, repair date, and number of days since the last repair or maintenance incident.

Records were created for every repair to the car because, even when there is only one repair during the study period, there are two "censored" intervals in the data: the interval between the beginning of the study period and the repair and the interval between the repair and the end of the period. It was also vital to create records for cars even when there were no repairs performed, in order to record the "censored" interval composed of the entire study period.

The formats of these two records (the car repair summary record and the interval record) are illustrated in Exhibit II-7. Although these formats vary slightly because of the differences in the data available from the two firms, the organization and basic contents are comparable. The records, in the formats shown, represent an extensive process of selection, modification, and synthesis of the information contained in the original source files. This process of compiling the records required a considerable expenditure of time and effort, both manual and data processing.

The major factor affecting size of the data processing effort was the size of the source data records. For the leasing company (with 77,000 cars), the car repair billing history files consist of 150,000 to 200,000 records per month. To extract 3 years of data, 36 times that number of records had to be scanned. These 5 to 7 million records represent only a small portion of the total volume of records which had to be processed for both the railroad and the car leasing company.

Applying this costing methodology and determining consumption relationships for another fleet would require construction of a new data base for that particular fleet. The actual computer and person hours required to construct a comparable (in level of detail) data base will depend on the type of equipment being used and the experience of the programmer(s). However, the hours used by PMM&Co. to construct the data bases for the study can serve as benchmarks for future efforts.

The person hours and hours of computer time required for compiling the railroad data base (the larger and more complex of the two) are shown in Appendix C. The leasing company data required approximately 225 person hours and 7 hours of computer time.

EXHIBIT II-7

CAR REPAIR SUMMARY AND INTERVAL RECORD FORMATS

CAR REPAIR SUMMARY RECORD

FIELD NAME	CAR IDENTIFICATION		DESCRIPTIVE DATA						
	CAR INITIAL	CAR NUMBER	CAR TYPE	AGE (YRS.)	DOOR TYPE	BEARINGS	POOL	BLANK	TARE WEIGHT (00 lbs)
LOCATION	5	10			15			20	25

REPAIR DATA							REPAIR DATA									
1.1	1.2	1.3	1.4	1.5	1.6		7.5	7.	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8
	30			35				90		95		100			105	

						OPERATING DATA							
						CAR DAYS		CAR MILES		GROSS TON MILES	CLASSIFICATIONS		NO. OF LOADS
8.9		9.2	9.3	9.4	0.0	Loaded	Total	Loaded	Total		Hump	Total	
			115		120		125	130		135	140		145

INTERNAL RECORD

FIELD NAME	CAR ID		CAR TYPE	CAR AGE (YEARS)	REPAIR CATEG.	REP. QUAL.	REPAIR DATE			DAYS BETWEEN REPAIRS
	INITIAL	NUMBER					MO.	DAY	YR.	
LOCATION		5 10			15			20		25

A major factor affecting the level of effort required to compile a data base is the experience level of the analysts and programmers assigned to the project. To be able to work efficiently with the source files, a programmer would need to have acquired several years of experience and have a solid background in working with various types of records and information systems. Without extensive general experience, compiling this kind of data base would be difficult, if not impossible. Familiarity with the specific source files and formats would also be desirable, but is not a vital requirement.

In future attempts to construct a data base for the purpose of developing consumption relationships, the major factors affecting the level of effort required would be twofold: (1) the experience level of the personnel assigned to the project, and (2) the amount (size and complexity) of data to be processed.

NATURE OF THE DATA BASE

The data base compiled for the development of consumption relationships contains descriptive, repair, and operating data, as summarized in Exhibit II-8.

Descriptive data, most of which is extracted directly from equipment register (UMLER) files, includes car type, age, kind of bearings, and tare weight for cars from both fleets. In addition, sources for the railroad data yielded information on door type, pool membership, and commodity. Commodity data were not used in the analysis because they were not always available, were not reliable, and could not be easily quantified. Pool membership data were included despite the fact that they indicate only whether the car was assigned to a pool at the end of the study period and contain no information on the car during that period. Due to the short time span of the study period, the bias due to this circumstance was assumed to be minimal. The remainder of the descriptive data (car type, age, bearing, tare and door type information) are both comprehensive and accurate.

Repair information is derived from both industrywide and firm-specific sources. The repairs are summarized by repair category, which eliminates some of the details available in source files but permits analysis of components and component groups. Because of the different repair philosophies of the railroad and the car leasing company, program repair records were merged with CRB records for the railroad, but maintained separately for the leasing company. Due to the practice of putting cars through maintenance programs at predetermined intervals and more comprehensive care of the cars (especially automobile rack cars), the leasing company cars are probably in better repair than the railroad cars and thus less prone to failure.

EXHIBIT II-8

DESCRIPTIVE, REPAIR, AND OPERATING DATA

	VARIABLE	RAILROAD	CAR-LEASING COMPANY
DESCRIPTIVE DATA	Car type	Yes	Yes
	Car age	Yes	Yes
	Bearing type	Yes	Yes
	Tare weight	Yes	Yes
	Door type	Yes	No
	Pool membership	Yes	No
REPAIR DATA	*Commodity	Some	No
	Repair category	Yes	Yes
	Repair Type (CRB of program)	No	Yes
	Repair date	Yes	Yes
	*Repair location	Yes	No
	*Bad order location	Some	No
OPERATING DATA	Days between repairs	Yes	Yes
	Loaded car days	Yes	No
	Total car days	Yes	Yes
	Loaded car miles	Yes	No
	Total car miles	Yes	Yes
	Gross ton miles	Yes	No
	Hump classifications	Yes	No
	Total classifications	Yes	No
	Number of loads	Yes	No

* Not included in analysis

Bad order location and repair location were additionally available from the source records for the railroad fleet. This information, however, was not analyzed. Bad order location was only available if the car was bad ordered under certain conditions (as explained previously), so there is not a sufficiently complete source of information on which to base conclusions. Nonspecificity is the reason for not including the repair locations. Although specific shops can be identified for repairs performed on-line, off-line repair locations are identifiable only by railroad name.

The reporting of repair occurrences is an additional item which must be qualified. As mentioned before, the reason for the performance of a repair cannot always be differentiated between normal wear, failure, or damage due to unusual circumstances or rough handling. Thus, there is the possibility that many repairs included in the analysis were caused by careless handling or other abnormal conditions. This situation, as well as errors resulting from inaccurate reporting and/or editing, cannot be compensated for, however, and must merely be recognized as being part of the data base.

Operating statistics available in the data base include total car days and car miles for both fleets. They also include loaded car days and car miles, gross ton miles, hump and total classifications, and number of loads for the railroad fleet. These statistics are subject to some inaccuracies due to previously noted problems with reporting and editing and/or calculations using historical and average figures. With the exception of four statistics (hopper total mileage, total classification, hump classification, and number of loads), the statistics have been verified as being fairly accurate. The four inaccurate statistics, though included in the analysis, will produce skewed results because all four are too low due to incomplete reporting.

The completeness and accuracy of the data base variables have a substantial impact on analysis results, as does the fact that the data base contains information about two very different fleets. The railroad's fleet contains cars of nine different AAR car types, while the car leasing company's fleet contains only two. Analysis of fewer car types permits more reliable results for a specific car type. In addition, the age mix of the fleets is different. The leasing company's cars are, on the average, several years younger than the railroad's cars. This difference means that repairs to consumable components (such as wheels or trucks) should have a higher incidence in the older fleet, thus aiding analysis of the service lives of those components.

The two fleets are different in service characteristics, as well as in having different car types and age mixes. The leasing company's flat cars are free-running equipment--the cars, with some restrictions, can be used anywhere in the United States, Canada, or Mexico. This means that the cars might be traveling over any kind of terrain, over rail lines in varying physical condition, and in different types of train services at varying speeds.

By contrast, many of the railroad's cars are in captive service, so the terrain, track condition, and train service variables are relative constants. These factors concerning the kind of car service may have an effect on equipment and component wear. Although these factors are not quantifiable in either situation (free-running versus captive service), the variance in component life resulting from them would be greater in free-running cars than it would in captive service cars. It may be possible to make some observations about the two fleets based on a comparison of these service characteristics.

A final difference (and perhaps the most important in terms of impact on the analysis results) is the variance in the time period for which data was available from the two sources. For the railroad, only 6 months of data could be obtained for analysis; the car leasing company had 3 years of data available. Availability from both these sources was constrained by the lack of compatible data collection systems. Before the beginning of the study periods, either the necessary information had not been collected or the information had not been recorded and maintained on a data processing medium, making it difficult (if not impossible) to edit, modify, and combine the information with other data.

The constraints the time period imposes on the analysis pertain mainly to those components which have service lives which are longer than the study period. For these components, repair intervals would not be available except in "censored" form, which limits conclusions to not much more than the fact that the component service life is longer than 6 months or 3 years. Since the majority of freight car components have service lives which are longer than either of those periods, the limitations of the short study periods are severe.

DATA BASE REQUIREMENTS

The assembly of a data base and, ultimately, the analysis itself are dependent on the availability, centralization, and accuracy of the source data. Not only must needed information be collected, it must also be collected and maintained in a form which is compatible with other sources and which readily permits modification, extraction, and use of the pertinent data. The source must also yield accurate data to prevent bias of the results--data which are either reliably reported or developed with a minimal use of averages and other constructed statistics. The meeting of these criteria not only makes it feasible to physically create a data base but also lends more credibility and less bias to the results.

The major inadequacy of the information used in this report is the short time span. Six months or even 3 years of data is not adequate for the analysis of components, component groups, and cars whose lives may be as long as 35 years. The use of data spanning such as short time period makes conclusions about all but the most short-lived systems questionable.

A large volume of information pertaining to freight car characteristics and car repair and operating histories is currently collected by the industry, as evidenced by the information available for use in this study. Merely having a lot of pieces of information does not, however, mean that a usable data base is available. Of the total information available, only a fraction can be extracted and used because data are often incomplete, inaccurate, or in inappropriate form. As evidenced by the time and level of effort required to process data for use in this study, the content and arrangement of the source information precludes analysis:

- with accurate, complete, and comprehensive data;
- at frequent time intervals to keep the results current; and
- of components with long lives.

These inadequacies suggest changes in data collection procedures to tailor the data specifically for the purpose of consumption relationship development. First, data collected for this purpose should include only information which can be used for analysis and should be in a form which would require a minimum, if any, construction or manipulation of statistics. Secondly, the data that are collected should be arranged and stored in a format which can be used directly for analysis. Finally, the data should be collected in a continuing manner to permit ongoing analysis and the eventual examination of long-lived components.

DATA COLLECTION ALTERNATIVES

Due to the volume of the information necessary for developing car repair consumption relationships, computer processing of that information is a requirement. A variety of possible data collection alternatives exist for computer processing of car repair and activity information. Appendix D contains the findings of an investigation and assessment of data collection alternatives for use in the repair shop environment.

FREIGHT CAR REPAIR RECORDS

One of the most important pieces of data for the development of freight car consumption relationships is a record of car repairs. Repairs to foreign cars are well documented through the use of the AAR CRB procedures, although the cost of repairs are expressed only in terms of AAR standard costs. Few railroads have attempted to maintain similar records for their own cars, however. Three railroads surveyed in the Phase I state-of-the-art study do generate information on repairs made on owned cars; their records are described below.

One of the railroads studied has extended the use of the AAR CRB procedures to owned cars from which limited repair information is available on a per-car basis. Currently, when each owned car arrives at repair tracks or shops (but not those receiving repairs in train yards), shop personnel must complete a header form from the Original Record of Repair. Although these header forms are sent to the AAR billing department at the railroad's headquarters, the only information entered in the computer is:

- location of repair (the railroad's station number);
- repair status code (indicating repairs at repair track, on road, in yard, or in heavy shop);
- car initial and number;
- car type;
- load or empty status; and
- AAR "reason for shopping" code.

Although the nature of the repairs made is described on the header form by each category of component, none of the information on the nature of the repairs made is keypunched. The header forms are placed on microfilm, but this potential source of information is not available for use by the shops and other repair facilities in the preparation of management reports. No standardized reports are currently generated from this computerized data base for owned cars. Information is supplied on an inquiry basis for a particular car or for an entire series.

Another railroad maintains a computerized record of individual car data built around AAR's UMLER. The data include:

- car number;
- kind;
- date built;

- length;
- type of underframe;
- type of superstructure;
- type of sides;
- wheel data (kind, diameter, size journal, and number in truck);
- cost new; and
- all additions and betterments (both a description and dollar amount).

This information can be obtained on an inquiry basis for an individual car or for an entire series. However, no additional information is available on repair expenses or operating statistics.

Only one railroad studied maintains a complete unit record of repairs for individual owned cars that includes all types of repairs made during the life of a car. This railroad has created a car history file produced by merging data from UMLER and the computerized CRB system. This file represents the most advanced state of the art in freight car unit records.

The car history file is designed to compile and categorize repairs performed on and off line to system freight cars.

Inputs

Exhibits II-9 and II-10 summarize the flow of information through the car history file. Inputs are received from UMLER, the Original Record of Repair completed for repairs in a system shop, and the off-line billing statements received from other railroads. Information on repairs performed in the railroad's shops enters the file via optical scan techniques. Information on repairs to owned cars performed off line by other railroads enters the file when repair bills from foreign railroads are received and keypunched.

Program repairs are also included in the car history file and the shop performance system. Information on all program repair work is taken from a standard bill of material completed by the foreman, which lists the material that will be applied to each car and the amount of labor required to apply it. As each program car is released from the shop, the standard bill of material information is inserted into its car history file. If any repairs were made on an individual car over and above the program repairs, they are reported on the standard Original Record of Repairs form.

EXHIBIT II-9

FUNCTIONAL OVERVIEW OF FREIGHT CAR HISTORY AND UTILIZATION

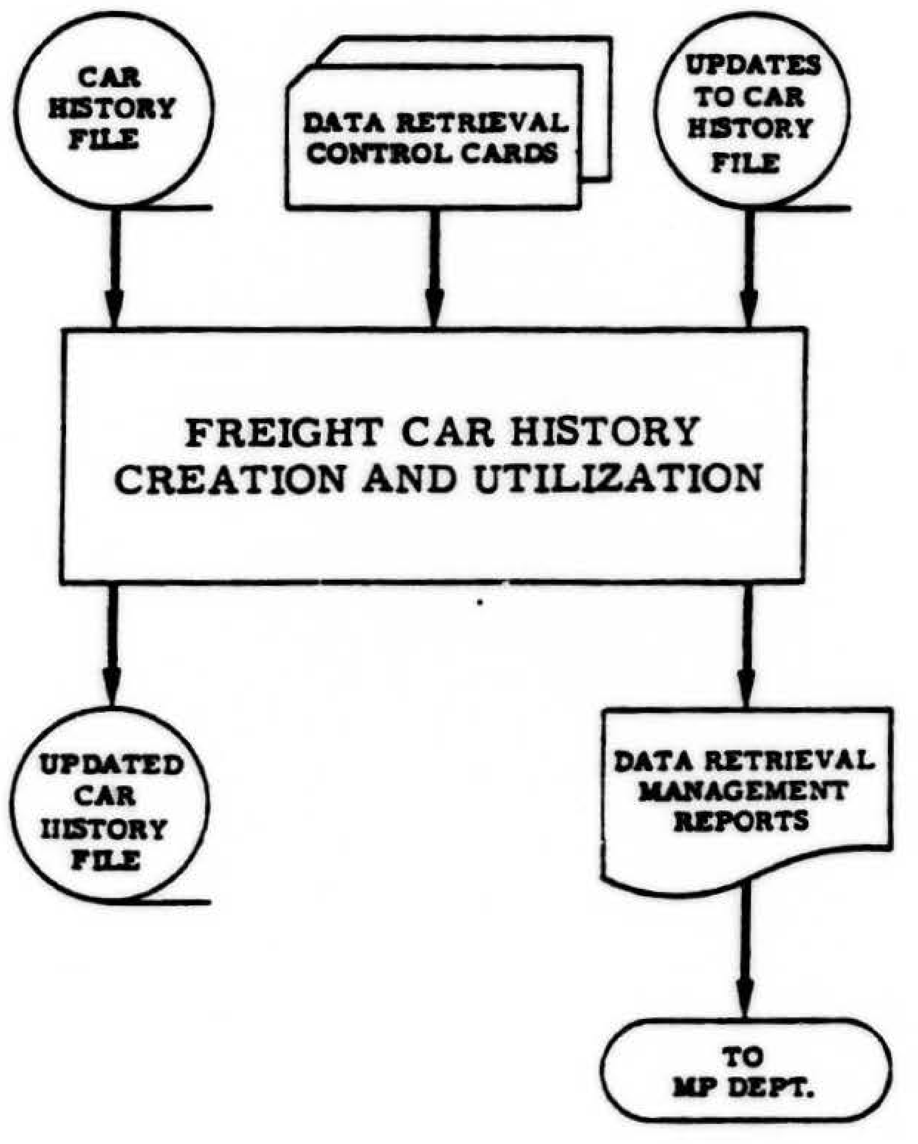
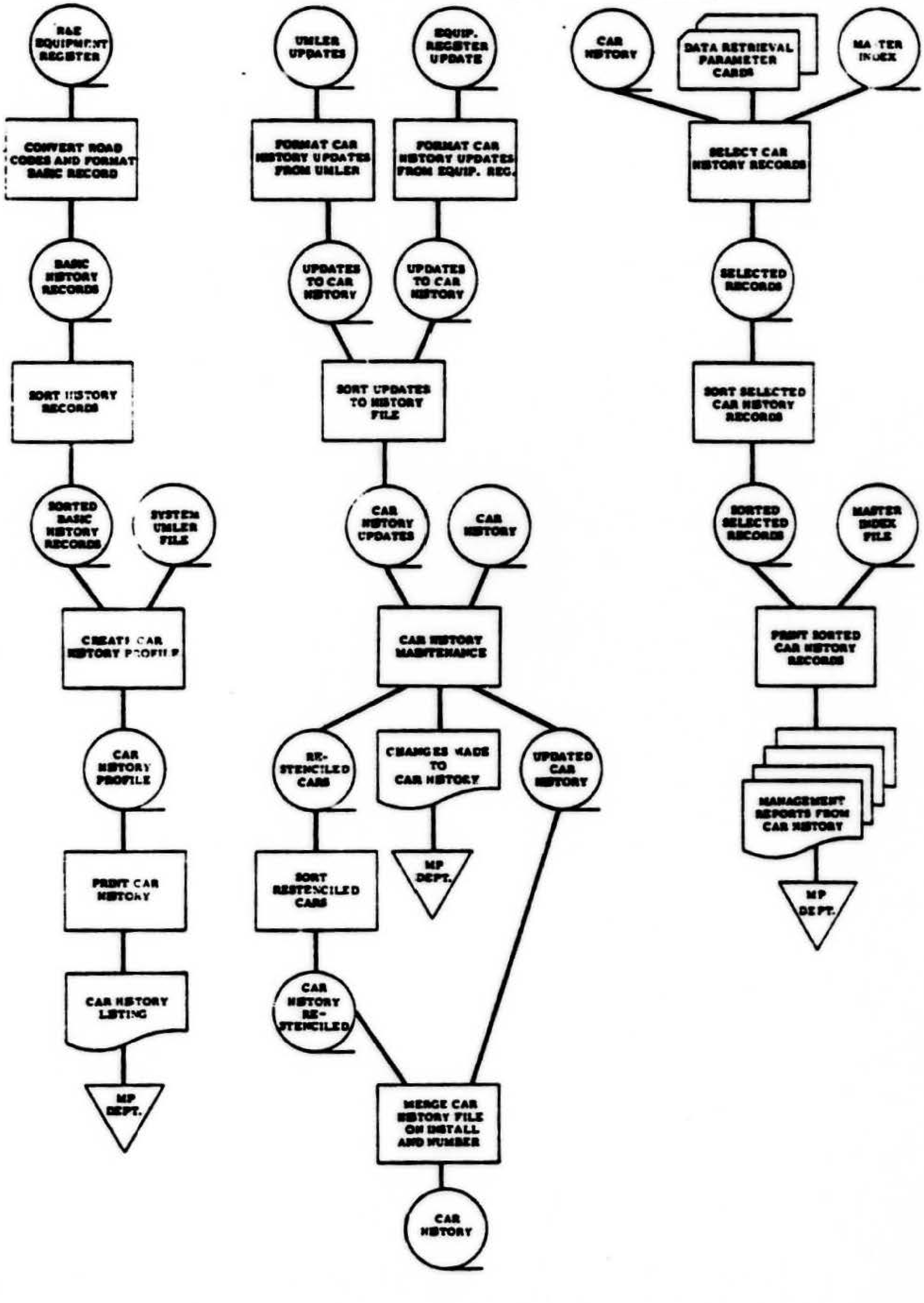


EXHIBIT II-10

DATA FLOW CHART OF THE FREIGHT CAR HISTORY AND UTILIZATION SYSTEM



Rcord Formats

Data from these various sources are merged into a profile record and a repair detail record. The profile record contains:

- car initial and number;
- car type;
- AAR designation;
- manufacturer;
- date in service;
- bearing type;
- length;
- light weight;
- capacity (cubic feet or pounds);
- pool assignment;
- restencil information (new initial and number, and date of restenciling); and
- date of retirement from service.

The repair detail record contains:

- car initial and number;
- car type;
- AAR repair rule number;
- date of repair;
- location of repair (SPLC);
- repair point code if repaired on line;
- location of repair (on car);

- quantity defective;
- condition code;
- applied job code;
- qualifier, applied;
- why-made code;
- removed job code;
- qualifier, removed;
- responsibility;
- defect card authorization (initial, date);
- AAR repair value (shown separately for labor and material);
- pool assignment;
- billing road;
- bill number; and
- microfilm number.

Outputs

The railroad's system has been designed to produce reports in a variety of formats. Although an almost unlimited retrieval capability is available, several standardized reports have been developed which can be related either to a repair point or to a car series. Several component "failure trend" reports have also been developed. The various possible trend reports are summaries of failures:

- to coupler yokes by yoke type;
- to draft gears by manufacturer;
- to lubrication by type of lubricator;
- to journal bearings by type of bearing;
- to journal wedges by type of wedge;

- to roller bearings by manufacturer;
- to wheels by type of wheel;
- to axles by type of axle;
- to truck bolsters by type of bolster;
- to side frames by type of side frame;
- to truck springs by type of spring;
- to air brake equipment by type of air brake;
- to mechanical and pneumatic adjusters by manufacturer;
- to brake beams by type of brake beam;
- to brake shoes;
- to geared hand brakes by manufacturer; and
- to coupler bodies by type of coupler.

File Uses

The system examined provides a data base from which reports can be generated to:

- support individual car decisions to repair or scrap;
- assist financial planning related to car replacement needs, capitalization studies, and new budget developments for both stores and shop organizations;
- provide a research data bank to support technical and profitability studies;
- analyze failure trends of components among car series for design and vendor problems;
- summarize modifications related to cost and failure;
- identify a road's leased cars in order to be billed through foreign car program;

- analyze manufacturer warranties;
- support the bills payable audit function;
- provide more accurate forecasting of freight car maintenance budgets;
- reduce current levels of report generation;
- assist in designing better preventive maintenance programs for freight cars; and
- increase the flexibility of retrieving data for special studies.

Since the three reporting procedures are basically an extension of an existing system, the tools for collecting car repair information on owned cars are already developed. The detail and sophistication of the reporting system used, as shown by the above examples, is dependent on the railroad's needs and resources. Reporting formats, data entry techniques, complexity of the recorded information, and report generation may be designed or adapted to provide railroad management and cost analysts with information to monitor repair activity and develop consumption relationships.

III. ANALYSIS OF FREIGHT CAR MAINTENANCE CONSUMPTION

The objective of this section is to determine whether the consumption concept is valid for freight car costing and, if possible, to demonstrate the development of freight car maintenance relationships for the two firms studied. The comparison of the results for the two firms can be used to determine whether the methodology is applicable to other rail firms.

There are at least three basic approaches to costing: accounting, engineering, and statistical. The accounting approach to costing is generally the least expensive and most convenient method. For this approach, the car repair categories of interest are related to an output measure to develop unit costs. Unfortunately, this approach does not establish a causal relation between consumption and output nor does it separate fixed from variable costs. For these reasons, the accounting approach was rejected.

The engineering approach establishes the technical relationship between maintenance requirements and utilization through engineering laws or empirically through controlled experiment. This approach is potentially very accurate though extremely costly to perform. The engineering approach neglects the impact of maintenance policy as well as the various environmental factors that influence actual operations and are absent from controlled experiments. Based on these drawbacks, the engineering approach was rejected.

The statistical approach was selected for this research as the most practical alternative. Statistical techniques are used to establish a relation between maintenance and output variables based on a sample of actual operations and maintenance records. For the two firms selected for study, the required information was developed from existing sources as described in the previous section.

The remainder of this section demonstrates how the statistical approach was used to develop freight car maintenance relations for the railroad and the car leasing company. The section begins with an orientation to the sample data and its limitations. This includes the car descriptive characteristics, operating activity level, and repair activity level. The distribution of maintenance cycles for selected components and component groups is studied and characterized. Next, the factors and operating activities which affect the incidence of maintenance are identified. Finally, these factors and statistics are combined to developed relations explaining the variation in car maintenance activity for costing purposes.

SAMPLE CHARACTERISTICS

The development of the data base for the analysis was discussed in the previous section. The sample of car histories was taken according to procedures outlined in Appendix B. This section describes the sample characteristics, including:

- freight car fleet - e.g., age distribution, car types;
- operating activity - e.g., miles per day, percent loaded days; and
- repair activity - e.g., repairs per mile, repairs by category.

The purpose of this exposition is two-fold. First, the particular firms analyzed are special cases, and differ from other firms in fleet characteristics, operating environment, utilization, and maintenance policy. Thus, the advisability of extrapolating the conclusions of this study to the universe of railroads can be assessed by evaluating the similarities and differences between this case study and the set of railroads in question.

Secondly, there are many limitations to the accuracy of the data. The data base is constructed from a random sample of automated sources. The data, however, are only as reliable as the source data and the algorithms used to construct the data base. Hopefully, this section can illustrate the many limitations of existing data sources. Exhibit III-1 defines the list of computer-coded variables used in this study.

Freight Car Fleet Characteristics

Exhibit III-2 displays the distribution of freight car types for the railroad and car leasing company fleets. For analysis purposes, the railroad's cars are grouped into six categories:

- equipped box;
- unequipped box;
- equipped hopper;
- unequipped hopper;

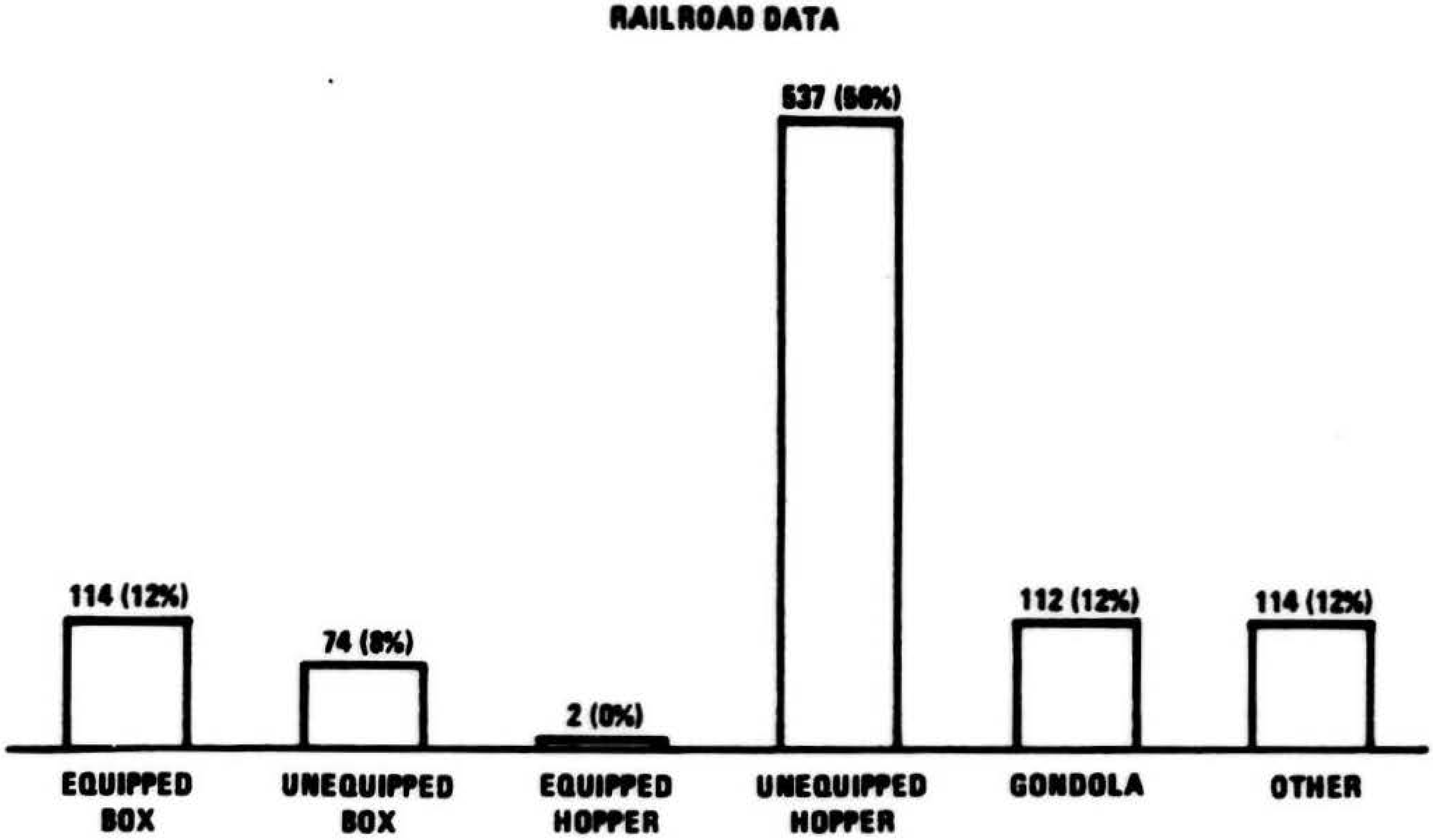
EXHIBIT III-1

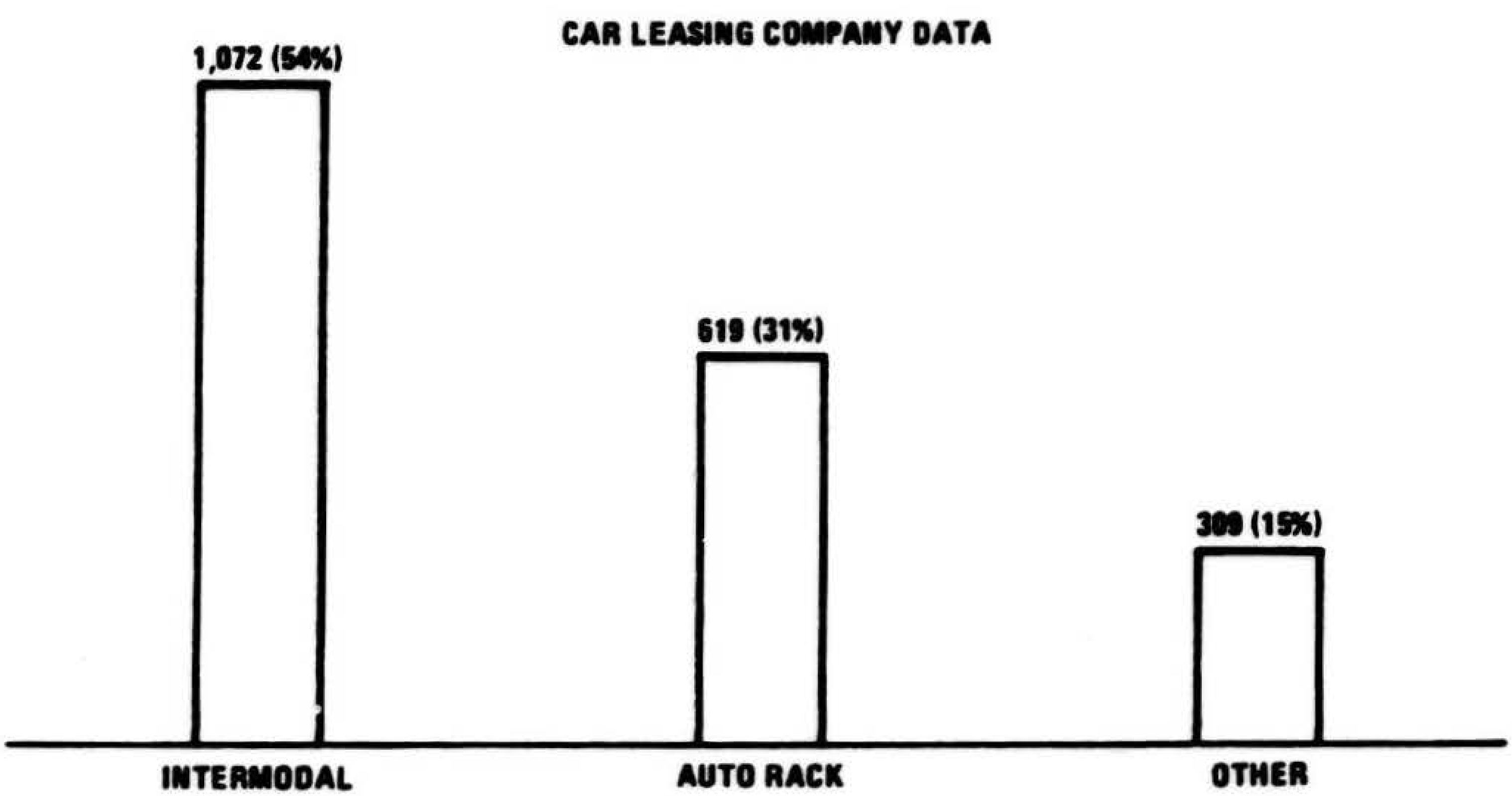
DEFINITIONS OF COMPUTER-CODED VARIABLES

COMPUTER CODE	DEFINITION
CTYPE	Type of Car
AGE	Age of Car (Years)
DOOR	Type of Door
BEARING	Type of Bearing (0 = Friction; 1 = Roller)
POOL	Type of Service (0 = Not Pool; 1 = Pool)
TARE	Tare Weight (hundreds of pounds)
LCDAYS	Loaded Car Days
TCDAYS	Total Car Days
LCMILE	Loaded Car Miles (hundreds of miles)
TCMILE	Total Car Miles (hundreds of miles)
GTMILE	Gross Ton-Miles (thousands of ton-miles)
HCLASS	Number of Hump Classifications
TCLASS	Number of Classifications
REPxy	Number of Repairs to Component x.y (Railroad)
REPSYSx	Number of Repairs to Car System x (Railroad)
CREPxy	Number of CRB Repairs to Component x.y (Car Leasing Company)
PREPxy	Number of Program Repairs to Component x.y (Car Leasing Company)
CRBx	Number of CRB Repairs to Car System x (Car Leasing Company)
PROGx	Number of Program Repairs to Car System x (Car Leasing Company)

EXHIBIT III-2

DISTRIBUTION OF FREIGHT CAR TYPES IN SAMPLE





- gondola; and

- other cars.

It should be noted that the majority of the railroad's cars are unequipped hoppers.

For analysis purposes, the leasing company cars are aggregated to three groups:

- intermodal;

- auto rack; and

- other cars.

It should be noted that the majority of leasing company cars are intermodal.

One reason that car type is an important consideration is that different types of cars have characteristic ranges of empty weight. Exhibit III-3 displays the average tare for freight cars by type. Note that the leasing company's cars are heavier than the railroad's cars, on the average. The average tare for the leasing company cars is 39 tons, versus 29 tons for the railroad's cars. The fact that the autorack car weight includes the autorack equipment accounts for part of the difference in average tare.

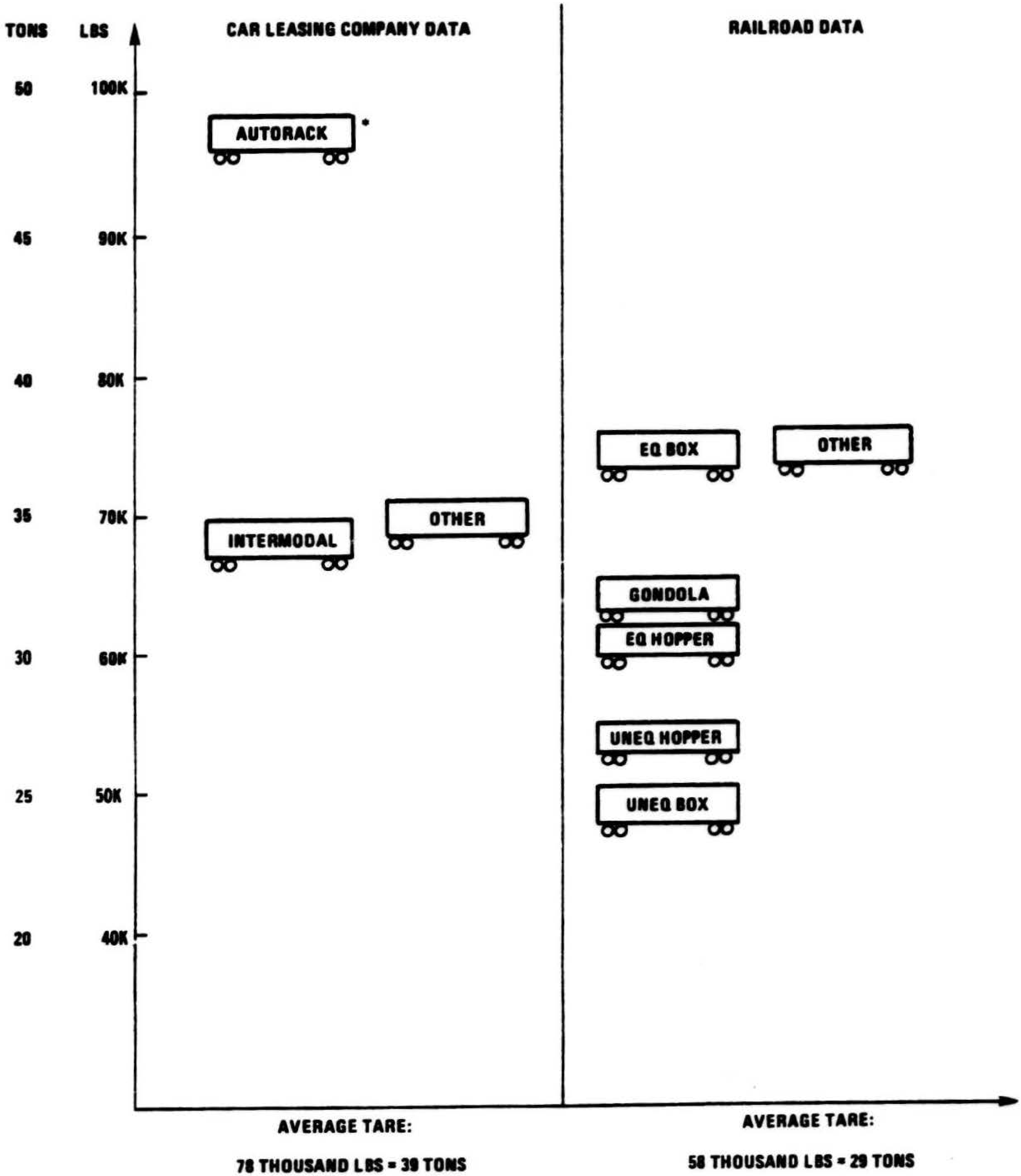
Another factor influencing maintenance requirements is the age of the car. Exhibit III-4 depicts the age distribution of freight cars for the two firms. Only one in 10 of the leasing company cars are over 15 years old, while 38 percent of the railroad's cars exceed 15 years. The average reported age of freight cars in the sample is 13.8 years for the railroad and 9.5 years for the car leasing company.

The type of bearing used can influence the maintenance activity in some categories. All leasing company cars have roller bearings. For the railroad's cars, Exhibit III-5 displays the percentage of cars with roller bearings versus those with friction (journal) bearings by car type and age. The type of bearing is highly correlated to age. The majority of cars under 15 years of age have roller bearings, while only 9 percent over 15 years use this type of bearing.

The cars in pool service generally have higher utilization rates; higher utilization, in turn, implies higher maintenance. Exhibit III-6 displays the

EXHIBIT III-3

AVERAGE TARE FOR FREIGHT CARS IN SAMPLE

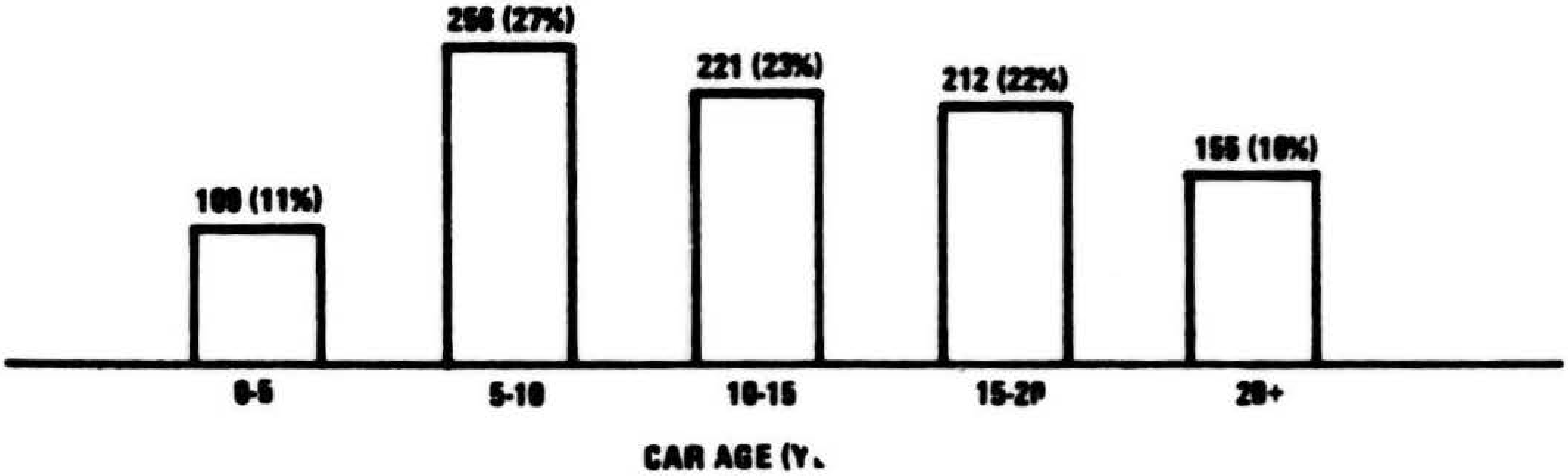


* This figure includes the weight of the autorack equipment.

EXHIBIT III-4

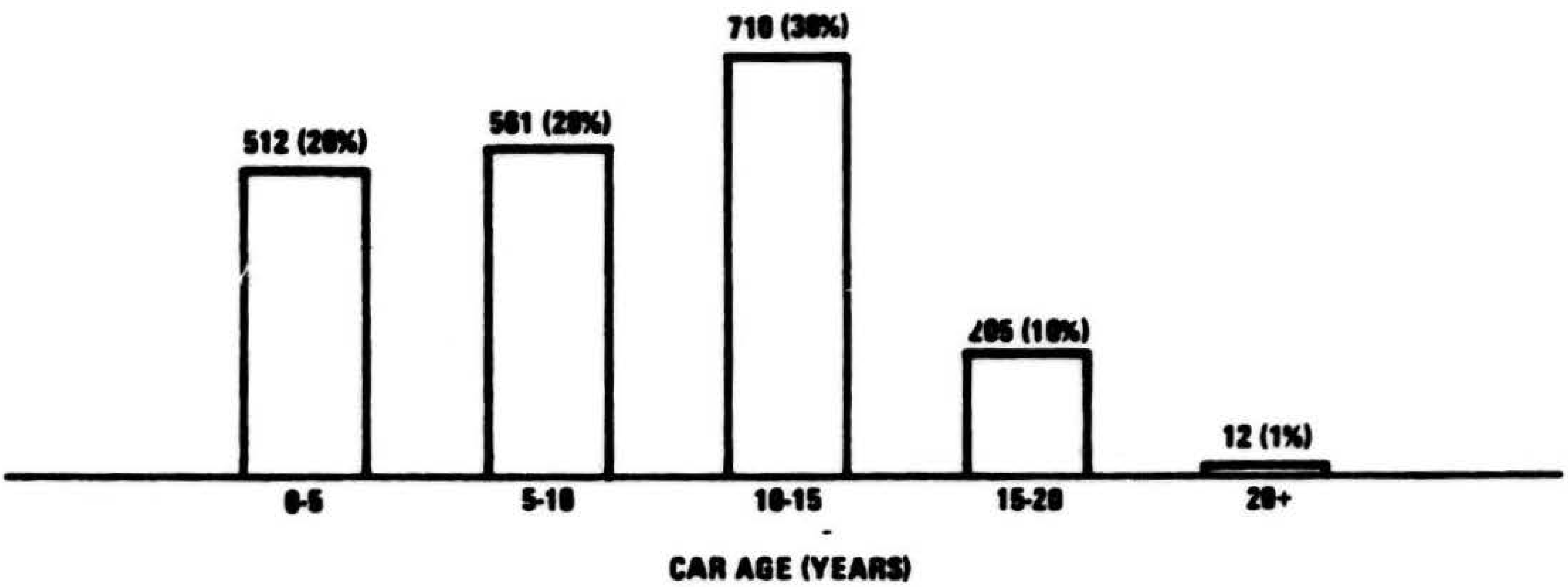
AGE DISTRIBUTION OF FREIGHT CARS IN SAMPLE

RAILROAD DATA



REPORTED AVERAGE AGE = 13.8 YEARS

CAR LEASING COMPANY DATA



REPORTED AVERAGE AGE = 9.5 YEARS

EXHIBIT III-5

DISTRIBUTION OF TYPE OF BEARING USED BY CAR TYPE AND AGE – RAILROAD DATA

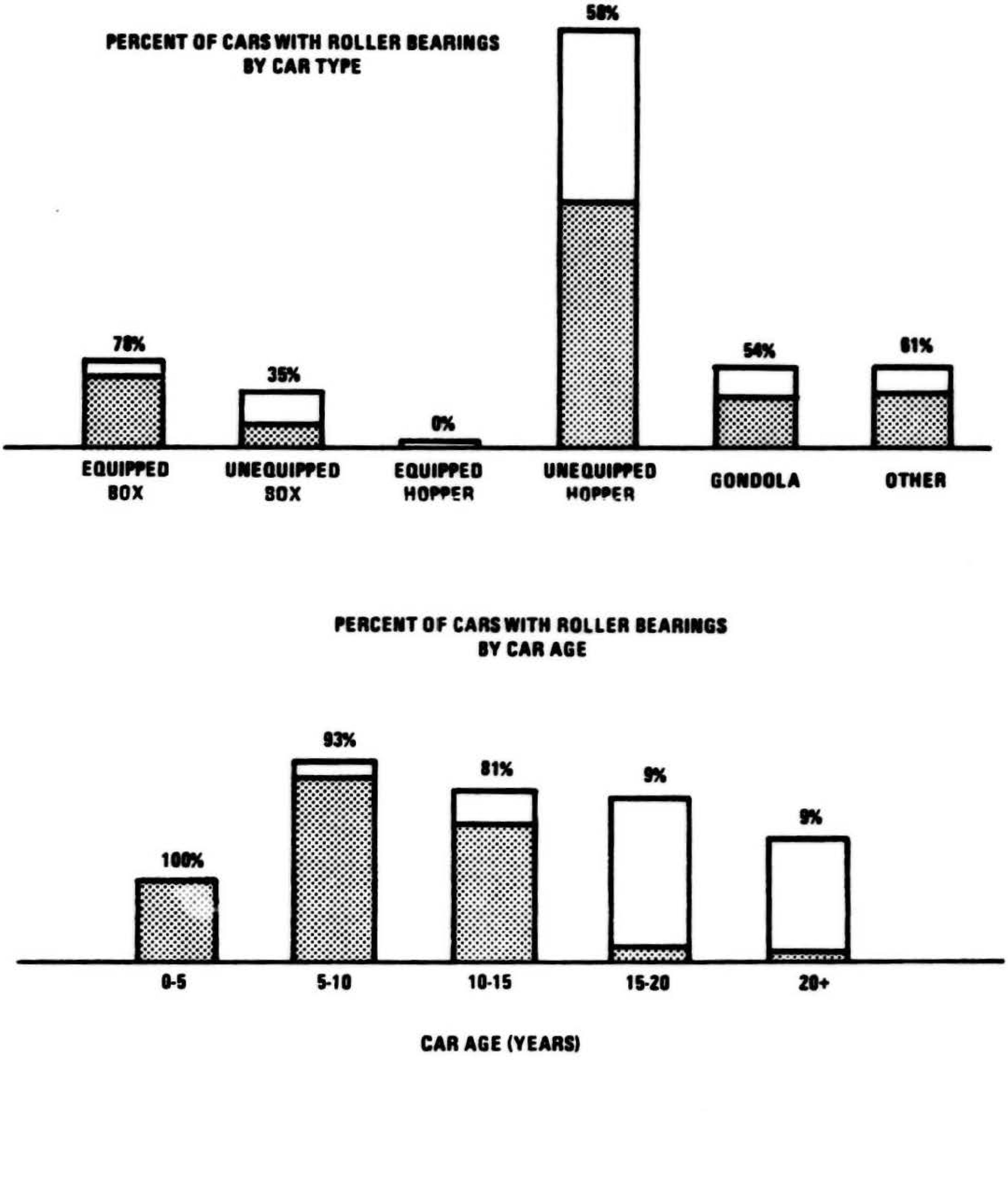
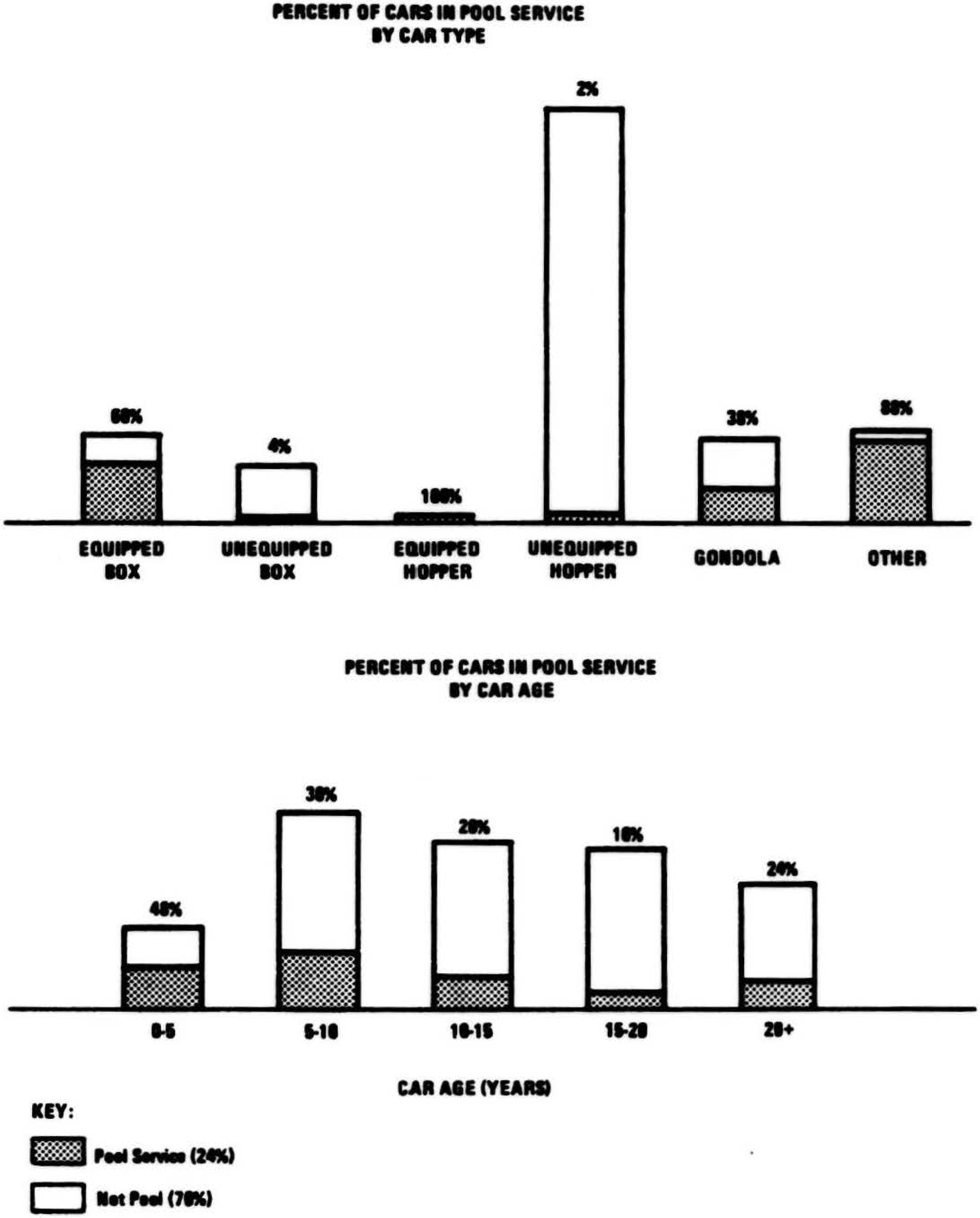


EXHIBIT III-6

DISTRIBUTION OF POOL CARS BY CAR TYPE AND AGE – RAILROAD DATA



percentage of the railroad's cars in pool service by car type and age. Data for the leasing company's cars are not available for this characteristic. Equipped box cars and other types of cars constitute most of the pool cars for the railroad.

Operating Activity

The railroad's data indicate the operating activity of cars for a seven-month sample interval, in which each car is attributed 213 car days. By contrast, the car leasing company's data range from zero to 1,302 car days per car. In this case, a car day signifies a car day in use (per diem) Exhibit III-7 displays a histogram of the total car days per car for the leasing company's cars. The median number of car days is 1,018, and two thirds of the cars fall in the range of 900 to 1,100 total car days for the three-year period.

The leasing company's cars travel more miles per car day than the railroad's cars. Exhibit III-8 illustrates the average total car miles per car day, by car type, for the two fleets. As previously indicated, some of the empty car-mile estimates for the railroad's cars are low, which in turn, biases the estimates of miles per day on the low side. In both firms, the average total miles per day varies significantly by car type. For the railroad firm, older cars tend to be used less. On the other hand, for the car leasing company, older cars have a slightly higher rate of utilization.

For the railroad, more detailed operating statistics are available, as tabulated in Exhibit III-9. For every operating activity, an analysis of variance indicates a significant difference in activity levels among car types. The exhibit also reveals obvious limitations and inaccuracies in the data base. Apparently, the reported activity is low for:

. empty car miles;

. number of loads; and

. number of classifications.

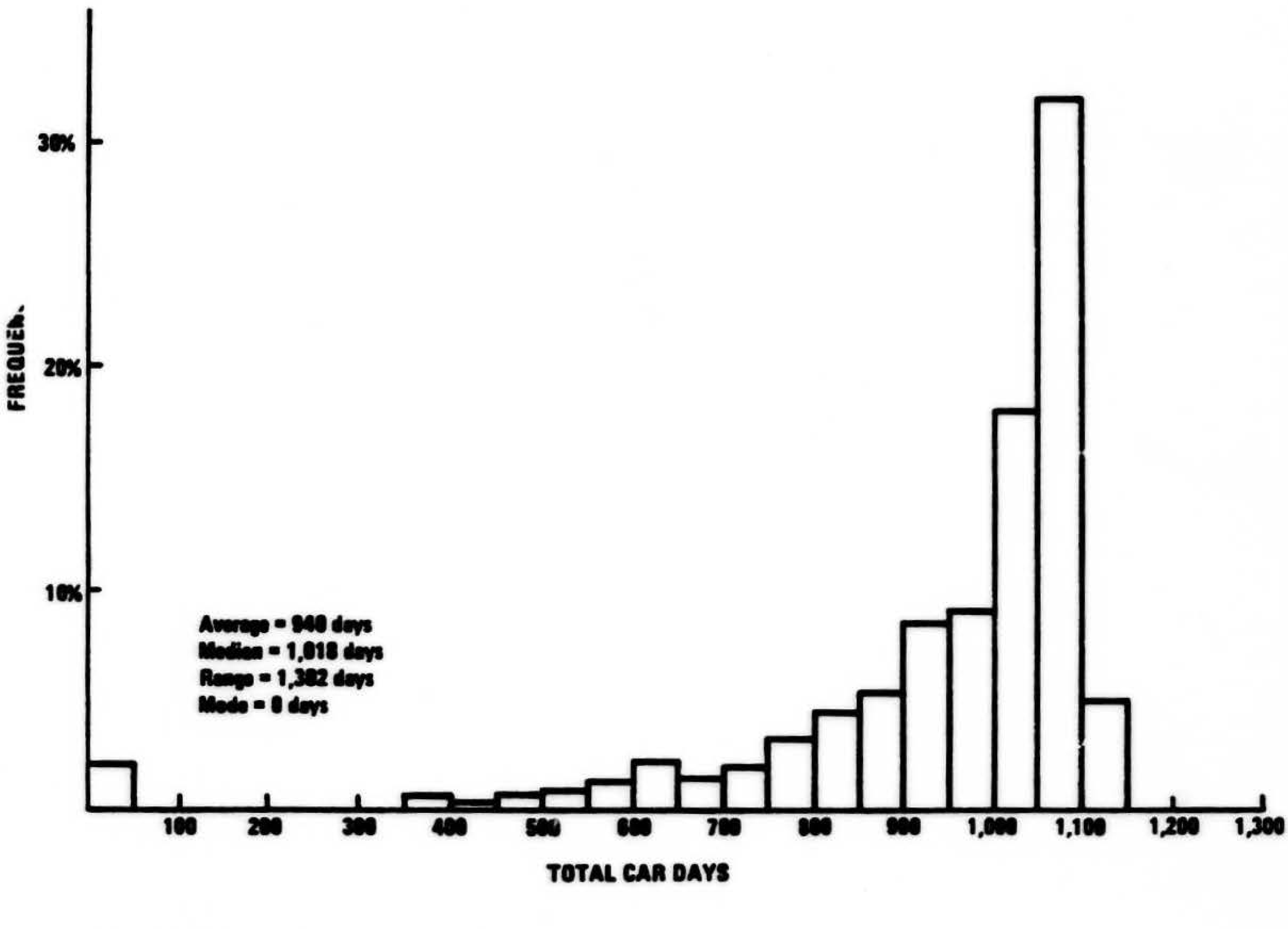
The reasons for this problem were discussed in the section dealing with data collection procedures.

Maintenance Activity

Maintenance activity for freight cars was broken down into 10 major component groups (e.g., brake system) and then into the individual components within each group. A complete definition of these components and groups was

EXHIBIT III-7

DISTRIBUTION OF TOTAL CAR DAYS PER CAR – CAR LEASING COMPANY DATA



NOTE: Car days in use (per diem) for three-year sample period.

EXHIBIT III-8

AVERAGE TOTAL CAR MILES PER CAR DAY BY TYPE OF CAR

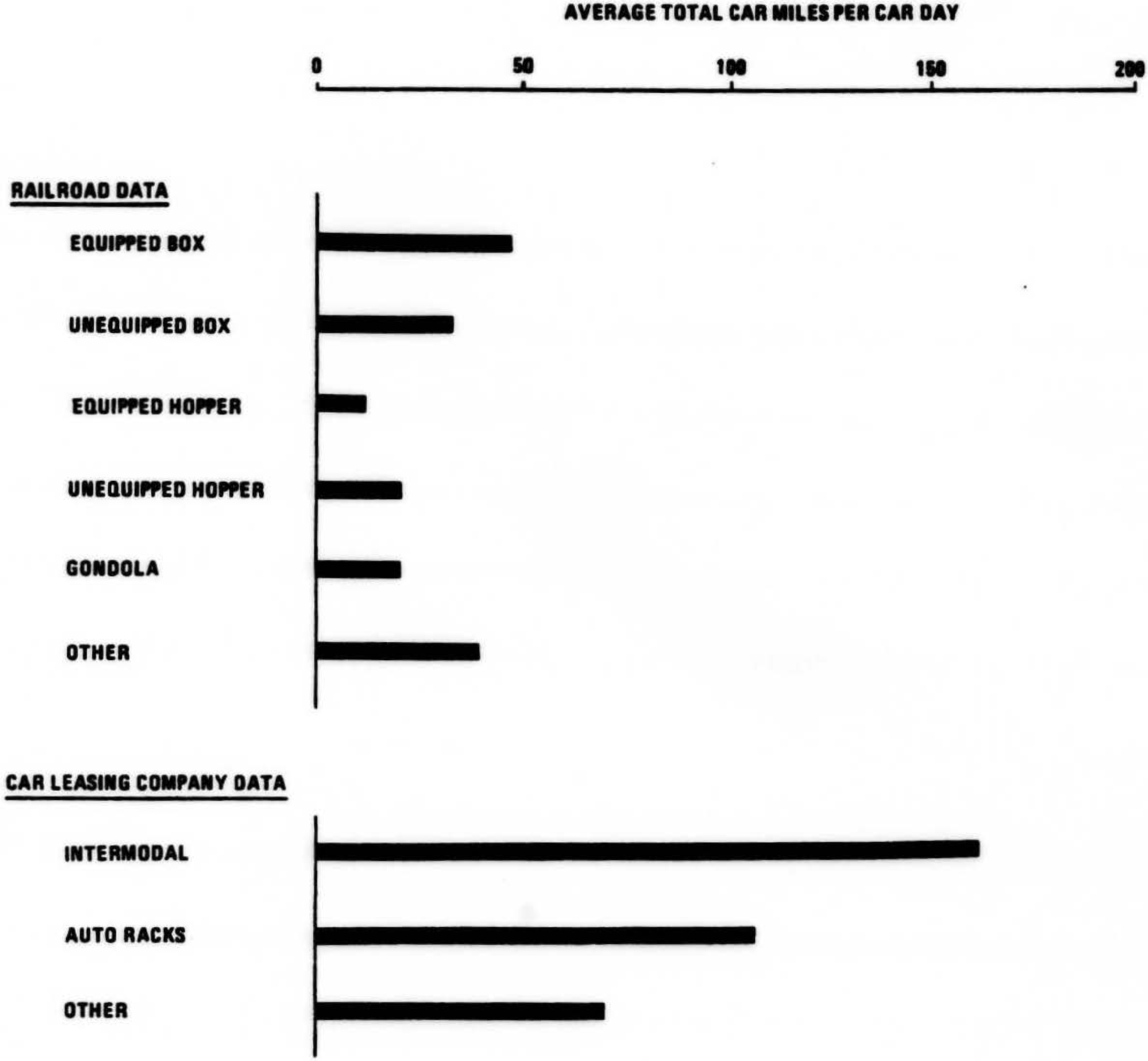


EXHIBIT III-9

OPERATING ACTIVITY BY CAR TYPE – RAILROAD DATA

ACTIVITY VARIABLE	CAR TYPE						ALL CARS	$F_{5,900}$ STATISTIC	SIGNIFICANT DIFFERENCE BETWEEN GROUPS? (91 % LEVEL)
	EQUIPPED BOX	UNEQUIPPED BOX	EQUIPPED HOPPER	UNEQUIPPED HOPPER	GONDOLA	OTHER			
Miles Per Day	46.0	31.4	10.1	20.0	19.4	38.6	26.2	60.7	Yes
Miles Per Load	3,222.	2,071.	337.	580.	1,645.	1,803.	1,231.	102.3	Yes
Miles Per Classification	1,342.	806.	139.	219.	796.	1,071.	547.	46.8	Yes
Percent of Days Loaded	28%	25%	19%	39%	28%	33%	34%	23.5	Yes
Percent of Miles Loaded	48%	51%	49%	71%	51%	49%	62%	141.7	Yes
Gross Ton Miles Per Loaded Car Miles	112 tons	81 tons	132 tons	125 tons	113 tons	132 tons	120 tons	36.2	Yes

NOTE: Chart shows data limitations in some cases (i.e., reported activity is low for empty car miles, number of loads, and number of classifications for some car types).

provided earlier in this report. For this analysis, it is important to aggregate repairs into categories which may exhibit similar incidence of repair characteristics.

Exhibit III-10 displays the number of repairs per thousand car days by component group for the railroad and the car leasing company. For both firms, the brake system repairs account for more than half the total repairs per day. Overall, the leasing company's cars have more repairs per day; however, there is no clear dominance on a group-by-group basis. The railroad's cars incur more repairs per day for draft gear, trucks, doors (leasing company cars do not have doors) and car body exterior. The leasing company's cars show more repairs per day in the four other car systems and in the miscellaneous category.

Exhibit III-11 represents a similar breakdown of repairs per 100,000 car miles. Although the overall repairs per car day is higher for the leasing company, the overall repairs per car mile is much higher for the railroad. In all but the special equipment category, the railroad's cars incur more repairs per mile than the leasing company cars.

Exhibit III-12 compares the distribution of repairs by group for the railroad and the car leasing company. In both cases, repair or maintenance to the brake system is the predominant repair activity. Draft gear, trucks, and bearing and axle repairs constitute a greater percentage of total repairs for the railroad than for the car leasing company. The frequency of truck repair is related more to car age than to use (see Exhibits III-24 and III-25). Since, on the average, the railroad cars are older (see Exhibit III-4), more truck repairs are expected for this firm. Also, 42 percent of the railroad's cars are equipped with the higher-maintenance friction bearing (see Exhibit III-5), whereas the car leasing company fleet is fully equipped with roller bearings. This accounts for the lower repair activity in the bearing and axle system for the leasing company's cars.

Overall, the leasing company's cars are younger and travel more miles per day than the railroad's cars. Consequently, the distribution of repairs displayed in Exhibit III-12 shows a higher incidence in the mileage-related repairs for the car leasing company and a higher incidence in time-or age-related repairs for the railroad. A more detailed analysis of correlations is presented in a later section on maintenance-related factors and operating statistics.

EXHIBIT III-10

NUMBER OF REPAIRS PER THOUSAND CAR DAYS

COMPONENT GROUP	RAILROAD DATA	CAR LEASING COMPANY DATA
Brakes	10.9	31.2
Draft Gear	3.1	2.1
Trucks	1.0	0.3
Bearings and Axles	2.2	2.6
Wheels	0.3	1.2
Doors	0.3	0.0
Car Body – Interior	0.2	0.9
Car Body – Exterior	2.7	2.5
Special Equipment	0.0	2.0
Miscellaneous	1.0	5.8
All Repairs	21.7	48.9

NOTE: Railroad data include CRB and program maintenance. Car leasing company data represent CRB repairs only.

EXHIBIT III-11

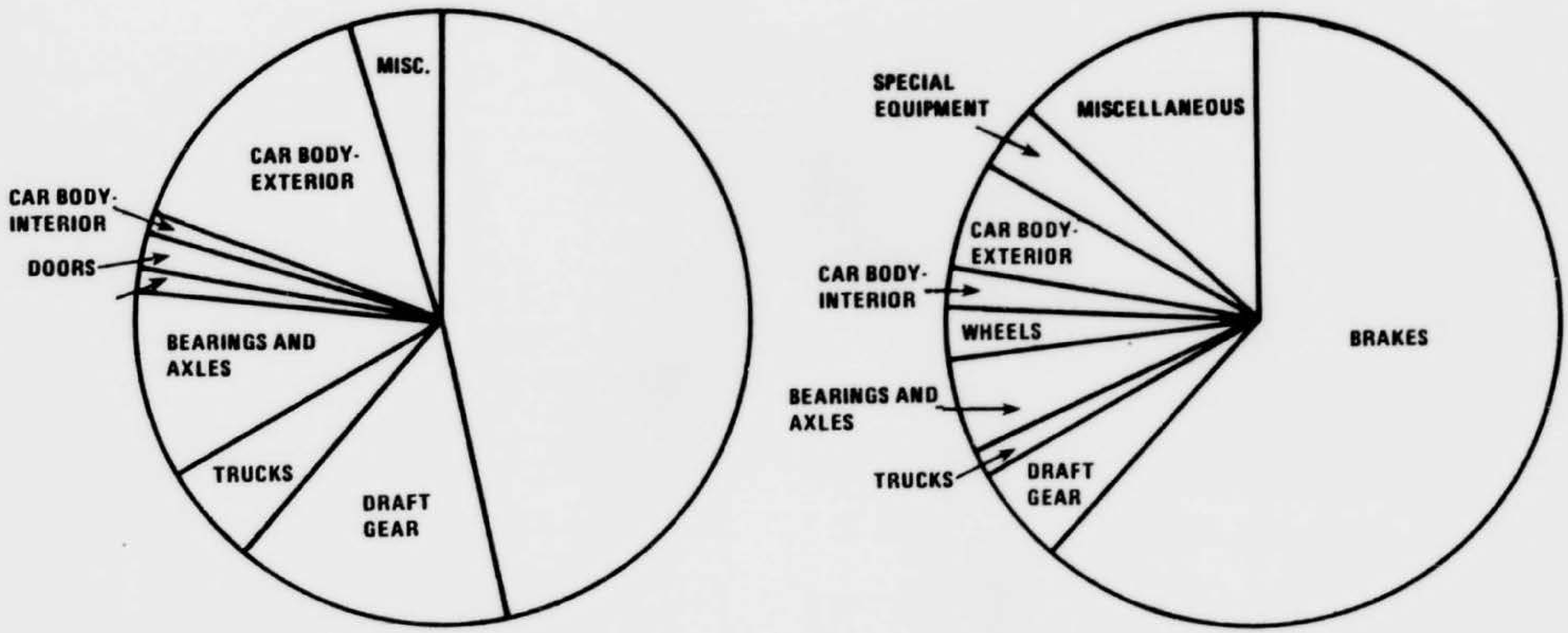
NUMBER OF REPAIRS PER HUNDRED-THOUSAND MILES

COMPONENT GROUP	RAILROAD DATA	CAR LEASING COMPANY DATA
Brakes	48.8	24.1
Draft Gear	15.7	2.0
Trucks	5.4	0.3
Bearings and Axles	11.8	2.1
Wheels	1.5	1.0
Doors	2.6	0.0
Car Body – Interior	1.1	0.8
Car Body – Exterior	16.2	2.3
Special Equipment	0.0	1.3
Miscellaneous	5.2	4.9
All Repairs	106.4	38.9

NOTE: Railroad data include CRB and program maintenance. Car leasing company data represent CRB repairs only.

EXHIBIT III-12

DISTRIBUTION OF REPAIRS BY COMPONENT GROUP



NOTE: Railroad data include CRB and program maintenance. Car leasing company data represent CRB repairs only.

DISTRIBUTION OF MAINTENANCE CYCLES

To establish relations between utilization and incidence of maintenance, regression and analysis of variance techniques are used to estimate average behavior. However, values for average repairs per mile or average days per repair have meaning only in relation to the underlying frequency distribution assumed by the data. For example, if the distribution of maintenance cycles is characterized by a normal distribution, the average cycle time is at a point where 50 percent of the cars have a longer maintenance cycle. However, if the distribution of maintenance cycles is characterized by an exponential distribution, the average cycle time is at a point where only 37 percent of the cars have a longer maintenance cycle. These two hypotheses are depicted in Exhibit III-13.

The purpose of this subsection is thus to characterize the distribution of maintenance cycles for freight car components. The subsection discusses:

- estimation of survival curves for freight car components;
- comparison of survival curves to theoretical reliability functions and;
- implications of maintenance cycle distribution for regression testing.

Survival Curves

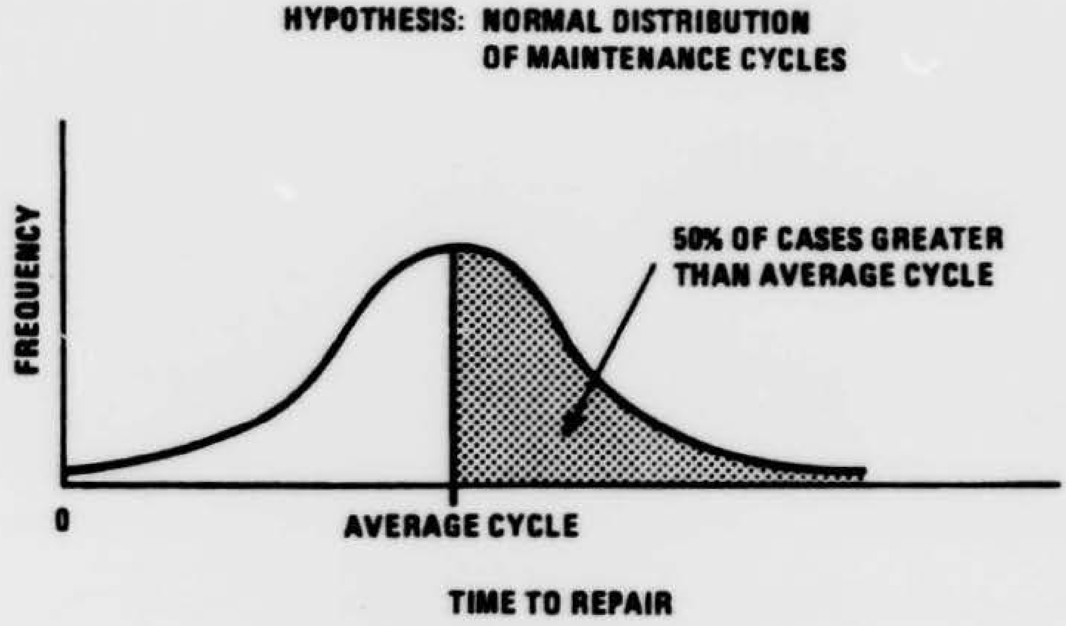
A survival curve represents the distribution of the length of time that a component operates before it requires repair. The observed data consist of time intervals which represent the "lifetime," or maintenance cycle, of components.

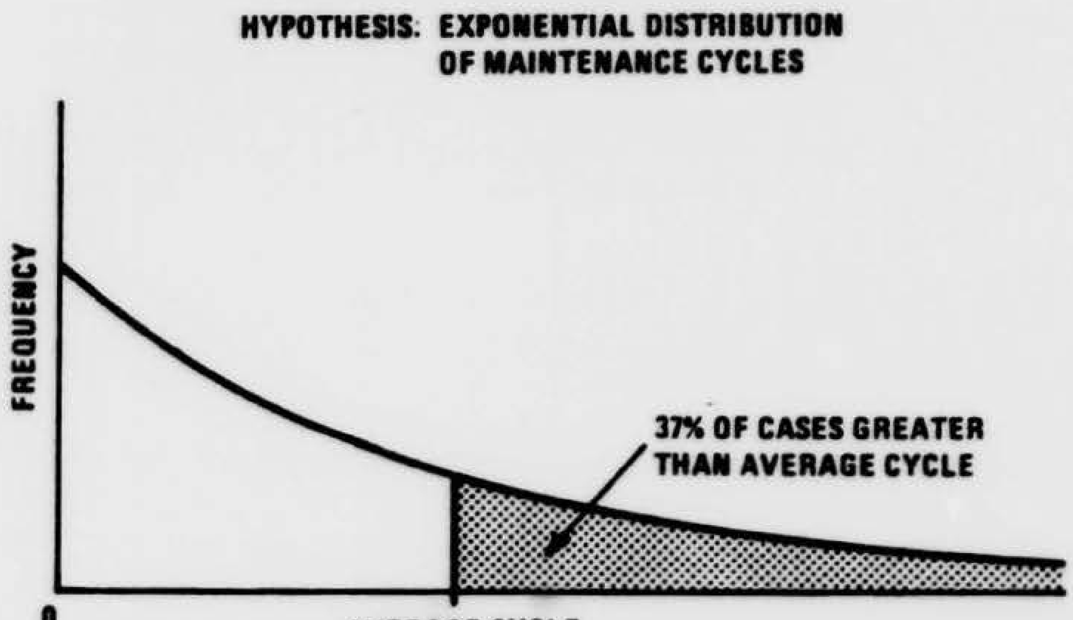
In this study, it is impossible to control the conditions under which the car components are observed or to obtain data on complete lifetimes for components. This problem of incomplete (or "censored") observations is particularly acute for the railroad data, since the maintenance cycle of most car components is longer than the seven-month time span of the car sample. Only a small percentage of the cars in the sample have any complete and valid component maintenance cycles (two or more repairs to the same component) in the sample interval. Where full cycles are observed, they represent a considerably biased sample of maintenance cycles. The following describes how an unbiased survival curve is derived. There are only three types of observations which occur for the data base, as illustrated in Exhibit III-14:

- Type A - The interval between successive repairs to the same component or component group;

EXHIBIT III-13

COMPARISON OF HYPOTHESES ON DISTRIBUTION OF MAINTENANCE CYCLES





- Type B - The interval between the beginning or end of the sample interval and the most proximate maintenance incident for the component or group; and

- Type C - The full sample interval, if no maintenance to the component or group is observed in the sample interval.

Type A observations are the only observations which represent complete maintenance cycles and are thus the only noncensored observations. If there are two maintenance incidents for a sample car history, there is one complete maintenance cycle; if there are three maintenance incidents, the car contributes two complete maintenance cycle observations.

Type B observations are censored observations. Every car history containing at least one incident of maintenance contributes two censored observations: (1) the interval between the beginning of the sample interval and the first maintenance incident and (2) the interval between the last maintenance incident and the end of the sample interval. These censored observations are important since they represent occasions where the complete maintenance interval exceeds the observed, partial interval.

Type C observations occur only for car histories with no maintenance incident observed in the sample interval. These censored observations are important since, like the Type B observations, they represent a lower bound on the full (unobserved) maintenance cycle of the component.

Exhibit III-14 illustrates the three types of observations, based on car histories of draft gear maintenance for the railroad. Note that most observations are censored. Since the data for the car leasing company cover a much longer time period, there would not be as many censored observations. For brake components, there would be fewer censored observations for the railroad since repairs are more frequent; however, there would be a greater number of censored observations for most other car components.

Conceptually, each maintenance cycle observation can be considered to begin at time zero; thus the length of the interval is called the "time to failure." In this way, each complete and censored observation can be numbered in ascending order of time to failure. At each time to failure, the percentage "surviving" can be determined. The estimate[1] of the survival function at the kth failure is:

$$S(t_k) = \left(\frac{N_1 - f_1 + 1}{N_1 + 1}\right)\left(\frac{N_2 - f_2 + 1}{N_2 + 1}\right) \cdots \left(\frac{N_k - f_k + 1}{N_k + 1}\right) = \prod_{i=1}^{k}\left(\frac{N_i - f_i + 1}{N_i + 1}\right)$$

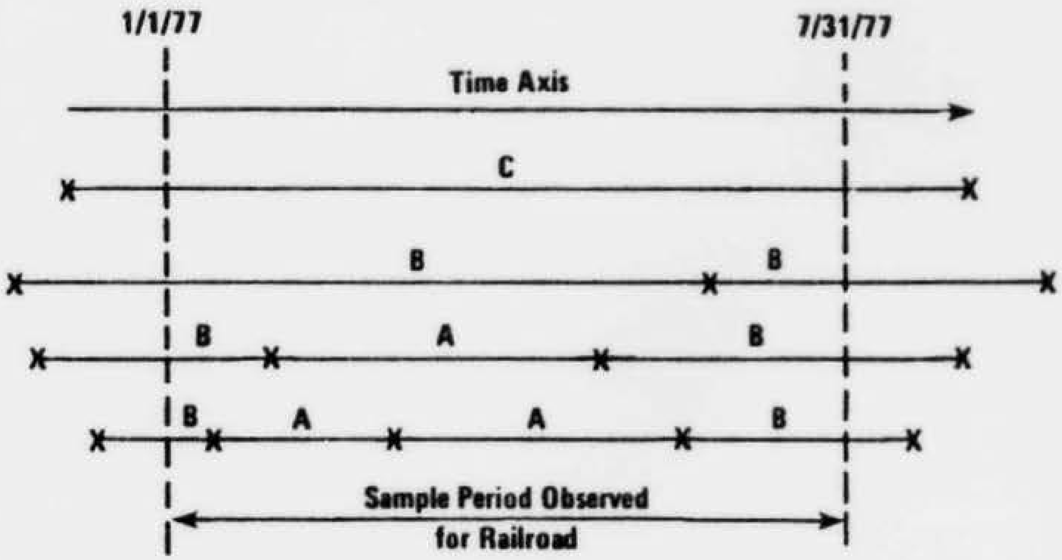
---

[1] William H. von Alven, ed., Reliability Engineering, ARINC Research Corporation, Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.

EXHIBIT III-14

ILLUSTRATION OF TYPES (A,B,C) OF MAINTENANCE CYCLE OBSERVATIONS – RAILROAD DATA

CAR HISTORIES AND TYPE OF OBSERVATION



PERCENT OF CARS HAVING CAR HISTORIES AS DEPICTED

	Draft Gear Components			
	Knuckles	Couplers	Yokes	Draft Gear (Hydraulics)
=	89%	71%	95%	93%
=	10%	22%	4%	6%
=	1%	6%	1%	1%
=	0%	1%	0%	0%
	100%	100%	100%	100%

X denotes incidence of maintenance for draft gear component where: N_i is the number of surviving observations beginning the interval which precedes the ith failure, and

f_i is the number of uncensored failures occurring at the time of the ith failure.

The variance of the estimate is:

$$\text{Var } S(t_k) = \prod_{i=1}^{k} \left(\frac{N_i - f_i + 1}{N_i + 2} \right) - \prod_{i=1}^{k} \left(\frac{N_i - f_i + 1}{N_i + 1} \right)^2$$

Appendix A tabulates the survival curves for the interval between repairs on any car component for the railroad and for the leasing company. The time interval between, for example, a brake repair and a car exterior repair is considered a maintenance interval if the repairs occur on different days. The table, generated by computer (see Appendix C), lists numbers surviving before periods, complete and censored obervations, survival rate, and proportion surviving by the time period.

Exhibit III-15 presents the survival curves from Appendix A in graphical form. Note that both curves descend very steeply before leveling out. This implies that repair activity to components is "clustered" in time.

Survival curves were estimated for each component group and for several components for both the railroad and the car leasing company. In this instance, only observations concerning the particular group or component are considered. As a result, the survival curves are typically less steep, because they represent the repair interval for the specific component or component group.

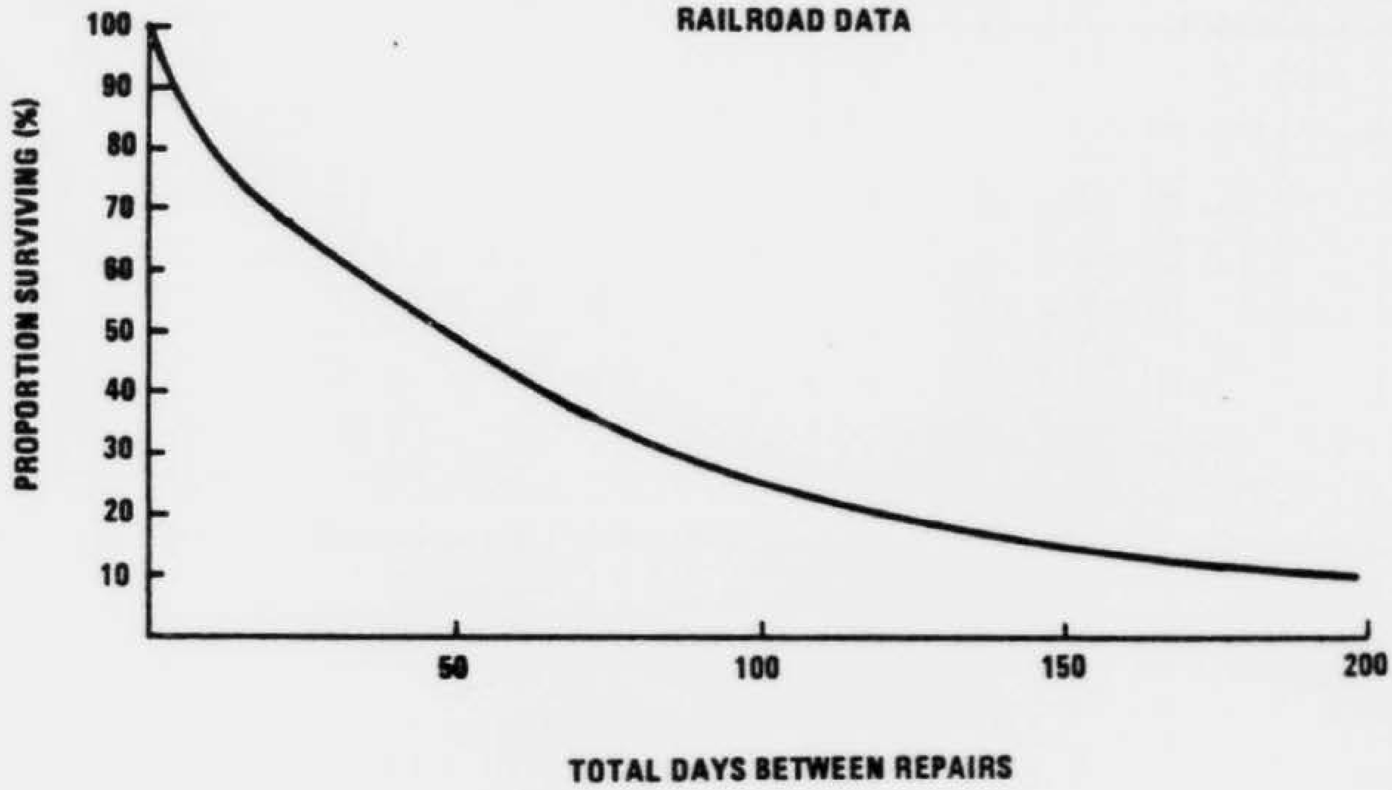
Theoretical Reliability Functions

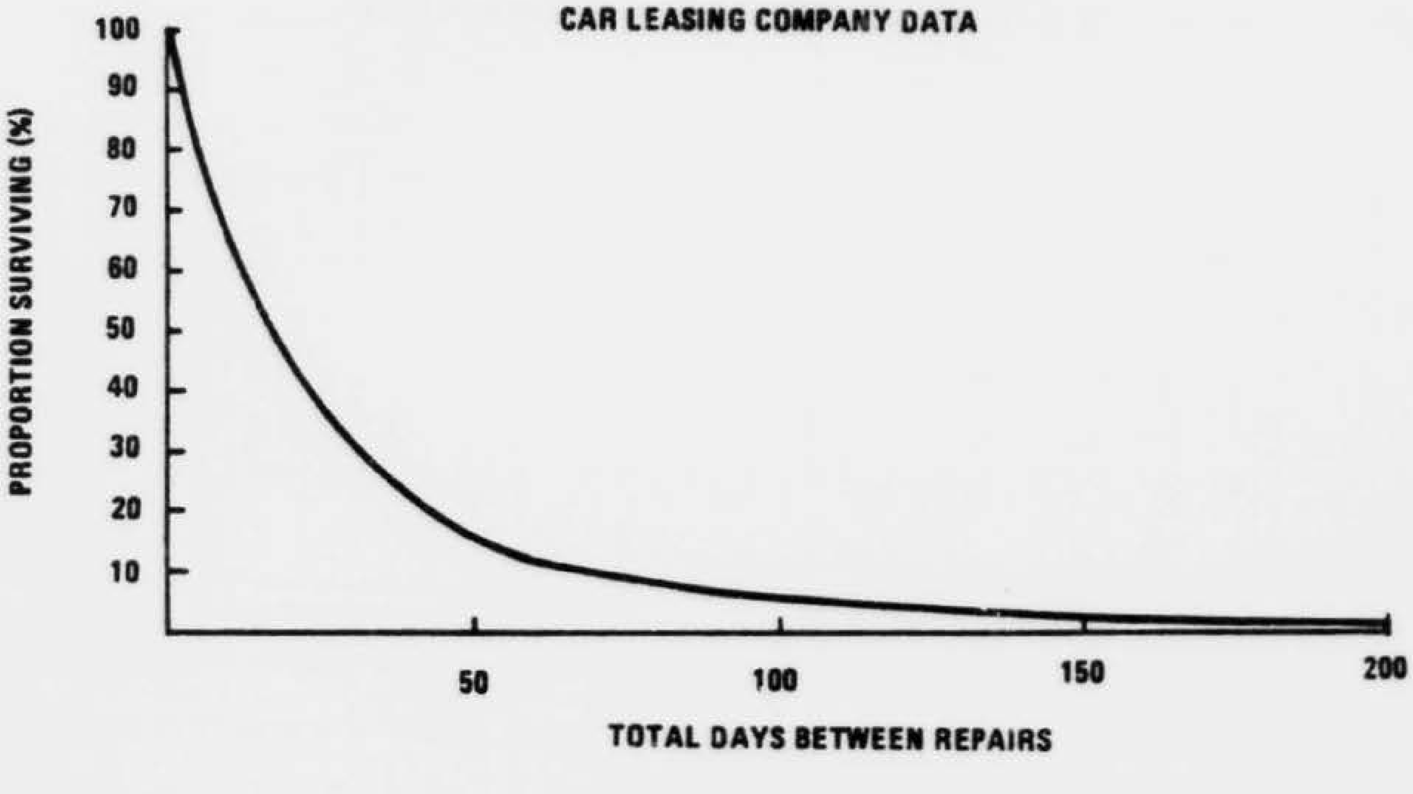
Generally, only a portion of the survival curve can be estimated for a component or group. The greater the true average time between repairs relative to the sample interval, the smaller the segment of the survival curve that can be computed reliably. To fully characterize the distribution of maintenance cycles, a means is needed to extrapolate from the measured segment of the survival curve.

The process of extrapolation assumes a theoretical form for the distribution of maintenance cycles. For example, the normal curve reflects the probability of survival for items for which the failure (survival) rate increases (decreases) with time. This is typical of components subject to gradual wear or components that are repaired at a regular interval. The exponential curve

EXHIBIT III-15

SURVIVAL CURVES – TIME INTERVAL BETWEEN REPAIR ACTIVITY OF AN TYPE





reflects the probability of survival for items for which the failure rate is constant with time. This is typical of items that can fail or be replaced at any time (regardless of the accumulated utilization) or items that fail when any one component of a group fails.

The appropriate theoretical function can be determined by graphical techniques in some cases. Repair 1.1 category groups COT&S (clean, oil, test, and stencil) and IDT&S (indate, test, and stencil) maintenance performed at fairly regular intervals constitutes most of the activity in this group. Thus, a normal distribution is an appropriate choice to test. Exhibit III-16 presents a plot of the observed survival curve for Repair 1.1 based on the railroad data. The curve is plotted on normal probability paper. A normal distribution plots as a straight line on normal probability paper so that the intercept with the 50-percent line indicates the average of the distribution and the slope of the line indicates the standard deviation. The line drawn on the graph (fitted either by linear regression or by eye fitting) reflects a theoretical normal distribution with a mean of 150 days and a standard deviation of 90 days. The hypothesis of normality appears feasible. Note that any estimate obtained by simply averaging the observed maintenance cycles would yield estimates far below the true average maintenance cycle, which is approximately 150 days.

The observed survival curve and the theoretical reliability function can be compared to assess the validity of the assumed theoretical form. If it cannot be determined visually that the reliability function is an adequate fit, the Kolmogorov-Smirnov (or "d-test") or the chi-square goodness of fit test is used.

Exhibit III-16 illustrates that the survival curve passes the d-test for the normal assumption. If assumptions are not rejected, confidence interval estimates can be derived for the average maintenance cycle based on the sample size and the standard deviation.

Draft gear system repairs can arise from a number of separate causes, regardless of how much time has passed since the last repair. Thus, a reasonable assumption can be made that the maintenance cycle for draft gear is exponentially distributed. To test this hypothesis, the observed survival curve for draft gear is plotted for the railroad in Exhibit III-17 and for the car leasing company in Exhibit III-18. The curves are plotted on exponential graph paper. An exponential distribution plots as a straight line on exponential paper, so that the intercept at 36.8 percent indicates the average maintenance cycle.

Exhibit III-17 indicates that the exponential hypothesis is reasonable based on the fit. Note that the estimated average maintenance cycle is 330 days,

EXHIBIT III-16

SURVIVAL CURVE FOR REPAIR 1.1 (COT&S AND IDT&S) – RAILROAD DATA

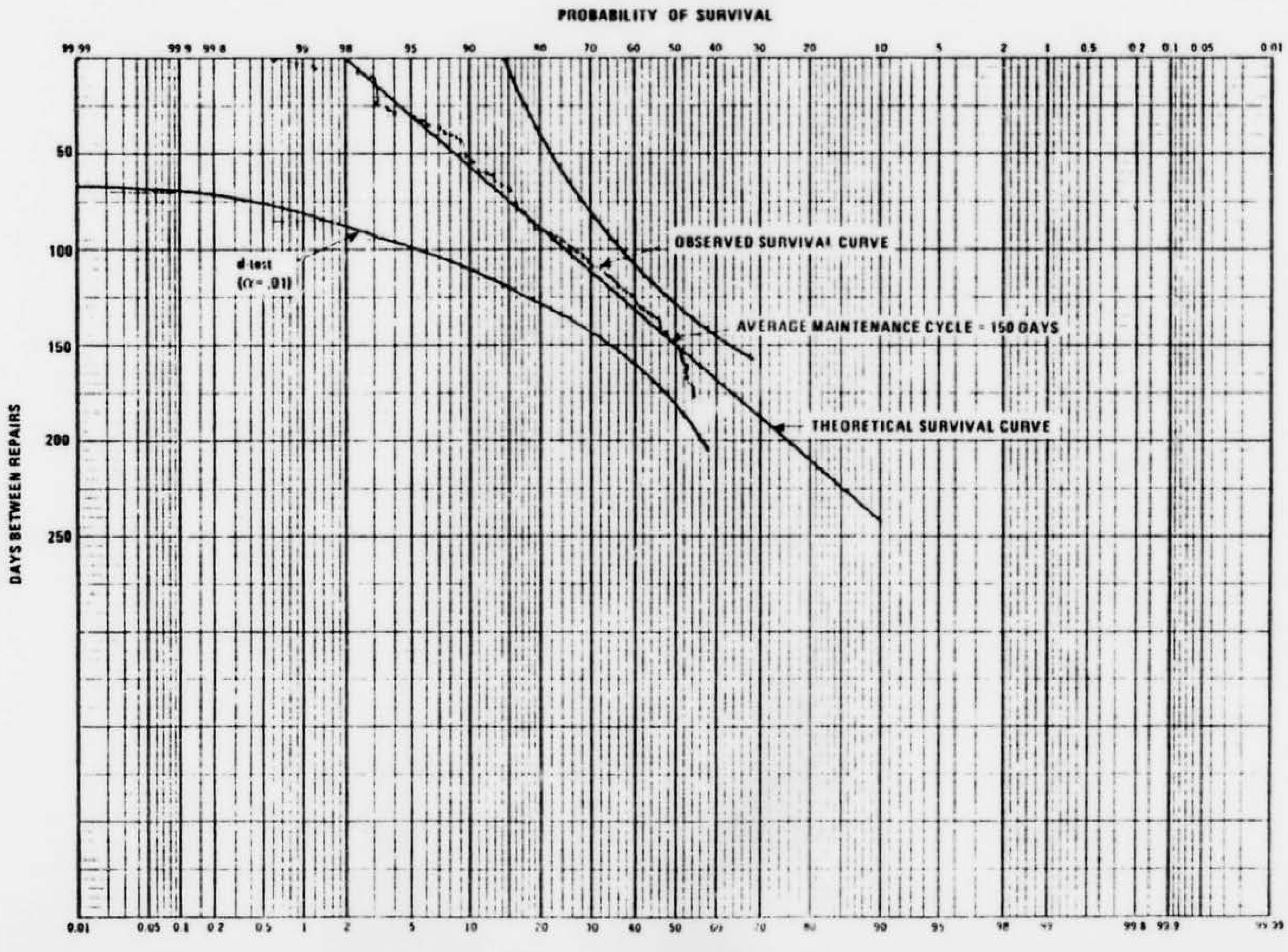
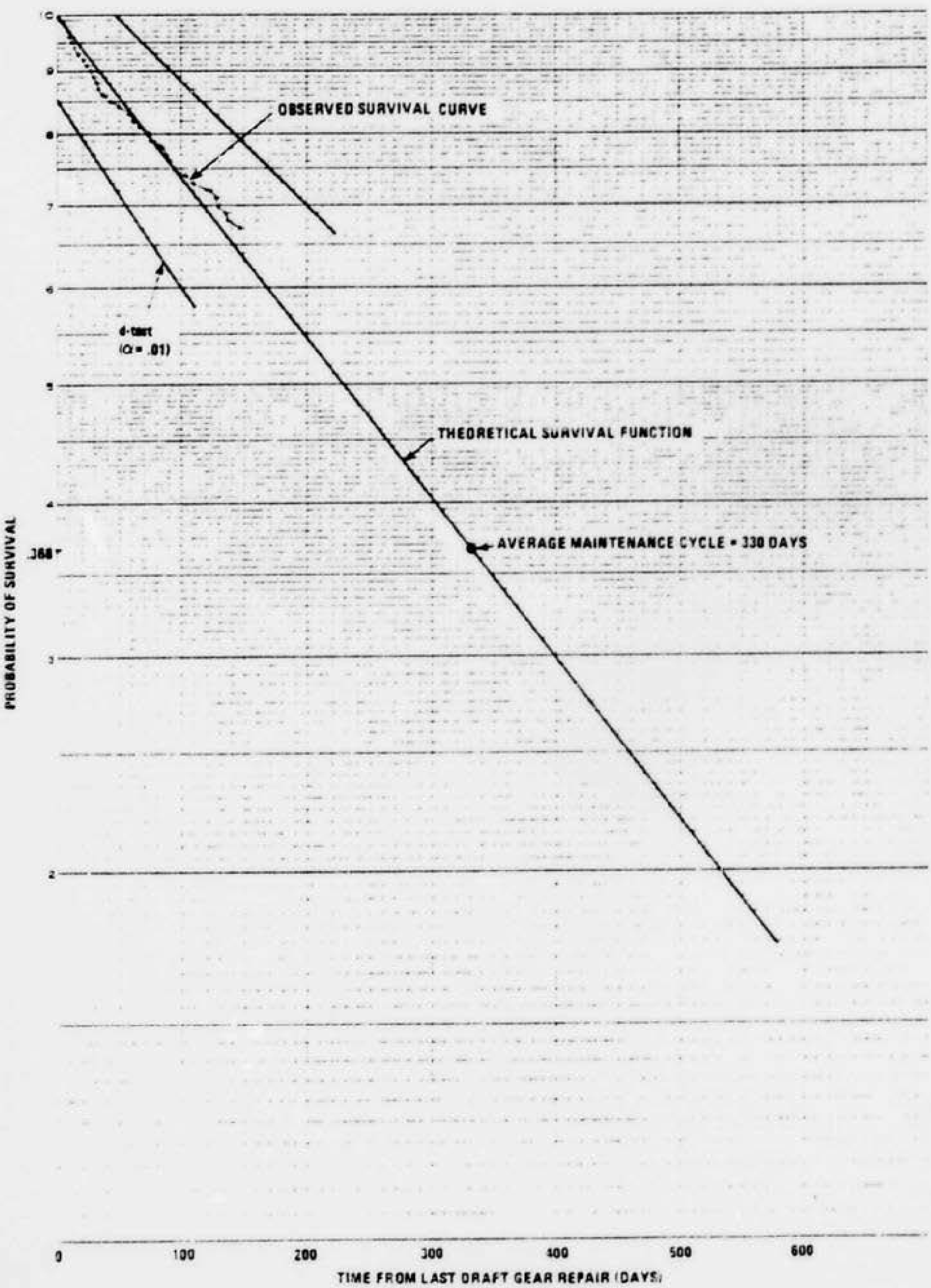


EXHIBIT III-17

SURVIVAL CURVE FOR DRAFT GEAR SYSTEM – RAILROAD DATA



which far exceeds both the largest cycle observed and the length of the sample interval (213 days). This illustrates that an estimate of mean maintenance cycle can be obtained even if the true mean cycle time exceeds the length of the sample interval.

Exhibit III-18 plots the same theoretical reliability function against the survival curve observed for the car leasing company. Note that a much greater segment of the survival curve is observed for this case. Although the curve resembles a line, it deviates beyond the tolerance set by the d-test. The bands are narrow because of the relatively larger sample for the car leasing company. This indicates that there is only a small chance that the observed survival curve represents an exponential distribution.

Brake shoes and keys (Repair 1.7) are subject to gradual wear, which implies an increasing failure rate and a normal type of distribution. The observed survival curve for the railroad, however, plotted in Exhibit III-19 on exponential paper, indicates that the distribution is not at all normal, but rather exponential. The estimated average maintenance cycle is 135 days.

The exponential behavior is caused by the circumstances under which the repair is performed. The repair is performed if any one of the components is inspected and seen to be worn beyond the tolerance limit. The measurement is subject to human variation and the decision to repair may be based on other miscellaneous factors. In addition, cars may be subject to inspection at irregular intervals and may experience different mile-per-day rates. These factors all contribute to the fairly constant rate of failure observed, which characterizes the exponential distribution.

Conclusion

The above illustrations of brake and draft gear system maintenance cycles demonstrate a principle applicable to most car systems and components. Extensive testing of observed survival curves has revealed that the distribution of maintenance cycles for component groups and for most individual components and groups subject to gradual wear are repaired at irregular intervals, for any number of reasons. Thus, the distribution of maintenance cycles typically does not center on an average value, but rather assumes a form resembling the exponential distribution.

Techiques for regression and analysis of variance, which are used to establish relations between utilization and maintenance activity, produce estimates of average behavior. This analysis makes a distinction between average and typical behavior. Characterization of maintenance cycles reveals the complexity of the causes of maintenance activity, a complexity which cannot be fully explained by a set of operating and descriptive factors which are

EXHIBIT III-18

SURVIVAL CURVE FOR DRAFT GEAR SYSTEM – CAR LEASING COMPANY DATA

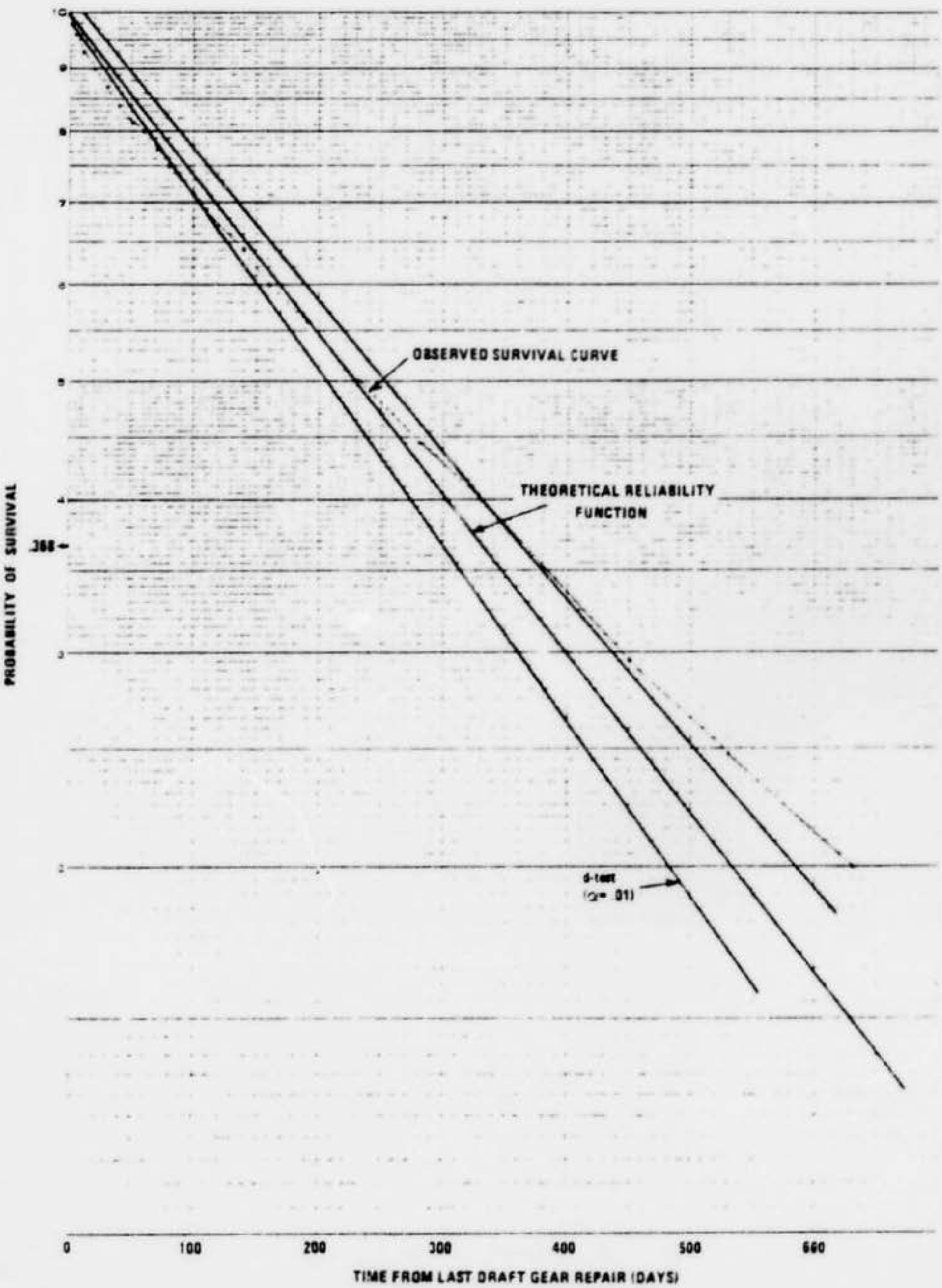
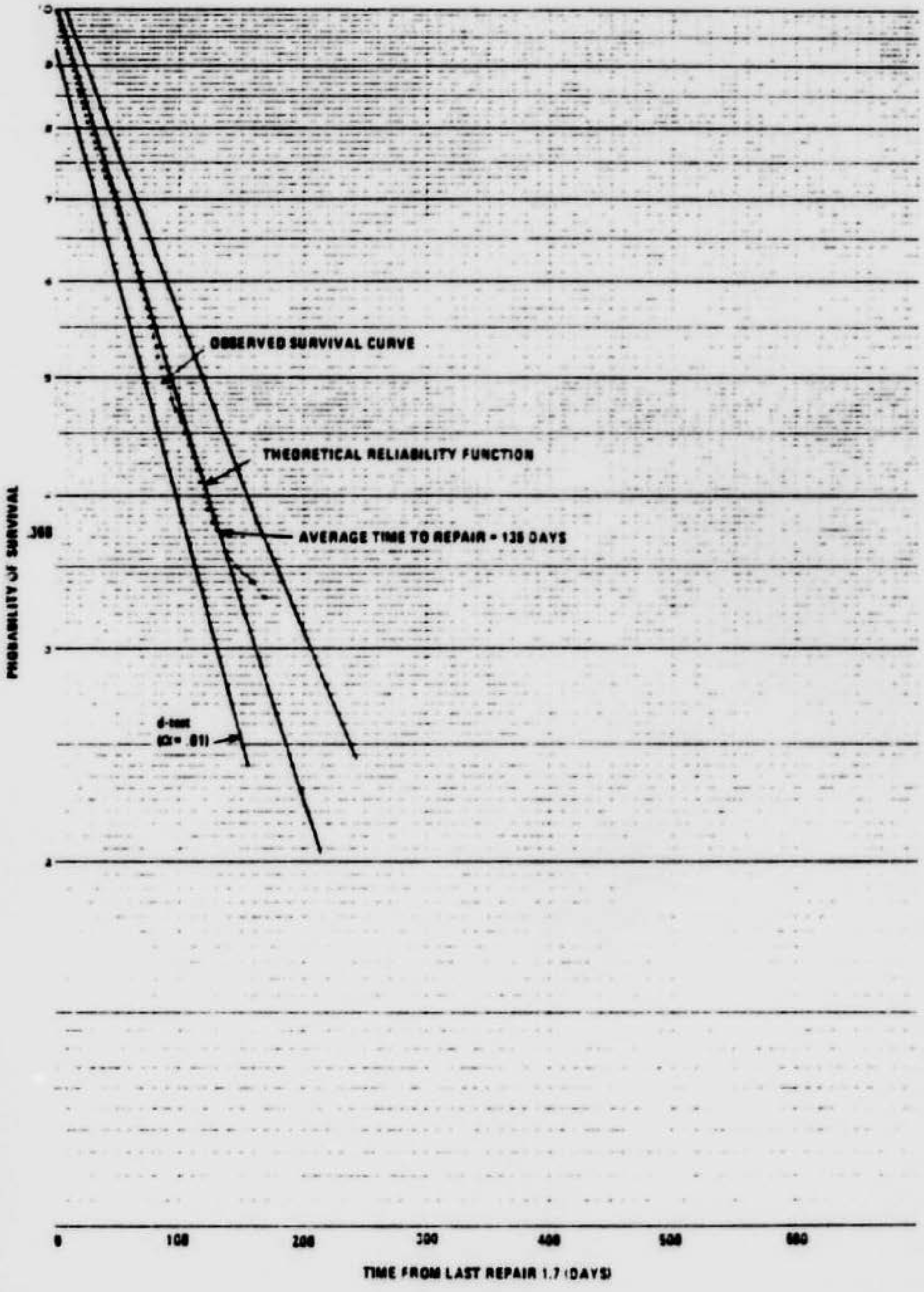


EXHIBIT III-19

SURVIVAL CURVE FOR REPAIR 1.7 (BRAKE SHOES AND KEYS) – RAILROAD DATA



limited for practical reasons. Thus, the statistical relations explaining maintenance consumption are expected to account for only a part of the variance in maintenance activity (low R^2 values), particularly for the railroad (short sample interval). However, this does not detract from the validity or utility of the relations derived later in this section for costing purposes.

MAINTENANCE-RELATED FACTORS AND OPERATING STATISTICS

This subsection investigates the interrelations among available descriptive factors, operating statistics, and maintenance activity. This analysis precedes the development of the car repair relations, with the aim of selecting the most appropriate combinations of variables for statistical testing. This includes evaluating the correlations between pairs of related factors, the coincidence of one type of repair with another, and the potential explanation of repair activity by selected factors. The available factors and their abbreviations were tabulated previously in Exhibit III-1.

Correlation Between Maintenance-Related Factors

As described, the operating statistics for the railroad are more detailed than the data for the car leasing company. In both cases, there are important links between variables that must be identified. For example, both the age of a freight car and the type of bearing used correlate with the incidence of bearing maintenance. It is important to note the very strong relation between car age and type of bearing, since the apparent relation between bearing and axle repairs and car age may result only from the strong relation between car age and a subsidiary causal variable--the type of bearing.

Exhibit III-20 tabulates the complete set of correlations between factors for the railroad. The correlations are Pearson product-moment correlation coefficients, which indicate the strength of the linear relationship between the variables. The square of this value measures the potential explanation of one variable for the other. The most statistically significant correlations are indicated by one or two asterisks.

The implication of the correlations is that certain key variables can summarize most of the available information on car characteristics and activity. Thus, the later development of repair relations can employ a convenient set of independent factors without redundancies or collinearity problems.

Exhibit III-21 tabulates the set of correlations between factors for the car leasing company. The car-type factor is not tabulated, but provides a large amount of information about tare weight since the tare weight for autorack cars includes the weight of the autorack equipment. In contrast, only 4 percent of the variance in car age is explained by car type. Car miles per car day is highly correlated to car type. Car type alone explains more than half of the variance in car miles per car day. In contrast, the three car-type groups have approximately the same average number of car days. The number of car days is correlated to total car miles, but explains less of the variance in car miles than car type (49 percent).

III.32

EXHIBIT III-20

CORRELATION BETWEEN FACTORS – RAILROAD DATA

- - - - - - - - - - - - - - PEARSON CORRELATION COEFFICIENTS - - - - - - - - - - - - -

	AGE	BEARNG	POOL	FARE	LCDAYS	TCDAYS	LCMILE	TCMILE	GTMILE	HCLASS
AGE	1.0000	-0.7022**	-0.1386**	-0.4470**	-0.1087**	0.0011	-0.2123**	-0.2017**	-0.3477**	0.0876*
BEARNG	-0.7022**	1.0000	0.1453**	0.3740**	0.0098*	0.0010	0.1964**	0.1838**	0.3415**	-0.0718
POOL	-0.1386**	0.1453**	1.0000	0.4664**	-0.0946*	0.0002	0.2814**	0.4315**	0.3083**	-0.2741**
FARE	-0.4470**	0.3740**	0.4664**	1.0000	0.0063	0.0028	0.2927**	0.3700**	0.4302**	-0.2222**
LCDAYS	-0.1087**	0.0098*	-0.0946*	0.0063	1.0000	0.0005	0.4022**	0.2649**	0.3853**	0.2584**
TCDAYS	0.0011	0.0010	0.0002	0.0028	0.0005	1.0000	0.0007	0.0004	0.0010	0.0001
LCMILE	-0.2123**	0.1964**	0.2814**	0.2927**	0.4022**	0.0007	1.0000	0.9558**	0.9164**	0.1471**
TCMILE	-0.2017**	0.1838**	0.4315**	0.3700**	0.2649**	0.0004	0.9558**	1.0000	0.8810**	0.0465
GTMILE	-0.3477**	0.3415**	0.3083**	0.4302**	0.3853**	0.0010	0.9164**	0.8810**	1.0000	0.1600**
HCLASS	0.0876*	-0.0718	-0.2741**	-0.2222**	0.2584**	0.0001	0.1471**	0.0465	0.1600**	1.0000
TCLASS	0.0256	0.0441	-0.2355**	-0.1507**	0.3464**	0.0008	0.2557**	0.1029**	0.2445**	0.5905**

* - SIGNIF. LE .01   ** - SIGNIF. LE .001   (99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED)

EXHIBIT III-21

CORRELATION BETWEEN FACTORS – CAR LEASING COMPANY DATA

- - - - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

	AGE	DEARNG	TARE	TCDAYS	TCMILL
AGE	1.0000	99.0000	-0.1160**	0.2569**	0.1301**
DEARNG	99.0000	1.0000	99.0000	99.0000	99.0000
TARE	-0.1160**	99.0000	1.0000	-0.0052	-0.3025**
TCDAYS	0.2569**	99.0000	-0.0052	1.0000	0.5093**
TCMILL	0.1301**	99.0000	-0.3025**	0.5093**	1.0000

* - SIGNIF. LE .01   ** - SIGNIF. LE .001   (99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED)

Correlation Between System Repairs

There are several reasons to anticipate significant correlations between number of repairs per car for different groups of repairs. Higher activity cars are likely to have more repairs in any category than lower activity cars. Thus, there may be an observed correlation simply because different repair or maintenance activities are related to the same utilization factors. Similarly, car characteristics which strongly influence repair activity (such as car type, tare weight, and age) can cause a statistical correlation between repair groups. Finally, when one car component is repaired, it becomes more likely that related car components will be repaired or replaced while the car is in the shop. Other repair or maintenance requirements can be more easily identified in the shop, and a failure in one component can increase the wear on other components.

Exhibit III-22 presents the correlations between component group repairs per car for the railroad. Note that all correlations are positive and that most of these are statistically significant at the $p=.001$ level.

Exhibit III-23 presents the correlations between component-group repairs per car for the car leasing company. In this case, CRB and program repairs are identified separately. Note that all statistically significant correlations between repair groups are positive.

The strongest tabulated correlations exist between program repair categories, as expected. The number of significant correlations between program repairs and CRB repairs reflects the potential (high) bias of some of the correlations observed for the railroad, since the railroad data do not distinguish CRB from program repair activity. The focus here is on the analysis of the CRB activities for the car leasing company and the combined CRB and program repairs for the railroad.

The highest correlation is observed between bearing and axle repairs and wheel repairs for both the railroad (65 percent) and the car leasing company (76 percent). Wheel maintenance activity implies replacement of wheels, which requires axle replacement and bearing maintenance since the components are physically integrated. Axle maintenance implies wheel replacement and bearing maintenance as well. The correlation between repairs per car to these systems is not 100 percent, since most maintenance in the bearing and axle category involves either lubricating rollers or replacing journals, activities which are required at regular intervals. This maintenance activity does not require replacement of major components.

The second highest correlation observed for the railroad is between car body interior and exterior maintenance (48 percent). By contrast, this correlation for CRB repairs for the car leasing company is only 18 percent;

EXHIBIT III-22

CORRELATION BETWEEN COMPONENT GROUP REPAIR ACTIVITIES — RAILROAD DATA

- - - - - - - - - - - - - - PEARSON CORRELATION COEFFICIENTS - - - - - - - - - - - - -

	REPSYS1	REPSYS2	REPSYS3	REPSYS4	REPSYS5	REPSYS6	REPSYS7	REPSYS8	REPSYS9	REP00
REPSYS1	1.0000	0.4422**	0.2748**	0.3419**	0.2235**	0.2776**	0.2269**	0.3360**	0.1028**	0.2429**
REPSYS2	0.4422**	1.0000	0.2668**	0.2936**	0.1372**	0.1819**	0.1858**	0.4105**	0.0317	0.2694**
REPSYS3	0.2748**	0.2668**	1.0000	0.3499**	0.1097**	0.0528	0.1600**	0.3311**	0.0115	0.2604**
REPSYS4	0.3419**	0.2936**	0.3499**	1.0000	0.2447**	0.0839*	0.1411**	0.2511**	0.1296**	0.1823**
REPSYS5	0.2235**	0.1372**	0.1097**	0.2447**	1.0000	0.0744	0.0667	0.1140**	0.1159**	0.1054**
REPSYS6	0.2776**	0.1819**	0.0528	0.0839*	0.0744	1.0000	0.2312**	0.1898**	0.0582	0.0835*
REPSYS7	0.2269**	0.1858**	0.1600**	0.1411**	0.0667	0.2312**	1.0000	0.4763**	0.2319**	0.2433**
REPSYS8	0.3360**	0.4105**	0.3311**	0.2511**	0.1140**	0.1898**	0.4763**	1.0000	0.0514	0.4045**
REPSYS9	0.1028**	0.0317	0.0115	0.1296**	0.1159**	0.0582	0.2319**	0.0514	1.0000	0.0544
REP00	0.2429**	0.2694**	0.2604**	0.1823**	0.1054**	0.0835*	0.2433**	0.4045**	0.0544	1.0000

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EXHIBIT III-23

CORRELATION BETWEEN COMPONENT GROUP REPAIR ACTIVITIES — CAR LEASING COMPANY DATA

- - - - - - - - - - - - - PEARSON CORRELATION COEFFICIENTS - - - - - - - - - - - -

	CRB1	CRB2	CRB3	CRB4	CRB5	CRB6	CRB7	CRB8	CRB9	CRB0
CRB1	1.0000	0.1967**	0.0859**	0.4549**	0.4041**	0.0204	0.3148**	0.2881**	0.6562**	0.4321**
CRB2	0.1967**	1.0000	0.1419**	0.2537**	0.2230**	-0.0112	0.1777**	0.4004**	0.5974**	0.4464**
CRB3	0.0859**	0.1419**	1.0000	0.2108**	0.1875**	0.0734**	0.0914**	0.1569**	0.1165**	0.2267**
CRB4	0.4549**	0.2537**	0.2108**	1.0000	0.7615**	0.0153	0.2416**	0.3557**	0.4009**	0.4439**
CRB5	0.4041**	0.2230**	0.1875**	0.7615**	1.0000	-0.0031	0.1760**	0.2868**	0.3458**	0.3633**
CRB6	0.0204	-0.0112	0.0734**	0.0153	-0.0031	1.0000	0.0028	-0.0038	0.0217	0.0394
CRB7	0.3148**	0.1777**	0.0914**	0.2416**	0.1760**	0.0028	1.0000	0.1807**	0.3011**	0.3372**
CRB8	0.2881**	0.4004**	0.1569**	0.3557**	0.2868**	-0.0038	0.1807**	1.0000	0.2474**	0.4648**
CRB9	0.6562**	0.5974**	0.1165**	0.4009**	0.3458**	0.0217	0.3011**	0.2474**	1.0000	0.4687**
CRB0	0.4321**	0.4464**	0.2267**	0.4439**	0.3633**	0.0394	0.3372**	0.4648**	0.4687**	1.0000
PROG1	[illegible]	[illegible]	0.1450**	0.1951**	0.2062**	-0.0167	0.1023**	0.1515**	0.2365**	0.2217**
PROG2	0.1791**	0.0233	0.1428**	0.1867**	0.2108**	-0.0157	0.1105**	0.1617**	0.2113**	0.2395**
PROG3	0.1662**	0.0094	0.1382**	0.1619**	0.1712**	-0.0152	0.0843**	0.1493**	0.1880**	0.2146**
PROG4	0.0587*	-0.0276	0.0237	0.0098	0.0349	-0.0083	0.0429	0.0172	0.0599*	0.0310
PROG5	0.0621**	-0.0266	-0.0016	0.0098	0.0301	-0.0066	0.0579*	-0.0076	0.0534*	0.0266
PROG6	99.0000	99.0000	99.0000	99.0000	99.0000	99.0000	99.0000	99.0000	99.0000	99.0000
PROG7	0.0449	0.0258	0.1057**	0.1150**	0.1352**	-0.0586	0.0683*	0.1723**	0.0692**	0.1167**
PROG8	0.1922**	0.0190	0.1348**	0.1979**	0.2016**	-0.0164	0.1118**	0.1623**	0.2208**	0.2326**
PROG9	0.2119**	0.0116	0.1468**	0.2153**	0.2124**	-0.0131	0.1660**	0.1748**	0.3413**	0.2968**
PROG0	0.2064**	0.0076	0.1412**	0.1935**	0.2040**	-0.0169	0.1100**	0.1492**	0.2311**	0.2230**

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EXHIBIT III-23 (Continued)

- - - - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - - -

	PROG1	PROG2	PROG3	PROG4	PROG5	PROG6	PROG7	PROG8	PROG9	PROG10
CRB1	0.2756**	0.1791**	0.1602**	0.0567*	0.0821**	99.0000	0.0449	0.1922**	0.2819**	0.2264**
CRB2	0.0088	0.0253	0.0044	-0.0270	-0.0266	99.0000	0.0358	0.0196	0.0110	0.0076
CRB3	0.1456**	0.1426**	0.1361**	0.0237	-0.0016	99.0000	0.1057**	0.1348**	0.1466**	0.1412**
CRB4	0.1951**	0.1667**	0.1619**	0.0196	0.0296	99.0000	0.1155**	0.1979**	0.2153**	0.1955**
CRB5	0.2062**	0.2126**	0.1712**	0.0349	0.0361	99.0000	0.1152**	0.2016**	0.2124**	0.2546**
CRB6	-0.0167	-0.0157	-0.0152	-0.0083	-0.0066	99.0000	-0.0086	-0.0164	-0.0131	-0.0169
CRB7	0.1123**	[illegible]	[illegible]	0.0142	0.0579*	99.0000	0.0685*	0.1116**	0.1660**	0.1120**
CRB8	0.1515**	0.1067**	0.1493**	0.0172	-0.0076	99.0000	0.1703**	0.1623**	0.1746**	0.1492**
CRB9	0.2355**	0.2113**	0.1666**	0.0599*	0.0534*	99.0000	0.0692**	0.2268**	0.3413**	0.2311**
CRB10	0.2217**	0.2399**	0.2146**	0.031[illegible]	0.0288	99.0000	0.1157**	0.2326**	0.2966**	0.2235**
PROG1	1.0000	0.6466**	0.6626**	0.3531**	0.2796**	99.0000	0.5146**	0.9236**	0.8536**	0.9824**
PROG2	0.6466**	1.0000	0.8118**	0.3927**	0.3062**	99.0000	0.4566**	0.8315**	0.7293**	0.8477**
PROG3	0.6626**	0.8118**	1.0000	0.4263**	0.3469**	99.0000	0.4981**	0.6711**	0.7540**	0.8654**
PROG4	0.3531**	0.3927**	0.4263**	1.0000	0.7005**	99.0000	0.2735**	0.3874**	0.2480**	0.3435**
PROG5	0.2796**	0.3062**	0.3469**	0.7005**	1.0000	99.0000	0.1641**	0.3129**	0.1929**	0.2741**
PROG6	99.0000	99.0000	99.0000	99.0000	99.0000	1.0000	99.0000	99.0000	99.0000	99.0000
PROG7	0.5146**	0.4566**	0.4981**	0.2735**	0.1841**	99.0000	1.0000	0.5227**	0.5062**	0.5143**
PROG8	0.9236**	0.8315**	0.6711**	0.3874**	0.3129**	99.0000	0.5227**	1.0000	0.8087**	0.9262**
PROG9	0.8536**	0.7293**	0.7540**	0.2480**	0.1929**	99.0000	0.5062**	0.8087**	1.0000	0.8602**
PROG10	0.9824**	0.8477**	0.8654**	0.3435**	0.2741**	99.0000	0.5143**	0.9262**	0.8602**	1.0000

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however, for program repairs the correlation is 52 percent. Apparently, the observed magnitude of the correlation for the railroad can be attributed to the mix of program repairs in the two categories that are naturally related.

When the brake system is repaired, problems with the draft gear system are more easily identified. Both systems wear as a result of use. Thus, a significant correlation is anticipated between repairs to these component groups. The railroad's data indicate a more significant correlation (44 percent) between draft gear and brake repair than the car leasing company's data (20 percent). From other statistics, the draft gear repair activity appears related more to time than mileage, while brake maintenance is related strongly to mileage and somewhat to time. Thus, the fact that the car leasing company's cars are more highly utilized than the railroad's cars may account for the observed difference in correlations between draft gear and brake maintenance.

There are at least two component groups that are likely to be damaged from mishandling in the hump yard. Draft gear and car body exterior maintenance are correlated at 41 percent for the railroad and 40 percent for the car leasing company. Thus, the independent sources reflect a comparable level of correlations, as anticipated.

Repairs to most component groups are correlated to the miscellaneous repair group and the special equipment group for both the railroad and the car leasing company. Apparently, when a car is in the shop for maintenance, special and miscellaneous equipment are often inspected for obvious problems. Thus, the degree of correlation may vary from one firm to the next, depending on maintenance policy.

<u>Correlation Between Repair Activity and Factors</u>

This subsection presents correlations which can be used to assess the potential explanation of repair activity by various factors. Analysis of the correlations can direct and conserve the amount of statistical testing needed to develop the appropriate relations.

Exhibit III-24 lists the correlations between number of repairs by component group and potential explanatory factors for the railroad. Note that the correlations between repairs and hump and total classifications are less than 15 percent. This does not preclude these variables from statistical testing; it indicates that these variables alone can explain only a small portion of the variance in maintenance activity.

Exhibit III-25 presents the correlations between number of repairs by component group and a more limited set of factors for the car leasing company. These correlations are generally stronger than correlations for the railroad,

EXHIBIT III-24

CORRELATION BETWEEN REPAIR ACTIVITY AND FACTORS – RAILROAD DATA

- - - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - - -

	AGE	EEARNG	PUDI	TARE	LCDAYS	TCDAYS	LCMILE	TCMILE	GTMILE	HCLASS
REPSYS1	0.1346**	-0.0805*	0.2571**	0.2077**	0.1626**	0.0005	0.3401**	0.3998**	0.2450**	-0.0832*
REPSYS2	0.1746**	-0.1695**	0.1698**	0.0886*	0.07[illegible]	0.0004	0.0975*	0.1433**	0.0530	-0.0466
REPSYS3	0.2944**	-0.2775**	0.0540*	-0.0966*	-0.0002	0.0001	-0.0040	0.0274	-0.0503	-0.0286
REPSYS4	0.2640**	-0.2278**	0.0544	-0.0406	0.0304	0.0005	0.0744	0.0958*	0.0066	-0.0259
REPSYS5	0.0010	0.0013	0.0050	0.0084	0.0061	0.0	0.0616	0.0704	0.0444	-0.0233
REPSYS6	-0.0440	0.0432	0.1672**	0.1819**	-0.0104	0.0	0.2125**	0.2880**	0.1648**	-0.0735
REPSYS7	0.0255	-0.0176	0.1274**	0.1480**	-0.0222	0.0	0.0623*	0.1257**	0.0484	-0.0973*
REPSYS8	0.1214**	-0.1200**	0.0802*	0.0580	-0.0316	0.0004	-0.0357	0.0119	-0.0527	-0.0637
REPSYS9	-0.0249	0.0091	0.0556	0.0719	0.0327	0.0	0.1511**	0.1602**	0.0984*	-0.0192
REPAIRS	0.2328**	-0.1926**	0.2359**	0.1369**	0.0975*	0.0003	0.2107**	0.2762**	0.1266**	-0.0894*

* - SIGNIF. LE .01   ** - SIGNIF. LE .001   (99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED)

since the car leasing company's data cover a wider span of operations, during which relations between maintenance and related factors can be observed.

For both firms, all significant correlations indicate that older cars require more maintenance than younger cars. To the extent that older cars are more (less) utilized, these correlations underestimate (overestimate) the true effect of age on maintenance requirements. Exhibit III-20 indicated that car age is negatively correlated with utilization (older cars are less utilized) for the railroad, so that the correlation between car age and repairs in Exhibit III-24 underestimates the effect of car age. On the other hand, Exhibit III-21 indicated that car age is positively correlated with utilization (older cars are more utilized) for the car leasing company, so that the correlation between car age and repairs in Exhibit III-25 overestimates the effect of car age.

Both firms show a 29 percent correlation between truck maintenance and car age. For the car leasing company, car age is the only factor which is correlated to truck maintenance; for the railroad, car age and type of bearing are the only significant factors. The inference is that trucks are subject to a very gradual deterioration with age that cannot be linked directly to operating activity in the time frame of the sample data.

An interesting observation is that the program repair activities are generally more correlated to car age than are the CRB repairs for the car leasing company. Also note that where significant correlations exist, tare is negatively correlated with program repairs and car miles is positively correlated with program repairs. These observations can be attributed to maintenance policy. Autorack cars are put through program maintenance less frequently than other cars.

For the car leasing company, the most important activity factors are car days and car miles. Note that for brake system repairs, car miles is correlated 82 percent, while car days is correlated 42 percent. On the other hand, car days (correlated 28 percent) may be more important than car miles (correlated 11 percent) in explaining the variance in draft gear maintenance activity. Thus, for different component groups, the relative importance of potential causal factors can be analyzed roughly by correlation analysis.

EXHIBIT III-25

CORRELATION BETWEEN REPAIR ACTIVITY AND FACTORS – CAR LEASING COMPANY DATA

- - - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

	AGE	BEARNG	TARE	TCDAYS	TCMILE
CRB1	0.2096**	99.0000	-0.3997**	0.4161**	0.6184**
CRB2	0.2644**	99.[illegible]	-0.1117**	0.2842**	0.1117**
CRB3	0.2929**	99.[illegible]	-0.0241	0.0446	0.0644*
CRB4	0.4110**	99.0000	-0.1239**	0.2681**	0.3989**
CRB5	0.3731**	99.[illegible]	-0.1[illegible]**	0.2343**	0.3633**
CRB6	0.[illegible]31[illegible]	99.[illegible]	-0.0155	0.0166	0.0349
CRB7	0.2211**	99.00[illegible]	-0.2[illegible]**	0.1721**	0.2343**
CRB8	0.3146**	99.[illegible]	-0.[illegible]72**	0.2833**	0.1673**
CRB9	[illegible].2497**	99.[illegible]	-[illegible].4967**	0.1351**	0.[illegible]53**
CRB0	0.2440**	99.[illegible]	-[illegible]77[illegible]**	[illegible]2044**	0.3[illegible]62**
PRUG1	0.4451**	99.[illegible]	-[illegible]2196**	-0.0232	0.1939**
PRUG2	0.4544**	99.[illegible]	-0.1701**	-[illegible]0169	0.1706**
PRUG3	0.4424**	99.0000	-0.1610**	-0.0220	0.1553**
PRUG4	0.2182**	99.[illegible]	[illegible]0168	-[illegible]0117	0.0757**
PRUG5	[illegible].1759**	99.[illegible]	[illegible]136	[illegible]155	0.0902**
PRUG6	99.0000	99.0000	99.0000	99.0000	99.0000
PRUG7	0.2814**	99.[illegible]	-0.1838**	-0.0563*	0.0000
PRUG8	0.4526**	99.[illegible]	-[illegible]2[illegible]7**	-[illegible]0232	[illegible].1770**
PRUG9	0.4342**	99.[illegible]	-0.3262**	-0.04[illegible]8	0.2491**
PRUG0	0.4420**	99.[illegible]	-[illegible]221[illegible]**	-0.0219	0.1917**

* - SIGNIF. LE .01   ** - SIGNIF. LE .001   (99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED)

FREIGHT CAR MAINTENANCE RELATIONS

This subsection presents the relations developed to explain maintenance activity for groups of components by car descriptive and utilization factors. For each component group, the separate results from the railroad data and from the car leasing company data are compared. Both the differences and similarities impact the potential of these methods for application to other firms.

As explained in the subsection on maintenance cycles, low R^2 values encountered reflect the complexity of the causes of maintenance activity, but do not detract from the utility of the relations derived for costing purposes. The results capture the effect of utilization and other factors on maintenance activity which generally confirm a priori judgements concerning the causes of maintenance consumption.

Research Approach

As noted earlier, the research plan relies on the analysis of currently available historical data to test the consumption concept. The objective of the analysis is to obtain relationships which are useful for costing and other managerial decisions. Regression and analysis of variance are the principal techniques used to estimate these relations and to test for statistical significance.

A very useful "unit cost" to obtain is the expected number of repairs per car day or car mile as it varies with car type, car age, and so on. A relation is developed for each component group for both the railroad and the car leasing company. For each group, time or mileage is established as the predominant utilization factor. This judgment is based on knowledge of the component group and statistical correlations. Then, the number of repairs per that factor is used as the dependent variable. For example, car miles is the factor used for the brake system and car days is the factor used for the car interior. Other utilization factors, such as car loadings and classifications, could be appropriate but the unavailability of accurate statistics precludes their use. Furthermore, their use as factors in a consumption relation requires additional assumptions in costing applications.

For the car leasing company data, regressions are performed for some component groups in a series of steps. First, the number of repairs per car mile or per car day is expressed by car type. Then, additional variables (e.g., car age, tare weight) are added at each step. The criterion is to enter the variable in the equation which results in the largest increase in R^2. In this way, the relations are made as simple as possible while intermediate results can be used for alternate applications.

To demonstrate a slightly modified approach for the railroad data, analysis of covariance (ANOVA) and multiple classification analysis are performed. The analysis includes both quantitative independent variables (covariates) and qualitative independent variables (factors). The ANOVA table presented for each component group provides only the statistics necessary for significance testing. The multiple classification analysis presented with the ANOVA table provides the pattern of the independent variables' relation to repairs per car mile or repairs per car day. Interaction effects were eliminated for this analysis.

The equations developed by either of the above processes form the basic consumption relations for each component group. In a sense, the maintenance activity is "fully distributed" to the time and mileage traveled by the car; however, this may not represent the cost behavior of freight car maintenance in reality. For example, if the total number of car miles traveled for a freight car changes, there is typically a less than proportional change in the maintenance requirements. Thus, an interpretation can be made that maintenance activity is partly variable and partly fixed. The most direct way to estimate maintenance variability (elasticity) is with the geometric relation. For each component group, the geometric relation with both time and mileage variables is presented for the car leasing company data. The exponents of time and mileage represent the elasticities of maintenance activity with respect to time and mileage. These elasticities can be used to apportion maintenance costs by component group to car days and to car miles.

The remainder of this sub-section presents the derivation of freight car maintenance consumption relations for each component group. The brake system is emphasized, including an analysis of brake components, because roughly one-half of all freight car repairs are made to the brake system.

Analysis of Brake System Maintenance

Maintenance of the brake system constitutes the greatest number of repairs for both the railroad and the car leasing company. Maintenance of some brake components is required at intervals by regulation, and most components experience wear and deterioration with utilization. Different operating and descriptive factors have varying influences on the wear of the different brake components. Thus, an appropriate analysis considers maintenance at the component level, as well as at the total brake system level. The major components and their contribution to brake system repairs are shown in Exhibit III-26.

The first part of the following discussion develops relations to explain total brake system maintenance. The second part develops maintenance relations for the two major component subgroups of the brake system (Repairs 1.1, 1.7, and above).

EXHIBIT III-26

DISTRIBUTION OF BRAKE SYSTEM REPAIRS

BRAKE COMPONENT	RAILROAD	CAR LEASING COMPANY
1.1 COT&S and IDT&S	34%	11
1.2 AB Valves	1	1
1.3 Retainer Valves	0	0
1.4 Release Valves	2	2
1.5 Cylinder	0	0
1.6 Slack Adjusters	0	0
1.7 Brake Shoes and Keys	46	69
1.8 Hand Brakes	2	1
1.9 Miscellaneous	15	16
TOTAL	100%	100%

Total Brake System Maintenance

Based on experience and the correlations, brake system maintenance can be shown to be related foremost to car miles and secondarily to car days and car age. The type of car alone explains 12 percent of the variance in the absolute number of repairs to brakes for the railroad, but it is important to ascertain the true effects of car type once differences in car miles and car days for car types are considered. This can be accomplished by an analysis of variance of brake repairs per mile and per day.

Since car miles is highly correlated to repairs and is a natural unit of utilization, it is appropriate to estimate brake repairs per car mile to establish a maintenance relation. Exhibit III-27 presents an analysis of covariance for the railroad. Note that a straight average number of repairs per car mile alone accounts for over 15 percent of the variance in number of repairs. The analysis indicates that car type and car age strongly influence the rate of repair. The average number of repairs per mile increases steadily with car age group (since data include program repairs). In the 20+ year-old group, repairs per mile are more than twice as frequent as in the 0 to 5 year-old group. However, note that there is no obvious correspondence between high repair rates and the heavier car types. The analysis of variance of repairs per day by car type and age yields similar significant differences for car age and type.

Exhibit III-28 is a scatter plot of observed number of brake system repairs versus number of miles traveled for leasing company cars. In general, cars with more mileage in the sample interval experienced more brake repairs. Brake repairs and car miles are correlated 82 percent, which means that roughly two-thirds of the variance in repairs per car can be explained by a formula assuming a constant number of repairs per car mile, such as:

Number of brake repairs: CRB1 = 24.1 x (number of 100,000 car miles)

or

CRB1/100,000 car miles = 24.1

ANALYSIS OF COVARIANCE OF BRAKE REPAIRS PER MILE – RAILROAD DATA

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
                RPM1
             BY CTYPE
           WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	1687.125	1	1687.125	78.038	0.001
AGE	1687.125	1	1687.125	78.038	0.001
MAIN EFFECTS	1450.614	5	290.123	13.420	0.001
CTYPE	1450.614	5	290.123	13.420	0.001
EXPLAINED	2837.059	6	472.843	21.871	0.001
RESIDUAL	19500.477	902	21.619		
TOTAL	22337.535	908	24.601		

COVARIATE	BETA
AGE	0.184

953 CASES WERE PROCESSED.
44 CASES (4.6 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
                RPM1
             BY   CTYPE
           WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 4.66

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	105	-0.69				-0.20	
2 UNEQ BOX	64	-0.11				-0.85	
3 EQ HOPPER	2	5.45				5.20	
4 UNEQ HOPPER	532	-0.44				-0.52	
5 GONDOLA	97	3.11				3.56	
6 OTHER	109	0.01				-0.04	
			0.23				0.26
MULTIPLE R SQUARED							0.140
MULTIPLE R							0.375

* Scale is number of repairs per ten-thousand car miles (includes CRB and program maintenance).

The line drawn on Exhibit III-28 represents the above formula. A more detailed formula accounts for the differences in repair rate by car type and other factors. Regressions performed stepwise yield:

Step 1

$$\frac{\text{CRB1/100,000}}{\text{car miles}} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 25.7 & \text{intermodal} \\ 20.0 & \text{autorack} \\ 26.2 & \text{other} \end{array}\right\}$$

R^2 = 10 percent

Step 2

$$\frac{\text{CRB1/100,000}}{\text{car miles}} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 21.6 & \text{intermodal} \\ 16.5 & \text{autorack} \\ 22.4 & \text{other} \end{array}\right\} + \underset{(0.038)}{0.41} \times (\text{AGE})$$

R^2 = 15 percent

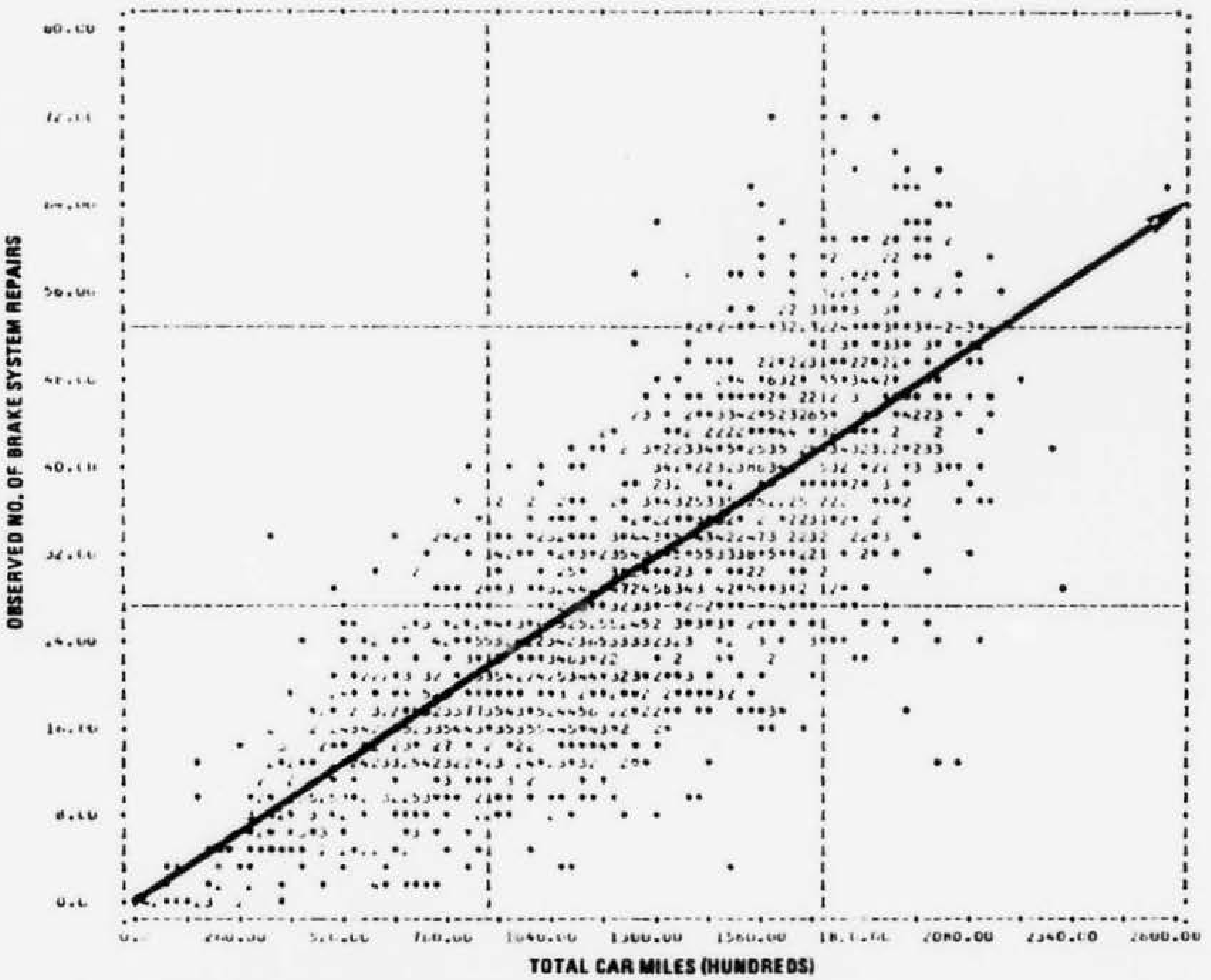
The number in parentheses below coefficients denotes the standard error of the coefficient. Note that car age is a significant factor in explaining repairs even after car mileage and car type have accounted for most of the explainable variance in brake maintenance activity. The equation implies that, after 10 years, a car will require repairs at a rate of 4.1 more repairs per 100,000 car miles than at the start.

It is interesting to compare the above results for the car leasing company with the results obtained for the railroad. In the first approach, using analysis of covariance, the result consists of a rectangular table of factors depending on car type and car age that is applied to total mileage. Using the regression approach, the maintenance activity is estimated by an explicit formula. The two forms illustrated are based on the same hypothesis: that brake maintenance activity is proportional to car miles at a rate which varies with car type and age.

Exhibit III-29 illustrates the interpretation of the simple regression result within the format of the original scatter plot (Exhibit III-28). The line labeled "average" car is the same best fit line presented in Exhibit III-28. Exhibit III-29a displays the predicted relationship between maintenance activity and car miles by car type. This represents the results of Step 1. Note that autorack cars have fewer repairs than other car types, on an average, for a given number of car miles.

EXHIBIT III-28

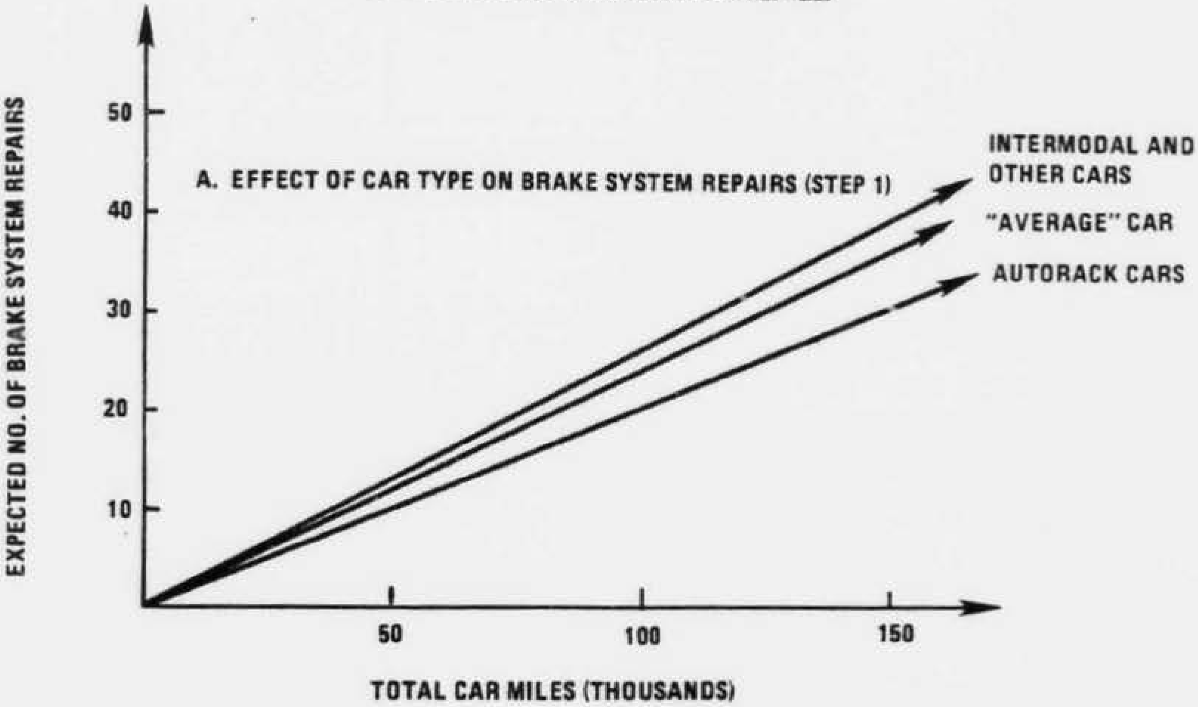
SCATTER PLOT OF REPORTED BRAKE SYSTEM REPAIRS VERSUS CAR MILES - CAR LEASING COMPANY DATA



NOTE: Digits on scatter plot indicate number of cars observed at that point.

EXHIBIT III-29

INTERPRETATION OF A REGRESSION RESULT FOR BRAKE SYSTEM MAINTENANCE



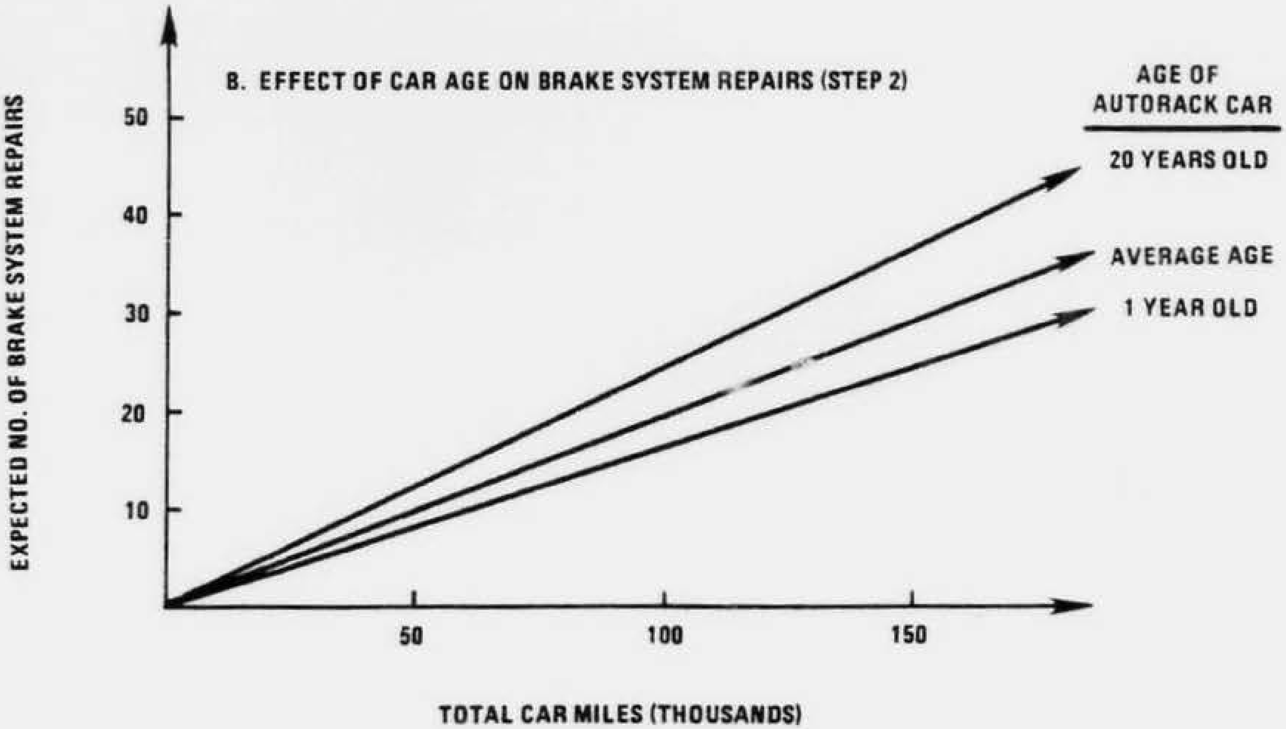


Exhibit III-29b incorporates the results of Step 2, using autorack cars as an example. The graph indicates that older autorack cars have more repairs than younger cars, on an average, for a given number of car miles. In fact, though autorack cars incur fewer repairs per mile on an average, the graph indicates that a 20-year-old autorack car is expected to have more repairs per mile than an "average" car of average age.

The stepwise regression process can be continued either until all potential factors are employed or until it is judged that additional steps will not contribute materially to the explanation of maintenance activity. Controlling first for car type, at each successive step, the variable is introduced which contributes the greatest explanation of maintenance activity. In this case, the next factor added to the formula is car days, yielding:

<u>Step 3</u>

$$\frac{\text{CRB1}/100{,}000}{\text{car miles}} = \left\{\begin{matrix} & \underline{\text{car type}} \\ 15.2 & \text{intermodal} \\ 9.6 & \text{autorack} \\ 15.9 & \text{other} \end{matrix}\right\} + \underset{(0.038)}{0.35\,(\text{AGE})} + \underset{(0.0010)}{0.0074\,(\text{TCDAYS})}$$

R^2 = 18 percent

Note that the coefficient of car days is statistically significant and that the new variable passes an F-test for inclusion in the relation. Depicting this new result graphically for a given car type and car age, the relation between brake repairs and car miles is represented by different rays for different numbers of car days. Naturally, this relation should not be extrapolated carelessly, since only certain ranges of car miles are feasible with a given number of car days.

The next variable added to the relation is tare, which enters with a positive coefficient. This means that heavier cars of a given type, age, and number of car days are expected to incur more brake repairs per mile than lighter cars. It is interesting to note that the correlation between brake repairs per mile and tare is -28 percent. However, once corrected for differences in car type and age, the partial correlation between brake repairs per mile and tare is slightly positive. The relation including tare is not presented here, since the variable does not pass an F-test for inclusion in the relation.

The relations discussed above estimate brake repairs per car mile, since car miles is the operating factor most logically related to brake repairs. As was noted in Exhibit III-25, brake repairs show a significant correlation (42 percent) to car days for the car leasing company. (For the railroad data, all cars experience the same number of car days.) A regression on brake repairs per car day yields:

Step 1

$$\frac{\text{CRB1}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 41.2 & \text{intermodal} \\ 20.5 & \text{autorack} \\ 16.7 & \text{other} \end{array}\right\}$$

R^2 = 58 percent

Step 2

$$\frac{\text{CRB1}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 23.0 & \text{intermodal} \\ 7.9 & \text{autorack} \\ 9.1 & \text{other} \end{array}\right\} + \underset{(0.06)}{1.2}\ (\text{TCMILE})$$

R^2 = 66 percent

Step 3

$$\frac{\text{CRB1}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 17.0 & \text{intermodal} \\ 0.4 & \text{autorack} \\ 3.2 & \text{other} \end{array}\right\} + \underset{(0.06)}{1.2}\ (\text{TCMILE}) + \underset{(0.042)}{0.17}\ (\text{AGE})$$

R^2 = 66 percent

The result indicates that a large part of the variance in brake repairs per car day is explained by car type. Step 2 then shows that a significant part of the variance explained by car type may be due to differences in mileage, since the paired difference between car type factors narrows when the car miles variable is included. Note, however, that, with the inclusion of car age, the car type coefficients change in magnitude, but the difference between coefficients does not narrow. This implies that age accounts for a separate aspect of repair rate.

In comparing the above results with the results of estimating repairs per car mile, it is important to note that brake repairs are correlated 82 percent to car miles and 42 percent to car days. The relation developed for brake repairs per car mile achieved R^2 = 18 percent, while the relation developed for brake repairs per car day achieved R^2 = 66 percent. However, the former relation is superior since it provides the better explanation of the total number of brake repairs.

These analyses obtain reasonable results based on either time or mileage separately, although mileage appears the most important factor. Thus, it may be fruitful to estimate brake repairs per car mile and per car day simultaneously. This can be done by means of a geometric relation. Regression with logarithmic transformation yields:

$$\log(\text{CRB1}) = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ -5.748 & \text{intermodal} \\ -6.244 & \text{autorack} \\ -6.153 & \text{other} \end{array}\right\} + \underset{(0.049)}{0.73}\,(\text{TCDAYS}) + \underset{(0.031)}{0.60}\,(\text{TCMILE})$$

R^2 = 71 percent

This relation implies:

$$\text{CRB1} = \left\{\begin{array}{ll} & \underline{\text{car type}} \\ 3.19\text{x}10^{-3} & \text{intermodal} \\ 1.94\text{x}10^{-3} & \text{autorack} \\ 2.13\text{x}10^{-3} & \text{other} \end{array}\right\} \text{ x } (\text{TCDAYS})^{0.73}\,(\text{TCMILE})^{0.60}$$

There are several interesting implications of this relation. One important result is obtained by computing the marginal maintenance activity with respect to car miles:

$$\frac{d\text{CRB1}}{d\text{TCMILE}} = (0.60)\ A\ (\text{TCDAYS})^{0.73}\,(\text{TCMILE})^{-0.40}$$

This indicates that the maintenance requirement increases with car miles, but that the rate of increase is lower for higher values of total car miles. Similarly, the maintenance requirement increases with car days, but the rate of increase is lower for higher values of total car days.

The relation implies that the elasticity of brake repairs is 60 percent with respect to car miles and 73 percent with respect to car days. This means that for a given number of car days, a 10 percent increase in number of car miles obtains a 6 percent increase in repair activity. Similarly, for a given number of car miles, a 10 percent increase in number of car days obtains a 7.3 percent increase in repair activity.

This analysis shows an interesting dependence of brake maintenance activity on time and mileage utilization and car type and age characteristics. An important question is whether the dependence on time and mileage results from: (1) the fact that each component requires maintenance due to both time and mileage, or (2) the fact that some components require maintenance due to time, while others require maintenance due to mileage.

Brake Component Maintenance

The most frequently repaired brake components are Repair 1.1 (COT&S and IDT&S) and Repair 1.7 (brake shoes and keys). These cases are used to illustrate the contrasting importance of time and mileage on brake component maintenance.

The COT&S maintenance occurs every few years, depending on the type of control valve. In some cases, firms can obtain a waiver for s me car types. The IDT&S maintenance is recommended every 90 days, but is frequently performed during other backshoppings. Thus, Repair 1.1 activity should be related more to time than to mileage.

Mileage is measured by total car miles in each sample interval. Time is measured by loaded car days for the railroad and by total car days for the car leasing company. The correlations between Repair 1.1 activity and these factors are shown below.

CORRELATION BETWEEN REPAIR 1.1 AND TIME AND MILEAGE

Firm	Time	Mileage
Railroad	16%	13%
Car Leasing Company	48%	23%

It is reassuring that, in both cases, time is more highly correlated to Repair 1.1 than is mileage. The figures are lower for the railroad because, during the limited time frame of the data, the underlying pattern is more difficult to observe.

To test the relative importance of time and mileage for Repair 1.1 activity, the geometric relation is estimated from the car leasing company data:

$$\log(CREP1.1) = \left\{ \begin{array}{ll} -5.629 & \text{intermodal} \\ -5.847 & \text{autorack} \\ -5.540 & \text{other} \end{array} \right\}^{\underline{\text{car type}}} + \underset{(0.074)}{1.02} \log(TCDAYS) - \underset{(0.045)}{0.005} \log(TCMILE)$$

R^2 = 18 percent

which implies:

$$\text{CREP1.1} = \left\{ \begin{array}{ll} & \underline{\text{car type}} \\ 3.59\text{x}10^{-3} & \text{intermodal} \\ 2.89\text{x}10^{-3} & \text{autorack} \\ 3.93\text{x}10^{-3} & \text{other} \end{array} \right\} \text{x (TCDAYS)}^{1.02} \text{ (TCMILE)}^{-0.005}$$

Note that the exponent of car days is not significantly different from one, and that the exponent of car miles is not significantly different from zero. This result contrasts sharply with the results obtained for total brake system repairs with the geometric relation. Thus, for Repair 1.1 activity, it seems reasonable to assume that mileage is unrelated and that maintenance activity is roughly proportional to time. This implies that the relevant dependent variable for a maintenance relation is Repair 1.1 activity per car day.

An analysis of variance for Repair 1.1 activity per car day based on the railroad data shows that car type and car age are statistically significant factors. Using the car leasing company data, Repair 1.1 activity per car day is estimated by regression:

Step 1

$$\frac{\text{CREP1.1/1,000}}{\text{car days}} = \left\{ \begin{array}{ll} & \underline{\text{car type}} \\ 4.16 & \text{intermodal} \\ 3.34 & \text{autorack} \\ 4.59 & \text{other} \end{array} \right\}$$

R^2 = 6 percent

Step 2

$$\text{CREP1.1/1,000} = \left\{ \begin{array}{ll} & \underline{\text{car type}} \\ 2.81 & \text{intermodal} \\ 2.20 & \text{autorack} \\ 3.35 & \text{other} \end{array} \right\} + \underset{(0.008)}{0.13} \text{ (AGE)}$$

R^2 = 16 percent

Note that the car type effect (paired differences in factors) remains relatively fixed from Step 1 to Step 2. This implies that the age variable accounts for a separate aspect of the variance in maintenance activity per car day. Of all brake components, age is correlated highest to Repair 1.1 activity for both the railroad (correlated 19 percent) and the car leasing company (correlated 38 percent). One hypothesis is that the car age variable accounts for the different control valve technology in the younger cars. As described earlier, the frequency of COT&S maintenance depends on the type of valve, the older valve technology requiring more maintenance.

This analysis has shown that Repair 1.1 activity is related primarily to car days, while the total brake system activity is related to both time and mileage. Brake repair component 1.7 (brake shoes and keys) is the most frequent of all repairs for both the railroad and the car leasing company. The component is subject to wear when the brake is applied; logically, wear may be more severe for the older or heavier cars. For this reason, gross ton miles is considered as a potential utilization measure. The analysis has shown that total car miles (rather than gross ton miles) is a superior measure. With time measured as before, the correlations between Repair 1.7 activity and these factors are shown below:

CORRELATION BETWEEN REPAIR 1.7 AND TIME AND MILEAGE

Firm	Time	Mileage
Railroad	14%	44%
Car Leasing Company	33%	82%

It is reassuring that, in both cases, mileage is more highly correlated to Repair 1.7 than is time. The figures are lower for the railroad because, during the limited time frame of the data, the underlying pattern is more difficult to observe.

To test the relative importance of time and mileage for Repair 1.7 activity, the geometric relation is estimated from the car leasing company data:

$$\log(\text{CREP1.7}) = \left\{ \begin{array}{ll} & \underline{\text{car type}} \\ -5.191 & \text{intermodal} \\ -5.746 & \text{autorack} \\ -5.646 & \text{other} \end{array} \right\} + \underset{(0.060)}{0.28} \log(\text{TCDAYS}) + \underset{(0.039)}{0.92} \log(\text{TCMILE})$$

R^2 = 71 percent

which implies:

$$CREP1.7 = \left\{\begin{matrix} 5.57\times10^{-3} & \text{intermodal} \\ 3.20\times10^{-3} & \text{autorack} \\ 3.53\times10^{-3} & \text{other} \end{matrix}\right\}_{\text{car type}} \times (TCDAYS)^{0.28} (TCMILE)^{0.92}$$

The relation implies that the elasticity of Repair 1.7 is 28 percent with respect to car days and 92 percent with respect to car miles. For a given number of car miles, this means that a 10 percent increase in car days obtains less than a 3 percent increase in expected repair activity. On the other hand, for a given number of car days, a 10 percent increase in car miles obtains over a 9 percent increase in expected repair activity.

The analysis indicates the dominance of car miles in the explanation of Repair 1.7 maintenance activity. This contrasts with the result obtained for Repair 1.1 activity, where car miles is somewhat unrelated to repairs and car days is most relevant. Car miles alone accounts for one-fifth of the variance in Repair 1.7 activity for the railroad and two-thirds of the activity for the car leasing company. Thus, the analysis seeks to explain aspects of Repair 1.7 activity per car mile.

An analysis of variance of Repair 1.7 activity per car mile for the railroad shows that car type and car age are statistically significant factors. Using the car leasing company data, the Repair 1.7 activity per car mile is estimated by regression:

Step 1

$$\frac{CREP1.7/100{,}000}{\text{car miles}} = \left\{\begin{matrix} 21.83 & \text{intermodal} \\ 13.98 & \text{autorack} \\ 16.01 & \text{other} \end{matrix}\right\}_{\text{car type}}$$

R^2 = 24 percent

Step 2

$$\frac{CREP1.7/100{,}000}{\text{car miles}} = \left\{\begin{matrix} 16.50 & \text{intermodal} \\ 8.30 & \text{autorack} \\ 10.62 & \text{other} \end{matrix}\right\}_{\text{car type}} + \underset{(0.0008)}{0.0057}\,(TCDAYS)$$

R^2 = 26 percent

Step 3

$$\frac{\text{CREP1.7/100,000}}{\text{car miles}} = \left\{\begin{array}{ll} 15.89 & \text{intermodal} \\ 7.88 & \text{autorack} \\ 10.10 & \text{other} \end{array}\right\} + \underset{(0.0008)}{0.0052}\,(\text{TCDAYS}) + \underset{(0.032)}{0.104}\,(\text{AGE})$$

(car type: intermodal, autorack, other)

R^2 = 27 percent

Note that the car type effect (paired differences in factors) remains relatively fixed from Step 1 through Step 3, and the coefficient of car days varies only slightly from Step 2 to Step 3. This implies that car type, car days, and age variables account for separate aspects of the variance in Repair 1.7 maintenance activity.

Summary of Brake System Maintenance Findings

Freight car maintenance relationships imply that brake maintenance requirements depend on both time and mileage utilization. Car type and car age are significant descriptive factors.

The dependence of brake maintenance on time and mileage results from the fact that time and mileage utilization, to a varying extent, affect the incidence of maintenance on brake components. Repair 1.1 activity (COT&S and IDT&S) is roughly proportional to time while unrelated to mileage. On the other hand, Repair 1.7 activity (brake shoes and keys) is most related to mileage and is related to time to a lesser extent.

Analysis of Draft Gear System Maintenance

The draft gear system constitutes a significant proportion of the total number of repairs, particularly in the case of the railroad. The four major components and their contribution to draft gear system repairs are shown below:

DISTRIBUTION OF DRAFT GEAR SYSTEM REPAIRS

	Draft Gear Component	Railroad Data	Car Leasing Company Data
2.1	Knuckles	17%	18%
2.2	Couplers	63%	80%
2.3	Yokes	7%	1%
2.4	Draft gear and end-of-car hydraulics	13%	1%
	TOTAL	100%	100%

Evidently, couplers are the most frequently repaired components of the draft gear system. Maintenance is the result of gradual wear through service, influenced by loaded versus empty service, curvature of track, grade, and slack. More than any other draft gear component, coupler maintenance is correlated to car age for both the railroad (14 percent correlation) and the car leasing company (32 percent correlation). On the other hand, the railroad's data show a more significant correlation between coupler repair and total mileage than the car leasing company's data (14 percent versus 6 percent). For the latter firm, there is a 25 percent correlation between coupler repair and total car days; there is a 7 percent correlation between coupler repair and loaded car days.

Repairs to the yoke and draft gear and end-of-car hydraulics categories constitute a minor part of draft gear system repairs. The difference in activity between the two firms in these two categories is due to the fact that the railroad data include program maintenance. The respective correlations to factors are remarkably similar for the two firms, as is shown below:

CORRELATION BETWEEN REPAIR ACTIVITY AND FACTORS

	Repair 2.3 (Yokes)		Repair 2.4 (Draft Gear and Hydraulics)	
Factor	Railroad	Car Leasing Company	Railroad	Car Leasing Company
Car Age	12%	16%	13%	13%
Car Miles	3%	4%	8%	4%
Total or Loaded Car Days	2%	1%	3%	2%

Note that repair activity is not strongly related to utilization but is rather most highly correlated with the age of the car.

Knuckle maintenance constitutes less than one-fifth of draft gear maintenance activity for both firms; yet it is the second major component of draft gear system repair. Unlike the other three draft gear components, which show significant correlation between repair activity and car age, knuckle maintenance is no more frequent for older freight cars. The railroad data do not reveal a pattern of repair activity with any specific factor available.

The car leasing company data show a correlation to knuckle maintenance of 18 percent for car miles and 17 percent for car days. No other draft gear component showed a significant relation to car miles for the car leasing company. One hypothesis is that knuckle maintenance is related to weather, the number of classifications, and mileage in general. Thus, the data at least support the contention that knuckle maintenance is related to utilization.

Frequently, knuckles are changed out in yards and on rip track in the course of inspection. Inspection or repair of other freight component groups may relate to draft gear maintenance for other components as well. Draft gear repair activity is more highly correlated to brake system, truck, bearing and axle, exterior, or miscellaneous repair activity than to any potential causal factor. Thus, it may be difficult to observe causal relations explaining draft gear maintenance, given the confounding effect described above.

Despite these limitations, the following geometric relation was estimated from the car leasing company data:

$$\log(\text{CRB2}) = -3.14 + \left\{ \begin{array}{rl} & \underline{\text{Car Age}} \\ -.416 & \text{0-5 years} \\ .066 & \text{5-10 years} \\ .036 & \text{10-15 years} \\ -.045 & \text{15-20 years} \\ 0 & \text{20+ years} \end{array} \right\} + \left\{ \begin{array}{rl} & \underline{\text{Car Type}} \\ -.335 & \text{intermodal} \\ -.429 & \text{autorack} \\ 0 & \text{other} \end{array} \right\}$$

$$+ \underset{(0.1278)}{0.469} \log(\text{TCDAYS}) + \underset{(0.0734)}{0.148} \log(\text{TCMILE})$$

R^2 = 13 percent

This relation implies:

$$\text{CRB2} = A\,(\text{TCDAYS})^{0.47}\,(\text{TCMILE})^{0.15}$$

where:

A = (values below) X 10^{-2}

Car Type	Car Age (Years) 0-5	5-10	10-15	15-20	20+
intermodal	2.04	3.31	3.21	2.96	3.10
autorack	1.86	3.01	2.92	2.69	2.82
other	2.85	4.62	4.48	4.14	4.33

Note that the exponent of car miles is significantly different from zero at the 95 percent level, but by a very fine margin. In fact, given the total number of car days, knowledge of the number of car miles adds little explanation of the variance in draft gear maintenance activity. Thus, car days (or a correlate of car days) is the major utilization factor relevant to the draft gear system.

Apparently, car age and car type are important descriptive factors for predicting draft gear maintenance. In particular, the repair rate for the youngest cars (0-5 years old) is much lower than for other cars (although otherwise, age is not an important effect). Autorack cars are the heaviest cars; yet they have the lowest draft gear repair rate. Thus, tare was not found to be a significant variable.

Draft gear maintenance is usually thought to be related to the number of classifications and car miles, as well as the length of the train, grade, curvature, and so forth. Unfortunately, most of these statistics are impractical to use. Both the total number of classifications and hump classifications are available for the railroad, but there are too few draft gear repairs in the data time span to establish a meaningful pattern between these factors and draft gear repairs. Note the interesting relation between factors shown below:

CORRELATION BETWEEN FACTORS

FACTORS	TCLASS	HCLASS
LCDAYS	26%	35%
TCMILE	5%	10%

Classifications are usually thought to be related more to mileage than to time. These correlations indicate the opposite--that number of classifications is most related to time, as measured by loaded car days. If the number of classifications is an important underlying causal factor, these correlations may explain why car days, rather than car miles, is shown to be the most important utilization factor for the car leasing company's cars.

Using the car leasing company's data, draft gear maintenance per car day is estimated by regression:

Step 1

$$\frac{\text{CRB2}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} 2.16 & \text{intermodal} \\ 1.65 & \text{autorack} \\ 2.86 & \text{other} \end{array}\right\} \quad (\text{Car Type})$$

R^2 = 3 percent

Step 2

$$\frac{\text{CRB2}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} 1.03 & \text{intermodal} \\ 0.71 & \text{autorack} \\ 1.82 & \text{other} \end{array}\right\} + \underset{(0.010)}{0.11}\,(\text{AGE}) \quad (\text{Car Type})$$

R^2 = 9 percent

Step 3

$$\frac{CRB2/1{,}000}{\text{car days}} = \begin{Bmatrix} -0.09 & \text{intermodal} \\ -0.08 & \text{autorack} \\ 1.34 & \text{other} \end{Bmatrix} + \underset{(0.010)}{0.11\,(AGE)} + \underset{(0.0001)}{0.0007\,(TCMILE)}$$

(Car Type heads the column intermodal, autorack, other.)

R^2 = 10 percent

Note that the car type effect (paired differences in factors) is the same for Step 1 and Step 2 but changes in Step 3. This implies that part of the explanation provided by car type is caused by different average car miles per day for the three car types. On the other hand, car age explains a separate aspect of the variance in maintenance activity.

Exhibit III-30 presents an analysis of variance of draft gear system repairs per car day by car age for both firms. Note that the repair activity levels out for the leasing company, while it increases steadily by car age for the railroad. The railroad's data include program repairs as well as CRB repairs. For the leasing company, program repairs to draft gear are more highly correlated to car age (45 percent correlation) than is any other program repair category. If a similar relationship holds for the railroad data, it could explain the observed difference between the railroad data and the car leasing company data.

Exhibit III-30 shows a dramatic difference between maintenance activity per car day for the 0-5 year-old group and other freight car age groups. It is expected that older cars will have more frequent draft gear repairs because of older components, gradual wear, and the greater likelihood of problem detection (since older cars are in the shop more often). An additional factor is the introduction of freight cars with floating center sills. The cushioned underframe is designed to prevent shocks and impact stresses from damaging the car structure and the lading. The center sill member is detached and travels longitudinally through the bolsters, cross-bearers, and end sills, hydraulically resisted by cushion gears. This technology, present in the younger cars, may explain part of the difference in maintenance activity for the 0-5 year-old group and other freight car groups.

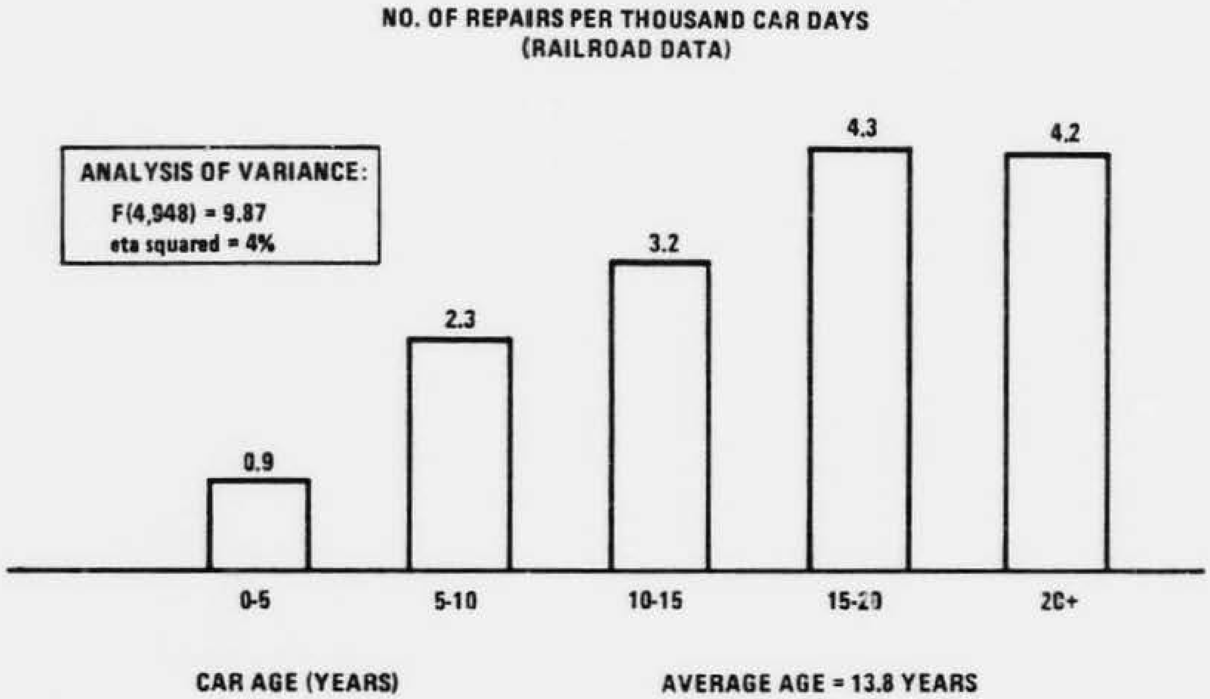
Analysis of Truck System Maintenance

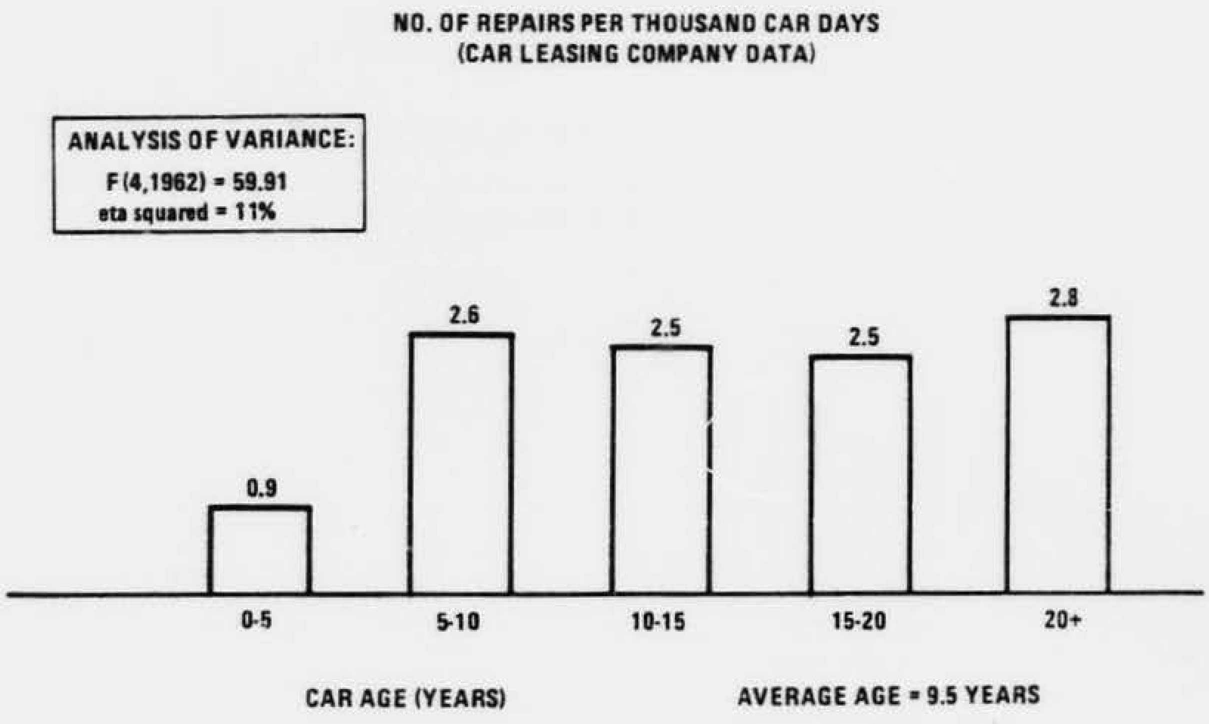
The truck system is the complete assembly (aside from wheels) which supports the car body at each end. The major components are:

- bolsters;

EXHIBIT III-30

DRAFT GEAR MAINTENANCE ACTIVITY BY CAR AGE





NOTE: Railroad data include CRB and program maintenance.
Car leasing company data represent CRB repairs only.

- side frames;
- springs; and
- side bearings and snubbers.

Exhibit III-31 displays the breakdown of truck maintenance activity into these four components. Note the important difference between CRB and program maintenance activity for the car leasing company. Since maintenance activity is relatively infrequent, it is difficult to observe patterns between truck maintenance and utilization within the limited time frame of the data. However, the truck maintenance activity shows a uniformly higher correlation to mileage than to time.

Springs and bolsters are the components subject to normal wear. Bolsters connect the side frame and carry the weight of the car. The bolster wear limits are regulated, and wear is attributed to mileage for both bolsters and springs.

Springs comprise a larger proportion of total repairs for the railroad, partly because of the different loading procedures and car types for the two firms. The car leasing company fleet consists of flat cars handling more fragile ladi g that is loaded gradually onto the car. On the other hand, the majority of the railroad's cars are hoppers, which are gravity fed coal in large quantities. The impact on the springs may be substantial. A related observation from Exhibit III-31 is that side bearings and snubbers contribute an extremely small number of repairs for the railroad. Again, the cause of the difference between the two firms is linked to car type (or lading). Snubbers dampen the recoiling effect of the springs for a smoother ride. Thus, snubber maintenance activity should be related to car type.

Exhibit III-32 shows an analysis of covariance of truck maintenance activity per mile for the railroad. Both car age and car type are significant sources of variation. As anticipated, hopper cars experience the lowest rate of maintenance once the results are adjusted for car age. The unadjusted deviations indicate that equipped box cars have the lowest repair rate. This results from the relatively low average age of box cars.

Estimation of the geometric relation from the car leasing company's data obtained nonsignificant coefficients, since the period of data collection was

EXHIBIT III-31

BREAKDOWN OF TRUCK MAINTENANCE ACTIVITY (COMPONENT PROPORTION OF TOTAL NUMBER OF REPAIRS)

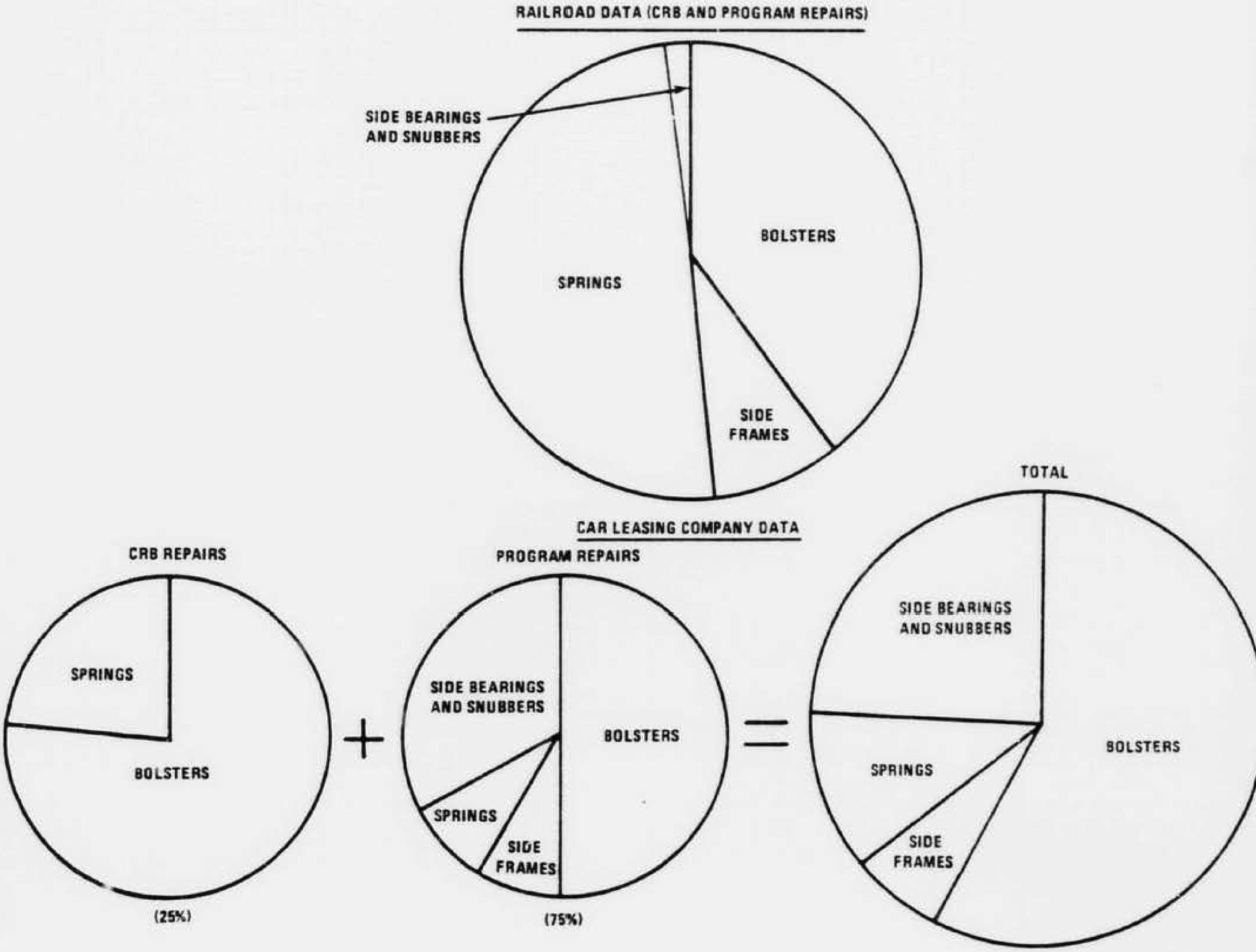


EXHIBIT III-32

ANALYSIS OF COVARIANCE OF TRUCK REPAIRS PER MILE* – RAILROAD DATA

```
* * * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * * *
           RPM3
        BY CTYPE
      WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	226.664	1	226.664	83.700	0.001
AGE	226.664	1	226.664	83.700	0.001
MAIN EFFECTS	38.218	5	7.644	2.823	0.015
CTYPE	38.218	5	7.644	2.823	0.015
EXPLAINED	263.576	6	43.929	16.222	0.001
RESIDUAL	2442.681	902	2.708		
TOTAL	2706.257	908	2.980		

COVARIATE	BETA
AGE	0.068

953 CASES WERE PROCESSED.
44 CASES (4.6 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
           RPM3
        BY   CTYPE
      WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 0.54

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	105	-0.24				-0.06	
2 UNEQ BOX	64	0.38				0.11	
3 EQ HOPPER	2	-0.54				-0.63	
4 UNEQ HOPPER	532	-0.10				-0.13	
5 GONDOLA	97	0.37				0.48	
6 OTHER	109	0.23				0.21	
			0.12				0.12
MULTIPLE R SQUARED							0.098
MULTIPLE R							0.313

* Scale is number of repairs per 10,000 car miles.

insufficient to represent a reliable pattern of maintenance for the relatively young fleet. The following maintenance rate was estimated:

Step 1

$$\text{CRB3/100,000 car miles} = \left\{ \begin{array}{ll} & \underline{\text{Car Type}} \\ 0.219 & \text{intermodal} \\ 0.238 & \text{autorack} \\ 0.383 & \text{other} \end{array} \right\}$$

R^2 = 1 percent

Step 2

$$\text{CRB3/100,000 car miles} = \left\{ \begin{array}{ll} & \underline{\text{Car Type}} \\ -0.130 & \text{intermodal} \\ -0.056 & \text{autorack} \\ 0.062 & \text{other} \end{array} \right\} + \underset{(0.0028)}{0.034}\,(\text{AGE})$$

R^2 = 8 percent

Statistically, the most significant factor related to truck maintenance is car age. For the railroad firm, bolster and spring repairs are correlated to car age at 17 percent and 29 percent, respectively. For the car leasing company, bolster and spring repairs are correlated to car age at 28 percent and 12 percent, respectively. No other factor is significantly correlated to any truck maintenance activity for the car leasing company. Car age and total truck repairs are correlated 29 percent for both firms. Though older cars are more susceptible to truck damage, the observed effect of age must be attributed to the greater accumulated mileage which occurs before the sample interval for the older cars.

Analysis of Bearing and Axle System Maintenance

It is natural to address bearing and axle maintenance as one component group, since the repair activities and the causes of wear and damage are related for both components. The observed distribution of bearing and axle system repair activity differs for the two firms, as shown below:

DISTRIBUTION OF BEARING AND AXLE REPAIRS

Repair	Railroad	Car Leasing Company
Lubricate Bearings	40%	12%
Replace Bearings	48%	58%
Replace Axles	12%	30%
TOTAL	100%	100%

The car leasing company's cars all have modern roller bearings. On the other hand, 58 percent of the railroad cars are equipped with high maintenance journal or friction bearings. Exhibit III-5 illustrated that all railroad cars in the 0-5 year age group are equipped with roller bearings, but only 9 percent of cars over 15 years old are equipped with this type of bearing.

Roller bearings usually require lubrication every 48 months, while journal bearings require lubrication every 36 months. Both types of bearings are also changed out periodically. Axle maintenance is fairly infrequent, but usually accompanies wheel replacement. In fact, the highest correlation between component group repairs is found for bearing and axle system and wheel system repairs for both the railroad (correlated 64 percent) and the car leasing company (correlated 76 percent).

Exhibit III-33 presents an analysis of covariance of bearing and axle repairs per car mile for the railroad. Note that car type and car age are significant effects. The unadjusted deviations for bearing type are highly significant; however, the effect is diminished when the deviations are adjusted for car age.

EXHIBIT III-33

ANALYSIS OF COVARIANCE OF BEARING AND AXLE REPAIRS PER MILE*

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
              RPM4
          BY CTYPE
             BEARNG
        WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	288.855	1	288.855	28.574	0.001
AGE	288.855	1	288.855	28.574	0.001
MAIN EFFECTS	191.372	6	31.895	3.155	0.005
CTYPE	191.371	5	38.274	3.786	0.002
BEARNG	4.877	1	4.877	0.482	0.999
EXPLAINED	703.316	7	100.474	9.939	0.001
RESIDUAL	9077.883	898	10.109		
TOTAL	9781.199	905	10.808		

COVARIATE	BETA
AGE	0.114

953 CASES WERE PROCESSED.
47 CASES (4.9 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
              RPM4
          BY  CTYPE
              BEARNG
        WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 1.18

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	105	-0.47				-0.22	
2 UNEQ BOX	63	0.82				0.44	
3 EQ HOPPER	2	-1.18				-1.20	
4 UNEQ HOPPER	530	-0.16				-0.20	
5 GONDOLA	97	0.98				1.25	
6 OTHER	109	-0.10				-0.15	
			0.13				0.14
BEARNG							
0 FRICTION	376	0.66				-0.13	
1 ROLLER	530	-0.47				0.09	
			0.17				0.03
MULTIPLE R SQUARED							0.049
MULTIPLE R							0.222

* Scale is number of repairs per 10,000 car miles.

The correlations between bearing and axle maintenance and factors are similar for the two firms, as shown below:

CORRELATION BETWEEN REPAIR ACTIVITY AND FACTORS

Factor	Railroad	Car Leasing Company
Car Age	29%	41%
Car Miles	10%	40%
Total or Loaded Car Days	3%	29%

The correlations are uniformly lower for the railroad because of the shorter time span of the railroad data. Note that mileage appears to be the dominant utilization factor, although time is potentially an important factor.

Using mileage as the utilization factor, the following maintenance rate was estimated:

Step 1

$$\text{CRB4/100,000 car miles} = \left\{ \begin{array}{ll} & \underline{\text{Car Type}} \\ 2.09 & \text{intermodal} \\ 2.04 & \text{autorack} \\ 2.35 & \text{other} \end{array} \right\}$$

R^2 = 0 percent

Step 2

$$\text{CRB4/100,000 car miles} = \left\{ \begin{array}{ll} & \underline{\text{Car Type}} \\ 0.37 & \text{intermodal} \\ 0.58 & \text{autorack} \\ 0.77 & \text{other} \end{array} \right\} + \underset{(0.0084)}{0.17}\,(\text{AGE})$$

R^2 = 17 percent

Step 3

$$\text{CRB4/100,000 car miles} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ -0.06 & \text{intermodal} \\ 0.11 & \text{autorack} \\ 0.33 & \text{other} \end{array}\right\} + 0.16\ (\text{AGE}) + \underset{(0.0002)}{0.0005}\ (\text{TCDAYS})$$

R^2 = 17 percent

To consider the simultaneous effect of time and mileage, the geometric relation is estimated for the car leasing company.

$$\log(\text{CRB4}) = -3.42 + \left\{\begin{array}{ll} & \underline{\text{Car Age}} \\ -.851 & 0\text{-}5 \text{ years} \\ -.356 & 5\text{-}10 \text{ years} \\ -.264 & 10\text{-}15 \text{ years} \\ -.347 & 15\text{-}20 \text{ years} \\ 0 & 20+ \text{ years} \end{array}\right\} + \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ .286 & \text{intermodal} \\ .075 & \text{autorack} \\ 0 & \text{other} \end{array}\right\}$$

$$+ \underset{(0.1224)}{0.298} \log(\text{TCDAYS}) + \underset{(0.0675)}{0.354} \log(\text{TCMILE})$$

R^2 = 22 percent

This relation implies:

$$\text{CRB4} = A\ (\text{TCDAYS})^{0.30}\ (\text{TCMILE})^{0.35}$$

where:

A = (values × 10^{-2})

Car Type	Car Age (Years) 0-5	5-10	10-15	15-20	20+
intermodal	1.86	3.06	3.35	3.08	4.36
autorack	1.51	2.47	2.71	2.50	3.53
other	1.40	2.30	2.52	2.32	3.28

The exponent of car days is significant and the exponent of car miles is highly significant. As usual, the older cars have a higher rate of repair. Intermodal cars (the most heavily used cars) have a higher rate of repair than autorack and other cars of comparable age. The result implies that a 10 percent increase in utilization obtains a 6.5 percent increase in maintenance requirements; of the increase, 3.0 percent is attributed to time and 3.5 percent is attributed to mileage.

Analysis of Wheel System Maintenance

Wheel maintenance is one of the less frequent repair activities. The data indicate 1.5 repairs per 100,000 car miles for the railroad and 1.0 repairs per 100,000 car miles for the car leasing company. Note that a "repair" for this study may involve one, two, or more wheel replacements at one time, though this information is not available in the data base. Furthermore, the three-year period of the car leasing company data and the seven-month period of the railroad data cannot capture the full life of a wheel in most cases. Much of the wear is developed outside the interval for cars encountering wheel repair in the sample interval.

With these limitations, it is still possible to observe relations between wheel repair and utilization, although the results may have less statistical significance. For the railroad, no factor is significantly correlated to wheel maintenance, but the highest correlating factor is total car miles (correlated 7 percent). The correlations for the car leasing company are statistically significant (.001 level) and show a similar pattern, as noted below:

CORRELATION TO WHEEL MAINTENANCE ACTIVITY

Factor	Railroad Data	Car Leasing Company Data
Car Age	6%	37%
Car Miles	7%	36%
Car Days or Loaded Car Days	1%	23%

Data collected over a longer period of time for either firm should yield significantly higher correlations with respect to car mileage. The correlation with car age reflects the importance of the accumulated mileage on the car wheels prior to the sample interval.

For the car leasing company data, the estimation of the geometric relation yields:

$$\log(\text{CRB5}) = -.35 + \left\{\begin{array}{lll} \multicolumn{3}{c}{\underline{\text{Car Age}}} \\ -.32 & 0\text{-}5 & \text{years} \\ 0 & 5\text{-}10 & \text{years} \\ -.01 & 10\text{-}15 & \text{years} \\ .01 & 15\text{-}20 & \text{years} \\ 0 & 20+ & \text{years} \end{array}\right\} + \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ .12 & \text{intermodal} \\ .01 & \text{autorack} \\ 0 & \text{other} \end{array}\right\}$$

$$+ \underset{(0.0463)}{0.252} \log(\text{TCMILE})$$

R^2 = 12 percent

This relation implies:

$$\text{CRB5} = A\,(\text{TCMILE})^{0.25}$$

where:

A =

Car Type	Car Age (Years) 0-5	5-10	10-15	15-20	20+
intermodal	.213	.292	.289	.295	.292
autorack	.189	.260	.258	.263	.260
other	.188	.260	.258	.263	.260

Note that a time variable is not included in the regression; the F-level for the car days variable is below 0.001 given the explanation provided by car miles. It is reassuring that the car-mile variable is highly significant and that the time variable is not significant. Based on the three-year period of the car leasing company data, a 10 percent increase in car miles is expected to result in a 2.5 percent increase in wheel repairs.

Exhibit III-34 presents an analysis of variance of wheel repair per 100,000 car miles by car age. For both firms, car age is a statistically significant factor. Controlling for car age, a separate analysis showed that car type is not a significant factor for either firm.

Exhibit III-34 indicates different behavior for the two firms. The car leasing company shows a gradual increase in the likelihood of wheel repair with car age. Program repairs, not included for the car leasing company estimates, comprise a minor portion of total wheel maintenance and are not

EXHIBIT III-34

ANALYSIS OF VARIANCE OF WHEEL REPAIR PER HUNDRED-THOUSAND CAR MILES BY CAR AGE

RAILROAD DATA

	SUM OF SQUARES	df	MEAN SQUARE
BETWEEN GROUPS	9.80	4	2.45
WITHIN GROUPS	466.37	904	0.52
TOTAL	476.17	908	

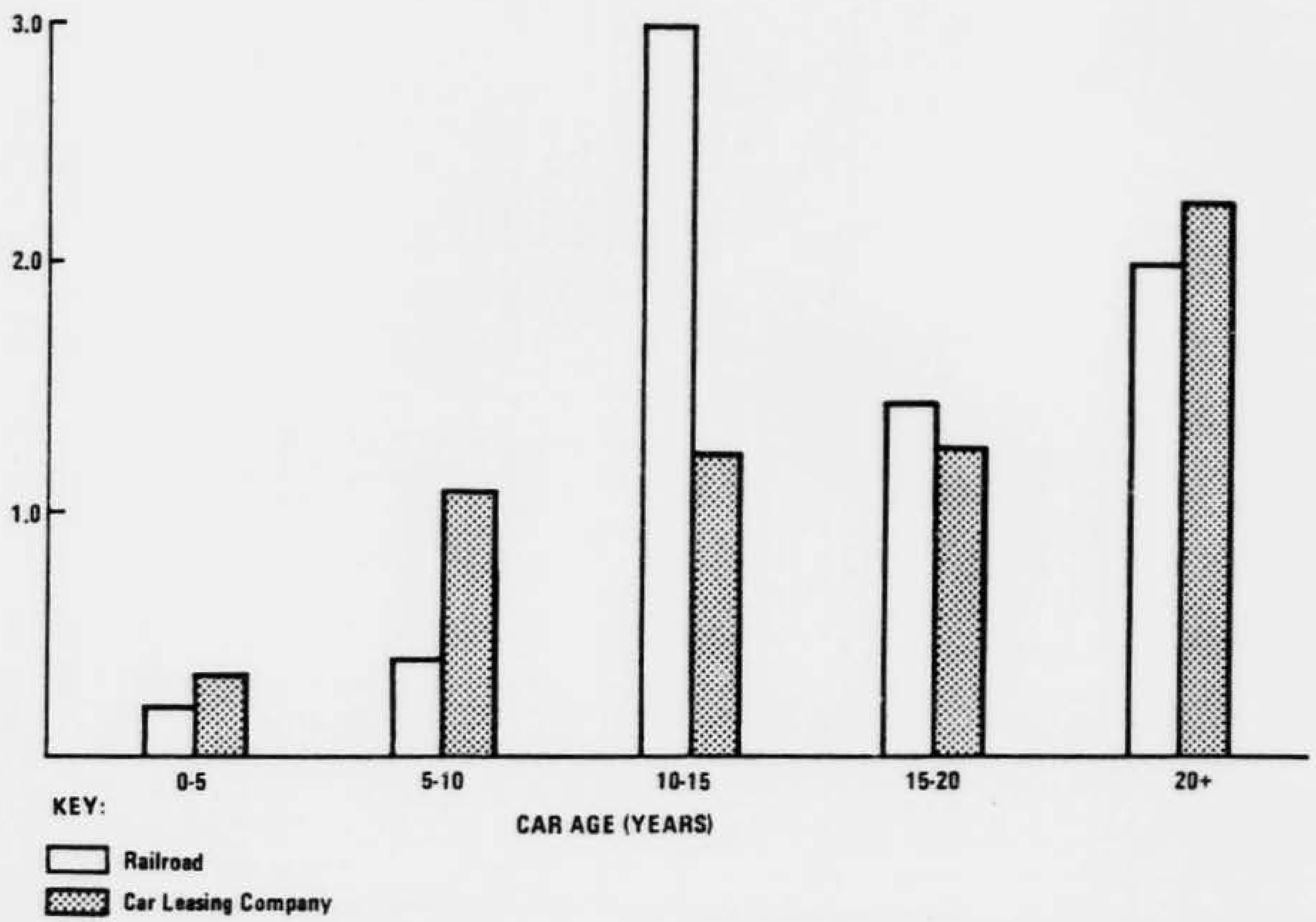
F = 4.75 eta sqrd = 2%

CAR LEASING COMPANY DATA

	SUM OF SQUARES	df	MEAN SQUARE
BETWEEN GROUPS	2.84	4	0.71
WITHIN GROUPS	21.89	1,966	0.01
TOTAL			

F = 73.05 eta sqrd = 13%

WHEEL REPAIRS PER ONE-HUNDRED-THOUSAND CAR MILES BY CAR AGE



NOTE: Railroad data include CRB and program maintenance.
Car leasing company data represent CRB repairs only.

highly correlated to car age. If this is also true for the railroad's data (including program repairs), the observed difference between the two firms must be explained by some other reason.

The railroad's data indicate that the highest incidence of repair occurs in the 10-15 year bracket. Of the many car wheels that are replaced in this time bracket, most will not need repair for a few years. Thus, a decline in repair rate for the next five-year interval is reasonable. For wheels not repaired in the 10-15 year bracket, maintenance in the 15-20 year interval is more likely. Thus, the observed behavior of wheel maintenance activity with age for the car leasing company may be due to higher utilization, causing more gradual wheel maintenance. Even though the car leasing company has a younger fleet than the railroad, the former's cars experience wheel repairs at four times the railroad's rate per 1,000 car days.

Analysis of Door System Maintenance

Since the car leasing company's fleet consists of flat cars, the cars have no doors and no door repairs are reported. For the railroad, the relevant car types are equipped box, unequipped box, and the "other" car type. Doors are coded into 16 door types for the railroad; they were, however, recoded into four categories for this analysis:

- no door;
- regular door - single or double, centered or staggered;
- plug door - single or double, centered or staggered; and
- other - combination, or split refrigerator, hinged, overhead, or other.

The distribution of door types by car type is shown below:

DOOR TYPE

Car Type	No Door	Regular	Plug	Other	Total
equipped box	0%	54%	42%	4%	100%
unequipped box	14%	86%	0%	0%	100%
other type	82%	4%	14%	0%	100%

The unequipped box cars without doors are 40- and 50-foot box cars used to carry cement and limestone. The load is blown in and out through the ends of the car, while the door openings are covered with paper.

Exhibit III-35 presents an analysis of covariance for door repairs per 1,000 car days which accounts for 21 percent of the variance in door maintenance activity. Car age is not significant as a covariate, which is interesting, since most other component groups have shown a high correlation between repair activity and car age. For doors, it appears that new cars are fairly resistant to damage but, beyond 5 years of age, there is not much difference in door repair rates by car age.

Car type and door type are highly significant factors, as might be expected. In particular, a higher repair rate is shown for equipped box cars and for cars equipped with plug doors. Equipped box cars are generally the most utilized and the most frequently repaired cars for the railroad. Thus, a door is more likely to be damaged and damage is more likely to be detected on equipped box cars than on other cars.

The estimated higher repair rate for cars with plug doors was anticipated, since regular sliding doors are mechanically less complicated than plug doors. Because there are four bars on the outside of the door, it is particularly susceptible to damage. Interchange rules require that plug doors be closed and locked before the car is moved.

Analysis of Car Interior Maintenance

Car interior maintenance includes activities associated with repairing wooden or steel floors, lining sides or ends, and loading equipment. The observed distribution of repair activity differs for the two firms, as shown below:

DISTRIBUTION OF CAR INTERIOR REPAIRS

	Interior Repair	Railroad	Car Leasing Company
7.1	Wooden or Steel Floors	39%	0%
7.3	Lining Sides or Ends	7%	99%
7.5	Miscellaneous	17%	0%
7.7	Lading Equipment	37%	1%
	TOTAL	100%	100%

EXHIBIT III-35

ANALYSIS OF COVARIANCE OF DOOR REPAIRS PER CAR DAY*

```
* * * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * * *
          RPD6
       BY CTYPE
          DOOR
     WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	0.032	1	0.032	0.025	0.999
AGE	0.032	1	0.032	0.025	0.999
MAIN EFFECTS	321.260	8	40.157	31.553	0.001
CTYPE	60.092	5	12.018	9.443	0.001
DOOR	29.352	3	9.784	7.688	0.001
EXPLAINED	324.214	9	36.024	28.305	0.001
RESIDUAL	1200.158	943	1.273		
TOTAL	1524.372	952	1.601		

COVARIATE	BETA
AGE	0.001

953 CASES WERE PROCESSED.
0 CASES (0.0 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
          RPD6
       BY CTYPE
          DOOR
     WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 0.26

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	114	1.47				1.05	
2 UNEQ BOX	74	0.19				-0.11	
3 EQ HOPPER	2	-0.26				-0.15	
4 UNEQ HOPPER	537	-0.26				-0.15	
5 GONDOLA	112	-0.26				-0.14	
6 OTHER	114	-0.13				-0.15	
			0.44				0.31
DOOR							
0 NO DOOR	755	-0.26				-0.11	
1 REGULAR	129	0.80				0.36	
2 PLUG	64	1.43				0.68	
3 OTHER	5	-0.26				-1.31	
			0.42				0.20
MULTIPLE R SQUARED							0.211
MULTIPLE R							0.459

* Scale is number of repairs per 1000 car days.

Virtually all of the car leasing company's interior repairs are classified as lining and a negligible number are classified as floor repairs or as repairs to lading equipment. All of the program repairs for the car leasing company (not included in the above distribution) are classified as floor repairs. The analysis here is performed on the total car interior maintenance activity.

Car interior repair activity should vary with utilization, but more with time than with mileage. Naturally, the most important factor to explain the variation in repair activity is the type of car.

Exhibit III-36 presents an analysis of covariance of car interior repair per 1,000 car days for the railroad. The analysis shows that car type is a highly significant factor, as anticipated. No repairs were reported for hoppers (hoppers do not have interiors), but gondolas have the highest interior repair rate of all cars. Equipped box cars also have a very high rate of interior repair, one which is significantly higher than the rate for unequipped box cars. If adjusted for car age, the difference is widened slightly.

The analysis shows that older cars generally have a higher rate of interior repair than younger cars. For the car leasing company, interior car repair is significantly correlated to age (correlated 22 percent), while the correlation for the railroad data was positive but not significant (correlated 3 percent). This is reflected by the positive beta coefficient for age, which is not statistically significant. Interior repair rate generally increases with car age, but cars in the 15-20 year age group have a lower repair rate than cars in the 5-10 year, 10-15 year, and 20+ year age groups. The leasing company's cars display a steadier and more statistically significant increase in interior repair rate with car age.

Based on the car leasing company's data, the geometric relation obtains:

$$\log(\text{CRB7}) = 1.64 + \overset{\text{Car Age}}{\begin{Bmatrix} -.020 & \text{0-5 years} \\ .085 & \text{5-10 years} \\ .155 & \text{10-15 years} \\ .115 & \text{15-20 years} \\ 0 & \text{20+ years} \end{Bmatrix}} + \overset{\text{Car Type}}{\begin{Bmatrix} .126 & \text{intermodal} \\ -.013 & \text{autorack} \\ 0 & \text{other} \end{Bmatrix}}$$

$$+ \underset{(0.1005)}{0.267} \log(\text{TCDAYS})$$

R^2 = 4 percent

EXHIBIT III-36

ANALYSIS OF COVARIANCE OF CAR INTERIOR REPAIRS PER CAR DAY*

* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
RPD7
BY CTYPE
WITH AGE
* *

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	2.707	1	2.707	2.387	0.119
AGE	2.707	1	2.707	2.387	0.119
MAIN EFFECTS	55.811	5	11.162	9.844	0.001
CTYPE	55.811	5	11.162	9.844	0.001
EXPLAINED	56.543	6	9.424	8.311	0.001
RESIDUAL	1072.708	946	1.134		
TOTAL	1129.251	952	1.186		

COVARIATE	BETA
AGE	0.007

953 CASES WERE PROCESSED.
0 CASES (0.0 PCT) WERE MISSING.

* * * M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S * * *
RPD7
BY CTYPE
WITH AGE
* *

GRAND MEAN = 0.20

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	114	0.33				0.35	
2 UNEQ BOX	74	0.12				0.08	
3 EQ HOPPER	2	-0.20				-0.21	
4 UNEQ HOPPER	537	-0.20				-0.20	
5 GONDOLA	112	0.34				0.36	
6 OTHER	114	0.21				0.21	
			0.22				0.22
MULTIPLE R SQUARED							0.052
MULTIPLE R							0.228

* Scale is a number of repairs per 1,000 car days.

This relation implies:

$$CRB7 = A\ (TCDAYS)^{0.27}$$

where:

	Car Type	Car Age (Years) 0-5	5-10	10-15	15-20	20+
A =	intermodal	.216	.240	.257	.247	.220
	autorack	.188	.208	.224	.215	.191
	other	.190	.211	.227	.218	.193

Note that car miles does not enter into the regression. This is reassuring since, given the number of days in service for a car, the number of miles traveled should not affect the incidence of interior repair. The number of car loadings is probably an important factor, but this statistic is not available. Since car loads are related more to car days than to car miles, this is additional evidence supporting the relation.

The geometric relation implies that car interior maintenance is partly attributable to utilization of the car and partly fixed. For a 10 percent increase in time utilization, there is a long-run increase of 2.7 percent in maintenance activity. On the other hand, two comparable cars, used for the same number of days but with quite different mileage, should incur the same interior maintenance activity according to the relation.

To assess the average interior maintenance activity per car day for the car leasing company, the following relation is estimated:

Step 1

$$\frac{CRB7/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \text{Car Type} \\ 1.219 & \text{intermodal} \\ 0.517 & \text{autorack} \\ 0.669 & \text{other} \end{array}\right\}$$

R^2 = 8 percent

Step 2

$$\frac{CRB7/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \text{Car Type} \\ 0.866 & \text{intermodal} \\ 0.221 & \text{autorack} \\ 0.345 & \text{other} \end{array}\right\} + \underset{(0.0054)}{0.034\ (AGE)}$$

R^2 = 10 percent

The car type and age variables are highly significant. Note that the car miles variable does not enter into the regression as before.

Analysis of Car Exterior Maintenance

Car exterior maintenance includes activities associated with repairing crossovers, brake steps, ladders, roof hatches, underframes, and side, end, slope, and roof sheets. The observed distribution of car exterior repair activity differs for the two firms, as shown below:

DISTRIBUTION OF CAR EXTERIOR REPAIRS

Exterior Repair		Railroad	Car Leasing Company
8.1	Crossovers, Brake Steps, Hand Holds, Ladders, etc.	29%	12%
8.2	Painting, ACI, etc.	24%	82%
8.3	Side Sheets	15%	0%
8.4	End Sheets	5%	0%
8.5	Roof Sheets	3%	0%
8.6	Hopper Outlets and Roof Hatches	5%	0%
8.7	Underframe	14%	6%
8.8	Miscellaneous	4%	0%
8.9	Slope Sheets	1%	0%
	Total	100%	100%

The immediate distinction between the two firms is explained by the different mix of car types. Since all of the leasing company's cars are flat cars, they cannot have repairs to side, end, roof, or slope sheets, or to hopper outlets and roof hatches. Most of the reported exterior repairs for the car leasing company are CRB repairs. Program repairs are more evenly distributed to the three active repair codes listed in the table (8.1, 8.2, 8.7).

Like car interior repair activity, car exterior repair activity should vary with utilization but is more related to time than to mileage. Exhibit III-37 presents an analysis of covariance of exterior repair activity per 1,000 car days, based on the railroad's data. The analysis indicates that both car type and car age are highly significant factors. This contrasts with the analysis of interior maintenance, which does not show a statistically significant relation between repair activity and car age. For the railroad, cars over 20 years old average seven times as many exterior repairs as cars less than 5 years old.

As expected, gondolas have the highest rate of repair. Most of the spot painting occurs for gondolas and hoppers, but program painting occurs for all car types. Side sheets may deteriorate with age for the hopper cars, but box cars are less susceptible. On the other hand, end sheet damage due to internal stress is possible for box cars and gondolas. The most common exterior repair for the railroad (Repair 8.1 on the table) occurs somewhat randomly. Most of these repairs should relate more to time than to mileage. However, underframe repair may relate more directly to mileage.

Based on the car leasing company's data, the geometric relation obtains:

$$\log(\text{CRB8}) = -3.84 + \left\{\begin{array}{lll} -.475 & 0\text{-}5 & \text{years} \\ -.176 & 5\text{-}10 & \text{years} \\ -.116 & 10\text{-}15 & \text{years} \\ .033 & 15\text{-}20 & \text{years} \\ 0 & 20+ & \text{years} \end{array}\right\}_{\text{Car Age}} + \left\{\begin{array}{ll} -.259 & \text{intermodal} \\ -.545 & \text{autorack} \\ 0 & \text{other} \end{array}\right\}_{\text{Car Type}}$$

$$+ \underset{(0.1265)}{0.614} \log(\text{TCDAYS}) + \underset{(0.0724)}{0.138} \log(\text{TCMILE})$$

R^2 = 15 percent

This relation implies:

$$\text{CRB8} = A\,(\text{TCDAYS})^{0.61}\,(\text{TCMILE})^{0.14}$$

where:

A =

	Car Age (Years)				
Car Type	0-5	5-10	10-15	15-20	20+
intermodal	1.03	1.39	1.48	1.71	1.66
autorack	0.78	1.05	1.11	1.29	1.25
other	1.34	1.80	1.91	2.22	2.10

EXHIBIT III-37

ANALYSIS OF COVARIANCE OF CAR EXTERIOR REPAIRS PER CAR DAY*

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
                RPDB
             BY CTYPE
            WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	774.168	1	774.168	26.296	0.001
AGE	774.168	1	774.168	26.296	0.001
MAIN EFFECTS	1472.643	5	294.529	10.004	0.001
CTYPE	1472.643	5	294.529	10.004	0.001
EXPLAINED	1964.187	6	327.365	11.120	0.001
RESIDUAL	27850.605	946	29.440		
TOTAL	29814.793	952	31.318		

COVARIATE	BETA
AGE	0.120

953 CASES WERE PROCESSED.
0 CASES (0.0 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
              RPDB
        BY    CTYPE
        WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 2.70

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	114	0.96				1.29	
2 UNEQ BOX	74	-0.86				-1.42	
3 EQ HOPPER	2	1.99				1.84	
4 UNEQ HOPPER	537	-0.81				-0.85	
5 GONDOLA	112	1.99				2.25	
6 OTHER	114	1.41				1.37	
			0.20				0.23
MULTIPLE R SQUARED							0.075
MULTIPLE R							0.275

* Scale is number of repairs per 1,000 car days.

To assess the average exterior maintenance activity per car day for the car leasing company, the following relation is estimated:

<u>Step 1</u>

$$\frac{\text{CRB8}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 2.78 & \text{intermodal} \\ 1.60 & \text{autorack} \\ 3.12 & \text{other} \end{array}\right\}$$

R^2 = 7 percent

<u>Step 2</u>

$$\frac{\text{CRB8}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 1.40 & \text{intermodal} \\ 0.44 & \text{autorack} \\ 1.85 & \text{other} \end{array}\right\} + \underset{(0.0105)}{0.134\ (\text{AGE})}$$

R^2 = 14 percent

<u>Step 3</u>

$$\text{CRB8}/1{,}000 = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 0.44 & \text{intermodal} \\ -0.20 & \text{autorack} \\ 1.46 & \text{other} \end{array}\right\} + \underset{(0.0104)}{0.135\ (\text{AGE})} = \underset{(0.00015)}{0.0006\ (\text{TCMILE})}$$

R^2 = 15 percent

In contrast to the analysis of interior maintenance, car miles enters as a significant factor in both relations, even though mileage is not as important as car days. The effect of age is highly significant, though less dramatic than the railroad data indicate. The relation shows that, generally, other types of cars have the highest rate of exterior repair and autoracks have the lowest rate. For inter or repairs, intermodal cars have the highest repair rate. Thus, there is no clear relation between interior and exterior maintenance for car types.

The geometric relation indicates that if car days are held constant, a 10 percent increase in car miles yields only a 1.4 percent increase in repair activity. For a given number of car miles, the relation predicts a 6.1 percent increase in repair activity for a 10 percent increase in car days. In total, the result implies that three-fourths of exterior maintenance activity is variable with utilization.

Analysis of Special Equipment Maintenance

Special equipment maintenance includes activities associated with repairing refrigeration equipment, trailer-on-flatcar (TOFC) equipment, and automobile racks. Special equipment repairs are very infrequent for the railroad and the observed distribution of repair activity differs for the two firms as shown below:

DISTRIBUTION OF SPECIAL EQUIPMENT REPAIRS

	Special Equipment Repair	Railroad	Car Leasing Company
9.1	Refrigeration Equipment	0%	0%
9.2	TOFC Equipment	0%	98%
9.3	Automobile Equipment	68%	2%
9.4	Miscellaneous	32%	0%
	TOTAL	100%	100%

There are no refrigerator equipment repairs, since the railroad leases all its refrigerator cars from a firm which maintains them. The railroad's refrigerator cars, acquired by merger, are either not used or have their motors removed and are used as insulated box cars.

The automobile equipment category for the railroad (which concerns racks on box cars which secure automobile parts) comprises the majority of special equipment repairs. Virtually all special equipment repairs for the car leasing company are repairs to TOFC equipment since the autoracks are owned by the railroads. Special equipment activity is strongly dependent on the type of car, since not all cars have certain types of special equipment.

The maintenance activity on special equipment should logically depend to a greater degree on time than on mileage. Exhibit III-38 presents an analysis of covariance of special equipment maintenance per 1,000 car days for the railroad. Car type is a highly significant factor, since box cars are the only cars for which repairs are reported.

EXHIBIT III-38

ANALYSIS OF COVARIANCE OF SPECIAL EQUIPMENT REPAIRS PER CAR DAY*

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
            RPD9
         BY CTYPE
        WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	0.145	1	0.145	2.125	0.141
AGE	0.145	1	0.145	2.125	0.141
MAIN EFFECTS	1.263	5	0.253	3.699	0.003
CTYPE	1.263	5	0.253	3.699	0.003
EXPLAINED	1.322	6	0.220	3.226	0.004
RESIDUAL	64.593	946	0.068		
TOTAL	65.915	952	0.069		

COVARIATE	BETA
AGE	-0.002

953 CASES WERE PROCESSED.
0 CASES (0.0 PCT) WERE MISSING.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
            RPD9
         BY   CTYPE
        WITH AGE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

GRAND MEAN = 0.01

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
CTYPE							
1 EQ BOX	114	0.03				0.02	
2 UNEQ BOX	74	0.11				0.12	
3 EQ HOPPER	2	-0.01				-0.01	
4 UNEQ HOPPER	537	-0.01				-0.01	
5 GONDOLA	112	-0.01				-0.02	
6 OTHER	114	-0.01				-0.01	
			0.13				0.14
MULTIPLE R SQUARED							0.021
MULTIPLE R							0.146

* Scale is number of repairs per 1,000 car days.

A similar analysis is performed for the car leasing company's data by regression:

Step 1

$$\frac{\text{CRB9}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 3.58 & \text{intermodal} \\ 0.11 & \text{autorack} \\ 0.06 & \text{other} \end{array}\right\}$$

R^2 = 60 percent

Step 2

$$\frac{\text{CRB9}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 2.95 & \text{intermodal} \\ -0.42 & \text{autorack} \\ -0.52 & \text{other} \end{array}\right\} + \underset{(0.0071)}{0.061\,(\text{AGE})}$$

R^2 = 61 percent

Step 3

$$\frac{\text{CRB9}/1{,}000}{\text{car days}} = \left\{\begin{array}{ll} & \underline{\text{Car Type}} \\ 2.09 & \text{intermodal} \\ -1.02 & \text{autorack} \\ -0.88 & \text{other} \end{array}\right\} + \underset{(0.0070)}{0.062\,(\text{AGE})}$$

$$+ \underset{(0.00010)}{0.00056\,(\text{TCMILE})}$$

R^2 = 61 percent

The relation implies that intermodal cars have, by far, the highest special equipment repair rate. Older leasing company cars also have a (statistically significant) higher rate of special equipment repair. Trailer hitches of older cars are of a different design.

An interesting implication of the relation is that mileage affects maintenance activity controlled for car days. This hypothesis is examined further by estimating the geometric relation with the car leasing company's data:

$$\text{Log (CRB9)} = -8.209 + \left\{ \begin{array}{ll} & \underline{\text{Car Type}} \\ .866 & \text{intermodal} \\ -.130 & \text{autorack} \\ 0 & \text{other} \end{array} \right\} + \left\{ \begin{array}{ll} & \underline{\text{Car Age}} \\ .001 & \text{0-5 years} \\ .132 & \text{5-10 years} \\ .236 & \text{10-15 years} \\ .264 & \text{15-20 years} \\ 0 & \text{20+ years} \end{array} \right\}$$

$$+ \underset{(0.1368)}{1.023 \log (\text{TCDAYS})} + \underset{(0.1027)}{0.182 \log (\text{TCMILE})}$$

R^2 = 32 percent

This relation implies:

$$\text{CRB9} = A\ (\text{TCDAYS})^{1.02}\ (\text{TCMILE})^{0.18}$$

where:

$A =$ (values $\times 10^{-4}$)

Car Type	Car Age (Years) 0-5	5-10	10-15	15-20	20+
intermodal	6.48	7.38	8.19	8.43	6.47
autorack	2.39	2.73	3.03	3.11	2.39
other	2.72	3.11	3.45	3.54	2.72

The geometric relation confirms that mileage is an important aspect of utilization affecting special equipment maintenance activity. In total, the relation predicts that a 10 percent increase in utilization (time and mileage) yields a 12 percent increase in special equipment activity. With such an increase in maintenance activity, about 10 percent is apportioned to time and 2 percent to mileage.

SUMMARY

The analysis presented in this section has illustrated a methodology to determine the relations between car system or component maintenance activity and car descriptive and utilization factors for costing purposes. This summary subsection discusses:

- implications that the findings from railroad and leasing company data may have for other firms;
- statistical considerations of car sample size and required time span for car histories; and
- the feasibility of implementing this methodology for a rail firm.

Summary of Findings

The specific relations developed for each component group confirm a priori judgments concerning the causes of maintenance consumption. In most cases, both a geometric relation and a relation based on repair per car day or per car mile were estimated. Depending on the particular application, one or the other of the forms is appropriate for the costing methodology. For example, the repair per car mile relation is appropriate for a "fully distributed" cost, while the variability estimated from the geometric relation can be used to derive variable or incremental cost.

Exhibit III-39 summarizes the relative importance of factors explaining maintenance activity for the two firms studied. The exhibit indicates the high degree of conformity of these two very different firms. For most car systems, older cars experience a higher rate of repair. The only exceptions are the door, car interior, and special equipment systems for the railroad. Car systems located physically below the truck experience a repair rate that is only moderately influenced by car type. However, above the truck, the car interior, exterior, doors, and special equipment systems are physically very different for various car types and, as a result, the repair rates differ greatly.

For most component groups, both time and mileage utilization effect maintenance activity. Mileage is the most crucial factor for component groups physically below the truck except for the draft gear systems. Time utilization is the most crucial factor for the draft gear system and for components physically above the truck. It is anticipated that other rail firms would exhibit similar behavior with minor exceptions.

EXHIBIT III-39

RELATIVE IMPORTANCE OF FACTORS EXPLAINING FREIGHT CAR MAINTENANCE ACTIVITY

CAR SYSTEM	FACTORS			
	DESCRIPTIVE		UTILIZATION	
	CAR TYPE	CAR AGE	TIME	MILEAGE
Brakes	L	M	M	H
Draft Gear	M	H/M*	M	L
Truck	L	H	L	M
Bearings and Axle	M	H	M	H
Wheels	L	H	NS	H
Doors	H	NS	M	L
Car Interior	H	L/M	M	NS
Car Exterior	H	H	H	M
Special Equipment	H	NS/M	H	L

KEY

Level of Importance:

- H high or very high
- M medium
- L low
- NS not significant

* High for railroad/medium for car leasing company

A comparison of the separate relations developed for the railroad and the car leasing company supports the application of this methodology to other firms. The coefficients will change, of course, as will the relative importance of factors in the relations for each firm to which the methodology is applied. However, the same procedures employed for the firms in this study can be used to develop relations for other rail firms.

Some refinements to this methodology may be possible in the future. If reliable statistics on car loadings, classifications, and so forth are available, these statistics could be used in place of time and mileage. The potential benefit would be a greater explanation of maintenance activity, but a costing methodology based on these relations would require more detailed information to apply. A greater explanation of maintenance activity could also be attained with a longer time span of car histories. If this were possible, various patterns between maintenance activity and use might appear which have not yet been detected--particularly for components with very long maintenance cycles. For costing purposes, a finer breakdown of car types than provided in this analysis may be useful in some cases. Again, this analysis could be performed only at the cost of a larger sample size.

Statistical Considerations

Before developing freight car maintenance relations for a firm, the time span of data collection and the car sample size must be decided. The former question is the most critical statistical consideration.

This study illustrates results based on a very short time interval for the railroad (7 months) and an intermediate time interval for the car leasing company (3 years). For practical applications, the time span of data collection preferably exceeds 3 years.

As noted, a longer time interval of data collection enables patterns to form between maintenance activity and utilization. Relations between maintenance activity and utilization are more difficult to observe within short time intervals, especially for components with average maintenance cycles that are long in relation to the sample interval. Thus, the appropriate time interval depends on the average maintenance cycle of the car components being studied. For example, a much longer interval than 3 years is necessary to assess the impact of utilization on maintenance activity for trucks. Trucks may outlast the useful life of a freight car in some cases.

The second statistical consideration, car sample size, is addressed by a two-round sampling strategy. In the first round, a convenient-sized random sample of cars is used to develop suitable car maintenance relations. Based on these results, a second-round sample size is determined to achieve satisfactory statistical precision. The second round is optional, since the precision objectives can be attained, in some cases, with the first-round sample. The sample selection strategy is detailed in Appendix B.

Implementation

Assuming that data collection and data processing efforts are feasible, applying this methodology successfully involves additional personnel and computer resources over several months. The level of effort depends on the depth of the analysis performed and the skill and experience of personnel applied to the project.

Although most analysis of maintenance activity was performed at a component group level in this study, either a more or less disaggregate approach is possible (e.g., maintenance relations could be developed separately for each car component). The particular level of detail (or disaggregation) of maintenance activity determines the amount of effort required to develop the relations. Thus, maintenance activity should be analyzed at a level appropriate to the detail of the costing methodology.

IV. CAR REPAIR FACILITIES

Exhibit IV-1 is a diagram of the car repair process. Although this process is basically the same for all shops at the level depicted by the flow chart, the actual performance of repairs can vary greatly from shop to shop. This variance can be attributed to, among other factors, the type of repair being performed and the staffing, facilities, physical structure, and equipment of the individual shop.

REPAIR CATEGORIES

Three general types of repairs were being performed by the car repair shops visited: running/periodic repairs, light repairs, and heavy repairs. These types can be separated by the level of effort, time, skill, and equipment required to complete the repair. At the lower end of the spectrum are running/program repairs, which require a minimum of equipment and often entail merely changing out a component. These repairs may include replacing brake shoes and air hoses and periodic inspections such as a COT&S (clean, oil, test, and stencil). Light repairs are less standardized and require more sophisticated equipment and tools than do running repairs. Light repairs also allow a carman more room for personal discretion about how the repair will be effected. The upper end of the spectrum is occupied by heavy repairs. Making a heavy repair is akin to rebuilding a car and may involve modifying or reconstructing a portion of a car which has been damaged or is outdated. Shops which are not equipped to make heavy repairs will often either patch a car they cannot repair or load it on a flat car and ship it to the closest heavy repair shop.

The five shops visited perform one or more of these types of repairs. The shops differ in the type of equipment and facilities they possess and in their methods of performing the repairs. Some of these differences are summarized in Exhibit IV-2. The shops selected comprise a fairly representative cross-section of the participating railroad's car repair shops in terms of the kinds of repairs they perform and their ages, locations, and equipment.

Shop A

Shop A is the smallest of the five facilities and is located in a major freight facility. Three tracks are used for repair work; however, wheel replacement is limited to one track. There is no covered enclosure protecting these tracks, so all work is performed in full exposure to the weather. The only building on the premises is used for paper work, office space, and a storage area for materials that cannot be stored outdoors. The shop is

EXHIBIT IV-1

FREIGHT CAR REPAIR PROCESS

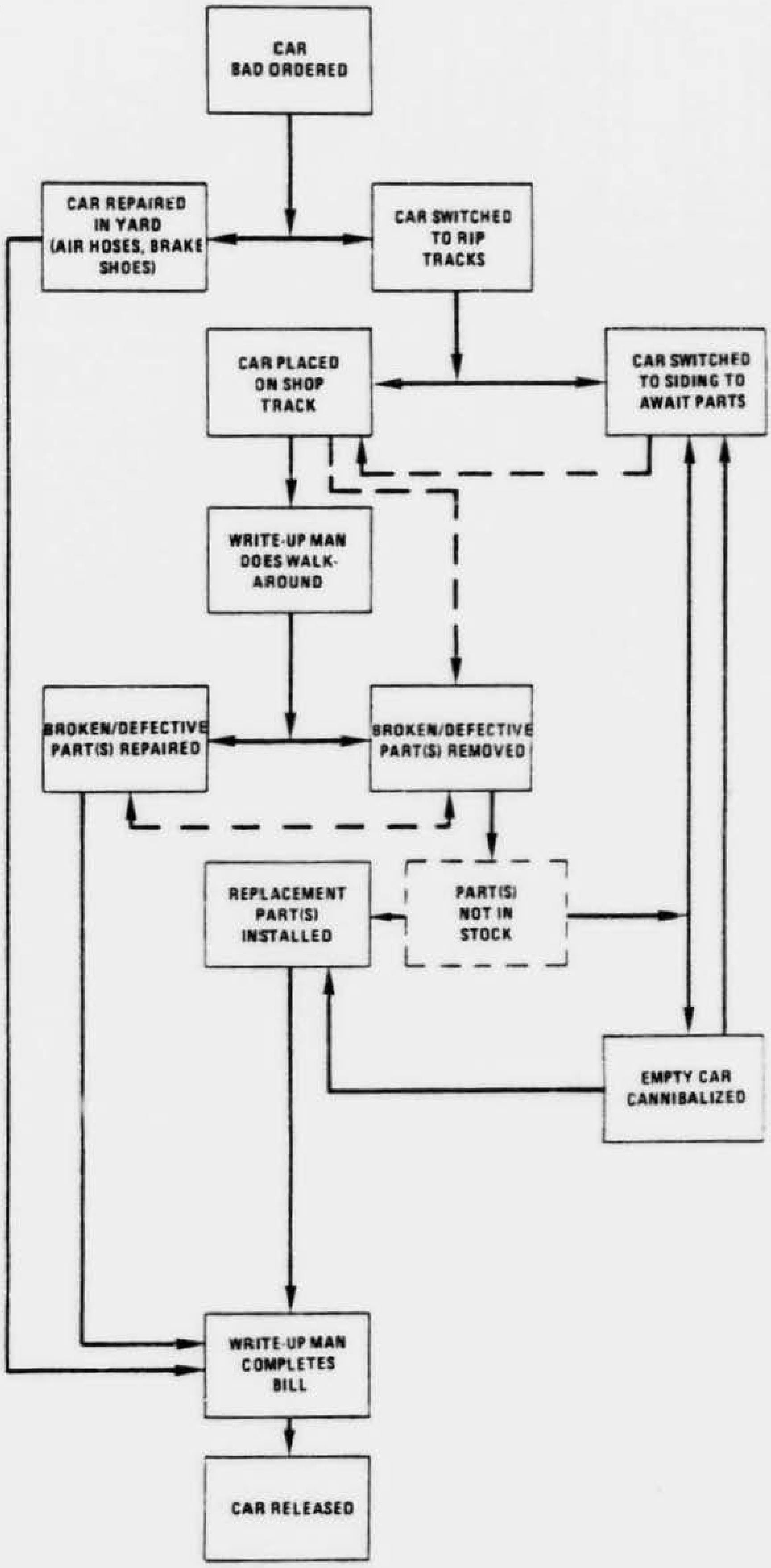


EXHIBIT IV-2

COMPARISON OF CAR REPAIR FACILITIES VISITED

	SHOP A 25-30 cars/day	SHOP B 45-50 cars/days	SHOP C 30-35 cars/day	SHOP D 30-40 cars/day	SHOP E 50-60 cars/day
STAFFING	• operates 1 shift per day • operates 7 days per week • total staff is 39 carmen, 1 administrative person, 5 supervisors	• operates 3 shifts per weekday, 2 shifts on weekend days • total staff is 123 carmen, 1 administrative person, 18 supervisors	• operates 2 shifts per day • operates 7 days/week • total staff is 71 carmen, 1 administrative person, 9 supervisors	• operates 3 shifts per day (24 hours) • operates 7 days/week • total staff is approximately 170 carmen, 2 administrative people, 20 supervisors	• operates 3 shifts per day • operates 7 days/week • total staff is approximately 175 carmen, 1 administrative person, 21 supervisors
MATERIAL INVENTORY	• small items (nuts, bolts, etc.) charged when shop gets them • larger, expensive items charged when used • must absorb expense of materials lost through theft • some inventory reordered based on average usage rate	• small items (nuts, bolts, etc.) charged when shop gets them • larger, expensive items charged when used • materials reordered when supply is low or an item requested	• small items (nuts, bolts, etc.) charged when shop gets them • larger, expensive items charged when used • some frequently used material is inventoried and reordered once a week	• small items (nuts, bolts, etc.) charged when shop gets them • larger, expensive items charged when used • performs weekly inventory of select items • reorder materials when inventory is low or item requested	• small items (nuts, bolts, etc.) charged when shop gets them • larger, expensive items charged when used • materials inventoried regularly • materials physically distant from car repair location, causing delays in getting materials to cars
PHYSICAL LAYOUT OF SHOP	• 3 outdoor tracks • physically limited to doing wheel replacement on a single track • little room for expansion	• 3 indoor tracks • try to do specific repairs on designated tracks, but mix of repairs thwarts this	• 2 indoor tracks • most repairs done in shop • sometimes wheels changed in yard • building cannot accommodate 89' cars unless the door is open • limited space to move inside the shop	• 2 indoor tracks • 4 other shops in facility for heavy repairs, car cleaning, program modifications and tank equipment repair	• 3 covered tracks for repairs • wheel repair facility • paint shed • heavy repair facilities • enclosure is short in length and narrow • drainage problem affects ability to jack up cars
MOBILITY OF CARS	• cannot move cars once they're placed—transportation switches once a day	• have tractor to move/switch cars—use cable within the shop	• have tractor to move/switch cars • rely on transportation to spot cars when shop is busy and to move cars to holding tracks	• have tractor to move/switch cars	• have tractor to move/switch cars within shop • cars are humped directly to shop
MATERIALS TO CARS	• move materials to car • less mobility since forklifts are not available • mostly outdoor storage	• move materials to cars, many materials are stored outdoors	• move materials to cars • have forklifts to move large articles • some outdoor storage	• move materials to cars • most materials kept indoors close to cars	• move materials to cars • running repair shop distant from inventory (half a mile)
REPAIRS VS. REPLACE	• mostly replace • can do some repairs other shops cannot because there is a blacksmith at the shop	• mostly replace • decision dependent upon availability of parts	• repair unless backlog of bad ordered cars	• mostly replace because it is more efficient—will repair parts later and put them on another car	• mostly replace but do some repairing
NATURE OF REPAIRS	• cars bad ordered from through trains—mostly brakes, bearings, wheels • no heavy repair work	• cars bad ordered from through trains • heavy repair work shipped to other shops • cars damaged in hump yard (shifted loads, broken couplers)	• maintain pool and assigned cars • heavy repair work shipped to other shops	• cars bad ordered from through trains • can perform heavy repairs	• cars bad ordered from through trains • can perform heavy repairs • cars damaged in hump yard (shifted loads, broken couplers)
AVAILABILITY OF PARTS	• stores cars awaiting parts • can usually get parts from other roads in area • little (if any) cannibalism	• store cars (usually private) awaiting parts • will often cannibalize an empty to repair a load	• parts on consignment often do not arrive on time • 50-60% of parts stored on shop floor—difficult to find • occasional cannibalism • can get parts from other roads in the area	• good system for maintaining parts inventory—parts reordered based on historical use	• inventory is inaccurate for running and light repairs due to physical distance
ODD JOBS	• carmen do miscellaneous work to repair equipment, machinery and tools • carmen must remove snow and ice	• carmen sweep floors and repair tools and support equipment	• carmen occasionally shovel snow • laborer sweeps floors & does errands • send out a lot of equipment for repair	• carmen do miscellaneous jobs • write-up man monitor hot box detectors • have special shop to make repairs on tools and equipment	• carmen keep shop clean, do some tool and equipment repair
SHOP EQUIPMENT	• 6 sets of air jacks • 2 portable welders • small crane (limited capacity)	• 1 crane • 1 tractor • 2 6000-lb. forklift trucks • 2 portable welders • 1 15-ton gantry • 2 sets floor jacks • 3 jib cranes • 1 6000-lb forklift truck • 1 stationary grinder • 4 stationary welders • 1 drill press • 1 power hack saw • 2 sets of truck equipment • 2 winch car movers	• 4 jib cranes • 6 portable air jacks • 2 forklift trucks • 2 crane trucks • 4 [illegible] welders • 2 welder trucks • 2 portable welders • tractor	• built-in jacks on both tracks • swinging gantries • portable hydraulic jacks • tractor • forklift truck • portable welders • 2 wreckers	• 5 sets of air jacks • 2 swing cranes • portable welder • tractor • forklift truck
OTHER FACTORS	• weather a big factor—men must have more frequent breaks than at an indoor shop		• restroom and lunchroom in separate building causes delays • high turnover (low seniority/experience level)	• snow decreases shop throughput considerably since it makes it more difficult to switch cars in & out of the shop	

located between a mainline and a classification yard which limits room for expansion. (The shop tracks are, in fact, part of the yard.) Despite the lack of sophisticated facilities or equipment, this shop meets the anticipated (budgeted) performance standards established by the railroad.

Shop B

Shop B, by comparison, is a relatively new facility. The enclosed car repair shop covers three tracks with built-in floor jacks on the center track. A transfer table located outside the shop at the incoming end allows some flexibility for channeling cars with particular repairs to a special track, although the mix of repairs often makes that impossible. The shop is located adjacent to a hump yard, which impacts the types of repairs the shop must complete. Many of the repairs performed (such as straightening shifted loads and repairing passed couplers) are necessitated by hump-related damage. Running/periodic and some light repairs are performed at the shop. Cars needing heavy repairs are patched or loaded on flat cars for forwarding to a larger facility.

Shop C

Repairs at Shop C are made largely to automobile pool cars, and many carmen are assigned to work at pool docks or auto loading docks where such cars are used. The shop itseld is enclosed, but the construction of the building does not make adequate provision for free movement of forklift trucks and 89-foot cars cannot be worked on without leaving the doors open. Shop C performs only running/periodic and some light repairs, and heavy repairs are sent to larger facilities. One problem interferes with a smooth flow of cars through the shop--there is not much room on the outgoing tracks to store completed cars. As a result, cars get backed up and work must be done outdoors if a switch is not provided in a timely fashion.

Shop D

Shop D comprises several shops, which gives the facility the capability to perform a wide range of repairs. Heavy repairs are performed, as well as running/periodic and light repairs, although the two types of repairs are physically separated in different buildings. The lighter repairs are performed in an enclosed building containing two through tracks, with two storage tracks on the inbound side and one on the outbound side. The running/periodic and light repairs at Shop D are usually made on cars that are bad ordered from through trains, while the heavy repairs are sent from elsewhere in the system.

Many materials used in the car repair process are bulky and heavy and cannot practically be stored in proximity to the car repair location. Wheel sets, for example, are both large and heavy. The wheels are usually stored outdoors because space is needed both for storage and for maneuvering the forklift trucks which move a set of wheels to the car being repaired. Replacing a set of wheels therefore involves getting a fork lift truck, going outside the shop, and retrieving the wheels. The proximity of the wheels, or any other materials, to the car repair location affects the time required to complete a repair. At Shop D, materials are stored close to the place where they are used, so the effect of materials retrieval time on work output is minimal. The size and layout of the shop buildings permit unhampered movement.

Shop E

Shop E also has the capability to perform all three types of repairs. The running/periodic and light repair shop has three tracks, but the building housing them is quite short and narrow, making it difficult to accommodate cars. Because it is located close to a hump yard, much of the repair work is hump-related. Repairs which cannot be completed at the rip track can be performed at one of the other shops, so there is no need to patch heavily damaged cars for forwarding.

FACTORS AFFECTING EFFICIENCY AND VARIANCE

The differences noted in Exhibit IV-2 and in the discussions have a considerable impact on the efficiency and variances in the repair process. The types of repairs (running/periodic, light, or heavy) and the mix of repairs (bad orders from through trains versus hump-related damage) are important variables, particularly as they affect the time it takes to complete a repair. Because the work is not of a standardized nature, the carman must use his own discretion in deciding how to effect a repair. There is also more leeway the less standardized (heavier and more damage-related) the repair is. Equipment availability and sophistication, as well as the physical layout of the facilities, impact both the time in which a repair can be made and the type of repair work that can be performed. An additional factor is the availability of materials and their proximity to the cars. The ready availability of materials cuts down on duplicative efforts to position, jack up, and otherwise prepare a car for repair, plus the time involved in cannibalizing another car.

Another factor which accounts for part of the differences between shops is the personnel. As pointed out, carmen must use their own discretion in carrying out most repairs. The number of personnel, their experience, work habits, supervision, and responsibilities (as well as the physical factors such as equipment, facilities, and materials) impact the time it takes to do a job and the variances that are observed.

FACTORS AFFECTING MAINTENANCE

The railroad studied by the project team has maintained high equipment maintenance standards for many years and has consistently maintained a bad order ratio of less than 6 percent. Several factors influenced this high level of maintenance beyond the basic requirement of an adequately maintained supply of equipment. They include corporate profitability, the demand for particular car types, new car investment, and the desire to maintain a stable workforce and minimize unit repair costs.

At the railroad studied, budgets and expenses for running repairs are not distinquished between repairs to foreign and system cars. All freight car repair expenses are debits to a single account. This accounting practice conforms to the Interstate Commerce Commission Uniform System of Accounts, which is used by all Class I railroads. Railroads make no effort to apply foreign CRB receipts as credits to expenses at the individual shop level. AAR standard costs do not, in general, reflect actual costs on a particular railroad or in a particular shop. Depending on the repair, a railroad may make or lose money on repairs costed by AAR standards.

The railroad has begun to make a comparison of AAR standard costs and actual labor and material charges for freight car running repairs. This comparison has indicated that total actual labor and material cost (system and foreign car) exceed total costs at AAR standard rates. The comparison, however, can be made only on a total running repair basis for foreign and system cars since, while full CRB procedures are in use for both system and foreign cars repaired in the railroad's facilities, material expenses are charged to general function accounts and labor hours are charged to general function codes that do not differentiate between repairs to system and foreign cars.

AAR CAR REPAIR BILLING PROCEDURES

System Repairs to All Cars

The sample railroad has an efficient computerized CRB system. This system captures both on-line repairs to foreign equipment and off-line repairs to system equipment, as well as all on-line repairs to system equipment for both light and heavy repairs.

The AAR CRB codes and required information are used to record the majority of repairs at over 120 of the railroads repair points. Exhibit IV-3 shows both sides of the Original Record and Repairs form used for recording the majority of repairs. The only additional field forms used are a supplemental wheel and axle form used to record additional information required in these areas and a train yard repair form used to record group billable repairs that are performed without switching the car out of the train. The Original Record of Repairs form was developed from a study to determine what repairs were being made in the field and their frequency. Preprinted codes in Part 1 of this form represent an estimated 85 percent of system repairs, based on the special study. Part 2 of the form provides space for recording repairs not included in the preprinted codes section.

Exhibit IV-4 is a process flow chart showing the flows of the major components of this system.

Repairs to System Cars

The railroad's system captures all repair costs on railroad-owned equipment. Foreign road repairs to owned equipment enter this system as the foreign road bills are received. Repairs made by the railroad enter through the completion of field forms at the repair points. It should be noted that the railroads heavy and wreck repairs also enter this system. This is accomplished through use of the AAR CRB codes, supplemented by CRB-type codes which will be designed by railroad personnel to cover work not normally reported in the CRB system. These repairs will be reported on the same form, and in the same manner, as normal running repairs.

Program repairs will also be captured by the system for inclusion in the Car History File and the Shop Performance System. All program repairs have a standard bill of material, completed by the foreman, listing the material that will be applied to each car and the amount of labor required to apply such material. As each program repair car is released from the shop, the repair information is inserted into its Car History File.

If any repairs are made to an individual car beyond program repairs, they are reported on the standard repair form (Original Record of Repairs).

The Car History File is designed to compile and categorize repairs performed on-and off-line to owned freight cars. The railroad's system provides a data bank which can be used to:

. support the bills payable to audit function;

. support technical and profitability studies;

EXHIBIT IV-3

SAMPLE ORIGINAL RECORD OF REPAIRS

ORIGINAL RECORD OF REPAIRS

CAR INITIAL	CAR NUMBER	KIND	DATE REPAIRS COMPLETED (MO / DAY / YR)	REPAIR POINT	DEFECT CARD INITIAL	DEFECT CARD DATE (MO / DAY / YR)

MTY LOAD	DEFECT	REASON	DATE SHOPPED (MO / DAY / YR)	DATE ON SHOP TRACK (MO / DAY / YR)

LUB DATE ____________ IDT ____________

AIR DATE ____________ REPAIRS CERTIFIED BY ____________

PART 1

√	RULE	ITEM	LOCATION	QTY	CC	JCA	Q	WHY MADE CODE	JCR	Q	RESP.
	2	COTS, AB, 1-SET		1	7	1000		12 13 21 22 31 32	1000		1 2 3
	2	COTS, ABD, 1-SET		1	7	1048		12 13 21 22 31 32	1048		1 2 3
	3	IDT, 1-SET		1	7	1140		21 22	1140		
	4	ANGLE COCK, SEAL RING		1 2	1 2 3	1160		01 02 03 15 31	1160		1 2 3
	4	AIR HOSE SUPPORT COMPLETE		1 2	1 2	1165		02 03	1165		1 2 3
	4	AIR HOSE "S" HOOK		1 2 3 4	1 2	1166		02 03 05 06	1166		1 2 3
	4	ARMORED HOSE 1-1/4" OVER 30"		1 2	2	1184		01 02 03 15 31	1184		1 2 3
	4	AB VALVE VENT PROTECTOR		1	1 2	1340		02 03 31	1340		1 2 3
	4	BRAKE CYL REL VAL C B/OR R		1	1 3 7	1348		01 02 09 12 15 31 32	1348		1 2 3
	4	QUICK SERVICE VAL C B/OR R		1	1 3 7	1388		01 02 09 12 15 31 32	1388		1 2 3
	4	NO 8 VENT VALVE C B/OR R		1	1 3 7	1400		01 02 09 12 15 31 32	1400		1 2 3
	5	AIR BRAKE HOSE		1 2	1	1628		03 04	1628		1 2 3
	6	BRAKE BEAM, HANGER, NO 18	1 2 3 4	1	1 3	1648	8	01 02 03 05	1648	8	1 2 3
	6	BRAKE BEAM, UNIT, NO 18	1 2 3 4	1	1 3	1652	8	01 02 03 05	1652	8	1 2 3
	6	BRAKE BEAM, UNIT, NO 24	1 2 3 4	1	1 3	1660	24	01 02 03 05	1660	24	1 2 3
	9	BRAKE CONNECTOR PIN			1 2	1748		01 02 03	1748		1 2 3
	12	BRAKE SHOE, CAST IRON			1	1828		01 02 03	1828		3
	12	BRAKE SHOE, COMP, 1-1/2 IN			1	1838		01 02 03	1838		1 2 3
	12	BRAKE SHOE, COMP, 2 IN			1	1840		01 02 03	1840		1 2 3
	12	BRAKE SHOE KEY			2	1852		01 02 03	1852		1 2 3
	16	COUPLER KNUCKLE, E50HT	A B	1	1 2 3	2052		01 02 03	2052		1 2 3
	16	COUPLER KNUCKLE LOCK, TYPE E	A B	1	1 2	2056		01 02 03	2056		1 2 3
	16	COUPLER LOCK LIFTER, BOTTOM, E	A B	1	1 2	2068		01 02 03 06	2068		1 2 3
	16	COUPLER KNUCKLE THROWER, E	A B	1	1 2	2072		01 02 03 05	2072		1 2 3
	16	COUPLER KNUCKLE PIN	A B	1	1 2	2076		01 02 03 05	2076		1 2 3
	16	COUPLER TOP HOLE CAP, WELDED	A B	1	1	2080		02 03	2080		1 2 3
	16	COUPLER CROSS KEY RETAINER LOCK	A B	1 2	1 2	2108		01 02 03 05 06	2108		1 2 3
	16	UNCOUPLING LEVER	A B	1	1 2 3	2136		02 03 06	2136		1 2 3
	16	UNCOUPLING LEVER R R & R	A B	1	8	2136		05	2136		1 2 3
	16	UNCOUPLING LEVER, TELESC	A B	1	1 2 3	2142		02 03 06	2142		1 2 3
	16	UNCOUPLING LEVER, TELESC R R & R	A B	1	8	2142		05	2142		1 2 3
	16	COUPLER CARRIER &/OR STRIKER SHIM	A B	1	1	2160		02 6	2160		1 2 3
	24	LUBRICATOR, GROUP A	R 1 2 3 4 L 1 2 3 4	1	1	2500		01 05 09 31 32	2500		1 2 3
	25	JOURNAL BOX REPACK, 4-WHL TRUCK		1	7	2520		09 21 22 31 32	2520		1 2 3
	26	LUB ROLLER BEARINGS, 4-WHL TRUCK		1	7	2550		09 21 22	2550		1 2 3
	27	LUB HITCH OR STANCHION		1	7	2570		21 22	2570		1 2 3
	30	JOURNAL BRASS, S B, 10 IN	R 1 2 3 4 L 1 2 3 4	1	1	2604		01 02 03 09	2604		1 2 3
	30	JOURNAL BRASS, S B, 11 IN	R 1 2 3 4 L 1 2 3 4	1	1	2608		01 02 03 09	2608		1 2 3
	30	JOURNAL BRASS, F B, 10 IN	R 1 2 3 4 L 1 2 3 4	1	1	2624		01 02 03 09	2624		1 2 3
	30	JOURNAL BRASS, F B, 11 IN	R 1 2 3 4 L 1 2 3 4	1	1	2628		01 02 03 09	2628		3
	31	JOURNAL WEDGE, S B, 10 IN	R 1 2 3 4 L 1 2 3 4	1	1 2	2674		01 02 03 05 09	2674		1 2 3
	31	JOURNAL WEDGE, S B, 11 IN	R 1 2 3 4 L 1 2 3 4	1	1 2	2678		01 02 03 05 09	2678		1 2 3
	33	JOURNAL BOX LID, GR A, 11 IN OR LGR		1	1	2754		01 02 03 06	2754		1 2 3
	37	PEDESTAL ADAPTER, NARROW, 11 IN	R 1 2 3 4 L 1 2 3 4	1	1 2	2970		01 02 03 07	2970		1 2 3
	37	PEDESTAL ADAPTER, NARROW, 12 IN	R 1 2 3 4 L 1 2 3 4	1	1 2	2974		01 02 03 07	2974		1 2 3

EXHIBIT IV-3 (Continued)

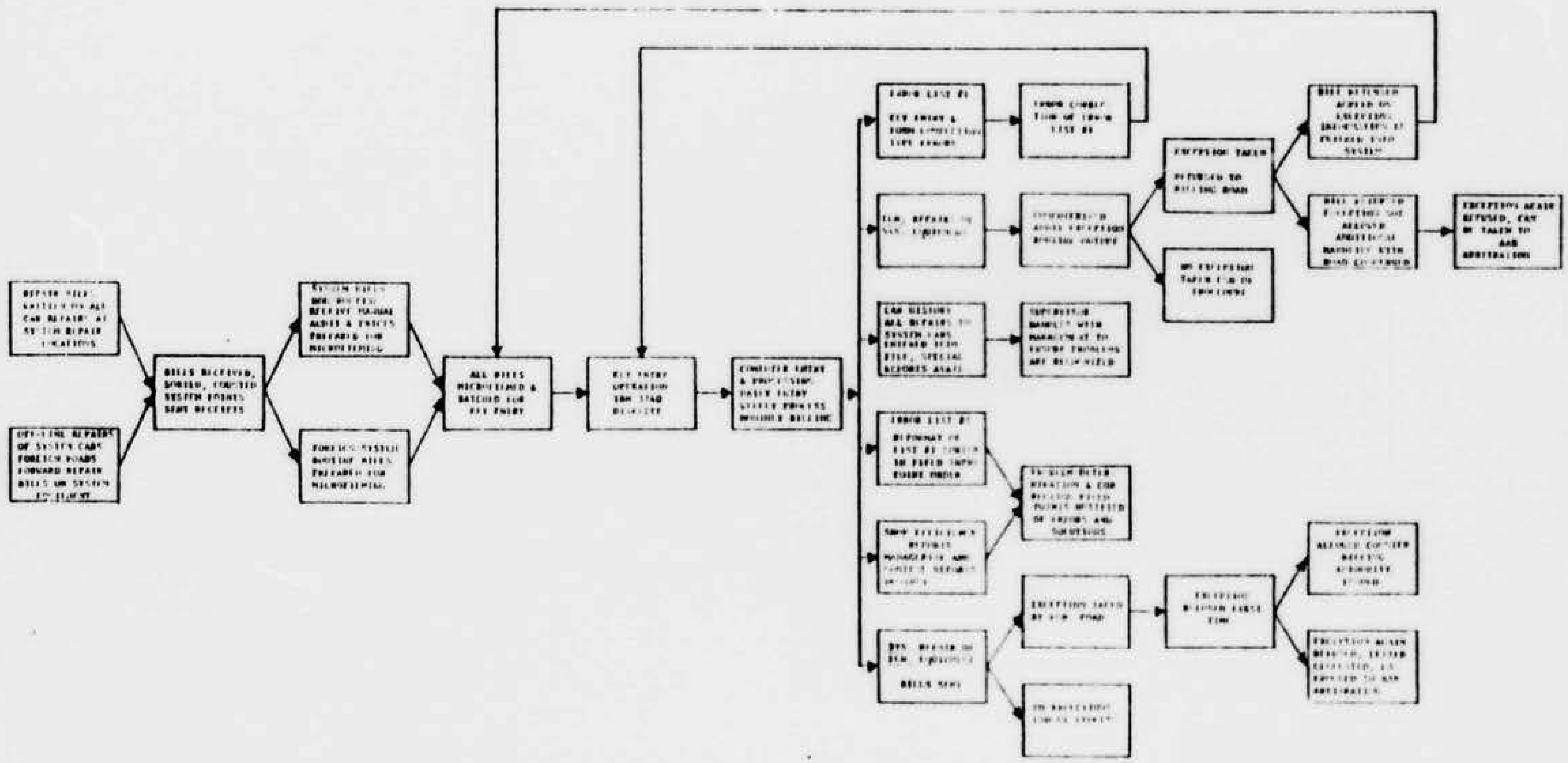
/	RULE	ITEM	LOCATION	QTY	CC	JCA	Q	WHY MADE CODE	JCR	Q	RESP	2 QUALIFIER DESCRIPTION
	37	PEDESTAL FRAME KEY			1 2	2882		01 02 03	2882		1 2 3	
	47	TRUCK SIDE BEARING, ROLLER OR BLK	AR AL BR BL	1 2	1 2	3572		01 02 03	3572		1 2 3	
	70	WEIGH AND STENCIL		1	7	4300		09 21 22 25 31	4300		1 2 3	
	71	CARDBOARD, DEFECT OR DESTINATION		1 2	1	4320		02 03 31	4320		1 2 3	
	73	ACI LABEL CLEANING		1	1	4368		09	4368		1	
	74	COTTER OR SPLIT KEY			1	4400		01 02 03	4400		1 2 3	
	4	PIPE FITTING, EX HVY, 1" OR 1-1/4"			1 2	1208		01 02 03 15 31	1208		1 2 3	
	69	STEEL PLATE, STRUCT OR PRESSED			1 2	4204		01 02 03 06 09 10	4204		1 2 3	
	74	BOLT, 12 IN OR LESS			1	4404		01 02 03 09 10 18	4404		1 2 3	
	74	RIVET, 2-PIECE, 5/8" OR OVER			1	4428		01 02 03 09 10 18	4428		1 2 3	
	75	LABOR, FREIGHT CAR		•	0	4450		05 09	4450		1 2 3	
	76	STRAIGHT OR FORGE WELD PART, OFF CAR			8	4490		02 05	4490		1 2 3	
	82	TACK OF FILLET WELD			0	4800		02 09	4800		1 2 3	
	82	BUTT WELD, 1/8" TO 1/2"			0	4808		01 02 09	4808		1 2 3	
	82	WELD REMOVED			0	4820		09	4820		1 2 3	

PART 2

JCA DESCRIPTION PER SECTION F	LOCATION	QTY	CC	JCA	Q	WHY MADE	JCR	Q	RESP	2 QUALIFIER DESCRIPTION WHERE APPLIED	RULE 72 ONLY NET CHARGE	RULE 72 ONLY DESCRIPTION - CLASS & ITEM NUMBER

EXHIBIT IV-4

SYSTEMS PROCESS FLOW CHART



- analyze failure trends of components;

- assist financial planning related to car replacement needs;

- provide more accurate forecasting of freight car maintenance budgets;

- reduce current levels of report generation; and

- assist in designing better preventive maintenance programs for freight cars.

The railroads system has also been made very flexible in the report generation area. Almost unlimited retrieval capability is offered, while holding the number of standard reports to a minimum.

V. ACCOUNTING PROCEDURES

The description of accounting procedures presented in this section reflects the information system used by the railroad that participated in this study. Employees in the railroad's Mechanical Department record their hours on a daily time card (Exhibit V-1) by function code and work location code. The separate function codes to which labor hours are charged are subsets of ICC accounts. Separate function codes have been established for repairs done in shops, for repairs in train yards, for dismantling equipment, for program repairs, for servicing freight cars, for road repairs, and for servicing TOFC trailers. For example, the functions developed for repairs performed on shop tracks include those described below:

Primary Account	Functional Account Included in Column 1	Description
314	206	Inspecting freight cars
314	219	Repairs to cabooses
314	235	Regular maintenance to freight cars
314	240	Periodic lightweighting
314	291	FRA periodic inspection
327	407	Regular maintenance to work equipment
402	452	Servicing work equipment
314	269	Oil and lubrication
402	272	Servicing freight cars
402	273	DF equipment repairs and equipping cars
402	782	Adjusting lading

A Labor Function and Material Reporting Manual is supplied to all employees in the Mechanical Department. This manual includes a description of all activities included under each function code. In some cases, work is performed at a specific location under a specific shop order number. This shop order number accompanies the function code on the employee's time card and implies a specific activity at a specific location. These forms are submitted to the appropriate clerk in each shop and input into the management information computer files.

FUNCTIONAL HIERARCHY

A functional hierarchy has been established that combines the individual function codes into groups of functions at several levels of aggregation for reporting purposes. In this hierarchy, individual function codes are defined as

V.2

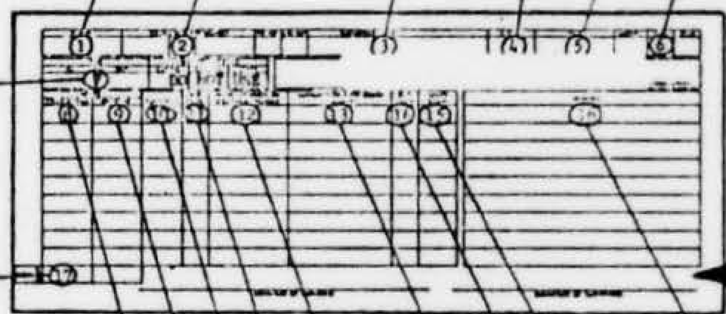
EXHIBIT V-1

MECHANICAL DEPARTMENT DAILY TIME CARD – FORM AD-522

The daily timecard is for use by hourly rated employees. The top line will be preprinted with information described below. Each employee should complete the "Time In and Out" (#7) section, sign the card and return to his foreman. The foreman will complete the form, sign and give to the appropriate clerk for further handling. When necessary, blank copies may be secured from the Motive Power Department in [redacted].

1. (Preprinted) Reporting Identification Number.
2. (Preprinted) Employee's Social Security Number.
3. (Preprinted) Employee's Initials and Last Name.
4. (Preprinted) Anplicalbe I.C.C. Classification of Employee.
5. (Preprinted) Employees Applicable Rate of Pay.
6. (Preprinted) Month, Day, Year.

7. Employee Starting and Ending Time.



17. Total Straight Time and Overtime Hours Worked by Employee.

Employee and Supervisor must sign card on this line.

16. If further descriptions are required, use this column.
15. Do not use.
14. Overtime Code.
13. If work performed is covered by a shop order, it is to be reported in this column.
12. Work location or equipment number. The proper method of filling in this column will be explained on the pages of this book where applicable.
11. Sub Code 1 for freight and Sub Code 2 for passenger. The passenger sub code is only to be used at [redacted] and [redacted]
10. Function number applicable to work performed.
9. Overtime hours worked by employee.
8. Straight time hours worked by employee.

Revised 5/1/74

the "fourth functional level." These codes provide the most detailed breakdown of repair activity. At the "budget analysis" level (level three), individual functions that are aggregated into separate labor and material categories are combined into a single line item in the budget. The level of aggregation (level one) summarizes the budget line items into even more generalized categories.

RESPONSIBILITY HIERARCHY

In addition to the functional hierarchy discussed previously, the carrier has a hierarchial management structure within each department. Responsibility levels have been developed that show the scope of responsibility of individuals in the management hierarchy and parallel the corporate organization chart. The narrowest (most localized) area of responsibility is identified by a responsibility identification number (RIN).

The relationship of the responsibility levels to the geographical and managerial subsections of the railroad (system, region, division, and territory) varies from department to department. Certain departments, such as Finance, operate only at the system level. In the Mechanical and Transportation Departments, however, the fourth level of responsibility corresponds to the territory in the maintenance of equipment hierarchy. In the maintenance-of-way section of the Mechanical Department and in the Transportation Department, the fourth responsibility level corresponds to the division.

RESPONSIBILITY PERFORMANCE REPORTS

A series of "responsibility performance" reports are generated on a monthly basis to monitor activity at repair points. These are summarized at the different function and responsibility levels. The shop performance system summarizes shop activity by function. Each report compares actual labor, hours, and dollars with work function.

MATERIAL ACCOUNTING DEPARTMENT

The railroad's material accounting procedures vary both with the type of repair facility and with the type of material. Material accounting procedures in running, light, and heavy repair facilities differ from procedures used in car rebuilding programs or new car construction programs. In the repair facilities, car repair materials and components are classified as either standard or nonstandard materials. Standard materials are common components that are repeatedly ordered, such as wheels, axles, and couplers. Quantities on hand (by item and location) are maintained in a computerized inventory system that automatically reorders the economic order quantity from a supplier whenever inventory levels for a particular part fall below a computer-maintained order point.

Within the standard material classification, items are classified as either select or nonselect materials. Select materials are items of relatively high value. These materials make up approximately 80 percent of the dollar value of materials used in car repairs and 20 percent of the physical inventory. Because of the relative value of these parts, a perpetual inventory is maintained at the individual stocking points, and each item remains in the perpetual inventory until applied. This determination of inventories at each material location allows inter-storehouse transfers--materials in short supply at one location can be transferred from locations where supplies exist. Select materials are charged out to the individual shop and the appropriate ICC account or function account at the time of issue from the storehouse.

Nonselect materials include items of lower value that are not expensive enough to justify extensive inventory control on an individual basis. Examples include screws, bolts, or pins. These components are generally ordered in bulk and are carried in inventory at distribution storehouses. They are charged out of inventory when transferreed to other material locations or received directly from vendors. Nonselect materials are charged out to the individual shop and the appropriate ICC account at the time of shipment from the distribution storehouse.

Material usage is not recorded by car number or car series. A carman requests a component on a charge-out ticket (see Exhibit V-2), often using the store's clerk to aid in the completion of the form.

The second major class of materials are termed nonstandard materials. They are usually specially designed or made to order for a particular application. These items are not charged out to the appropriate ICC account until the shop placing the order actually receives the component ordered. Inventory controls of nonstandard material are conducted without the use of a computerized inventory system.

For materials maintained in inventory, reaching the computer-maintained order point initiates the following sequence of events:

- The computer indicates that the order point has been reached.

- The order is placed with the proper vendor and entered into computer.

- The computer indicates that the material is on order.

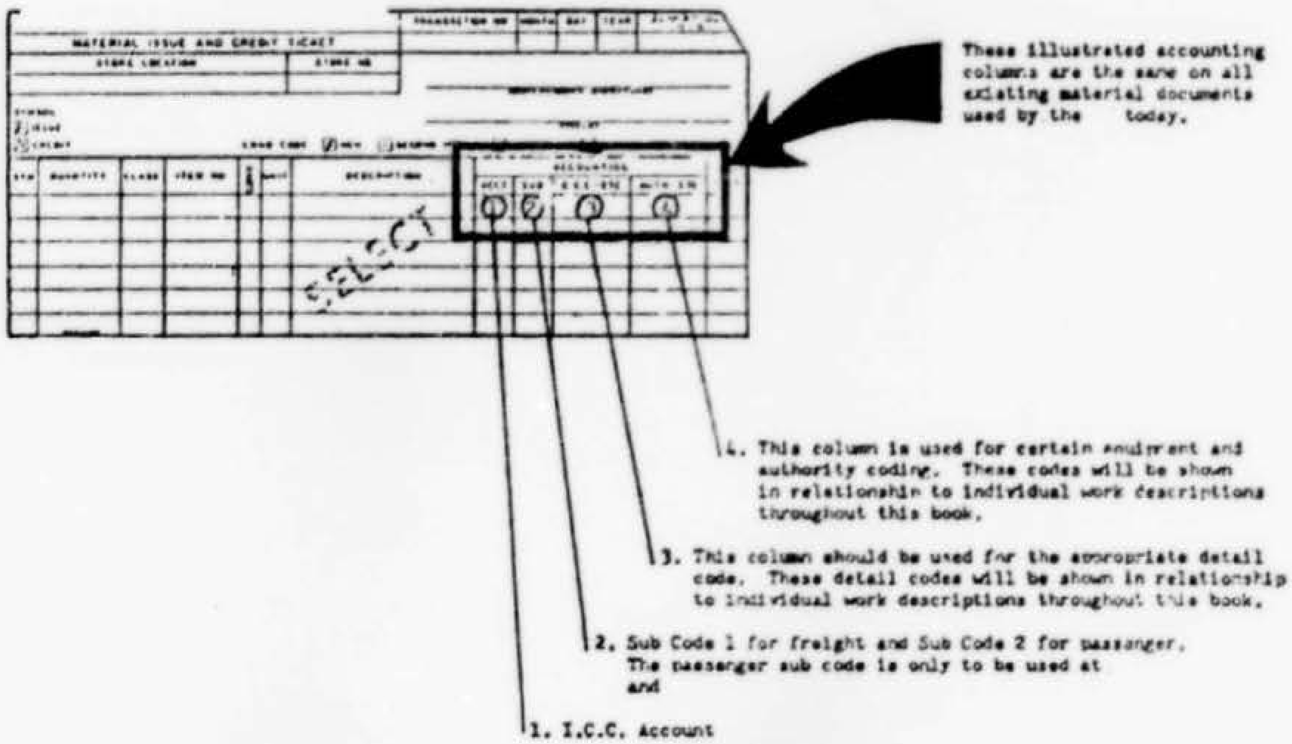
EXHIBIT V-2

MATERIAL DOCUMENTATION CODING – ALL DOCUMENTS

The four columns circled on the illustration below are known as the "Accounting" columns and are important as they are the key to identifying work performed. These columns indicate who is using the material (Locomotive, Car, etc.), the type of equipment and in many cases the number of an individual piece of equipment worked. These columns in some cases also indicate the proper authority to which the material is to be charged.

Throughout this book, you will find these columns to the right of each job description. The proper numbers to place in them will also be illustrated.

For information on how to fill out the remainder of this and all other material documents, refer to <u>The Field Instruction Manual for Material Reporting</u>, revised August 1, 1970.



V.S

- The material is received, and receipt is entered into the computer.
- The computer adjusts inventory levels, and the on-order condition is removed.
- An invoice is received from the vendor and is entered into the computer.
- The invoice is checked by the computer against the corresponding purchase order, and a receipt is recorded if everything checks.
- The computer prints a voucher.

The computer-maintained order varies for each item based on frequency of usage, cost, expected delivery date, and other factors.

Material usage is closely monitored in rebuilding programs. Before such a program is approved, labor and materials costs are estimated from a small sample of the cars to be rebuilt to establish a budget for the program. As materials are received at shops for use in the program (and costs are incurred), they are charged out to an account and function code assigned to the rebuild program. Labor hours are also charged to the function code.

VI. LABOR INCURRENCE

CONSTRAINTS TO VARYING CAR REPAIR SHOP LABOR HOURS IN RESPONSE TO CHANGES IN DEMAND

Investigation has shown that repair shop labor hours are not highly variable. In other words, the number of labor hours does not respond to changes in output volume in any consistent manner. This behavior is predictable in the short term, since a shop foreman cannot readily adjust his staff to minor variations in demand. Labor hours should, however, be responsive to long-term changes in output levels.

Estimates on cross-section data consisting of an average of time series observations for five study shops indicate that labor hours (and hence, costs) for these shops vary approximately 45 percent in the long run. Admittedly, these estimates are the results of analysis performed only to illustrate a methodology and cannot be relied upon with much confidence or extrapolated to other shops. The long long-run variability indicated does, however, suggest a failure on the part of car repair shops to adjust their labor force to fluctuations in demand, as measured by the number of cars processed. While this failure may not be of the magnitude implied by the 45 percent figure, there may be constraints to adjusting labor hours that adversely affect the railroad's ability to respond to fluctuations in demand.

Ultimately, decisions concerning repair shop staffing rest with upper railroad management. Nevertheless, management decisions are influenced by other factors. Constraints to the railroad's responsiveness may exist in one or more of the following areas:

- labor agreements and work rules;
- the nature of car repair work; and
- management policies.

These areas were investigated to determine whether constraints exist and to what extent they explain the railroad's behavior.

Labor agreements and work rules specify the amount of flexibility management has in hiring, laying off, transferring, or otherwise determining the size of the labor force in a particular shop. Some of these agreements are national in scope, while others apply only to individual shops. In most shops, positions from general foreman on down are subject to the labor agreements. In only one of the five shops are there noncontract supervisors. Although many crafts and unions are involved, carmen and laborers and their respective unions are the major organizations dealt with in the shops.

Agreements address most phases of employment, some in more detail than others. Hiring policies specify that the railroad must offer openings to furloughed employees before "going to the street." A new employee is required to pass a physical examination and the railroad has 30 to 60 days, depending on the agreement, to approve or reject the applicant. Once the application is approved, the employee (who must join the union within this same time frame) is automatically subject to the terms and provisions of existing labor agreements. Any employee whose application has been approved cannot be disciplined (including dismissal) without following formal investigation procedures. Furlough, mobility, and transfer issues are more complex, however, since they involve the question of protection or job security.

Protection had its beginning in 1936 with the Washington Agreement. This agreement ensures that employees are not placed in a worse employment position as a result of a railroad consolidation, merger, or other "coordination" between two or more carriers. In 1944 and 1952, the Oklahoma and New Orleans agreements, respectively, expanded protection to all qualified employees affected by an ICC approved transaction. Regular agreement provisions may apply to protected employees; the railroad must also comply with more stringent constraints when dealing with protected positions.

In the event that a reduction in force is indicated, conditions are specified for furloughing both nonprotected and protected employees. Nonprotected employees must be given 5 working days' notice for an indeterminate furlough. The agreements further stipulate that workers must be furloughed in reverse seniority order (from the bottom of the roster) and recalled in seniority order. Protected employees can only furloughed under certain conditions specified by national agreement. Five working days' notice is sufficient if certain negotiated "yardstick" conditions indicate that a reduction is in order. This condition is usually avoided, since the exact measure is difficult to negotiate. A second condition permits the railroad to furlough employees temporarily for the duration of an emergency. Furloughing employees to adjust for changes in demand is subject to a 5-day lag because of the notice requirement and may not be used at protected locations. It is not, however, otherwise restricted.

An employee's mobility can be affected by agreements in two ways, within a particular shop and between shops. Within a shop, the agreement (classification of work rule) and common practice determine what work belongs to each craft and, therefore, what jobs a particular employee may perform. There are, however, exceptions to this rule which give the railroad some latitude in staffing. If there is not enough work at any location for a particular craft job, a person of another craft can perform the work if he or she is capable. Another work rule (called the incidental work rule) further stipulates that a person can disconnect equipment and machinery (whose maintenance belongs to another craft) as long as he or she makes no repairs and the disconnection takes no longer than the repair work would. These rules combine to give the railroad flexibility in using employees of different crafts at all locations.

Employee mobility between locations is affected by agreement conditions pertaining to transfer. Agreements specify conditions under which employees can be transferred as follows:

. The employee must be given 90 days' notice (employees to be transferred are listed--junior people are transferred first).

. The employee must be given the choice of transferring or being severed.

. An employee with more seniority may transfer in place of the junior employee but may not choose severance instead.

In either situation (transfer or severance), the railroad must pay. If the worker decides to transfer, the railroad must "make whole" his or her costs involved in moving. If the worker decides to leave, he or she gets separation pay. Either way, it costs the railroad to transfer employees.

As previously discussed, the need for protection can arise from a merger or other "coordination" situation or from conditions such as abandonment of a point, as specified in a September 1974 agreement. In such a situation, an employee must transfer, with his or her work, or loose protection. The railroad must then "make whole" the employee for the move. Protection can last varying lengths of time, depending on the maximum specified by the agreement. Protection is prorated according to the length of service; some protection, however, applies as long as an employee maintains a relationship with the company. The protection agreement results in a disincentive to the railroad to get into the kind of situation to which protection might apply.

Overall, the work rules and agreements pose some restrictions on the railroad's ability to adjust its work force but do not prevent it from responding to changes in demand. Nonprotected employees can be furloughed with only 5 working days' notice and then rehired when demand increases. Provisions pertaining to protected employees are more stringent, but they merely provide a disincentive to the railroad in the short-term. In the long-term, the railroad can vary its work force in any way it wants for a certain cost.

The nature of car repair work is in itself a constraint which the railroad has less leeway to surmount. The railroad cannot control the number of cars or repairs at each shop other than by shifting program work or bringing cars out of storage to repair. Program or storage cars, however, usually require more work than most cars, which suggests that the number of cars processed may not be an accurate measure of output (although it may be a good measure of demand). Since the supply of cars to be repaired varies widely from day to day, variations in the work load cannot be predicted or dealt with unless there is a shift in traffic patterns. One other aspect of car repair work which affects staffing is the fact that carmen must be assigned to the transportation yard whenever a train comes in and, even if only one train comes in during an 8-hour shift, a crew must be employed for at least 6 hours (and usually 8) just for that train.

Since management has the ultimate responsibility for adjusting the work force, constraints within management must also be considered. The labor force may not be adjusted for small drops in demand, either as a hedge against the time when demand will pick up or because rejustifying a position creates a larger problem than employing an extra person for a short period of time. These possibilities, however, apply only in the short term, when demand can be expected to increase within a brief period. Short-term downturns in demand, coupled with labor restrictions, allow management to assign shop personnel to shop and equipment repair activities. This flexibility prevents employees from recording large periods of idle time. In the intermediate term, adjustment is accomplished by shifting work (program repairs and stored cars) when demand can be expected to increase after a while. It is only in the long term that the railroad really seems to adjust its work force to accommodate traffic shift or other major change.

In conclusion, the railroad appears to cope with changes in demand in different ways, depending on the time frame of the change. Labor agreements and work rules allow some flexibility but, in the case of protected employees (approximately 58 percent of the total), the penalties involved do not justify short-term action. In addition, the nature of car repair work does not aid identification and reaction to short-term fluctuations. Finally, management policies seem to encourage little adjustment in the short-term, although they cope well enough in the longer time frame. There seem to be few long-term constraints on the adjustment of work forces. This suggests that the 45 percent variability is low, perhaps because there were no major demand changes at the shops during the study period. A more comprehensive analysis (encompassing more shops and a time frame longer than 9 months would include some major shifts) might result in a higher indication of variability.

THE VARIABILITY OF SHOP HOURS WITH NUMBER OF CARS OUTPUT

Regression analysis is used to measure the response of cost to output and to attribute cost to different causes. The objective of this subsection is to illustrate a methodology for determining the long-run variability of labor expenditures with the output of shops.

Data Base

The data base for this example analysis consists of the records of the same five railroad repair shops over a 7-month period. The data on number of cars output, actual labor dollars, actual labor hours, and summary statistics are provided in Appendix A.

The average wage rate may vary from one location to the next. To isolate this factor, this analysis measures expenditure by the actual labor hours rather than labor dollars. In this way, the true expenditure of shops is more comparable. The actual labor hours are related to the number of cars processed by the shop. For this analysis, the number of cars processed is considered the relevant measure of shop output.

The individual time series data for each shop reflect the short-term variation of expenditure with output. As anticipated, the labor hours are not highly variable and do not respond to minor changes in output in a consistent manner. The short-term percent variable is apparently low, since the shop manager cannot adjust his staff to minor fluctuations in demand.

In contrast, the expenditures should respond to long-term changes in output levels. Long-run costs are estimated from cross-section data on a number of shops. The data consist of an average of time series observations for each shop. This is an essential technique to avoid the effects of the "regression fallacy," a potentially serious bias which can be caused by costs incurred in one period being entered into accounts in another. The regression fallacy also arises because some shops are processing more cars than planned, whereas others are processing fewer than planned. If time averages are not taken, estimated relations between labor hours and output may produce a smaller slope than either short-run or long-run cost.

Exhibit VI-1 summarizes the time-averaged cross-section data for this analysis. Shop D has a greater expenditure of labor hours per car. Consequently, this "outlier" must be excluded from the subsequent statistical analysis.

Derivation of Cost Formulae

The small number of valid data points restricts the analysis to the most simple formulae. Any hypothesis on the relation between expenditure and output must be evaluated on the basis of:

- the underlying assumptions of the hypothetical formula;
- the statistical significance of the regression results; and
- the implications of the results for the estimated variability of expenditure with output.

This subsection concerns the first of these criteria. The second and third criteria are addressed in the following subsections.

The most simple assumption regarding the response of expenditure to output is that there is a constant change in labor hours per unit of increased output, regardless of the existing level of output. This hypothesis translates into the linear case:

$$\text{Labor hours} = a + b \text{ (number of cars)}$$

or

$$Y = a + bX$$

In the linear case, the percent variable, or elasticity, is computed:

$$\frac{dY}{dX}\frac{X}{Y} = \frac{bX}{a+bX}$$

Typically, this means that percent variable increases as output increases.

EXHIBIT VI-1

TIME-AVERAGED CROSS-SECTION DATA FOR SHOPS

SHOP	AVERAGE NO. OF CARS PER MONTH	AVERAGE ACTUAL LABOR HOURS PER MONTH	AVERAGE LABOR HOURS PER CAR
A	524	3,079	5.9
B	1,186	6,684	5.6
C	801	3,624	4.5
D	431	31,135	72.2
E	1,482	3,988	2.7

Another simple assumption is that a percentage change in car output yields a percentage change in labor hours expenditure. Mathematically,

$$\frac{\text{Percentage change in expenditure}}{\text{Percentage change in output}} = \frac{\frac{dY}{Y}}{\frac{dX}{X}}$$

$$= \frac{dY}{dX}\frac{X}{Y}$$

$$= \text{Elasticity (percent variable)}$$

Thus, this assumption implies constant elasticity or percent variable. The assumption translates into the geometric case:

$$\text{Labor hours} = a\ (\text{number of cars})^b$$

or

$$Y = a\ X^b$$

This function can be estimated in a linear regression by the transformation:

$$\log Y = \log a + b \log X$$

Both the linear and geometric forms are considered in this analysis.

Regression Results

This subsection presents the results of regression tests for the linear and geometric cases. As indicated, a greater number of shops is required to provide confidence in these estimates.

Exhibit VI-2 plots the five shops by labor hours versus number of cars output. Excluding Shop D, the least-squares line obtained is:

$$\text{Labor hours} = 2,454 + 1.893\ (\text{number of cars})$$

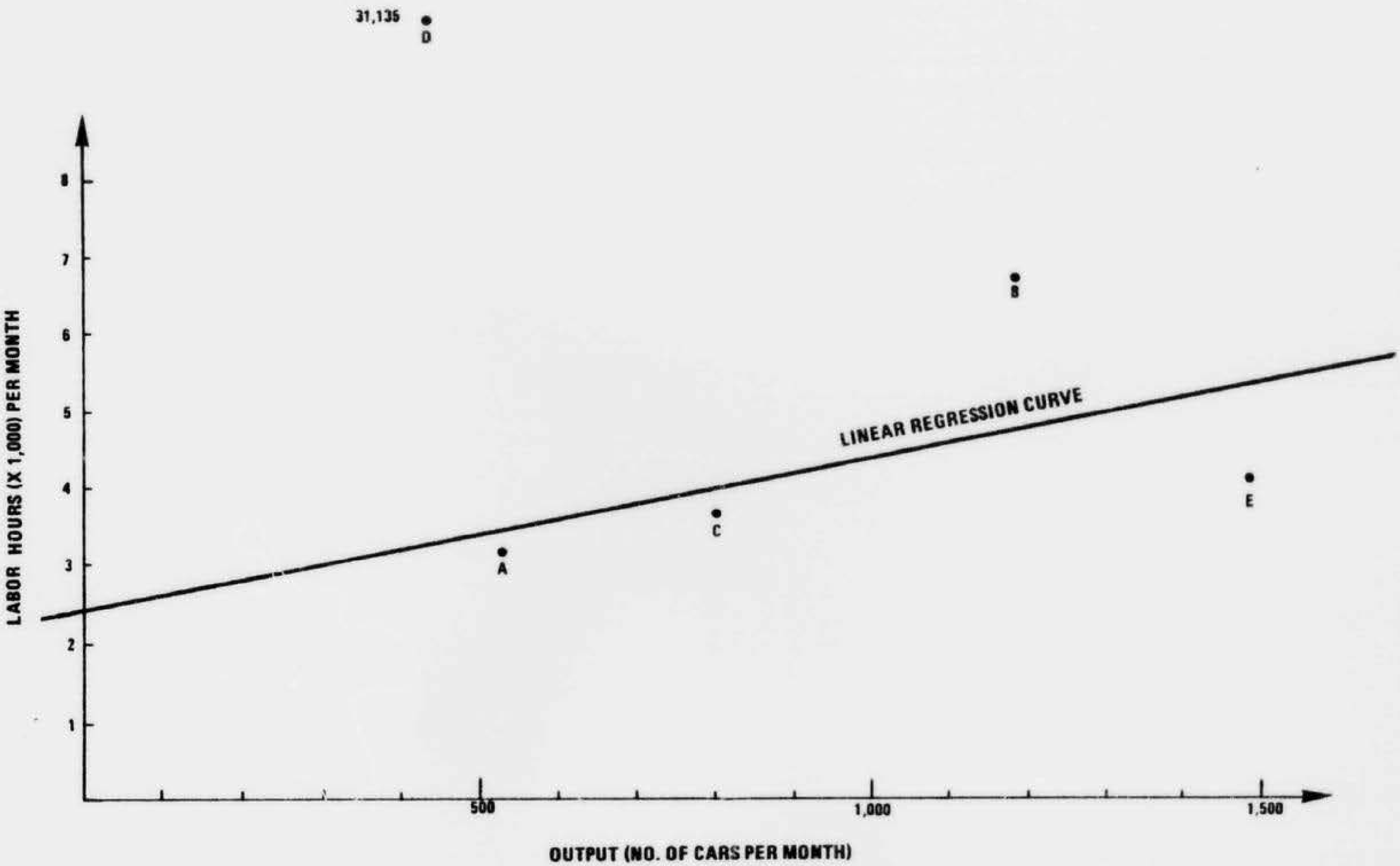
or

$$Y = 2,454 + 1.893\ X$$

which is drawn on the scatter plot.

EXHIBIT VI-2

SCATTER PLOT AND BEST-FIT LINE:
LABOR HOURS VERSUS CARS OUTPUT



If Shop D is included in the regression, the line obtained is:

$$\text{Labor hours} = 22,181 - 14.1 \text{ (number of cars)}$$

or

$$Y = 22,181 - 14.1 X$$

The dramatic change in the slope and intercept of the line indicates the instability of the results with a small number of shops. Thus, Shop D is excluded from this analysis (Shop D is a heavy repair shop with a different mix of capital and labor than the other four shops).

Exhibit VI-3 displays the scatter plot of Exhibit VI-2 with the best-fit geometric curve obtained by regression. Shop D is excluded from this analysis also. The regression obtained the relation:

$$\text{Labor hours} = 179.1 \text{ (number of cars)}^{0.420}$$

or

$$Y = 179.1 X^{0.420}$$

Comparing Exhibits VI-2 and VI-3, it is apparent that the two curves are very similar in the range of output for the four shops. Exhibit VI-4 quantifies the comparison with a tabulation of residuals and R^2 measures. In summary, linear and geometric regression explained 25 and 28 percent, respectively, of the observed variance in labor hours. The remaining unexplained variance is attributed to differences among shops or variables not included in the equation.

Variability of Shop Hours

Both of the derived relations between labor hours and cars output can be interpreted by establishing the respective elasticities or percent variable. Exhibit VI-5 is a comparative plot of percent variable versus output for the geometric and the linear hypotheses.

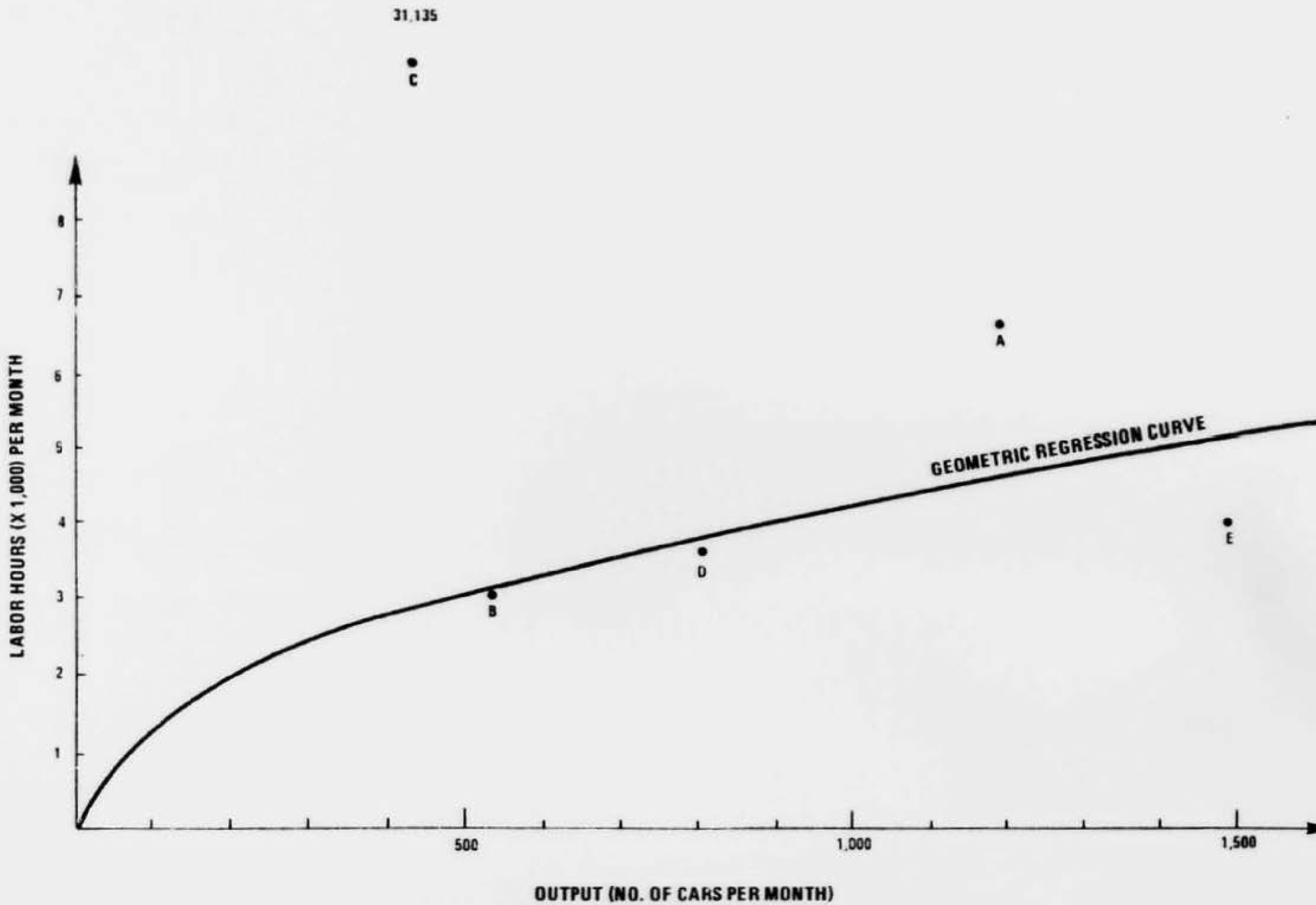
In the linear case, the percent variable is computed:

$$\frac{1.893 X}{2.454 + 1.893 X}$$

As indicated in the upper graph of Exhibit VII-5, variability increases with output. At an average output level of 1,000 cars per month, labor hours are 44 percent variable.

EXHIBIT VI-3

SCATTER PLOT AND BEST-FIT GEOMETRIC CURVE:
LABOR HOURS VERSUS CARS OUTPUT



VI.11

EXHIBIT VI-4

COMPARISON OF LINEAR AND GEMOETRIC RELATIONS

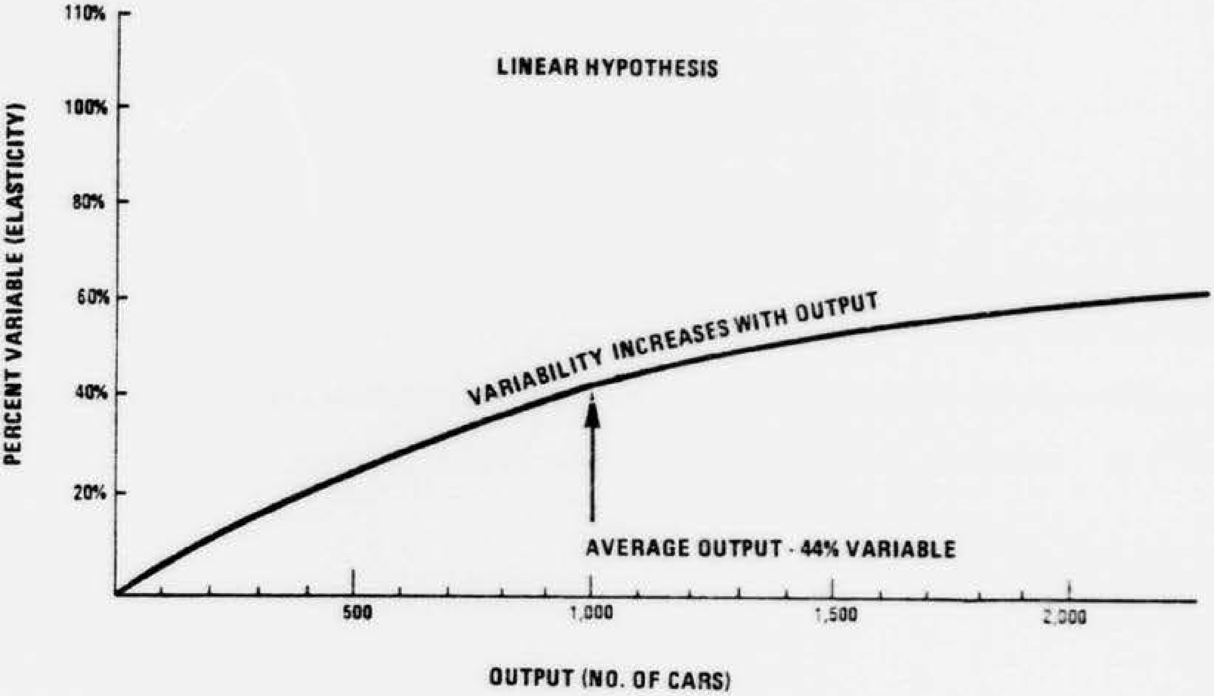
SHOP	ACTUAL HOURS	LINEAR			GEOMETRIC		
		PREDICTED HOURS	RESIDUAL	SQUARED ERROR	PREDICTED HOURS	RESIDUAL	SQUARED ERROR
A	3,079	3,446	−367	134,689	3,191	−112	12,544
B	6,684	4,699	+1,985	3,940,225	4,647	2,037	4,149,369
C	3,624	3,970	−346	119,716	3,879	−255	65,025
D	31,135	–	–	–	–	–	–
E	3,988	5,259	−1,271	1,615,441	5,148	−1,160	1,345,600

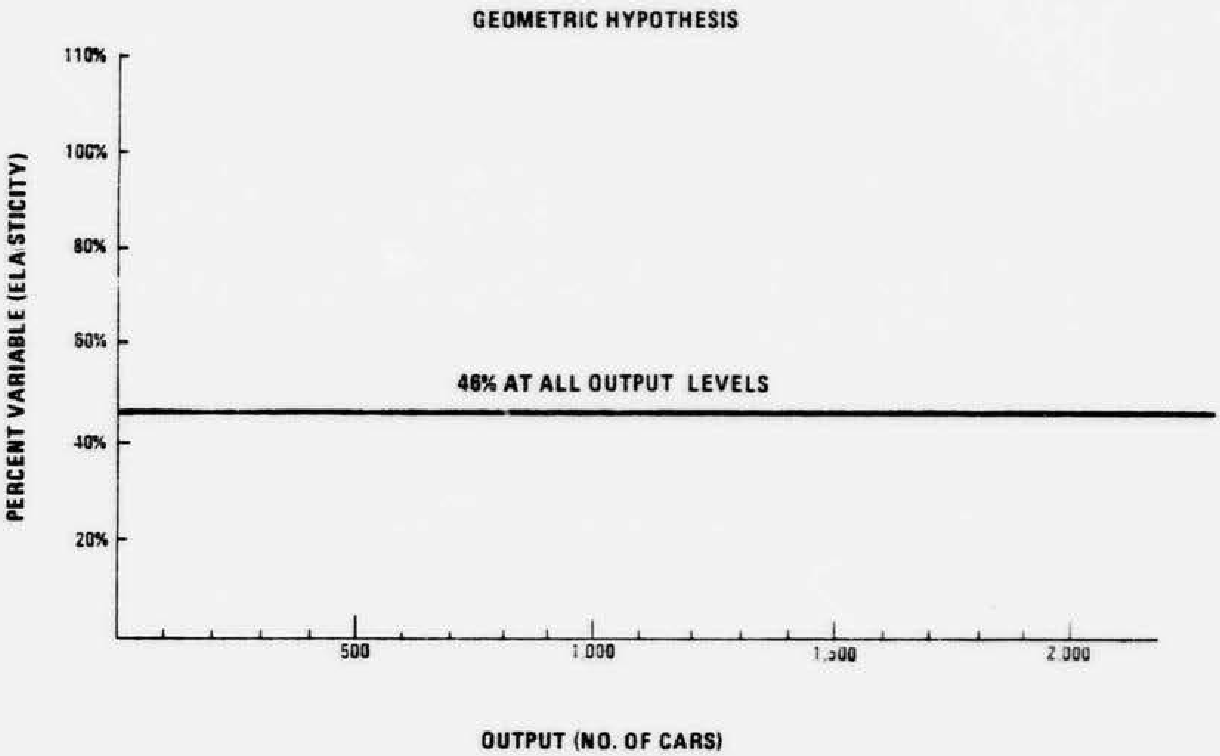
SUMMARY:

	Linear	Geometric
Standard Error	1,205 hours	1,180 hours
Correlation	.50	.53
R^2	25%	28%

EXHIBIT VI-5

GRAPHICAL COMPARISON OF PERCENT VARIABLE (ELASTICITY) FOR LINEAR AND GEOMETRIC HYPOTHESES





In the geometric case, the estimated elasticity, or percent variable, is 46 percent, regardless of the output level. This is depicted in the lower graph of Exhibit VI-5

Conclusion

The estimated variability for the shops in this analysis is tabulated in Exhibit VI-6. The linear hypothesis and the geometric hypothesis yield fairly comparable results for the long-run variability of shop hours.

This analysis was performed only to illustrate the use of regression analysis to derive long-run variability. The specific results from this limited sample cannot be extrapolated to other shops. With a broader cross-section of shops, the methodology outlined may provide an estimate of the long-run variability of s?.n hours with number of cars output.

EXHIBIT VI-6

TABULATED COMPARISON OF ESTIMATED VARIABILITY FOR LINEAR AND GEOMETRIC HYPOTHESES

SHOP	PERCENT VARIABLE (ELASTICITY)	
	LINEAR	GEOMETRIC
A	29%	48%
B	48%	48%
C	38%	48%
D	–	–
E	53%	48%

VII. MATERIAL INCURRENCE

MATERIAL USE AND BILLING

The AAR annually publishes rules pertaining to the maintenance and repair of freight cars used in interchange service. The AAR Interchange Rules address both the performance and billing of repairs and deal specifically with material use. Material requirements for particular repairs; specification for the reclamation, reconditioning, and reuse of materials; the dollar amount to be billed for certain materials; and the penalty to be assessed if the wrong material is used are all specified by the rules. Compliance and/or deviation from any of these rules is monitored through the CRB system.

A railroad making a repair to a foreign car is required to record (in addition to general information about the repair) the following information applicable to the use and billing of materials:

- condition code - indicates new, secondhand, etc.;
- job code applied - indicates type of material(s) and/or repair work applied to the car;
- qualifier - indicates the type and/or manufacturer of the component;
- why made code - indicates the reason a repair was necessary;
- job code removed - indicates type of material(s) and/or repair work removed from the car;
- qualifier - same as for job code applied; and
- responsibility code - indicates the responsibility for repairs made (owner, handling line, etc.).

This information forms the basis on which it can be determined whether "correct" repairs were performed. Correct repairs are specified in the AAR Field Manual of Interchange Rules mainly in terms of what type(s) components can be applied to replace the type removed and what substitutions are acceptable.

In addition to specifying what type of materials may be used, the Interchange Rules also specify their condition. The condition code on the repair record indicates basically five allowable conditions for materials applied during the repair process:

- use new material;
- use secondhand material;
- use reconditioned material;
- use owner's material; and
- remove, repair, and replace the same part.

Allowable conditions for each category of repair are exhibited in Exhibit VII-1. The Interchange Rules allow some choice in making most repairs. However, there are several rules permitting only new material to be applied.

New material is usually purchased either from a manufacturer or a distributor, but it can also be fabricated by the railroad. Railroads may have several reasons for manufacturing or fabricating materials: the most common are the use of existing facilities or investments (such as a foundry); cost effectiveness (some components may be fabricated less expensively than they can be bought); or the unavailability of manufactured parts. The most commonly fabricated items are safety appliances (such as hand holds and ladders), although other materials can be just as routinely fabricated by a railroad.

Secondhand material is obtained mainly from scrapped cars. When a car is sent to a scrap dealer, a railroad may mark particular components which it wants returned when the car is disassembled. Scrap dealers also salvage and sell other usable components to railroads when they cut up a car. Secondhand materials are also occasionally obtained from "cannibalized" cars, when other sources are unavailable.

Reconditioned material is that which has been removed from a car and repaired or rebuilt by either the railroad or manufacturer. One example would be AB valves removed from one car for periodic maintenance and later replaced in another. This differs from the fourth category above in that the latter is replaced in the same car from which it was removed.

Owner's material may be in any of the above conditions except the last. Owner's material is used only when a repair requires an unusual or atypical material which the repairing road does not stock. When this occurs, the owner is contacted by the repairing road and requested to send the material needed to complete the repair. The material might be new, secondhand, or reconditioned but that need not be noted on the repair record. Since there is

EXHIBIT VII-1

ALLOWABLE MATERIAL CONDITIONS FROM 1977 AAR FIELD MANUAL OF INTERCHANGE RULES

RULE NO.	NAME OR DESCRIPTION	NEW	SECONDHAND	RE-CONDITIONED	OWNERS MATERIAL	REPAIR AND REPLACE SAME PART
2	Air Brake – Periodic Attention COT&S	X				
3	IDT&S					
4	Air Brakes and Parts	X	X	X	X	
5	Air Brake Hose	X	X			
6	Brake Beams	X	X	X		
7	Brake Beam Hangars	X	X			
8	Brake Beam Hangars Brackets	X				
9	Brake Connection Pins, Hangar Pins or Bolts 1792	X	X			
10	Brake Beam and Bottom Rod Supports	X	X			
11	Brake Levers, Guides, – Connection Rods	X	X			X
12	Brake Shoes and Keys	X	X			
13	Hand Brakes – Geared and Non-Geared	X	X	X	X	X
16	Couplers, Type E and Parts	X	X	X	X	X
17	Couplers Type E/f and Parts	X	X	X	X	X
18	Couplers, Type f and Parts	X	X	X	X	
19	Yokes – Type E	X	X	X	X	
20	Yokes – Type E/f & f	X	X	X	X	
21	Draft Gears, Carriers and Followers	X	X	X	X	
24	Lubricators	X				
25	Periodic Lube of Plan Bearing Boxes					
26	Periodic Lube Roller Bearings					
27	Periodic Lube and Inspection of Trainer Hatches					
30	Journal Bearings	X				
31	Journal Bearing Wedges	X	X			
32	Journal Stops	X				

EXHIBIT VII-1 (Continued)

RULE NO.	NAME OR DESCRIPTION	NEW	SECONDHAND	RE-CONDITIONED	OWNERS MATERIAL	REPAIR AND REPLACE SAME PART
33	Journal Box Lids, Seals and Repair Seals	X				
36	Roller Bearings	X	X	X	X	
37	Roller Bearing Adapters and Frame Keys	X	X			
41	Wheels	X	X	X	X	
42	Axles – JRNL	X	X			
43	Axles – Roller	X	X		X	
47	Truck Bolsters	X	X		X	X
48	Truck Side Frames and Separable JRNL Boxes	X	X		X	X
49	Truck Side Planks	X	X		X	X
50	Truck Springs	X	X		X	
53	Metal	X	X		X	X
54	Wood	X				
57	Center Sills					
58	Side Sills					
59	Cushioned Underframe Devices					
65	Trailer Hitch Parts	X	X		X	
66	TOFC Bridge Parts	X	X		X	X
67	Misc. Instructions					
68	Refrigeration Equipment					
69	Misc. Material	X	X		X	
70	Lightweighting and Stenciling					
71	Cardboards and Receptacles	X				
72	Manufactured Material	X	X	X	X	
73	ACI	X				

EXHIBIT VII-1 (Continued)

RULE NO.	NAME OR DESCRIPTION	NEW	SECONDHAND	RE-CONDITIONED	OWNERS MATERIAL	REPAIR AND REPLACE SAME PART
74	Securement	X				
75	Misc. Labor	X				
76	Straightening and/or Forge Welding Parts Off Car					X
77	Door and Door Parts	X	X			
78	Lumber	X				
79	Ladders, Ladder Treads, Handholds and Sill Steps	X				X
80	Painting and Stenciling	X				
81	Tank and Tank Car Repairs	X				

often some delay in transporting the material from owner to the repair shop (anywhere from 2 days to a month), a car awaiting owner's material will be put on per diem relief.

The decision to use one rather than another condition of material is usually based on considerations of convenience, availability, cost, and, of course, compliance with the AAR Interchange Rules. To what extent these considerations (particularly cost) affect a decision depends on the information available to the railroad.

Convenience is primarily a consideration in the "repair versus replace" situation. When there is a backlog of cars at a shop, the decision may be made simply to remove a defective part and replace it, rather than repair and replace it, unless there are no replacement parts available. Not only does this save time when the repair is being made; the carmen can also return and repair the component when time permits.

As mentioned, the availability of a replacement part plays a role in repair versus replace, as well as in new versus secondhand versus reconditioned decisions. A car shop may prefer to use secondhand materials for a particular repair, but none may be available from the scrap dealer. Similarly, although reconditioned components might be preferred, it may be impossible to obtain them when needed. Although availability is often beyond the control of a railroad, it is also a matter of efficient inventory control.

Cost is perhaps the greatest single consideration when a railroad can make an informed decision on this basis. For the sake of billing, material prices are determined by an AAR committee and consist of an average of the prices paid by a variety of railroads. This method of pricing means that some railroads are going to be able to buy certain materials for less than the billing price (make money); others will have to pay more (lose money). The variance from the average may be quite different, depending on the condition of the material applied. For example, a railroad may make money on new couplers, break even on secondhand couplers, and lose money on reconditioned couplers. At the same time, it may lose money on new yokes and make money on both secondhand and reconditioned yokes. The variance may depend not only on component type, but also on fluctuations in prices. A railroad which knows how its costs differ from the AAR price will base material decisions on cost criteria whenever possible, using the materials with which it makes the most (or loses the least).

The fourth criterion mentioned was compliance with AAR Interchange Rules. This actually becomes a question of cost when the AAR billing procedures are considered. The computer program which verifies, prices, and bills repair records follows a complicated edit routine to determine whether a correct repair was made before pricing and billing the repair. If an error in the repair is detected, a penalty is assessed against the repairing road for making a wrong repair.

While there are about 600 AAR job codes, there are more than 6,000 "couplets," possible pairs of job codes applied and job codes removed. When the computer gets a repair record, it compares the job code applied/job code removed pair to the 6,000 couplets stored in its memory. If it cannot match the couplet, it assumes a wrong repair was made and assesses the penalty. If it finds the couplet, it checks further to determine whether the why made code, qualifiers, responsibility codes, and condition codes are correct. An error will trigger either an assessment of the penalty or an error message which allows the railroad to input a corrected record.

The use of different materials varies from railroad to railroad and within a single railroad over time. This makes it impossible to know what kind of materials will generally be used for a particular repair or cost-specific repairs with a single price. Furthermore, because of the vast number of possible materials (6,000 couplets plus iterations to include the various condition codes, qualifiers, responsibility codes, and why made codes), a standard bill of materials for a particular repair type would not be practical.

MATERIAL ACCOUNTING

Material accounting can be divided into two parts as follows:

- Determining the cost of materials acquired. This determination raises numerous issues. Should gross invoice price, net invoice price, or price actually paid be regarded as the basic cost of acquired materials? How should "freight-in" be added to the cost of materials? Should acquisition costs (purchasing and handling costs) be added to the basic cost? What accounting treatment should be accorded storage costs?

- Determining the part of material cost to be transferred to repairs in process. The cost of materials not transferred will be presented in the current asset section of the railroad's balance sheet. Cost of materials destroyed or damaged by forces not inherent in the repair process should be treated as an expense in the statement of repair costs.

The methods for determining the portion of material to be transferred to repairs accounts are: first-in, first-out; last-in, first-out; moving average; standard cost; and specific cost.

First-In, First-Out

The first-in, first-out method (FIFO) assumes that items first received are the first to be issued and that requisitions are priced at the cost at which these items were placed in stock.

Last-In, First-Out

This method of pricing requisitions assumes that the last items purchased are the first to be used, the balance on hand being priced at the cost of the earliest purchase.

Moving Average

This method, called the weighted average or running average method by some accountants, is used by those concerns desiring to spread total costs evenly over all goods on hand. To calculate the moving average unit cost, the procedure is as follows:

- Add total quantity received to total quantity on hand.
- Add cost of materials received to cost of those on hand.
- Divide total values by total quantities.

Average unit cost is used in pricing requisitions and balances on hand until new purchases are received, when it is necessary to calculate a new average unit cost.

Standard Cost

Under this method, materials are priced at a predetermined or standard cost. The accounting procedure for materials under a standard cost system depends upon which of the following methods is used:

- materials are kept at actual costs on stores cards and priced into the process at standard; or
- materials are kept at standard cost on stores cards and priced into the process at standard.

If stores ledger accounts are to be kept on an actual cost basis and requisitions are priced at standard, the stores ledger clerk keeps his records in the usual manner, but the cost clerk uses the standard prices to charge to production, with the difference between actual and standard cost being handled through a material variance account.

When standard costs are used from the point of receipt on through production, the accounting procedure for the receipt and issue of materials is greatly simplified. Under this method, only quantities of receipts and issues need be recorded on stores cards. When materials and supplies are received, the stores control account is charged at standard cost, the difference between actual and standard being charged or credited to a material price variance account. At the same time, the quantity received is entered on the proper stores card in the received and balance sections and the standard unit price is noted at the top of the ledger card. When requisitions are made, entries for quantities only are placed in the issued sections and deducted in the balance sections of the appropriate stores card. The standard cost of materials to be used on each job may be recorded on a cost sheet in advance. It is necessary for the cost clerk to occasionally determine the variance in quantity used, but this is handled through a material use variance account.

Specific Cost

Under this method, purchases made for particular repairs or programs are kept separate in the storeroom and stores cards are made out for the specific purchases. When materials are charged to a program or repair, requisitions are priced at the exact cost recorded on the stores cards. This system is employed effectively when nonstandardized units have to be purchased to meet a railroad's specifications.

ADJUSTMENT OF ACCOUNTS

It is important that unused materials be given appropriate account recognition. The costs of the unused materials, having been included among those costs charged to specified repairs or programs, are included in the total cost of materials transferred from the materials control account to the repairs-in-process account in the subsidiary ledger. Since these materials were not needed on the job or a repair order indicated on the stores requisition, it is appropriate that their related costs be removed from the repairs-in-process account and returned to the materials control account.

To serve as the basis for these accounting entries, a returned materials report is usually prepared.

Supplies Used

As a general rule, there is a definite distinction between materials purchased for repair and those purchased for supplies. These two groups are often segregated. In such cases, control accounts are established in the subsidiary ledger for materials or stores to record direct materials. Indirect materials or supplies are recorded in a supplies control account. Withdrawal of direct materials is distinguished from withdrawal of indirect materials by using requisition forms in different colors.

Scrap

Some accountants (as well as nonaccountants) use the terms "scrap," "spoilage," "waste," and "by-products" interchangeably. These terms describe the materials that result from repair activities. They are similar in that they are incidental to the achievement of the basic objective of repairing cars; they appear as the inevitable consequences of operations. They are also similar in that they ordinarily have little value in comparison to the major products.

In accounting for scrap, sound theory would indicate that the value assigned to it should be its "cost." If the scrap under consideration has a stable value in the scrap market, this may be used as the basis for making a scrap inventory, thus reducing the cost of repair components. Following this line of thought, the cost of scrap to be entered in the scrap inventory and removed from the repairs-in-process account or finished goods should be determined by subtracting the expected market value of the scrap.

In job-lot cost accounting, the materials-in-process account may serve as a control account, supported by cost summary sheets for jobs or production orders in process. Under these circumstances, the detail of the credit in the foregoing entry must be posted to the individual cost summary sheets.

If the value of scrap products is significant and if the quantity varies from job to job, it may be desirable to identify the scrap produced by each job and reduce the material cost of each job by the sales value of related scrap products. Only in rare cases, however, does this procedure appear to be justified. If several program orders are in process at a given time (each producing similar or nearly identical types of scrap), it might be difficult and costly to relate the value of scrap products with the individual program orders. Under these conditions, the value of the scrap may be regarded as a reduction in the cost of all repair orders.

VIII. OVERHEAD INCURRENCE

Overhead includes all repair-associated costs except direct labor and direct material. It is thus composed of all repair costs which cannot be traced to specific units repaired. For this study, overhead costs were divided into the three following groups:

- Indirect Labor - labor which is not identifiable with a specific repair but which performs a service associated with the repair facility operations. The following indirect labor costs were considered in this study:

  - Direct Supervision - car foreman and assistant, mechanical foreman, and gang leaders who are directly involved in repair of cars.

  - General Supervision - master mechanic, regional mechanical officer, general foremen, and supporting office force.

  - All Other Labor - laborers, machine operators, inspectors, maintenance crews (janitors), and write-up men.

- Indirect Material and Shop Supplies - includes the cost of material and supplies which cannot be charged to a specific unit repaired. The following indirect material and shop supplies were included in this study:

  - lubricants;

  - fasteners;

  - welding supplies and gases;

  - small tools; and

  - fuel and lubricants for facility-assigned vehicles.

- Shop Operations - items that keep the shop in working order and support repair shop operations. The following shop operations were included in this study:

  - water and sewage;

- electricity;
- telephone;
- equipment rent;
- fuel and lubricants for highway vehicles;
- power plant (if applicable);
- shop switching;
- stationery and printing;
- shops and support building;
- machinery (including power plant);
- track;
- assigned shop and highway vehicles;
- depreciation and taxes on applicable property and equipment;
- interest on land and building;
- machinery and track;
- liability and property damage; and
- computer and personnel allocation.

TREATMENT OF OVERHEAD ITEMS

The method selected by participating railroads for handling overhead items or components may vary due to individual preferences. These methods are discussed below.

Building Repairs and Maintenance

Building repairs and maintenance cost are accounted for in one of two ways:

- Actual costs incurred for repairs and maintenance each month are charged to a building repairs and maintenance cost account which is allocated at the end of each month.
- A maintenance reserve or allowance account is used.

Under both plans, the departmental distribution of repairs and maintenance cost is often based upon the area occupied by each department in the building, expressed as a percentage of total area.

Depreciation, Insurance, and Taxes

These costs are collected from records under the control of the following general ledger accounts:

- accumulated depreciation;
- prepaid insurance; and
- prepaid or accrued taxes.

Fixed charges resulting from the above accounts are analyzed and charged under the proper cost classification. Ledgers for property and plant, insurance, and taxes are maintained in valuation accounting. These records can be used to provide a detailed analysis of the fixed charges for each period.

Building Depreciation Cost

A property ledger is used to classify shop investment land, buildings, and equipment. This record should show location and cost, with accumulated depreciation. The allocation of building depreciation to departments is based upon three factors:

- cost of the building;
- total area of the building; and
- area occupied by each department in the building.

The cost of the building is obtained from a building and equipment ledger. The total area of each building (and also the area of each department within a given building) is obtained from an AFE or shop layout showing distribution of floor space. From this information, a worksheet analysis of depreciation can be prepared. This analysis provides the total depreciation charge for each building and the allocation, where necessary, to departments within each building.

Depreciation of Machinery and Equipment

Distribution of depreciation on shop machinery and equipment is made to the different departments based upon:

- cost of the equipment;
- rate of depreciation; and
- location of the machinery.

This information is provided by the equipment ledger. A worksheet analysis provides the information for the departmental expense distribution.

Insurance

Insurance cost consists of several types of coverage against losses. The insurance register is used to obtain coverages for equipment and facilities. This cost is charged on the basis of the insurable value of these items in each department.

Insurance cost should be collected with all other costs, to be prorated on a floor-space basis and distributed to all departments.

Workmen's Compensation Insurance

Workmen's Compensation and liability insurance cost should be accrued monthly. Distribution of Workmen's Compensation is based upon total shop labor, which includes both direct and indirect labor.

Insurance on Machinery and Equipment

Distribution of the cost of insurance on machinery and equipment is based upon the following factors:

- premium cost; and
- machinery and equipment cost.

The monthly insurance premium cost on machinery is obtained from the insurance register. The cost of machinery and equipment is obtained from the fixed asset ledger sheets.

Building Insurance

The basis for allocating building insurance cost is obtained from:

- premium cost;
- total area of the building; and
- area occupied by each department in the building.

The monthly premium cost is obtained from the insurance register. The distribution is similar to that for depreciation on buildings.

Real and Personal Taxes

Taxes on buildings are segregated from those on personal property. Any special taxes levied by county authorities, such as automobile taxes, are charged as site-specific.

Taxes on personal property should be allocated departmentally on the basis of the taxable values in each department.

Taxes on machinery and equipment should be charged to the individual departments, according to the valuation percentage of machinery and equipment in each department.

The taxes on materials and stores should be charged to the stores department.

Building Taxes

The distribution of building taxes is based on the area occupied by each department in a building, although other bases are possible. Where real property taxes are prepaid, the amount applicable to a given year is available from a Prepaid Property Taxes account. If property taxes are due sometime after the beginning of the fiscal year, the amount of taxes applicable to the fiscal year must be estimated. If land taxes are assessed separately from building taxes, it is necessary to prorate those taxes applicable to shop buildings in proportion to the area occupied by the buildings. Distribution of building taxes is similar to the computations made for other costs handled on an area basis.

Railroad Retirement

Distribution of this cost item can be computed in the same manner as Workmen's Compensation. The payroll tax rates applicable for a given year are multiplied by the departmental labor distribution totals in order to arrive at the allocation of departmental cost for Railroad Retirement.

Shop Office Supplies

There are two ways to account for this item:

- All purchases of office supplies may be charged to an inventory account when purchased. When supplies are needed, they are requisitioned and charged to the requisitioning shop.

- All purchases of office supplies are charged as a cost directly to the shop for which the purchase was made.

Shop Supplies and Indirect Materials

These include the cost of all materials and supplies that are applied directly to the equipment repaired account. The primary cost distribution of supplies is made on the basis of an analysis and a summary of the store's requisitions that show the shops to which the supplies were charged.

Fuel Cost

The purchase of fuel may be accounted for by charging the cost either to an inventory account or directly to a cost account. Under the former plan, allocation of fuel cost to departments is based upon the quantities consumed by each department using fuel. Quantities used are measured or estimated. Where fuel is charged to cost at time of purchase, the departmental allocation is indicated on the purchase voucher.

General Shop Cost

Most costs can be identified with a functional division or department. Regardless of how finely a shop is departmentalized, however, there are costs that are general to all departments of a shop. In order to collect these costs, a department or cost-center account entitled General Shop Cost or Factory Service is used. General shop costs are distributed on the basis of departmental use of nonproduction supplies.

Scrap Disposal

The cost of disposing of scrap may be charged either directly to the department producing the scrap or to Building Occupancy or General Shop Cost.

Indirect Labor

In the broadest sense, indirect labor refers to labor cost that cannot be specifically or directly associated with jobs or products. The distribution of indirect labor cost is obtained from an indirect labor or payroll distribution sheet. Indirect labor not specifically identified is distributed on total labor dollars directly allocated.

Interest on Investment

Whether imputed or implicit interest on investment should be considered a cost of repair is an unsettled question. If such interest is to be included, the charge for interest on building investment would be prorated on the basis of space occupancy, and the charge for interest on investment in machinery and equipment would be prorated on the basis of the location of these assets.

Utilities (Electricity, Gas)

The cost of utilities can be prorated on the basis of meter records of consumption or, lacking meters, on the basis of capacity of equipment and facilities. If a record of the use of equipment is not maintained, the distribution may be performed solely on the basis of the capacity of the equipment and shop. In some cases, using portable meters in each facility for limited periods is an economical method of obtaining an equitable basis for prorating utility costs.

Small Tools

One of three methods can be used to allocate the cost of small tools. At the time of purchase, such tools may be: (1) capitalized in a Small Tools account, (2) charged to Stores, or (3) charged to expense.

Capitalization Method

All purchases of small tools can be capitalized in a Small Tools account, which is considered a fixed asset. Depreciation is applied to establish the monthly and annual amounts to charge off as expense. It is difficult to administer this method properly because of the variation in (and the uncertainty of) the service life of many different small tools. Under this method, the monthly allocation of small tools cost is similar to that used for depreciation of machinery and equipment.

Charging to Stores

All small tool purchases can be charged to stores inventory. As tools are needed, they are requisitioned and charged to the proper department. Analysis of the requisitions provides a means of allocating the cost to departments.

Charging to Expense

Small tool purchases can be charged to expense at the time of purchase. This method is popular because of its simplicity. Analysis is made of all purchase vouchers which indicate a charge to the account for small tools, in order to allocate the charges to the several facilities.

Telephone

If a record of telephone calls by facility is kept, telephone cost can be distributed with considerable accuracy. In many cases, it is only the cost of long distance calls that can be identified on a facility basis. The basic monthly charge for local service can be allocated on the basis of the number of telephones in the facility or by means of a special study of telephone use.

Water and Sewage

When water is purchased from a public utility, the statement rendered is based on meter readings. If bills are rendered only quarterly, however, the monthly cost must be estimated. The schedule of rates provided by the utility company can be used to ascertain the estimated water cost.

FINAL STEP AFTER DISTRIBUTION OF OVERHEAD

After all service department costs have been distributed under whatever plan may be used, the total service costs are entered in the repair department accounts. The repair department cost totals now represent the direct department costs and indirect service costs distributed to repair departments.

These amounts can be used to obtain applicable overhead rates for assigning the departmental cost to repairs. If predetermined rates are used, the repair department cost totals will be compared with repair charges to determine the amount of overabsorbed (or underabsorbed) departmental overhead.

SHOP CLASSIFICATION FOR OVERHEAD COMPUTATION

The study team separated the five shops visited into three categories as follows:

- outside repair track;
- enclosed repair shop; and
- heavy repair shop.

Separate overhead rates for each class of shop were developed. In the development of overhead costs, the following ICC accounts provided the necessary documentation to support the overhead calculation:

Superintendence	301		
Shop Machinery - Maintenance	302		
Power Plant Machinery	304		
Shop Machinery - Depreciation	305	(44)	
Power Plant Machinery - Depreciation	305	(45)	
Dismantling Retired Shop and Power Plant Machinery	306		
Miscellaneous Equipment - Repairs	328		
Miscellaneous Equipment - Depreciation	331	(58)	
Dismantling Retired Equipment	329		
Retirements - Equipment	330		
Injuries to Persons	332		
Insurance	333		
Stationery and Printing	334		
Health and Welfare Expenses	335		
Joint Maintenance of Equipment Expenses	336	dr.	337 cr.
Other Expenses	339		
Shops and Engine House - Maintenance	235		
Shops and Engine House - Depreciation	266	(20)	
Tax Accruals - Maintenance of Equipment	532		

Exhibit VIII-1 illustrates the computation of overhead for the three classes of repair shops.

EXHIBIT VIII-1

SUMMARY OF OVERHEAD FOR SELECTED REPAIR SHOPS

A. OVERHEAD INDEX

	LABOR COMPONENT			NON-LABOR COMPONENT		
	OUTSIDE REPAIR TRACK	ENCLOSED REPAIR SHOP	HEAVY REPAIR SHOP	OUTSIDE REPAIR TRACK	ENCLOSED REPAIR SHOP	HEAVY REPAIR SHOP
Overhead Accounts (excluded Health and Welfare)						
Direct Supervision	16.49	36.84	6.67	1.25	3.46	4.32
General Supervision	4.92	14.45	31.24	1.76	5.06	9.89
All Other Labor	15.93	26.92	33.42	7.88	14.60	18.04
Subtotal	37.34	78.21	71.33	10.89	23.12	32.25
Shop Supplies				7.28	20.32	30.12
Shop Operations				27.77	105.67	88.30
Maintenance				4.53	9.86	27.59
Fixed Charges				10.40	69.76	52.39
Insurance				1.63	10.14	20.06
Car Repair Billing				.13	.34	.18
Subtotal				51.74	216.09	218.64

EXHIBIT VIII-1 (Continued)

B. OVERHEAD FOR SELECTED SHOPS

	1 LABOR	2 SUPPLIES	3 TOTAL LABOR AND SUPPLIES (1+2)	4 DIRECT LABOR INDEX	5 RATIO LABOR AND SUPPLIES TO DIRECT LABOR* 3/4
Outside Repair Track	48.23	51.74	99.97	46.49	215
Enclosed Repair Shop	101.33	216.09	317.42	110.38	288
Heavy Repair Shop	103.58	218.64	322.22	268.41	120

* Column 5 is the Overhead Rate as a % of Direct Labor Dollars.

EXHIBIT VIII-1 (Continued)

C. INDIRECT LABOR AND MATERIAL

OVERHEAD CLASSIFICATION	FIXED	VARIABLE	% VARIABLE	COMMENTS
Direct Supervision	Car Foreman and Assistant Mechanical Foreman Gang Leaders		*	
General Supervision	Master Mechanic Regional Mechanical Officer General Foreman	Clerical Office Staff		*
All Other Labor		Laborers Machine Operators Inspectors Write-up Men		
Shop Supplies		Lubricants Fasteners Welding Supplies Small Tools Fuel and Lubricants for Facilities Vehicles		
Shop Operations		Water and Sewage Electricity Telephone Equipment Rent Fuel and Lubricants for Highway Vehicles Power Plant Shop Switching Stationery and Printing	*	*

* See Exhibit IX-3,4,5 and 6.

VARIABILITY OF OVERHEAD WITH CAR OUTPUT

Regression techniques were used to measure the variability of shop overhead costs with output. The technical methodology employed is similar to the direct labor techniques discussed in Section V.

DATA BASE

The data base for this analysis consisted of the records of three classes of repair shops: heavy, modern light, and open light. A description of the general characteristics of these shops can be found in Section IV. Repair volume, which was averaged for a 7-month period, was regressed against four shop variables: all other labor, shop supplies, shop operations, and maintenance of the shop. The variables and their indexed dollar amounts are discussed in Section VI. Exhibit VIII-2 indicates the data that were analyzed.

REGRESSION RESULTS

Exhibits VIII-3, 4, 5, and 6 graphically display the results of the regression analysis. As indicated, a greater time period is required to perform long-run, as opposed to short-run, analyses.

VARIABILITY OF OVERHEAD COST COMPONENTS

As shown in Exhibits VIII-3, 4, 5, and 6, the variability of overhead components with shop output is low or fixed.

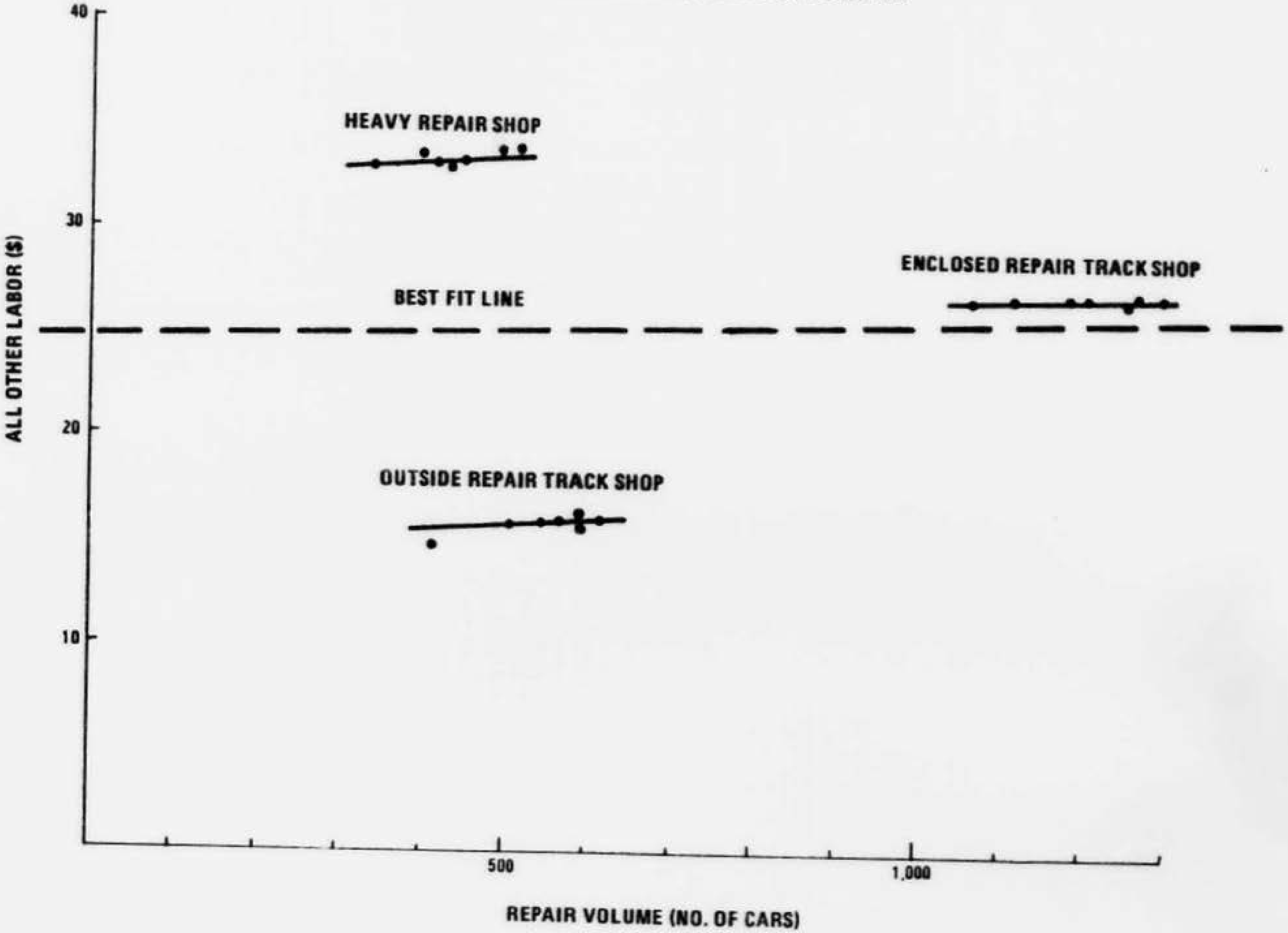
EXHIBIT VIII-2

AVERAGE MONTHLY DATA

SHOP	REPAIR VOLUME	ALL OTHER LABOR	SHOP SUPPLIES	SHOP OPERATIONS	MAINTENANCE
A (Heavy)	431	33.38	30.18	88.39	27.57
B (Open)	524	15.82	7.27	27.56	4.53
C (Modern)	1,186	26.97	20.34	105.69	9.81
Average	714	25.39	19.26	73.88	13.97
S.D.	412	8.89	11.49	41.04	12.07
Variance	112,991	52.64	88.06	1,122.65	97.13

EXHIBIT VIII-3

ALL OTHER LABOR/REPAIR VOLUME



VIII.16

EXHIBIT VIII-4

SHOP SUPPLIES/REPAIR VOLUME

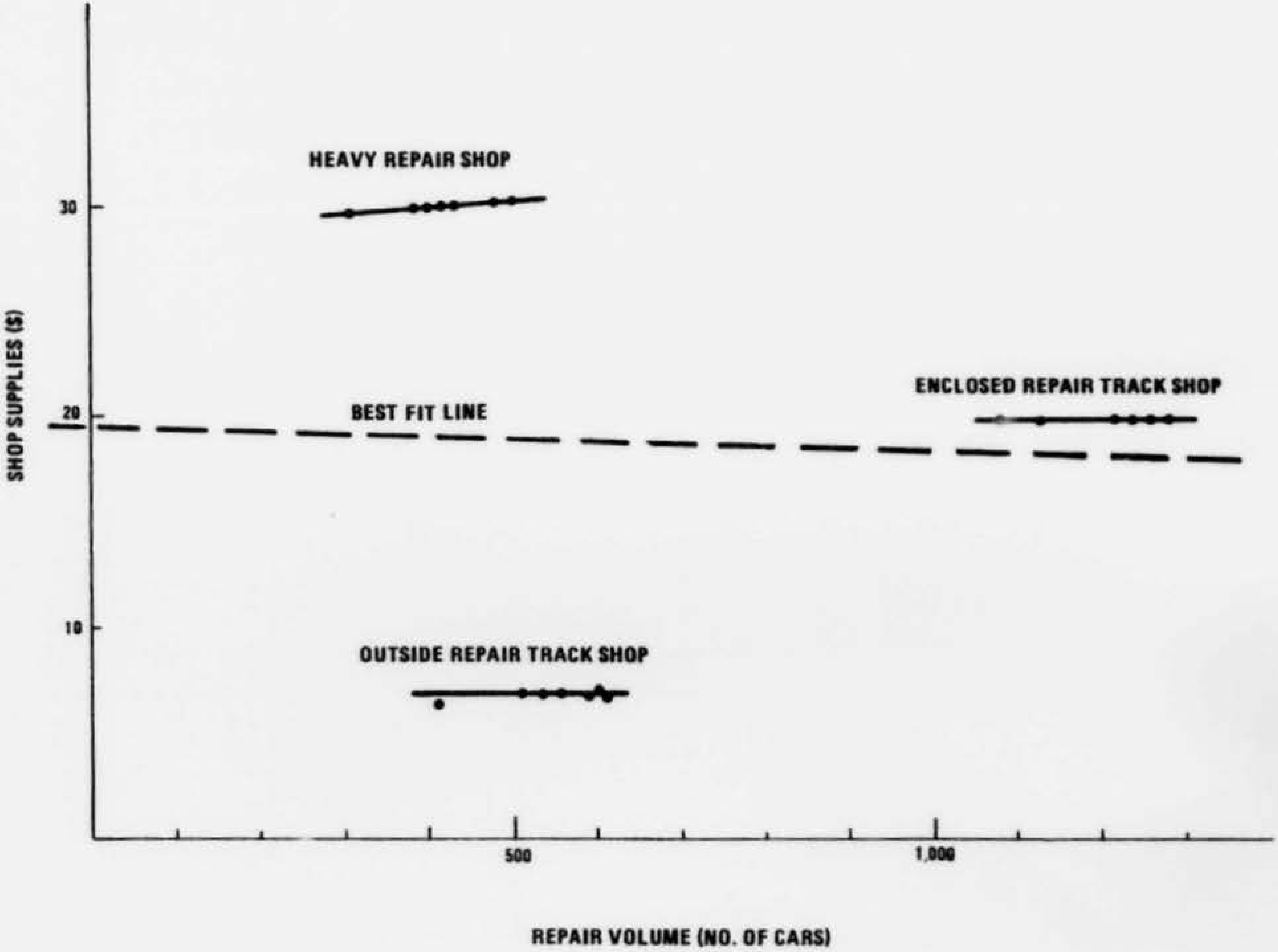
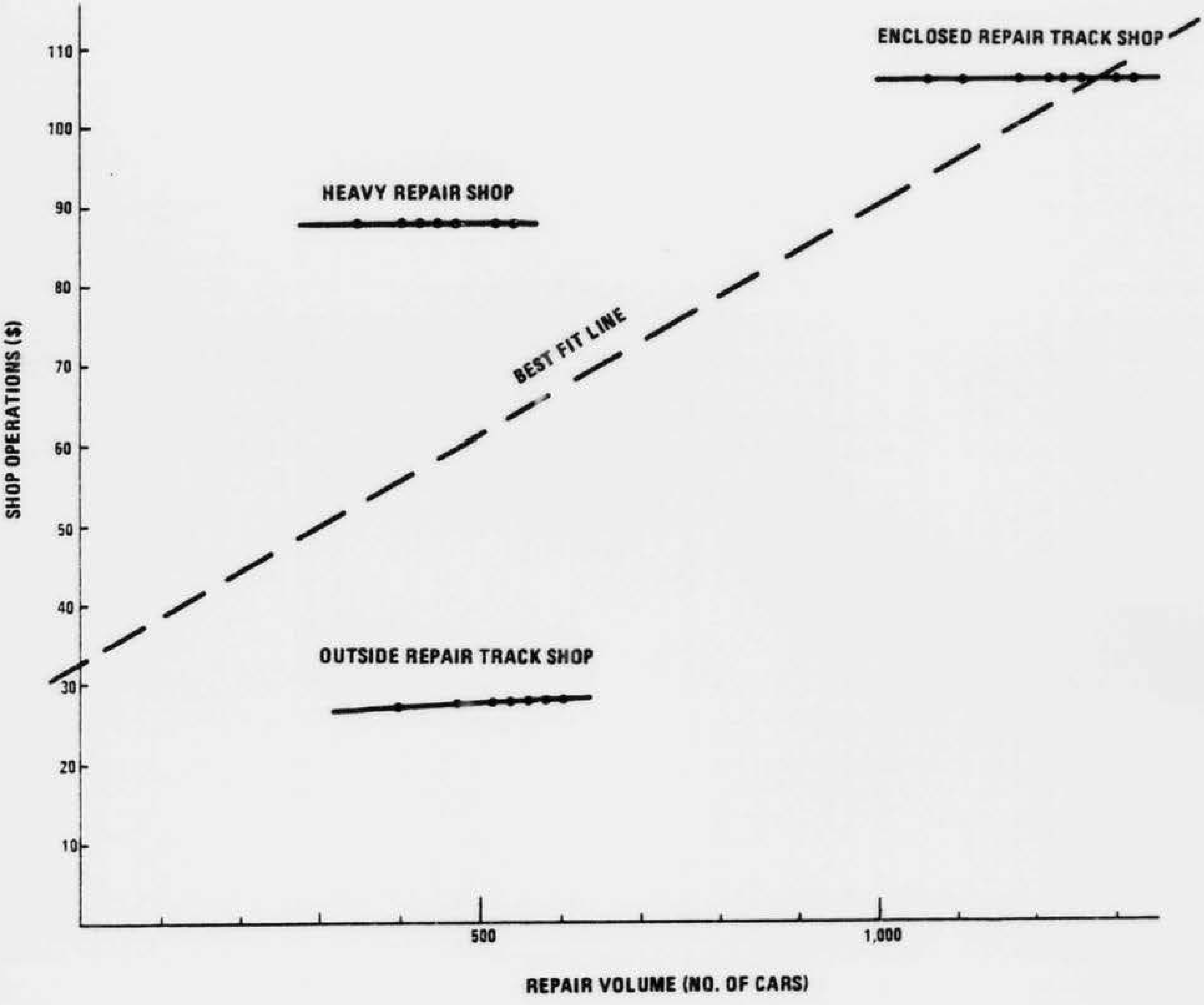


EXHIBIT VIII-5

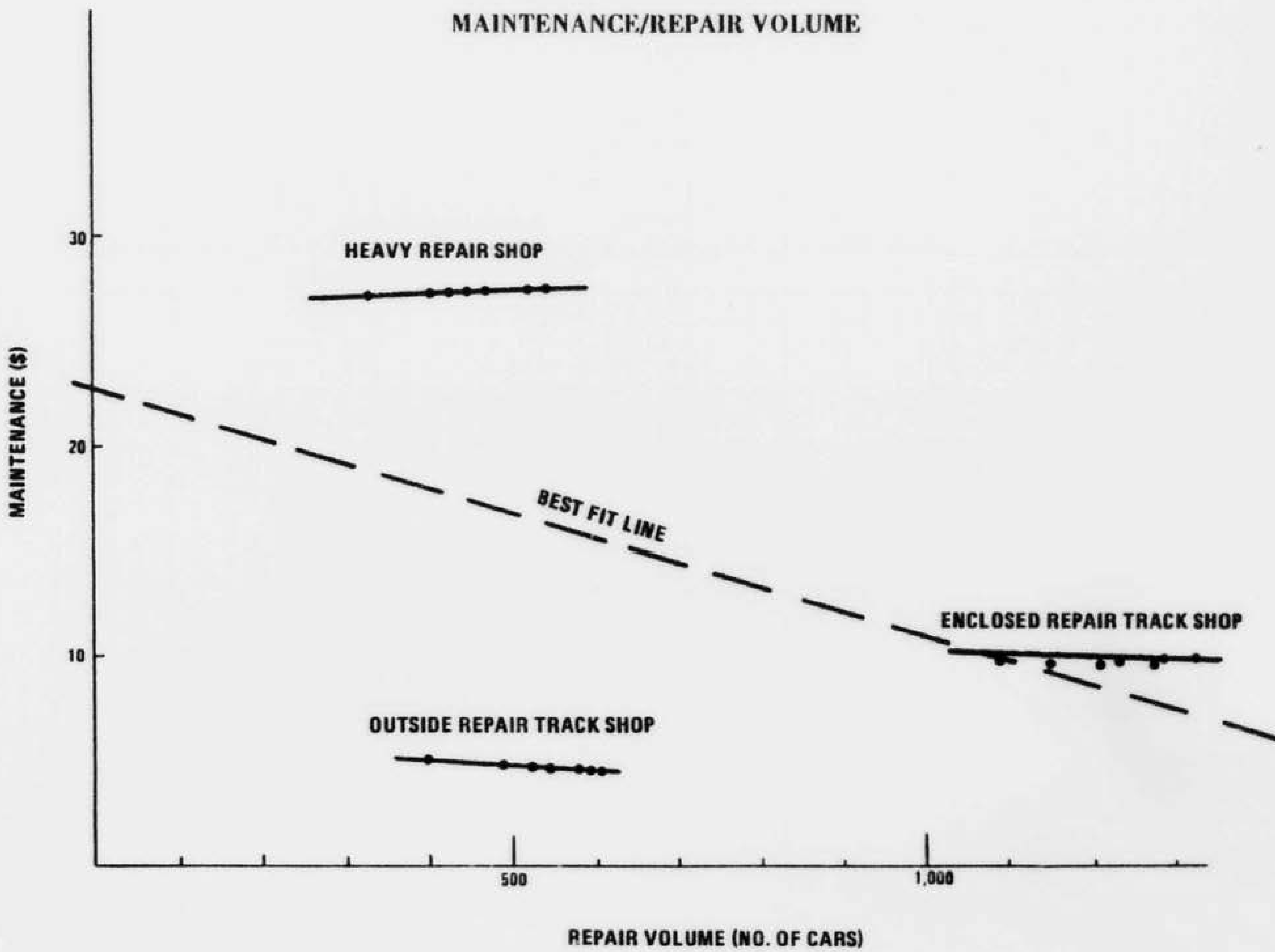
SHOP OPERATIONS/REPAIR VOLUME



VIII.18

EXHIBIT VIII-6

MAINTENANCE/REPAIR VOLUME



IX. COSTING BASED ON THE FRA METHODOLOGY

Though there are a multitude of applications for the results developed in this report, the effort focuses on a costing methodology based on the concept of incurrence and consumption. This section discusses how the analyses of incurrence and consumption can be used for direct costs associated with "commodity trips."

Two approaches to costing are proposed. The first approach assigns each category of repair to a primary causal factor. Then the repair costs, determined from the maintenance relationships and standard costs for repairs, are fully distributed to the factors. The second approach attributes the reported maintenance costs for each repair category to one or more activities based on the respective elasticities. This is used to determine the variable cost of a commodity trip.

Both approaches are first generalized and then applied to a specific example based on results developed in Section III. The section concludes with a comparison between this methodology and the ICC's regulatory costing methodology.

COSTING APPROACH ONE

This approach is based on standard costs for maintenance and the statistical relationships between repair activity and operating statistics. A repair category is assigned to a meaningful operating statistic. For this repair category, the cost per repair and the repair rate per the operating statistic are combined to yield the repair cost per the operating statistic. For costing a commodity trip, the relevant operating statistics are determined and applied to the cost rates to obtain the estimated cost of the move. This procedure is described briefly below. Then consumption relations developed in Section III are used to demonstrate the approach.

General Procedure for Approach One

For a given car "description" (e.g., car type, average car age, tare weight, commodity) the following steps are performed:

Step 1: Develop the Appropriate Level of Aggregation of Repair Groups

All of the various types of repairs should be aggregated in a logical way to form a number of repair groups. The repair group list should be mutually exclusive and collectively exhaustive of the repairs applicable to the car description. The repair groups should be at such a level of detail that statistical analysis can successfully identify the causes of maintenance.

Step 2: Develop a Standard Cost per Repair for Each Repair Group Established in Step 1

This step may involve computing a weighted average in some cases. For example, if the car described has any one of a number of different types of control valves, the cost of control valve maintenance is computed as the weighted average (weighted by the frequency of the valve type for the car described) of repair costs for control valves. If the repair group encompasses repairs to different components, the standard cost per repair for the group is computed as the weighted average (by the relative frequency of component repairs) of repair costs for components in the repair group.

Step 3: Assign an Operating Statistic to Each Repair Group

The operating statistic assigned to the repair group should be causally related to the wear or breakage of the components. This judgment may be aided by the use of statistical correlation in conjunction with professional judgment. For example, wheel wear is related to mileage, door damage is related to car loadings, and coupler damage is related to the number of classifications. In this case, the operating statistics car miles, car loadings, and classifications, respectively, would be assigned.

Step 4: Derive Repair Rates for Repair Groups and Operating Statistics (Assigned in Step 3) Based on Car Characteristics

This step involves selecting a consumption relationship in which the dependent variable is the ratio of repair group activity and the related operating activity. The car characteristics (e.g., car type, car age) are then input as the independent variables. This process yields a repair rate for each repair group.

Step 5: Compute Repair Cost per Each Operating Statistic Based on Standard Costs per Repair (Step 2) and Repair Rates (Step 4) for Each Repair Group

For example, brake repair cost per mile is obtained by multiplying the cost per brake repair by the expected number of brake repairs per mile. For other repair groups assigned the operating statistic car miles, the cost per mile should also be computed and totalled to obtain the total repair cost per car mile. This process should be repeated to obtain a cost per operating statistic for each operating statistic assigned to at least one repair group.

Step 6: Develop Values for Each Operating Statistic to Represent the Commodity Trip to Be Costed

For example, determine how many car miles are travelled, how many car loadings, and so on. The car miles statistic may include empty return mileage depending on the particular application.

Step 7: Compute Cost of the Commodity Trip Based on Repair Costs per Operating Statistic and the Values of Each Operating Statistic for the Commodity Trip

For example, multiply the repair cost per car mile by the number of car miles travelled, multiply the repair cost per car loading by the number of car loadings, and so on. The sum of these costs represents the cost for the commodity trip.

Costing Example for Approach One

This example demonstrates the costing of a commodity trip on intermodal flatcars with an average age of 10 years. The trip is assumed to require 3,500 car miles and 20 car days.

Step 1: Aggregate Repair Groups

For this application, the repair groups have been developed as follows:

- group 1 - brakes;
- group 2 - draft gear;
- group 3 - trucks;
- group 4 - bearings and axles;
- group 5 - wheels;
- group 6 - car interior;
- group 7 - car exterior;
- group 8 - special equipment; and
- group 9 - miscellaneous.

Note that door repair is not included as a repair group since this repair is not applicable to intermodal flatcars.

Step 2: Develop Standard Costs

The standard costs per repair are obtained by weighting the costs of individual component repairs. For example, the repair cost per component and the relative frequency of occurrence for the draft gear system are:

Draft Gear Component	Relative Frequency of Repair	Cost per Repair
2.1 Knuckles	18%	$ 35.66
2.2 Couplers	80%	$ 91.53
2.3 Yokes	01%	$146.30
2.4 Draft gear and end-of-car hydraulics	01%	$235.00
Standard Cost	100%	$ 83.45

The cost per draft gear system repair is obtained as follows:

$$.18(35.66) + .80(91.53) + .01(146.30) + .01(235.00) = 83.45$$

This procedure is performed for each repair group. The resulting costs per repair by repair group are:

Repair Group	Cost per Repair
1	$ 41.00
2	$ 83.00
3	$431.00
4	$102.00
5	$ 99.00
6	$ 95.00
7	$ 22.00
8	$ 60.00
9	$100.00

Step 3: Assign Operating Statistics

The statistical correlation between group repair activities and car days and car miles is as follows:

	Repair Group	Correlation to Repair Activity	
		Car Days	Car Miles
1.	Brakes	.42	**.82**
2.	Draft gear	**.28**	.11
3.	Trucks	.04	**.06**
4.	Bearing and axles	.29	**.40**
5.	Wheels	.23	.36
6.	Car interior	**.17**	.23
7.	Car exterior	**.28**	.17
8.	Special equipment	**.14**	.61
9.	Miscellaneous	.26	**.31**

For each repair group, either the car days statistic or the car miles statistic is chosen as the primary causal factor, indicated by the scored numbers. In five cases, car miles was chosen, while car days was chosen for the remaining four groups. Note that in some cases the statistic with the highest correlation to repairs was not the one chosen as the primary causal factor. The choice of factors was also based on professional judgment. For example, special equipment maintenance is more highly correlated to car miles than to car days; however, this results from the fact that (1) the vast majority of special equipment repairs are made to intermodal cars and (2) intermodal cars average more miles per day than other cars. When the special equipment repairs are viewed with these considerations in mind, the use of car days as a causal factor, instead of car miles, is justified.

Step 4: Derive Repair Rates

The repair rate for each repair group is determined from the relations that were presented in Section III. For example, given that car miles is the primary causal factor for brakes, the appropriate relation is:

$$\text{CRB1/100,000 car miles} = \overset{\text{Car type}}{\begin{Bmatrix} 21.6 & \text{intermodal} \\ 16.5 & \text{autorack} \\ 22.4 & \text{other} \end{Bmatrix}} + 0.41\ (\text{AGE})$$

Thus, for an intermodal flatcar which is 10 years old:

$$\text{CRB1/100,000 car miles} = 21.6 + 0.41(10) = 25.7$$

That is, the intermodal flatcar described is expected to have 25.7 repairs per 100,000 car miles. This procedure is performed for each repair group.

Based on the repair relations for the car leasing company in Section III, the repair rates for intermodal flatcars with an average age of 10 years are:

Repair Group	Repairs per 1,000 Car Days	Repairs per 100,000 Car Miles
1	-	25.7
2	2.13	-
3	-	0.21
4	-	2.07
5	-	0.96
6	1.21	-
7	2.74	-
8	2.71	-
9	-	4.69

Step 5: Compute Repair Costs

The repair cost per car mile and per car day are computed by multiplying the above repair rates (Step 4) by the repair costs (Step 2) and summing for car miles and for car days. For example, the repair cost per car mile for brakes (repair group 1) is computed:

($41 per repair) · (25.7 repairs per 100,000 car miles) = $1,054 per 100,000 car miles

This process yields:

Repair Group	Repair Cost per 1,000 Car Days	Repair Cost per 100,000 Car Miles
1	-	$1,054.00
2	$177.00	-
3	-	$ 91.00
4	-	$ 211.00
5	-	$ 95.00
6	$115.00	-
7	$ 60.00	-
8	$163.00	-
9	-	$ 469.00
TOTAL	$515.00	$1,920.00

Step 6: Develop Values for Operating Statistics

The operating statistics representing the commodity trip were provided:

- car days = 20; and
- car miles = 3,500.

Step 7: Compute Commodity Trip Cost

The cost of the commodity trip is computed by applying the above operating statistics to the corresponding cost rates developed in Step 5. This yields:

$$\text{(Repair cost per 1,000 car days)} \cdot \left(\frac{20}{1,000}\right) +$$

$$\text{(Repair cost per 100,000 car miles)} \cdot \left(\frac{3,500}{100,000}\right) =$$

$$515\ (.020) + 1,920\ (.03500) = 77.50$$

Thus, the cost of the commodity trip is approximately $78.00. Note that this represents the maintenance costs attributable to the trip. Other costs, such as the original cost of the car, are not included.

COSTING APPROACH TWO

This approach is based on standard costs for maintenance and the maintenance relationships (geometric) developed to estimate the variability (elasticity) of maintenance with respect to operating statistics. Thus, this approach derives variable, or incremental, costs. Approach one allocated all of the maintenance expense for a repair group to a primary causal factor for that group. In contrast, approach two recognizes that the maintenance requirement within a repair group may be related to more than one operating factor and, in fact, that some maintenance activity cannot be attributed to operations. Thus, approach two attributes the expenditure within repair groups to related operating statistics according to their respective elasticities of maintenance activity. Then the expenditure attributed to each operating statistic is used to develop variable unit costs.

The following description generalizes this procedure. Then the approach is demonstrated using the maintenance relationships developed in Section III.

General Procedure for Approach Two

For a given car description (e.g., car type, average car age, tare weight, commodity), the following steps are performed.

Step 1: Develop the Appropriate Level of Aggregation of Repair Groups

The repair groups should be selected at a level for which reliable estimates of variability can be obtained. For example, if variability is estimated at the car system level and these estimates are judged to be valid for the components involved, then component level repair groups are appropriate.

Step 2: Develop the Total Standard Cost for Each Repair Group Established in Step 1

The total standard cost by repair group may be estimated on an annual basis by multiplying a weighted standard cost per repair for a repair group by the projected or historical annual repair activity for the repair group. Both the standard cost per repair and the repair activity estimates are for the car described only, if possible.

Step 3: Derive Maintenance Elasticities of Operating Statistics for Each Repair Group

Maintenance elasticity of operating statistic X is derived as follows:

$$\text{Maintenance elasticity with respect to } X = \frac{dF(X,Y)}{dX} \frac{X}{F(X,Y)}$$

where:

$F(X,Y)$ = functional relationship between maintenance activity and operating statistics; and

X, Y = operating statistics

For the geometric relations, the maintenance elasticities are the exponents of the operating statistics. If possible, the maintenance elasticity can be specific to the car characteristic; however, elasticities should vary only slightly among car characteristics.

Step 4: For Each Operating Statistic, Compute the Variable Unit Cost Based on Standard Repair Costs and Maintenance Elasticities for Repair Groups

For each operating statistic, the unit cost is computed by multiplying the standard costs for each repair group by the respective elasticities, summing over repair groups, and dividing by the annual value of the operating statistic.

Step 5: Compute the Variable Cost of the Commodity Trip Based on Variable Unit Costs and the Value of Each Operating Statistic for the Trip

For example, multiply the variable unit cost per car mile by the number of car miles travelled, multiply the variable unit cost per car loading by the number of car loadings, and so on. The sum of these costs represents the variable cost for the commodity trip.

Costing Example for Approach Two

This example demonstrates the costing, by approach two, of a commodity trip on intermodal flatcars with an average age of 10 years. As before, the trip is assumed to require 3,500 car miles and 20 car days. Step 1 is identical to the previous example, so it will not be repeated here.

Step 2: Develop Standard Costs

Assuming that there are approximately 3,800 ten-year-old intermodal flatcars in the leasing company fleet and the corresponding repair activity is known, the annual expenditure is derived as follows:

Repair Group	Reported Number of Repairs	Cost per Repair	Total Annual Repair Cost
1	46,900	$ 41.00	$1,923,000
2	2,400	$ 83.00	199,000
3	400	$431.00	172,000
4	3,800	$102.00	388,000
5	1,800	$ 99.00	178,000
6	1,400	$ 95.00	133,000
7	3,100	$ 22.00	68,000
8	3,100	$ 60.00	186,000
9	8,600	$100.00	860,000
TOTAL	71,500		$4,107,000

As a check for reasonableness, this implies an average annual repair cost of $1,080 per car for ten-year-old intermodal flatcars. Note that if repair data cannot be obtained at this level of detail, then the repair rates, as used in approach one, can be applied to project the expected repair activity.

Step 3: Derive Maintenance Elasticities

From the geometric relations developed in Section III, the resulting elasticities (variability) with respect to car days and car miles are:

Repair Group	Maintenance Variability with Respect to: Car Days	Car Miles
1	.73	.60
2	.47	.15
3	.00	.00
4	.30	.35
5	.00	.25
6	.27	.00
7	.61	.14
8	1.02	.18
9	.65	.27

Step 4: Compute Unit Costs

For this example, suppose that the 3,800 ten-year-old intermodal flatcars travelled 1,824 hundred-thousand car miles and 1,140 thousand car days during the year. In this case, the variable unit costs are computed as follows.

First, the total cost by repair group is allocated to car days and car miles according to the elasticities developed in Step 3. For example, the total draft gear expense is $199,000. Thus,

(total cost) · (elasticity) = (199,000) · (.47) = $94,000 is attributed to car days

and

(199,000) · (.15) = $30,000 is attributed to car miles.

For each group, this process yields:

Repair Group	Total Expense	Total Variable Expense Attributed to: Car Days	Car Miles
1	$1,923,000	$1,404,000	$1,154,000
2	199,000	94,000	30,000
3	172,000	-	-
4	388,000	116,000	136,000
5	178,000	-	45,000
6	133,000	36,000	-
7	68,000	41,000	10,000
8	186,000	190,000	33,000
9	860,000	559,000	232,000
TOTAL	$4,107,000	$2,440,000 (59%)	$1,640,000 (40%)

Note that the sum of expenditures attributed to car days and car miles does not equal the total expense in general. The two figures will be equal only when the total variability is 100 percent.

Thus, the resulting variable unit costs are:

$$\text{Variable cost per 1,000 car days} = \frac{2,440,000}{1,140} = \$2,140$$

$$\text{Variable cost per 100,000 car miles} = \frac{1,640,000}{1,824} = \$899$$

Step 5: Compute Trip Cost

The variable cost of the commodity trip is computed by applying the variable unit costs to the operating statistics for the commodity trip:

$$\text{Variable cost of commodity trip} = \begin{pmatrix}\text{variable cost per} \\ \text{1,000 car days}\end{pmatrix} \cdot \begin{pmatrix}\text{car days for} \\ \text{trip [000]}\end{pmatrix} + \begin{pmatrix}\text{variable cost per} \\ \text{100,000 car miles}\end{pmatrix} \cdot \begin{pmatrix}\text{car miles for} \\ \text{trip [00,000]}\end{pmatrix}$$

$$= 2,140\ (.020) + 899\ (.03500) = 74.27$$

Thus, the variable cost of the commodity trip is approximately $74, slightly less than the average cost computed by approach one.

COMPARISON OF THE FRA COSTING METHODOLOGY TO REGULATORY COSTING METHODOLOGY

The FRA methodology discussed in this report is a system intended for managerial use while the ICC's Rail Form A is a costing system for regulatory use. The regulatory system seeks to estimate long-run incremental costs associated with railroad services in order to judge the reasonableness of rates. This is achieved by cross-s ctional analysis of broad expense and operating data from a large number of different railroads. In contrast, the FRA methodology develops more specific costs for managerial purposes, such as cost control, budgeting, profit analysis, repair/ ease/buy/make decisions, and pricing. This is achieved by analyzing large samples of freight car operating and maintenance histories for a particular railroad.

Managerial costs can be used for regulatory purposes but they are more difficult, and costly, to obtain. Managerial costs may also require the use of proprietary information. The confidentiality and cost issues diminish the use of managerial costs for regulatory purposes; however, the carriers are encouraged to present to the ICC their own evidence from special studies.

Though regulatory costs are not intended for managerial applications, many firms use Rail Form A in lieu of more costly managerial costing systems. The costs produced by Rail Form A are not as precise or correct as those obtained by the FRA methodology. The following discussion clarifies the differences between the two and suggests the benefits of the FRA approach to managerial costing.

Rail Form A Approach to Freight Car Costing

The ICC's Rail Form A costing methodology has continually evolved and is being revised even today. Simplifying the procedure for Freight Car Maintenance (Account 314), Rail Form A splits the reported expense between that which is related to mileage activity and that which is related to time. These factors are viewed as causal agents of car deterioration. Both the mileage and time portions of expense are multiplied by a variability factor to develop the respective unit costs.

Currently, the time/mileage split is 50 percent to time and 50 percent to mileage, though several years ago a split of 30 percent to time and 70 percent to mileage was employed. Before 1973, the ICC used a single variability factor of 80 percent for most accounts. In 1973, accounts were grouped into several categories and individual variability factors were estimated in a study by the ICC Bureau of Accounts. For freight car maintenance, the variability factor used since the study is 86 percent. The ICC has recently received suggestions for establishing a Uniform Rail Costing System to replace

Rail Form A, prescribing a variability factor that shifts for different levels of a railroad's size and annual output.

Advantages of the FRA Approach

The methodology proposed in this report develops elasticities to distribute repair costs for separate repair groups. This detail can more accurately represent the "consumption" of maintenance by freight car movements. The multitude of advantages of this approach are all based on the fact that better management decisions can be made when the true costs of operations are known.

Clearly, the Rail Form A methodology, which of necessity is based on viewing the similarities in cost behavior among diverse railroads, cannot capture some of the details of cost behavior which may distinguish individual railroads. The methodology proposed here, when implemented, would be based on data and assumptions tailored to the particular railroad. Thus, it can provide potentially more specific and correct costs for managerial decisions.

X. APPLICATIONS

The consumption of maintenance of equipment (M of E) costs was analyzed in Section III, and a method for estimating repair or replacement frequency distributions for each component was suggested. The consumption of the maintenance (i.e., assigning the M of E costs to the uses of rail cars) has also been discussed. In addition, a standard costing system with flexible overheads for managing M of E costs has been presented separately in Volume II. This section describes the application of these three concepts proposed by the Federal Railroad Administration to decision making. Our purpose here is to present options for the pragmatic use of these costing methods, so that their further development and implementation will make tangible contributions to railroad management.

It is assumed that cars and components are tracked in a data bank so that the frequency distributions of repair and replacement are known. These frequencies are largely determined by existing programmed maintenance (PM--synonomous here with planned maintenance and preventive maintenance) and inspection standards. Therefore, it is assumed that information is also available on the hypothetically unconstrained incidence of the three following basic occasions for M of E:

- failure of a component;
- increase in the expense of operating a component due to its deterioration; and
- detrioration in the performance of a component beyond acceptable service or safety standards.

A third assumption is that the standard costs for the activities of a shop are known, along with the amount and variability of overhead accounts. A final assumption is that accurate traffic forecasts are available.

This presentation of options does not presume to evaluate the profitability or feasibility of the options. Such conclusions would depend on the characteristics of a railroad's fleet, current maintenance operations, and current management practices.

The decisions that could be made using the M of E costing methods include:

- cost control decisions such as:
  - variance analysis; and
  - PM scheduling.

- budgeting for M of E.
- profit analysis, including profit by:
  - shipper;
  - product;
  - line;
  - shop; and
  - foreign car maintenance activity.
- investment decisions, including repair, make, lease, or buy decisions.
- pricing.

The presentation of applications of the costing method begins with those applicatons that are currently entirely within the province of most railroad M of E departments: cost control through variance analysis and PM scheduling. The discussion then proceeds to more central applications such as profit analysis and equipment specification.

COST CONTROL

Controlling the costs of maintenance operations is accomplished primarily through intelligent supervision at successive levels of management. However, the efficient use of manpower, materials, machines, and shops can be facilitated through variance analysis and PM scheduling.

Variance Analysis

Variance analysis is the process of diagnosing variations from standard costs and budgets. The standard costing and budgeting systems are designed so that the variances can be easily identified on the output reports.

Variations from standard costs indicate that the cost per unit is higher or lower than standard. These variances may occur in:

- labor, because of variation in the time from the time-standards or because of a variation from the standard compensation rate (e.g., because of a skewed mix in the labor classifications);

- materials, because of abnormal waste or change in price; or

- overhead, because of variation in capacity utilization, changes in rates (e.g, utility rates or rental payments), or variance in the efficiency of support activities (e.g., excess clerical overtime).

This analysis of overhead variance, which was described in Volume II, depends on the use of a flexible budgeting technique, so that variances in overhead accounts do not confuse volume variances with variances from standard cost.

When the total amount of the variance from standard costs is subtracted from the total variance from budget, the remainder is a volume/spending variance. This variance is the result of deviations from the budgeting volume of maintenance. It may be caused by unanticipated operating conditions (e.g., adverse weather), management decisions to depart from budgeted maintenance standards (e.g., bad ordering cars with 15/16" wheel wear rather than waiting for 13/16" wheel wear), or inaccurate budget projections.

The process of tracing variances back to each of these causes allows a manager to pinpoint and correct weaknesses in his M of E operation. The standard costing system described in Volume II is the basis for this variance analysis.

Preventive Maintenance Scheduling

A second cost control method is the adjustment of the mix between PM (maintenance performed before it is required for further operation of the car) and breakdown maintenance (maintenance required for further operation). This adjustment is among the most valuable applications of the incurrence/consumption data. The discussion of this application consists of:

- the fundamentals of preventive maintenance economics;

- a prototypical component's most economic maintenance interval; and

- a real-time decision process for determining the most efficient long-run maintenance decision.

Fundamentals

The basis of the decision to perform preventive maintenance is the belief that there is some cost or loss (above the actual cost of repair or replacement) resulting from the breakdown of a component in service. As suggested by the three basic occasions for performing maintenance listed above, the breakdown of a component may consist not only of its physical failure, but also of its falling below minimum economic, operational, or safety standards. All of these, however, are physically detected phenomena. As an example of an economic standard, wheel wear may cause the trucks to hunt for the rail to the extent that rail wear, further wheel wear, and energy inefficiency warrant the repair or replacement of the wheels. Similarly, the danger of derailment may be the constraining factor. In either case, a physical measurement of the wheel must be made to determine whether a "breakdown" has occurred.

The cost of such a breakdown, symbolized by the letter B, will be defined as the average cost, in addition to the cost required to shop the car and perform the repair or replacement. The cost B includes:

- costs of deadheading the car to the shop;
- costs in traffic congestion and delay caused by the breakdown;
- costs of any damage resulting from the breakdown;
- marketing losses (i.e., future profits foregone) resulting from delay or damage;
- costs of detecting the breakdown above the costs necessary to conduct a viable car inspection program; and
- any costs involved in repairing or replacing the component that would not be necessary if the component had not failed (e.g., necessity of replacement rather than repair).

The purpose of PM is to reduce the number of times that cost B is incurred by anticipating breakdowns. The amount of preventive maintenance is determined by trading off the costs of breakdowns against the increased number of repairs. One process for making this trade-off for a single component is described in the following paragraphs.

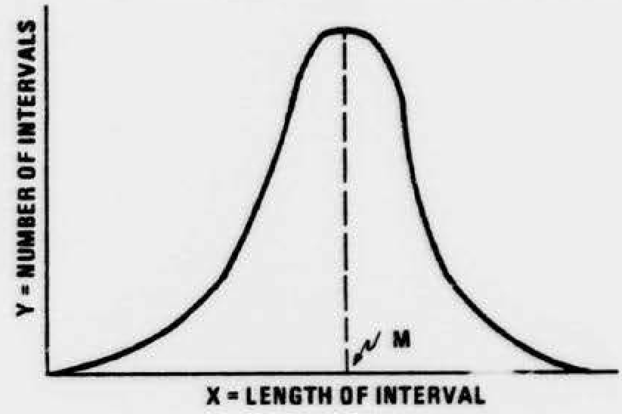
Determining the Most Economic Amount of Preventive Maintenance

Let us assume that the distribution of intervals between unconstrained breakdowns of a component is known (see Exhibit X-1a). We also know the cumulative function $l(x)$ = the length of interval such that x proportion of intervals have length $l(x)$ or less (see Exhibit X-1b).

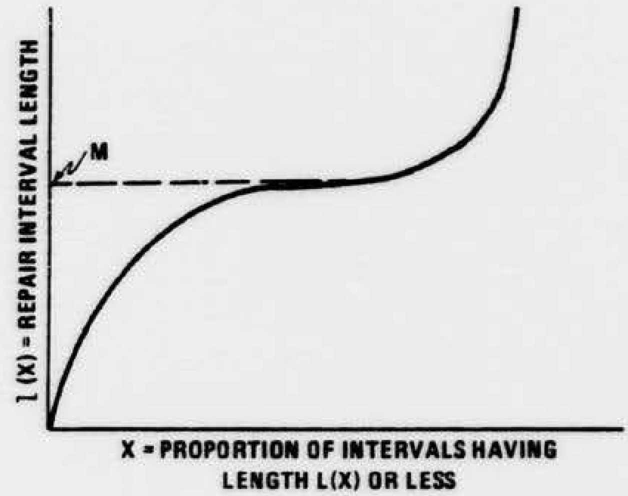
EXHIBIT X-1

DISTRIBUTION OF REPAIR INTERVALS

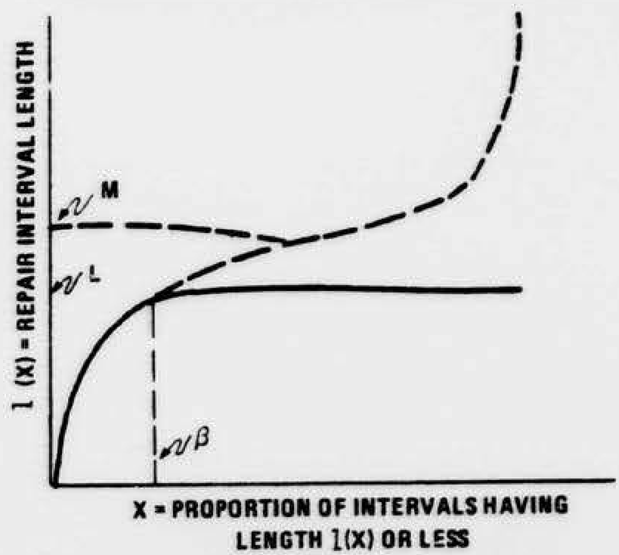
A. FREQUENCY DISTRIBUTION OF REPAIR INTERVALS



B. CUMULATIVE DISTRIBUTION OF INTERVALS



C. CUMULATIVE DISTRIBUTION WITH PREVENTIVE MAINTENANCE



The imposition of a maximum interval (i.e., the introduction of preventive maintenance) simply puts a ceiling L on the interval length, decreasing the average interval and increasing the total number of intervals in any given schedule of car miles (see Exhibit X-1c). The reason for imposing such a maximum (rather than simply letting all components run until breakdown) is to save the additional costs of an in-service breakdown, B. The most economic preventive maintenance interval, L, is the one which minimizes the total cost of repairs ($R per repair · T total intervals) and breakdowns ($B per breakdown · βT breakdowns). In other words,

where:

C = total cost affected by PM;

R = cost of repairing or replacing the component;

B = cost, above R, of a breakdown of the component in service;

β = the proportion of replacements resulting from in-service breakdowns; and

T = the total number of replacements.

then:

$$C = (\beta T \cdot B) + (R \cdot T)$$

Furthermore, the total number of trips must be enough to provide the required car miles, V. In other words, referring to the graph for PM,

where:

L = the maximum length of interval allowed;

l(x) = the longest interval in the shortest x fraction of intervals; and

V = total car miles in service;

then:

$$V = \left[\int_0^{\beta} l(x) + L\,(1-\beta)\right] \cdot T = \text{the shaded area in the exhibit.}$$

We assume that the railroad can estimate the values of the following variables:

- V, provided by demand projections;
- B, from cost analysis;
- R, from the standard costing system; and
- l(x), the incurrence distribution.

To solve for (and then minimize) C in terms of these known quantities we proceed as follows:

$$l(\beta) = L$$

$$\beta = l^{-1}(L)$$

$$T = V \div \left\{ \left[\int_0^{\beta} l(x) \right] + L\,(1 - \beta) \right\}$$

$$T = V \div \left\{ \left[\int_0^{l^{-1}(L)} l(x) \right] + L \left[1 - l^{-1}(L) \right] \right\}$$

By substitution:

$$C = l^{-1}(L) \cdot V \div \left[\int_0^{l^{-1}(L)} l(x) + L - L \cdot l^{-1}(L) \right] \cdot B$$

$$+ R \cdot V \div \left[\int_0^{l^{-1}(L)} l(x) + L - L \cdot l^{-1}(L) \right]$$

Although this equation has been derived using V, total car miles, the value of L which minimizes C does not depend on V. By dividing by V, we obtain:

$$\frac{C}{V} = l^{-1}(L) \div \left[\int_0^{l^{-1}(L)} l(x) \; + \; L \; - \; L \cdot l^{-1}(L)\right] \cdot B$$

$$+ R \div \left[\int_0^{l^{-1}(L)} l(x) \; + \; L \; - \; L \cdot l^{-1}(L)\right]$$

$$= \frac{l^{-1}(L) \cdot B \; + \; R}{\int_0^{l^{-1}(L)} l(x) \; + \; L \; - \; L \cdot l^{-1}(L)}$$

Since B and R are known, this equation can be solved for the L, which minimizes C/V, or the total M of E cost per mile.

As an illustration of the quantities involved, let us assume that we are to calculate the optimal replacement interval for couplers. In this case, the coupler almost never fails in service, but is often bad-ordered by an inspector. Therefore, we would expect that preventive maintenance intervals would be lenient, permitting a significant amount of "breakdowns," (i.e., bad-ordering). In fact, let us assume:

R = the cost of replacing a coupler = \$400

B = the additional cost incurred when the coupler is bad-ordered rather than preventively replaced (due to switching costs, transferring cargo, and an estimate for the disruption in yard operations) = \$150

Let us further assume the approximation of the distribution of breakdown intervals, l(x), as illustrated in Exhibit X-2, a through c. The continuous distribution has been approximated by a discreet distribution to illustrate the method. If adequate data were available, the distribution observed (Exhibit X-2a) could be converted to cumulative form and fitted to a curve as in Exhibit X-2b.[1] To avoid curve fitting and integral calculus, the cumulative distribution

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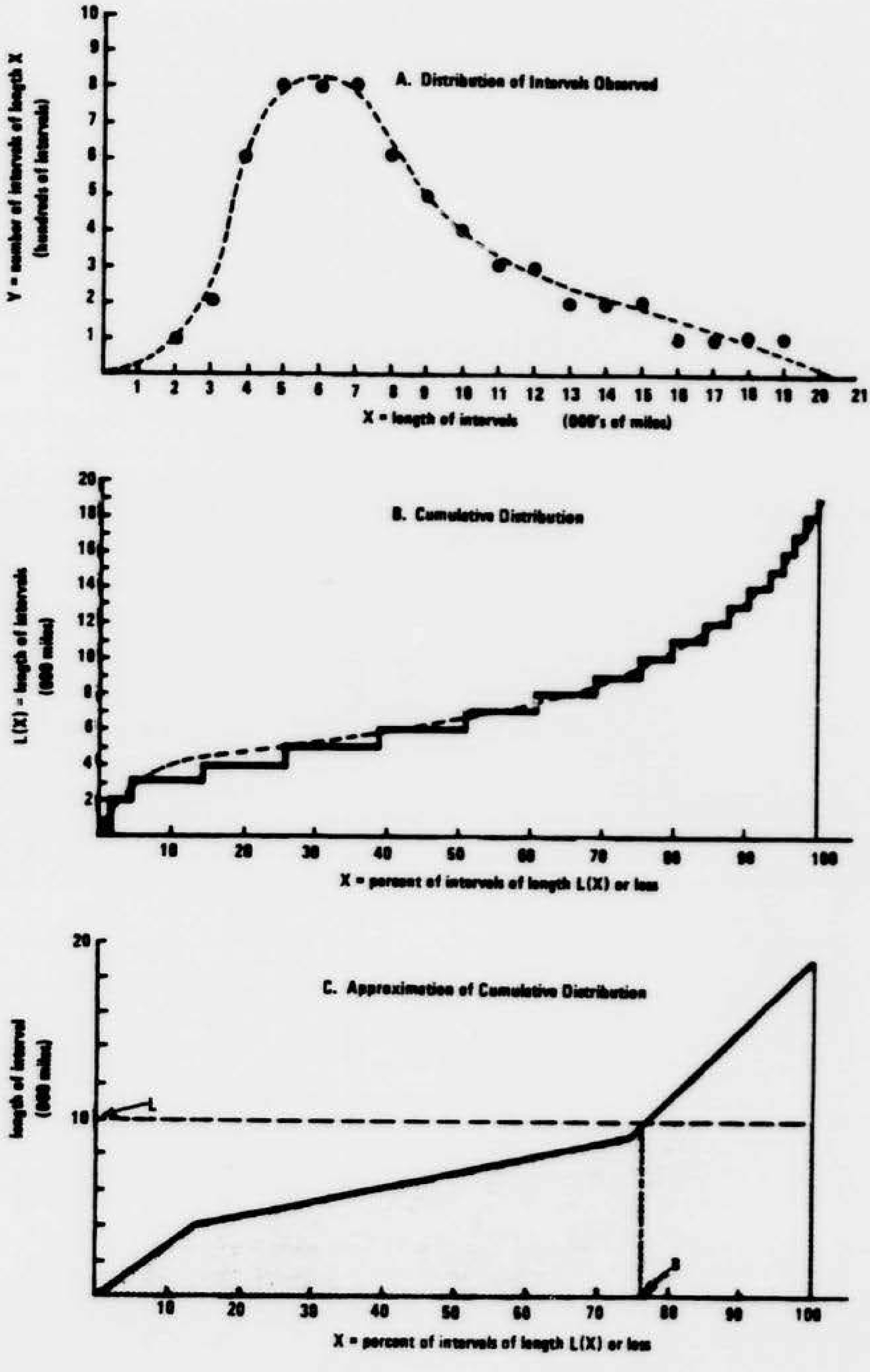
[1] Tangent functions can often be used in fitting a cumulative distribution curve. In this case, a transformation of the repair interval could be used to reflect the skewed distribution [e.g., $\beta = \tan(L^{1/2})$].

EXHIBIT X-2

HYPOTHETICAL DISTRIBUTION OF COUPLER BREAKDOWNS



of repair intervals is approximated by a discontinuous linear function in Exhibit X-2c. This approximation will be used in the following examples. In this case, the integral term in the cost-per-mile formula above can be calulated as the shaded area under the polygon in Exhibit X-2c. Calling this area A, the formula can be rewritten as:

$$C/V = \frac{\beta \cdot B + R}{(A + L) - (L \cdot \beta)}$$

In this example, we also know that in the critical section of the distribution, the relationship between β and L is the following linear equation:

$$L = l(\beta) = 40\beta - 21$$

By substituting the data values, the cost equation becomes:

$$C/V = \frac{\beta \cdot 150 + 400}{[6.495 + (L - 9)(.25 + 1 - \beta) \cdot .5] + L - \beta L}$$

$$= \frac{\beta \cdot 150 + 400}{[6.495 + (40\beta - 30) \cdot (1.25 - \beta) \cdot .5] + 40\beta - 21 - \beta(40 - 21)}$$

$$= \frac{\beta \cdot 150 + 400}{[101\beta - 60\beta^2 - 33.255}$$

To minimize the cost, we differentiate this quotient and find the values of β where the differential is zero:

$$\frac{dC}{d\beta} = \frac{(101\beta - 60\beta^2 - 33.255) \cdot 150 - (150\beta + 400)(101 - 120\beta)}{(101\beta - 60\beta^2 - 33.255)^2}$$

Using the quadratic formula to solve for a zero numerator yields:

$$\beta = .7681661$$

The second value produced by the quadratic formula, 6.5651672, is discarded. The solution for β also implies:

$$L = 40\beta - 21 = 9.7266$$

$$C/V = 57.7281$$

Thus, the optimal preventive maintenance interval is 9,727 miles, and the cost per mile if this interval is adhered to will be \$.0577. To demonstrate that thi nterval is optimal, the effect of shorter and longer intervals can be calculated to be:

- for L = 9,000 miles, C/V = $.0586 per mile.
- for L = 9,800 miles, C/V = $.0585 per mile.

As expected, the interval is long for coupler repair, and almost 77 percent of the repairs should result from breakdowns (inspections) rather than programmed maintenance.

To illustrate the effect on repairs where programmed maintenance is more important, let us examine a second repair, truck replacement, which is not caught by inspectors but can result in on-line breakdowns. For simplicity, let us assume that the breakdown interval distribution and repair costs are similar to those for couplers:

Cost to repair = R = $400

Cost of a breakdown, beyond basic repair cost = B = $2,000

Going through the same steps of substituting these data into the cost formula, differentiating the equation and solving for the zero differential using the quadratic formula, we find a minimum at:

β = .38013 C/V = $.02099 per mile

L = 5.9683

That is, only 38 percent of the repair intervals should be allowed to proceed to breakdown, and this can be accomplished with a programmed maintenance interval of 5,968 miles. The resulting cost minimum for this repair will be $.02099 per mile.

Real-Time Decision Making

In practice, a railroad manager is continually faced with shortages or surpluses of capacity and any number of car components which are approaching or have passed the mandatory maintenance mileage, L. How should the railroad decide how many cars to shop? For the cars that are shopped, how many of the components should be repaired? What circumstances will justify aying overtime or paying for idle capacity?

One paradigm for answering these questions, using the incurrence/consumption concept, is presented here. Let us assume that each of the 26 components has been lettered a through z, and that each has a PM interval derived as described above, L_a through L_z. Then let us assume that the total budgeted costs of M of E have been fully allocated to the repairs, C_a through C_z. A cost per mile C_a/V through C_z/V can be calculated for each component. The railroad's decision can now be analyzed on a profit maximizing basis. The railroad manager knows:

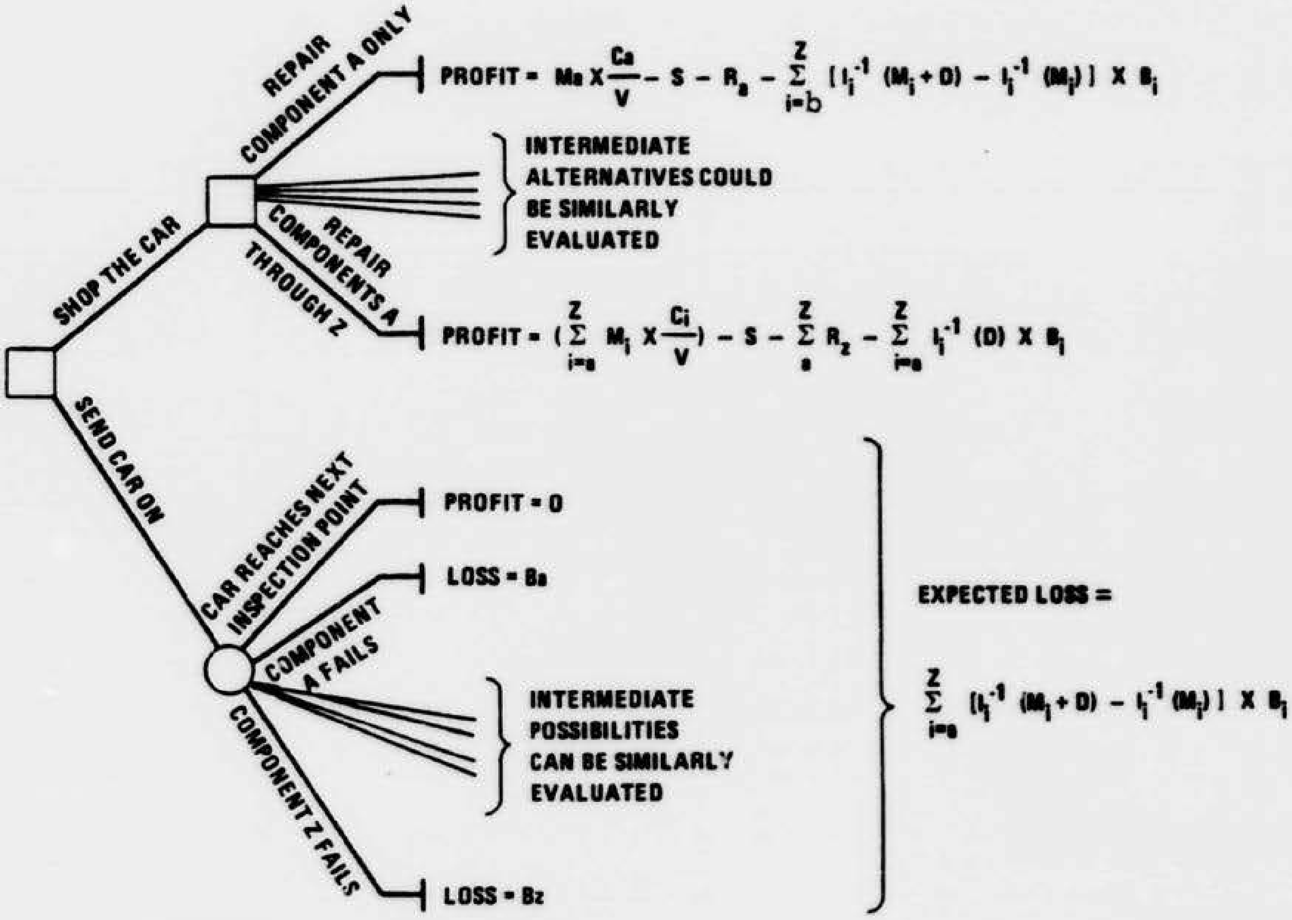
- S, the cost of shopping a car;
- R_a through R_z, the incremental cost above S of repairing components a through z;
- M_a through M_z, the mileage accumulated since the last repair of components a through z;
- B_a through B_z, the incremental cost of an in-service breakdown;
- D, the mileage before the car will reach the next classification yard; and
- $l_a^{-1}(M_a+D) - l_a^{-1}(M_a)$, the probability that component a will fail betwen the mileages M_a and $M_a + D$.

If the costs of maintenance are capitalized into a current asset called "capitalized maintenance" at the rate of $C_a/V \cdot M_a$, then each shop can continually evaluate the profitability to the railroad of shopping a ca , repairing components, or letting a car proceed to the next classification yard. Exhibit X-3 illustrates this decision. In the exhibit, it is assumed that each shop is charged for its actual expenses plus the standard costs, B, of any in-service breakdowns occurring before the next inspection point. As revenue, each shop is credited with the increases in capitalized maintenance (e.g., $M_a \cdot C_a/V$), with the standard cost of breakdowns B, which it repairs, and with the foreign car repair billings that it generates.

The decision, however, need not be so rigorously analyzed in practice. If the shop manager understands how the shop is credited with capitalized maintenance, foreign car repair billings, and breakdowns repaired, and that it will be charged for all breakdowns that occur between inspection points and the succeeding inspection points, as well as actual expenditures, he will be able to make the judgments that maximize profit.

EXHIBIT X-3

MAINTENANCE DECISION TREE



Key to Symbols

a through z	=	component types
M_i	=	mileage since last repair of component i
C_i/V	=	standard maintenance cost per mile for component i
S	=	actual cost of shopping the car
R_i	=	actual cost of repairing component i
$I_i^{-1}(x)$	=	cumulative probability that component i will have failed x miles after repair
D	=	mileage before next inspection
B_i	=	cost of in-service failure of component i

To illustrate the use of this real-time decision tool, let us consider only the repairs illustrated above, trucks (T) and couplers (C). The maintenance manager may be in the following situation:

$S = \$50$

$R_T = \$250$ $\quad$ $R_C = \$250$

$M_T = 5{,}000$ miles $\quad$ $M_C = 3{,}000$ miles

$B_T = \$2{,}000$ $\quad$ $B_C = \$150$

$D = 1{,}000$ miles

$C_T/V = \$.2099$ $\quad$ $C_C/V = \$.0577$

Note that the cost S and R are actual expenditures the manager expects to make. They could be adjusted to reflect the need for overtime or the availability of idle capacity. Because the optimal PM interval is calculated using fully allocated costs, and the cost used by the manager is an incremental cost, the costs here are less ($250 + $50 = $300) than was used for the optimal interval calculation ($400).

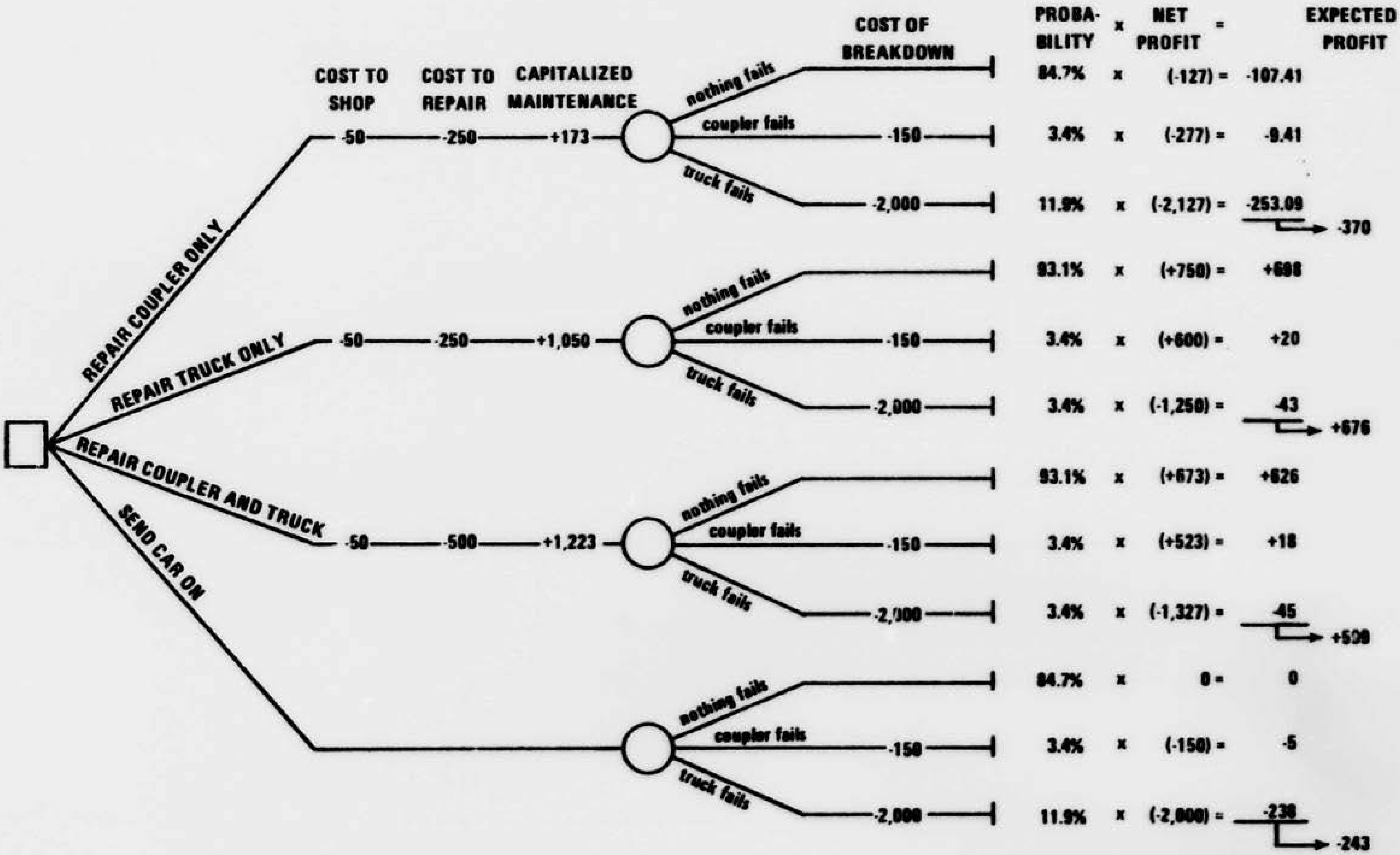
Assuming that the manager is not considering any other repairs, his decision tree is illustrated in Exhibit X-4. He has four choices:

- repair the coupler;
- repair the truck;
- repair both; or
- send the car on.

The costs incurred and the capitalized maintenance that would be credited are shown for each choice. When he sends the car on, one of the components may fail. Using the cumulative probability distribution from Exhibit X-2c for both types of repair, the probability of failure can be calculated for each case. The charge for a breakdown is also added into the net profit figures. Calculating the probability-weighted or expected profit, the manager can see that repairing only the truck is the proper decision, yielding an expected profit to his shop of $676. Although this manual analysis could not be performed

EXHIBIT X-4

ILLUSTRATIVE DECISION TREE APPLICATION



for every such decision, computers could assist in implementing the technique, either:

- by computing the costs, credits, and charges for periodic reports so that the manager learns to make the correct decisions empirically; or

- in an on-line system, by calculating the options (for all cars) open to the manager and listing them in descending order of profitability.

This real-time decision-making technique eliminates the need for rigid adherence to a planned maintenance interval, L, and still uses the incurrence frequency distribution to minimize maintenance costs.

BUDGETING/PLANNING

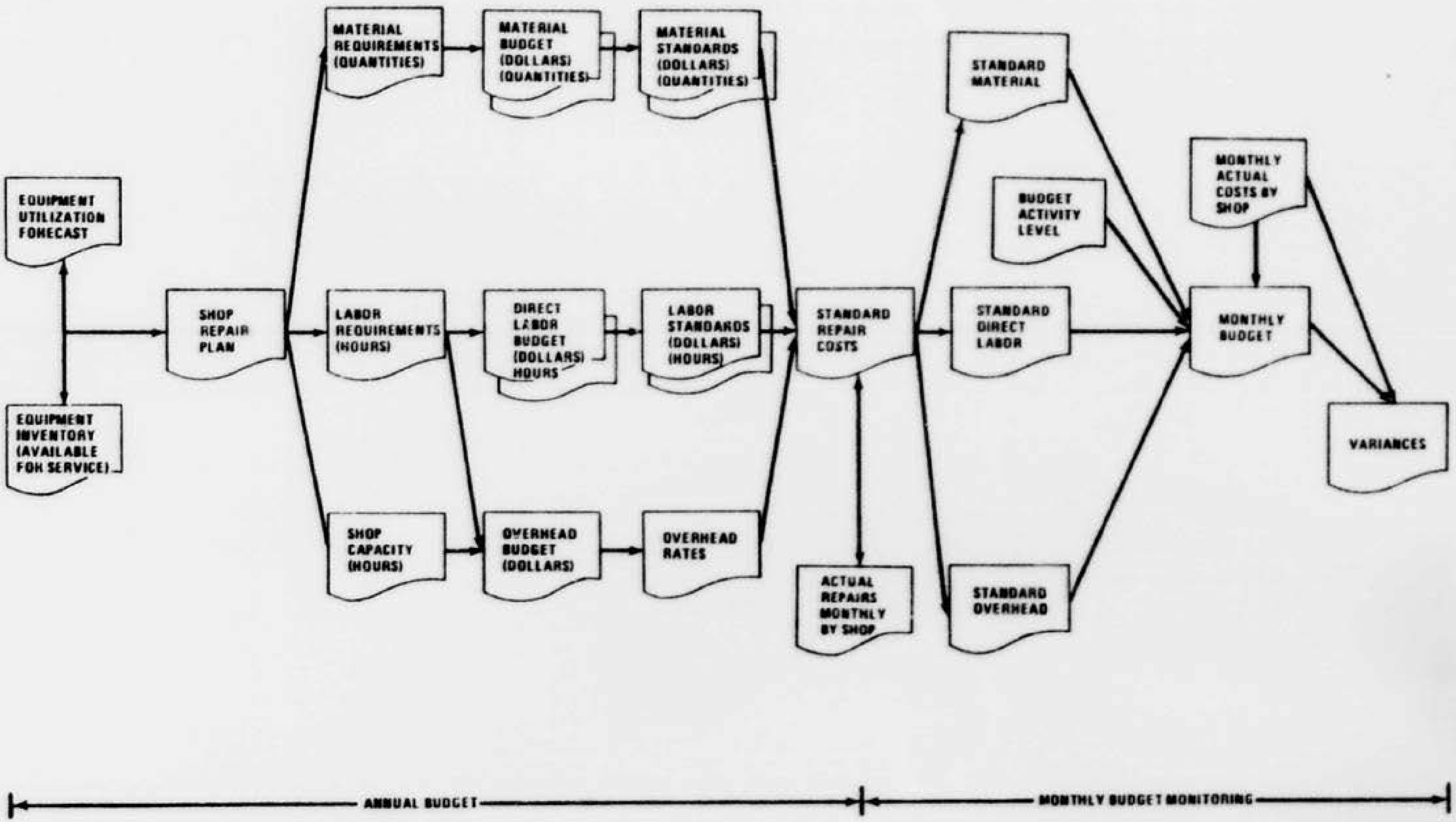
The uses of the standard costing system and incurrence/consumption relationships for cost control suggest similar uses for budgeting. Assuming that traffic projections are available so that the total car miles, V, is projected for each car type, then the number of each type of repair, a through z, can be anticipated. Some components may have the same consumption characteristics on more than one type of car; repair of such components can be treated as one repair type and the mileages for the respective car types can be summed and then divided by the average repair interval. The standard costs, after revision for any changes in wage rates or industrial engineering standards, can be applied to develop the budget.

Flexible budgeting implies a variable overhead rate which can be applied to the direct elements of the budget to derive the total M of E department budget. This budget can be allocated on the basis of a historical record of the volume of repairs for each shop. Exhibit X-5 illustrates this concept. In this way, the unique efficiencies or inefficiencies of individual shops are not disguised or rewarded.

This "top-down" budget can be merged with a "bottom-up" budget based on each shop's anticipated staffing, material, and overhead expenses. By merging budgets, the changing costs that influence the manner in which maintenance is performed can already be identified during the budget process. A comprehensive discussion of budgeting is presented in Volume II.

EXHIBIT X-5

BUDGETING AND PLANNING FOR REPAIR SHOPS



PROFIT ANALYSIS

One use of the incurrence/consumption data in profit analysis has already been discussed: the treatment of each shop as a profit center to decentralize maintenance scheduling. In addition, the standard costing system can be used to analyze the profitability of:

- repairs on foreign cars;
- car age and type;
- particular commodities;
- particular rail lines or loading points; and
- individual shippers.

The profitability of repairs on foreign cars has been alluded to, but deserves further emphasis. It is in the railroad's, as well as the national economy's, interest for each railroad to perform a disproportionate number of those repairs that it performs most efficiently. The standard cost system provides the railroad with information concerning its cost to repair and, especially if each shop becomes a profit center with some discretion concerning which repairs it will perform, the net profit for foreign car repairs may be maximized.

To perform the other types of profit analysis listed above, it is necessary to have standard costs and consumption characteristics for all railroad cost accounts. The amount of overhead to be allocated among the products, services, or shippers being analyzed should be determined by the time frame and the organizational scope of the decision to be made. For example, if a decision is to be made regarding the profitability of serving a particular shipper at its siding, very little overhead should be allocated--direct costing is appropriate. However, if a decision to abandon an entire line is being made, almost all overhead should be allocated, so that the line's long-run contribution can be estimated.

REPAIR/LEASE/BUY/MAKE

The decisions to repair or replace a component and (if to replace) to lease, buy, or make the component are similar to those decisions for an entire car. The range of values of the relevant variables is significant, but the analytical techniques used to make such decisions are the same in both cases.

These decisions, however, depend not only on the economic factors that are subject to these analytical techniques, but also on less easily analyzed factors. Among such factors are:

- the degree of independence from one or more external sources of supply;
- the degree of flexibility in controlling fleet size;
- the number of parts that must be kept on hand and the degree of standardization in maintenance operations;
- the availability of limited sources of capital such as equipment trust certificates and the effects of the decision on the future availability of such sources; and
- the overhead expenses and leverage of investment in assets resulting from the decision.

The influence of these and similar factors on the repair/lease/buy/make decision will depend on the individual characteristics of the railroad and its current situation.

In general, the decision to repair, lease, buy, or make the component, will depend on the nature of the maintenance expenses for the component, the costs of the replacement alternatives, and the railroad's cost of capital. It should be noted that these costs must always be calculated on an after-tax basis (i.e., if the railroad is paying 48 percent of its profit in income tax or has an equivalent carry-back opportunity, the before-tax expenses should be multiplied by 52 percent). Similarly, any available investment tax credits should be taken into account in analyzing investments. Having noted the importance of using after-tax figures, the remainder of this discussion will assume that taxation is either irrelevant or has already been accounted for. The decisions to be analyzed will be treated in two parts: repair or replace; and if replace, then lease, purchase, or make.

Repair or Replace

The decision to repair or replace depends on the nature of the repair frequencies. If the repair operation is so effective that the repair interval does not decrease with age (i.e., if the repaired component is as good as new), the decision is made strictly on a cost comparison of performing a repair versus the purchase price.

If (as is almost always the case) the component deteriorates with successive repairs so that the repair interval becomes shorter and shorter, the life cycle costs of the alternatives must be compared. This is most easily accomplished by assuming a utilization rate (e.g., 100,000 miles per year) and plotting the maintenance cost per year on the vertical axis against years on the horizontal axis. The result will be an upward sloping curve. The capital costs can be plotted against any specified useful life as a downward sloping curve that starts from the vertical axis at the purchase price itself (see Exhibit X-6). The point at which the sum of the annualized maintenance and capital costs (the upper curve) reaches a minimum indicates the year, and consequently the mileage, at which the component should be replaced.

Lease/Buy/Make

The economic impacts of the lease, buy, or make decision are largely determined by the railroad's cost of capital. If either the railroad or a vendor can achieve economies of scale (either volume discounts or manufacturing economies), this will also influence the decision. The basic technique is to calculate the net present value of the decision or, equivalently, to annualize the costs. For the lease decision, the usual case is that the railroad will own the car after a specified number, N, of lease payments, n. The railroad need only compare the present value of the lease payments,

$$n \sum_{y=0}^{N} (1 + i)^{-y}$$

to the purchase price to determine which option is cheaper.

The buy or make decision is similar in nature. The life span of the capital equipment, L, needed to manufacture the components and the number of new components per year, n, must first be determined. Then the stream of purchases at the full purchase price, P,

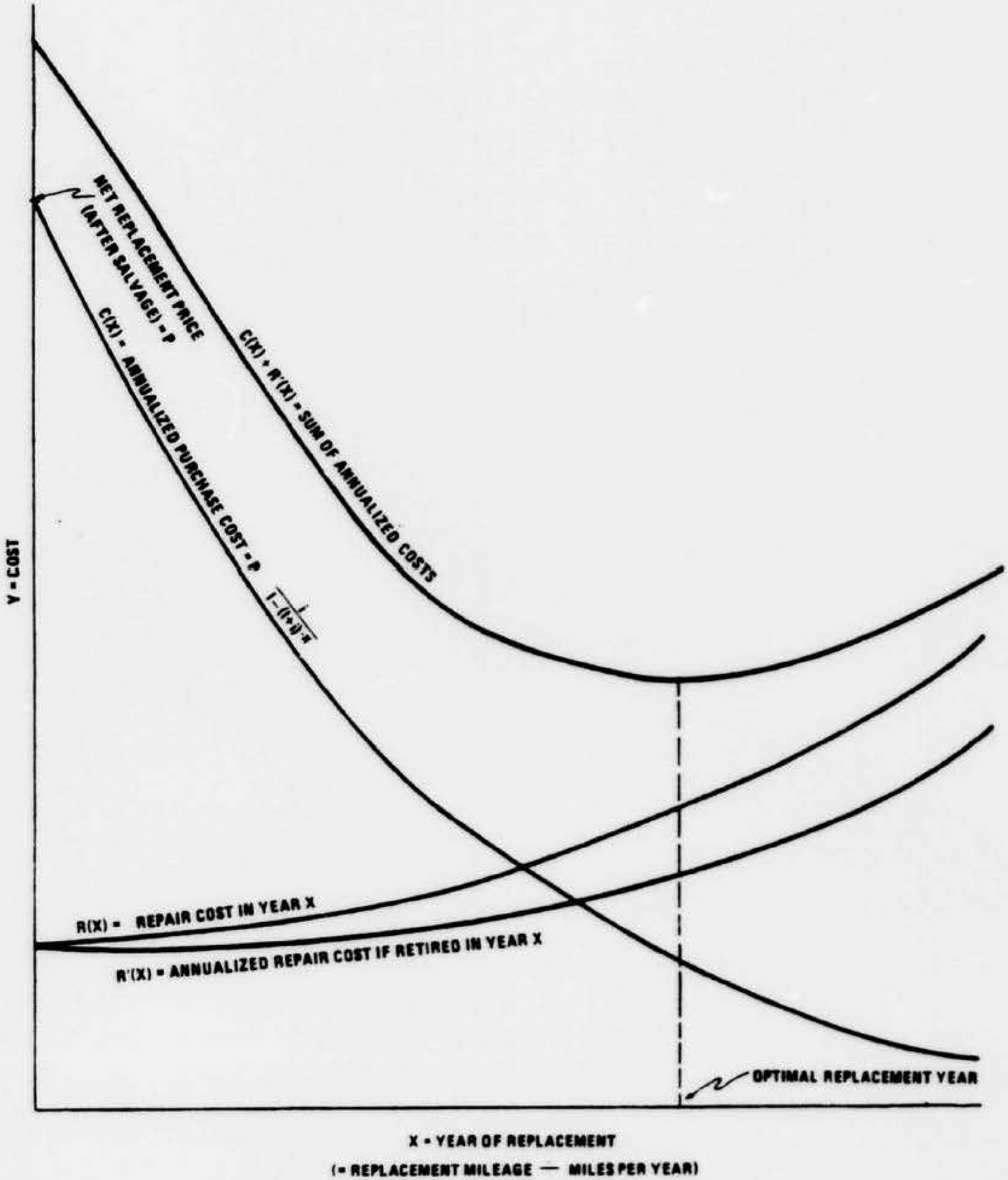
$$nP \sum_{y=0}^{L} (1 + i)^{-y}$$

is compared to the investment in equipment, I, plus the stream of slightly lower manufacturing costs, M,

$$I + nM \sum_{y=0}^{L} (1 + i)^{-y}$$

EXHIBIT X-6

OPTIMIZING THE REPAIR/REPLACE DECISION



Since generally a lease rather than buy decision will result from a high cost of capital and a buy rather than make decision will result from the same, these decisions can normally be taken in sequence. Only when a vendor, lessor, or manufacturer has a cost of capital that varies greatly from the industry in general will the sequence lead to an incorrect decision.

APPENDIX A

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVES FOR RAILROAD DATA AND CAR LEASING COMPANY DATA

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE
(Railroad Data)

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
0	0	3008				1.0000
1	0-1	3008	40	230	.9102	.9102
2	1-2	2738	22	13	.9872	.8986
3	2-3	2703	29	8	.9863	.8863
4	3-4	2666	19	11	.9887	.8763
5	4-5	2636	22	26	.9877	.8604
6	5-6	2588	19	15	.9868	.8491
7	6-7	2554	21	15	.9859	.8371
8	7-8	2518	12	16	.9888	.8278
9	8-9	2490	19	16	.9859	.8162
10	9-10	2455	23	14	.9849	.8039
11	10-11	2418	15	13	.9884	.7946
12	11-12	2390	21	20	.9828	.7809
13	12-13	2349	16	10	.9889	.7723
14	13-14	2323	16	16	.9862	.7617
15	14-15	2291	19	10	.9873	.7520
16	15-16	2262	12	11	.9898	.7444
17	16-17	2239	16	11	.9879	.7354
18	17-18	2212	19	15	.9846	.7241
19	18-19	2178	15	11	.9880	.7155
20	19-20	2152	15	9	.9898	.7075
21	20-21	2128	18	12	.9868	.6982
22	21-22	2100	20	10	.9857	.6882
23	22-23	2070	15	6	.9898	.6812
24	23-24	2049	15	8	.9887	.6736
25	24-25	2026	16	15	.9847	.6633
26	25-26	1995	12	2	.9929	.6586
27	26-27	1981	13	13	.9868	.6500
28	27-28	1955	20	14	.9826	.6387
29	28-29	1921	10	17	.9859	.6297
30	29-30	1894	19	10	.9846	.6201
31	30-31	1865	10	8	.9903	.6141
32	31-32	1847	7	18	.9864	.6058
33	32-33	1822	13	15	.9846	.5965
34	33-34	1794	7	12	.9894	.5902
35	34-35	1775	11	11	.9876	.5829
36	35-36	1753	18	5	.9868	.5752
37	36-37	1730	9	2	.9936	.5716
38	37-38	1719	19	14	.9809	.5606
39	38-39	1686	9	9	.9893	.5546
40	39-40	1668	9	19	.9832	.5453

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
41	40-41	1640	8	7	.9908	.5403
42	41-42	1625	8	8	.9901	.5350
43	42-43	1609	4	14	.9888	.5290
44	43-44	1591	5	8	.9918	.5247
45	44-45	1578	7	8	.9905	.5197
46	45-46	1563	4	10	.9910	.5151
47	46-47	1549	11	9	.9870	.5084
48	47-48	1529	7	15	.9856	.5011
49	48-49	1507	17	11	.9814	.4918
50	49-50	1479	4	12	.9891	.4865
51	50-51	1463	11	10	.9856	.4795
52	51-52	1442	6	11	.9882	.4739
53	52-53	1425	5	15	.9859	.4672
54	53-54	1405	8	11	.9864	.4609
55	54-55	1386	10	7	.9877	.4553
56	55-56	1369	8	5	.9905	.4509
57	56-57	1356	5	13	.9867	.4449
58	57-58	1338	6	8	.9895	.4403
59	58-59	1324	7	19	.9803	.4317
60	59-60	1298	13	13	.9799	.4230
61	60-61	1272	8	8	.9874	.4177
62	61-62	1256	8	6	.9888	.4130
63	62-63	1242	7	8	.9879	.4081
64	63-64	1227	10	10	.9837	.4014
65	64-65	1207	6	9	.9875	.3964
66	65-66	1192	8	10	.9849	.3904
67	66-67	1174	5	10	.9872	.3855
68	67-68	1159	5	13	.9844	.3795
69	68-69	1141	9	3	.9894	.3755
70	69-70	1129	4	8	.9893	.3715
71	70-71	1117	8	7	.9865	.3665
72	71-72	1102	6	7	.9882	.3622
73	72-73	1089	7	13	.9816	.3555
74	73-74	1069	4	9	.9878	.3512
75	74-75	1056	1	11	.9886	.3472
76	75-76	1044	5	13	.9827	.3413
77	76-77	1026	5	10	.9853	.3363
78	77-78	1011	4	13	.9832	.3306
79	78-79	994	5	9	.9859	.3260
80	79-80	980	2	7	.9908	.3230
81	80-81	971	4	9	.9866	.3187

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
82	81-82	958	1	8	.9906	.3157
83	82-83	949	5	16	.9778	.3087
84	83-84	928	4	6	.9892	.3054
85	84-85	918	5	7	.9869	.3014
86	85-86	906	5	9	.9845	.2967
87	86-87	892	2	6	.9910	.2941
88	87-88	884	3	11	.9841	.2894
89	88-89	870	1	1[illegible]	.9850	.2851
90	89-90	857		1[illegible]		
91	90-91	846	3	14	.9799	.2794
92	91-92	829	4	9	.9843	.2750
93	92-93	816	5	4	.9889	.2720
94	93-94	807	1	4	.9938	.2703
95	94-95	802	3	15	.9775	.2642
96	95-96	784	4	6	.9872	.2609
97	96-97	774	4	3	.9909	.2585
98	97-98	767		7		
99	98-99	760	3	8	.9855	.2548
100	99-100	749	3	4	.9906	.2524
101	100-101	742	3	4	.9905	.2500
102	101-102	735		6		
103	102-103	729	1	6	.9904	.2476
104	103-104	722		4		
105	104-105	718	6	5	.9847	.2438
106	105-106	707	5	3	.9887	.2411
107	106-107	699	1	4	.9928	.2393
108	107-108	694	2	6	.9884	.2366
109	108-109	686	7	5	.9825	.2325
110	109-110	674	1	10	.9837	.2287
111	110-111	663	3	4	.9894	.2263
112	111-112	656	2	6	.9878	.2235
113	112-113	648	4	3	.9892	.2211
114	113-114	641	4	3	.9890	.2187
115	114-115	634	4	13	.9732	.2128
116	115-116	617	4	12	.9741	.2073
117	116-117	601		3		
118	117-118	598	3	2	.9916	.2056
119	118-119	593	1	6	.9882	.2032
120	119-120	586	2	5	.9880	.2007
121	120-121	579	3	6	.9844	.1976
122	121-122	570	2	7	.9842	.1945

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
123	122-123	561	4	8	.9786	.1903
124	123-124	549	2	5	.9872	.1879
125	124-125	542		5		
126	125-126	537	1	2	.9944	.1869
127	126-127	534	2	8	.9813	.1834
128	127-128	524	2	3	.9904	.1816
129	128-129	519	4	3	.9865	.1792
130	129-130	512	3	4	.9863	.1767
131	130-131	505	1	10	.9782	.1729
132	131-132	494	1	2	.9939	.1718
133	132-133	491	1	12	.9735	.1673
134	133-134	478	3	4	.9853	.1649
135	134-135	471	1	5	.9872	.1628
136	135-136	465	3	6	.9806	.1596
137	136-137	456	1	4	.9890	.1579
138	137-138	451	1	8	.9800	.1547
139	138-139	442	3	5	.9819	.1519
140	139-140	434		3		
141	140-141	431	2	3	.9884	.1502
142	141-142	426	1	3	.9906	.1488
143	142-143	422	2	3	.9881	.1470
144	143-144	417	1	4	.9880	.1452
145	144-145	412	1	1	.9951	.1445
146	145-146	410		3		
147	146-147	407	1	5	.9852	.1424
148	147-148	401		2		
149	148-149	399		2		
150	149-150	397	3	1	.9899	.1410
151	150-151	393	1	7	.9796	.1381
152	151-152	385		5		
153	152-153	380		3		
154	153-154	377	1	4	.9867	.1363
155	154-155	372	1	2	.9919	.1352
156	155-156	369		4		
157	156-157	365	2	1	.9918	.1341
158	157-158	362	1	3	.9889	.1326
159	158-159	358	1		.9972	.1322
160	159-160	357		3		
161	160-161	354		4		
162	161-162	350		4		
163	162-163	346		4		

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
164	163-164	342	2	2	.9883	.1307
165	164-165	338	1	3	.9882	.1292
166	165-166	334		4		
167	166-167	330	1	5	.9818	.1268
168	167-168	324		4		
169	168-169	320	1	3	.9875	.1252
170	169-170	316				
171	170-171	316		2		
172	171-172	314		3		
173	172-173	311		7		
174	173-174	304		1		
175	174-175	303		2		
176	175-176	301		5		
177	176-177	296		2		
178	177-178	294		1		
179	178-179	293		3		
180	179-180	290		3		
181	180-181	287		3		
182	181-182	284		4		
183	182-183	280	1	6	.9750	.1221
184	183-184	273		3		
185	184-185	270				
186	185-186	270		3		
187	186-187	267	1		.9962	.1217
188	187-188	266		1		
189	188-189	265	2	1	.9887	.1203
190	189-190	262		4		
191	190-191	258		1		
192	191-192	257		4		
193	192-193	253		2		
194	193-194	251		3		
195	194-195	248				
196	195-196	248		1		
197	196-197	247		5		
198	197-198	242		3		
199	198-199	239		3		
200	199-200	236		4		
201	200-201	232		3		
202	201-202	229		3		
203	202-203	226		1		
204	203-204	225		1		

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 43.27953
SAMPLE LIFE VARIANCE = 1476.76656
EXPONENTIAL AVERAGE LIFE = 181.51217

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
205	204-205	224		3		
206	205-206	221		1		
207	206-207	220				
208	207-208	220		2		
209	208-209	218		4		
210	209-210	214				
211	210-211	214		214		
212	212+					
TOT			1109	1899		

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE
(Car Leasing Company Data)

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 27.66027
SAMPLE LIFE VARIANCE = 1579.51143
EXPONENTIAL AVERAGE LIFE = 32.45702

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
0	0	72304				1.0000
1	1-9	72304	6166	638	.6290	.6290
2	10-19	45480	4367	623	.6704	.4216
3	20-29	30490	8417	480	.7082	.2986
4	30-39	21593	5379	361	.7341	.2192
5	40-49	15853	3775	304	.7427	.1628
6	50-59	11774	2484	273	.7658	.1247
7	60-69	9017	1851	169	.7760	.0967
8	70-79	6997	1295	143	.7945	.0768
9	80-89	5559	953	110	.8088	.0621
10	90-99	4496	739	86	.8165	.0507
11	100-109	3671	507	75	.8415	.0427
12	110-119	3089	403	65	.8495	.0363
13	120-129	2624	348	66	.8422	.0305
14	130-139	2210	250	32	.8724	.0266
15	140-149	1928	230	28	.8662	.0231
16	150-159	1670	181	32	.8725	.0201
17	160-169	1457	139	24	.8882	.0179
18	170-179	1294	111	29	.8918	.0159
19	180-189	1154	121	18	.8796	.0140
20	190-199	1015	72	16	.9133	.0128
21	200-209	927	65	18	.9105	.0116
22	210-219	844	56	17	.9136	.0106
23	220-229	771	50	14	.9170	.0097
24	230-239	707	46	8	.9237	.0090
25	240-249	653	46	5	.9220	.0083
26	250-259	602	42	10	.9137	.0076
27	260-269	550	21	6	.9509	.0072
28	270-279	523	26	12	.9274	.0067
29	280-289	485	29	5	.9360	.0062
30	290-299	451	14	4	.9601	.0060
31	300-309	433	11	12	.9470	.0056
32	310-319	410	16	8	.9367	.0053
33	320-329	384	15	11	.9324	.0049
34	330-339	358	17	5	.9387	.0046
35	340-349	336	11	9	.9406	.0043
36	350-359	316	13	3	.9455	.0041
37	360-369	300	8	5	.9566	.0039
38	370-379	287	14	2	.9444	.0037
39	380-389	271	10	2	.9558	.0035
40	390-399	259	6	7	.9499	.0034

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 27.68327
SAMPLE LIFE VARIANCE = 1579.91143
EXPONENTIAL AVERAGE LIFE = 32.45702

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
41	400-409	246	4	2	.9757	.0033
42	410-419	240	6	3	.9626	.0032
43	420-429	231	5	3	.9655	.0030
44	430-439	223	6	2	.9642	.0029
45	440-449	215	3	1	.9814	.0029
46	450-459	211	5	1	.9716	.0028
47	460-469	205	6		.9708	.0027
48	470-479	199	4	4	.9599	.0026
49	480-489	191	7	2	.9531	.0025
50	490-499	182	2	5	.9617	.0024
51	500-509	175	2	4	.9659	.0023
52	510-519	169	4	2	.9647	.0022
53	520-529	163	2	3	.9695	.0021
54	530-539	158	2	10	.9245	.0020
55	540-549	146	4	2	.9591	.0019
56	550-559	140	2	2	.9716	.0018
57	560-569	136	3	3	.9562	.0018
58	570-579	130	2	1	.9770	.0017
59	580-589	127	2	6	.9375	.0016
60	590-599	119		5		
61	600-609	114	2	2	.9652	.0016
62	610-619	110	1	2	.9729	.0015
63	620-629	107	1	2	.9722	.0015
64	630-639	104		6		
65	640-649	98	1	3	.9595	.0014
66	650-659	94		3		
67	660-669	91		4		
68	670-679	87	1	4	.9431	.0013
69	680-689	82	2	4	.9277	.0012
70	690-699	76				
71	700-709	76		2		
72	710-719	74		1		
73	720-729	73		2		
74	730-739	71				
75	740-749	71	1		.9861	.0012
76	750-759	70		2		
77	760-769	68				
78	770-779	66		3		
79	780-789	65	1	1	.9696	.0012
80	790-799	63				
81	800-809	63		1		

ESTIMATION OF NON-PARAMETRIC SURVIVAL CURVE

TYPE REPAIRS SELECTED = 0-9.9

SAMPLE AVERAGE LIFE = 27.68027
SAMPLE LIFE VARIANCE = 1579.91143
EXPONENTIAL AVERAGE LIFE = 32.45702

PERIOD	TIME TO FAILURE	NUMBER SURVIVING BEFORE PERIOD	OBSERVATIONS COMPLETE	OBSERVATIONS CENSORED	SURVIVAL RATE	PROPORTION SURVIVING
82	810-819	62		1		
83	820-829	61				
84	830-839	61		1		
85	840-849	60		1		
86	850-859	59		4		
87	860-869	55				
88	870-879	55				
89	880-889	55				
90	890-899	55				
91	900-909	55				
92	910-919	55				
93	920-929	55		1		
94	930-939	54		1		
95	940-949	53				
96	950-959	53				
97	960-969	53				
98	970-979	53				
99	980-989	53				
100	990-999	53		1		
101	1000+	52				
102	1010+	52		1		
103	1020+	51				
104	1030+	51				
105	1040+	51				
106	1050+	51				
107	1060+	51				
108	1070+	51				
109	1080+	51				
110	1090+	51		51		
TOT			68404	3900		

APPENDIX B

SAMPLING STRATEGY FOR ESTIMATION OF FREIGHT CAR MAINTENANCE RELATIONS

APPENDIX B

SAMPLING STRATEGY FOR ESTIMATION OF FREIGHT CAR MAINTENANCE RELATIONS

For practical reasons, a two-round sampling strategy is recommended to develop freight car maintenance relations. A modest first-round sample can be used to test suitable functional forms. This preliminary analysis determines the total sample requirements to achieve satisfactory statistical precision. On this basis, the sample for analysis can be augmented in a second-round sample to achieve precision objectives.

WHY A SAMPLE (OF A SAMPLE)?

The data files available from the railroad (UMLER, CRB, and car movement records) represent a 7 month history of repairs and operating statistics for roughly 100,000 cars. The statistician is often tempted to use all the data available to him/her, but it is not practical for the railroad, the car leasing company, and most firms to which the methodology will be applied.

The predominant reason for selecting a sample is that the typical data base is too large. The merged data for the railroad consume over 200 magnetic tape reels. For data processing reasons, it is not feasible to work with this much material.

Fortunately, using only a sample from a large data base does not present severe limitations. In a sense, the total set of car histories represents a sample itself, since it covers only a limited period of operations. Thus there is nothing "sacred" about using the "total" sample, since it is not really complete anyway. Using a "total" sample of the car histories would provide no greater validity to the study, since the time span limitation is far more critical.

ANALYSIS OBJECTIVES

Sampling objectives must be defined before sampling strategies are discussed. There are two fundamental analysis objectives:

Objective 1 - To find predictive relations of maintenance activity by car descriptive and utilization factors.

Objective 2 - To achieve an acceptable level of precision on the parameters (coefficients of the independent variables) for each relation developed.

Objective 1 relates to the particular form chosen and not directly to sample size. The degree of attainment of Objective 1 is measured by the multiple coefficient of correlation (R^2), the standard error of estimate, and the residuals (difference between actual and estimated values). All of these statistics are provided by most statistical packages (e.g., SPSS, BMD).

Objective 2 relates directly to sample size. As a rule, the larger the sample size, the greater the precision that is realized. Although very specific objectives should be avoided before the analysis begins, there is a recommended measure for the precision of the regression coefficients. For example, the estimated coefficients should be within $\pm$ 10 percent or $\pm$ 20 percent of the "true" coefficient value. The "true" coefficient is an abstract term denoting the coefficient value that might be obtained by an infinite sample. The values $\pm$ 10 percent and $\pm$ 20 percent are not a particular recommendation; the value will depend on the number of coefficients in the given relation and other practical considerations.

The attainment of Objective 2 may be measured by analysis of the regression output. Specifically, the output provides the standard error of each estimated coefficient. Based on the standard error, a 95 percent confidence interval for the "true" coefficient is computed:

$$\text{confidence interval} = (a \pm tSE_a)$$

where: a is the estimated coefficient;
t is the value of the student's t distribution for the 95 percent level (approximately 1.96 for large samples); and
SE_a is the standard error of the estimated coefficient.

In the example for $\pm$20 percent precision, the objective is attained if the extreme edge of the confidence interval does not exceed 20 percent more than the coefficient itself. That is, if

$$tSE_a < .20a$$

Note: All computations in these notes ignore the finite population correction factor, since comparisons are made to the "true," as opposed to the total, sample value. In the latter comparison, the addend in the confidence interval should be factored by

$$\sqrt{\frac{N - n}{N}}$$

where N is the total universe size, and n is the sample size. Effectively, this results in a more "lenient" analysis.

SAMPLING STRATEGY

Given the criteria explained above, the proper sample of cars must be selected. There are no universal or magic constraints that dictate sample size requirements; the size is determined from the characteristics of the data and the hypothetical relation to be estimated. In other words, we must sample the data base to find how large a sample is needed.

This is accomplished economically by first selecting a modest random sample of cars. In this study, samples of 1,000 and 2,000 car histories were used for the railroad and the car leasing company, respectively. Sample sizes in this range are quite sufficient for the first round. With this practical data base, the hypothetical relations are tested with the regression programs. If acceptable precision is not achieved for the parameters of the relations, the sample will be augmented to achieve the precision requirements.

The expected margin of error for the estimation is equated with the chosen tolerance for error (example $\pm$ 20 percent):

expected confidence interval = tSE_a or $t\frac{s}{\sqrt{n}} = .20\, a$ = selected precision

where s is the standard deviation based on the initial sample.

This yields a sample size requirement of:

$$n = \left(\frac{ts}{.20\, a}\right)^2$$

Note that $\pm$ 10 percent precision requires four times the sample size corresponding to $\pm$ 20 percent precision.

For each parameter and each relation desired, the total usable sample size required is computed with the above equation. The maximum of all computed puted requirements, n*, is the total usable sample size required. To determine the number of additional cars to select, the initial sample size is subtracted from n* and this result is divided by the usable data percent rate. In the initial sample for the railroad, 4 percent of the cars selected had no records assignable; thus the usable data rate is 96 percent.

SUMMARY

The sampling strategy is comprised of seven steps:

Step 1 - Select a modest sample of cars for preliminary analysis (1,000-2,000 car histories).

Step 2 - Postulate freight car maintenance relations (form and specific variables).

Step 3 - Perform regression on postulated relations for the sample selected in Step 1.

Step 4 - Analyze relations for degree of prediction. Repeat Steps 2 and 3 until Objective 1 is attained or deemed unattainable.

Step 5 - Compute required sample size for each relation which was developed.

Step 6 - Select additional cars to achieve total usable sample size requirements.

Step 7 - Perform regression on augmented sample to verify that parameters are within precision requirements. (If not, repeat Steps 5 and 6.)

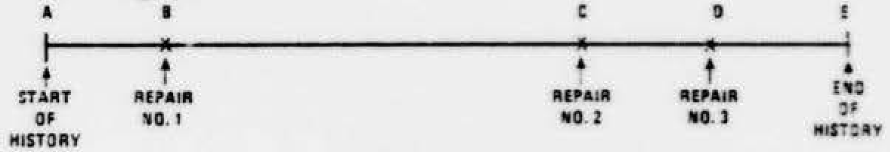
APPENDIX C

COMPUTATION OF NON-PARAMETRIC SURVIVAL CURVES

Procedure IRWVIVA was written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler. Its purpose is to compute and tabulate non-parametric survival curves for the car-leasing company's car repair history data. A comparable procedure, IRWVIVE, was prepared to compute and tabulate non-parametric survival curves for the railroad's freight car repair history data.

Non-parametric survival data are tabulated for one or more PMM&Co. major repair categories. Entries are printed for each period, a 10-day period being used for the car-leasing company's data and a 1-day period for the railroad's data. Columns contain time (days) to failure, the number of cars surviving before the period, the number of complete and censored observations, the survival rate, and the proportion surviving.

The distinction between a complete and a censored observation may be seen in the following exhibit:



Intervals A-B and D-E are censored observations. Intervals B-C and C-D are complete observations.

The number of cars surviving before each period is computed as follows:

```
COUNT(0)=SUM(COMP)+SUM(CENS);
  DO N=1 TO H;
  R=N-1;
  COUNT(N)=MAX(0,COUNT(R)-COMP(R)-CENS(R));
  END;
```

where COMP and CENS are vectors containing complete and censored observations and H is the number of periods.

The survival rate is computed as follows:

```
DO N=0 TO H;
TEMP=COUNT(N)+1;
IF TEMP=0
  THEN RATE(N)=0;
  ELSE RATE(N)=MAX(0,(TEMP-COMP(N)-CENS(N))/TEMP);
END;
```

The proportion surviving is computed as follows:

```
PROP(0)=1;
R=0;
  DO N=1 TO H;
  IF COMP(N) > 0
    THEN DO;
    PROP(N)=RATE(N)*PROP(R);
    R=N;
    END;
  END;
```

The sample average life (AVG), the sample life variance (SLV), and the exponential average life are also computed and printed for each table. They are computed as follows:

```
  DO N=0 TO H;
  AVG=AVG+MID(N)*COMP(N);
  CUMF=CUMF+COMP(N);
  SUM4P=SUM4P+COMP(N);
  SUM4PP=SUM4PP+COMP(N)*MID(N);
  SUM5PP=SUM5PP+CENS(N)*MID(N);
  SUM4PPBAR=SUM4PPBAR+COMP(N)*MID(N);
  SUM4PPBAR2=SUM4PPBAR2+COMP(N)*(MID(N)**2);
  END;
IF CUMF=0
  THEN AVG=0;
  ELSE AVG=AVG/CUMF;
TEMP=SUM4P*(SUM4P-1);
IF TEMP=0
  THEN SLV=0;
  ELSE SLV=(SUM4PPBAR2*SUM4P-SUM4PPBAR**2)/TEMP;
IF SUM4P=0
  THEN EAL=0;
  ELSE EAL=(SUM4PP+SUM5PP)/SUM4P;
```

where CUMF, SUM4P, SUM4PP, SUM5PP, SUM4PPBAR, and SUM4PPBARZ are working variables with initial values of O.

The procedures to compute non-parametric survival curves are not difficult to write; data processing obstacles are the chief problem.

Over the period of a single year, a typical Class I railroad will generate several million repair incidents. PMM&Co. processing was always performed on a restricted sample of these incidents. The sampling procedure itself can be quite time-consuming and expensive. Moreover, special input data must be prepared for the non-parametric survival curve programs. These data must combine information derived from two sources--namely, the UMLER File and the Freight Car History File--and merged.

Thus, although the results of the program may be interesting, the preparation of this information may represent too extensive an effort to be practical, unless associated data processing is also being performed.

The development of procedure IRWVIVE required approximately 4 hours of an expert programmer's time. Its modification as procedure IRWVIVA required an additional 2 hours. Preprocessing procedures required approximately 16 hours to develop.

All procedures were written in PL/I, an advanced, highly flexible programming language which facilitates program development.

Approximately 4 hours of CPU time on an IBM 370/155 was needed for all aspects of program development and data preparation. However, this did not include the cost of the extraction of sample cars from the complete Freight Car History Files. These extractions were performed by the railroad itself and undoubtedly required several hours of CPU time.

TECHNICAL APPENDIX

PROCEDURE NAME: IRWFCAR, A procedure to extract data for sample cars from the NW Freight Car History File.

AUTHOR: Robert W. Whitaker
Peat, Marwick, Mitchell & Co.
1025 Connecticut Avenue, N.W.
Washington, D.C. 20036
(202) 223-9525

LANGUAGE: Procedure IRWFCAR is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWFCAR is to extract material pertaining only to sample cars from the freight car history file. Inputs are the sample profile and the entire freight car history file. A version of the freight car history file containing only data for sample records is output. The freight car history file must be in sort by car identification (columns 1-10).

PROCEDURE IRWFCAR JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWFCAR. The REGION and TIME parameters may be specified. A REGION of 144K and a TIME of 15 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWFCAR execution time parameters.
	
	Example:
	//IRWFCAR EXEC PGM=IRWFCAR,REGION=144K,TIME=15,
	// PARM=('/ID=''EXTRACT SAMPLE CARS''','YEAR=76',
	// 'LOW.MONTH=1','HIGH.MONTH=7')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWFCAR load module.

C.5

PROCEDURE IRWFCAR JCL STATEMENTS, CONTINUED

Statement	Contents
	Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWFCAR,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWFCAR may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the sample car profile. Its assumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 80. Example: //SYSUT1 DD DSN=PMMCO.UMLER.SAMPLE,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the entire set of the freight car history data. Its assumed record characteristics are RECFM=FB and LRECL=130. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 130. Example: //SYSUT2 DD DSN=PMMCO.HISTORY.CAR.RECODED,DISP=(SHR,PASS)
SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a

PROCEDURE IRWFCAR JCL STATEMENTS, CONTINUED

Statement	Contents

	physical sequential output file where a version of the freight car history file containing only sample cars may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=130 and BLKSIZE=3120.
	
	Example:
	//SYSUT3 DD DSN=PMRCO.HISTORY.CAR.SAMPLED,UNIT=333C,
	// VOL=SER=PMRPAK,SPACE=(TRK,(19C,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWFCAR execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWFCAR-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWFCAR as REPORT and ISA(1CK), are adequate, and they may be omitted. Procedure IRWFCAR parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWFCAR PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''EXTRACT SAMPLE CARS'''
YEAR	The YEAR parameter may be used to indicate the year to be associated with extracted data. Its default value is 0. Example: 'YEAR=76'

PROCEDURE IRWFCAR PARM PARAMETERS, CONTINUED

Parameter	Contents
LOW.MONTH	The LOW.MONTH parameter may be used to indicate the lower in a range of months to be associated with extracted data. Its default value is 0. Example: 'LOW.MONTH=1'
HIGH.MONTH	The HIGH.MONTH parameter may be used to indicate the higher in a range of months to be associated with extracted data. Its default value is 0. Example: 'HIGH.MONTH=7'
STOPAFT	The STOPAFT parameter may be used to specify the maximum number of records to be read from file SYSUT2. When it is greater than zero, file SYSUT2 will be treated as though an end of file had been encountered after STOPAFT records have been read. Its default value is 0. Example: 'STOPAFT=5000'

PROCEDURE NAME: IRWCATS, A procedure to transform job codes in the Freight Car History File to their PMM&Co. equivalents.

AUTHOR: Robert W. Whitaker
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(202) 223-9525

LANGUAGE: Procedure IRWCATS is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWCATS is to substitute PMM&Co. equivalent job codes for the C.R.B. codes originally to be found in the Freight Car History File. The Freight Car History File containing sample cars is input together with a file of data statements relating PMM&Co. job codes to their C.R.B. job code and qualifier equivalents. A transformed Freight Car History File is output.

PROCEDURE IRWCATS JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWCATS. The REGION and TIME parameters may be specified. A REGION of 144K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWCATS execution time parameters.
	
	Example:
	`//IRWCATS EXEC PGM=IRWCATS,REGION=144K,TIME=2,`
	`// PARM=('/ID=''CONVERT JOB CODES''','PROB=0.01')`

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWCATS load module. Example:

PROCEDURE IRWCATS JCL STATEMENTS, CONTINUED

Statement	Contents
	//STEPLIB DD DSN=PMMCO.LOAD.IRWCATS,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWCATS may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state- may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the freight car history data which applies to sample cars. Its assumed record characteristics are RECFM=FB and LRECL=130. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 130. Example: //SYSUT1 DD DSN=PMMCO.HISTORY.CAR.SAMPLED,DISP=(SHR,PASS)

SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential output file containing freight car history data applying to sample cars and with transformed job codes. Its record characteristics are predefined as RECFM=FB, LRECL=130 and BLKSIZE=3120.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.HISTORY.CAR.PMMCODE,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

PROCEDURE IRWCATS JCL STATEMENTS, CONTINUED

Statement	Contents
SYSIN DD	The purpose of the SYSIN DD statement is to define a physical sequential input file where data statements defining the relationship between PMM&Cc. job codes and C.R.B. job codes and qualifiers may be placed. Its assumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE is taken from the SYSIN DD statement, the file label or may default to 80. Example: //SYSIN DD *

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWCATS execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWCATS-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWCATS as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWCATS parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWCATS PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CONVERT JOB CODES'''
PROB	The PROB parameter may be used to specify the probability that a particular job code transformation be formatted. Its default value is 0.

PROCEDURE IBWCATS PARM PARAMETERS, CONTINUED

Parameter	Contents
	Example: 'PROB=0.01'
STOPAFT	The STOPAFT parameter may be used to specify the maximum number of records to be read from file SYSUT1. When it is greater than zero, file SYSUT1 will be treated as though an end of file had been encountered after STOPAFT records have been read. Its default value is 0. Example: 'STOPAFT=5000'

JOB CODE TRANSFORMATION DATA STATEMENTS:

Job code transformation data statements are in the following format:

```
    CATEGORY=category-number
      CLIST='CRB-job-code-list'
      QLIST='qualifier-list';
```

where CLIST and QLIST are optional. The data statements actually used may be found in the following table.

DATA STATEMENTS INPUT TO PROCEDURE IBWCATS

```
+----------------------------------------------------------------------+
|CATEGORY=1.1                                                          |
|CLIST='1000,1008,1012,1016,1020,1024,1028,1032,1036,1040,1044,1046,   |
|   1048,1052,1060,1062,1064,1080,1092,1094,1116,1140,1144';           |
|CATEGORY=1.2                                                          |
|QLIST='AA,AB,AC,AK,AJ,AL,AM'                                          |
|CLIST='1296,1300,1304,1308,1312,1316,1320,1340,1424,1428,1432,1436,   |
|   1440,1444,1448,1452,1454,1456,1592,1596,1600,1604,1608,1612';      |
|CATEGORY=1.3                                                          |
|QLIST='DB,DC'                                                         |
|CLIST='1520,1524,1528,1532,1536';                                     |
|CATEGORY=1.4                                                          |
|QLIST='AH,CS,CV,CW,CX,CY,CZ,DA,DJ'                                    |
|CLIST='1344,1348,1352,1356,1360,1380,1384,1388,1392,1396,1400,1404';  |
|CATEGORY=1.5                                                          |
|QLIST='BK,BL,DL'                                                      |
|CLIST='1476,1480,1484,1488,1496';                                     |
|CATEGORY=1.6                                                          |
+----------------------------------------------------------------------+
```

DATA STATEMENTS INPUT TO PROCEDURE IRWCATS, CONTINUED

```
+------------------------------------------------------------------------+
|QLIST='DD,DE'                                                           |
|CLIST='1556,1560,1564,1568,1572,1576,1578,1584,1574';                   |
|CATEGORY=1.7                                                            |
|CLIST='1828,1830,1836,1838,1840,1852';                                  |
|CATEGORY=1.8                                                            |
|QLIST='BE,BF,BW,BX,BY,BZ,CA,CB,CC,CD,CE,CF,CG,CH,CI,CJ,CK,CL,CM,CN,     |
|   CO,CP,CQ'                                                            |
|CLIST='1856,1860,1864,1868,1872,1876,1888,1892,1894,1904,1916,1920,     |
|   1936,1940,1944,1960,1964,1968,1972,1976,1980';                       |
|CATEGORY=1.9                                                            |
|QLIST='AD,AE,AF,AG,AN,AP,AQ,AR,AS,AT,AU,AV,AW,AX,AY,AZ,BA,BB,BC,BD,     |
|   BH,BJ,BG,BM,BN,BP,BQ,BR,BS,BT,BU,BV,CR,CT,DF,DG,DH,DK,DM,DN,DO,DP,  |
|   DQ,DR,DS,DT,DU,DV,DW,DX,DY,EB,EC,ED,EE,EF,EG'                        |
|CLIST='1160,1165,1166,1172,1176,1180,1184,1188,1192,1196,1200,1204,     |
|   1208,1212,1216,1220,1224,1228,1232,1236,1240,1244,1260,1272,1276,    |
|   1492,1628,1648,1652,1656,1660,1664,1668,1672,1676,1692,1696,1708,    |
|   1720,1724,1740,1744,1748,1764,1768,1772,1776,1792,1796,1800,1804,    |
|   1808,1812,1264,1268,1168';                                           |
|CATEGORY=2.1                                                            |
|QLIST='HZ,JA'                                                           |
|CLIST='2052,2054,2056';                                                 |
|CATEGORY=2.2                                                            |
|QLIST='HR,HS,HT,HU,HV,HW,HX,HY,JB,JC,JD,JE,JF,JG,JH,JJ,JS,JT,JU,JV,     |
|   JW'                                                                  |
|CLIST='2008,2012,2016,2017,2020,2028,2032,2036,2042,2046,2047,2064,     |
|   2068,2072,2076,2080,2088,2092,2104,2108,2116,2124,2128,2136,2142,    |
|   2148,2152,2160,2184,2187,2188,2204,2212,2216,2222,2228,2232,2234,    |
|   2236,2241,2252,2256,2260,2264,2268,2272,2276';                       |
|CATEGORY=2.3                                                            |
|QLIST='JX,JY,JZ'                                                        |
|CLIST='2300,2301,2304,2308,2312,2313,2314,2316,2317,2320,2350,2354,     |
|   2355,2356,2358,2309,2352';                                           |
|CATEGORY=2.4                                                            |
|QLIST='JK,JL,JM,JN,JP,JQ,JR'                                            |
|CLIST='2400,2404,2408,2416,2420,2428,2432,2436,2452,2456,2460,2464';    |
|CATEGORY=3.1                                                            |
|QLIST='EA,EH,EJ,EN,EP,FF,FG'                                            |
|CLIST='3500,3504,3508,3512,3520,3524,3528,3532,3536,3540,3556,3560,     |
|   3564,3568,3572,3516,3576,3580';                                      |
|CATEGORY=3.2                                                            |
|QLIST='FJ,FK,FL'                                                        |
|CLIST='3700,3704,3708,3712,3716,3720,3724,3728,3732,3736,3740,3748,     |
|   3752,3772,3784,3788,3792,3796';                                      |
|CATEGORY=3.3                                                            |
+------------------------------------------------------------------------+
```

DATA STATEMENTS INPUT TO PROCEDURE IRWCATS, CONTINUED

```
+--------------------------------------------------------------------------+
|QLIST='FD,FE,FM'                                                          |
|CLIST='3850,3854,3858,3862,3900,3904,3908,3912,3916,3920,3924,3928,       |
|  3932,3940,3944,3948,3952,3956,3960,3964,3968';                          |
|CATEGORY=3.4                                                              |
|QLIST='FA,FB,FC,FH';                                                      |
|CATEGORY=4.1                                                              |
|CLIST='2500,2520,2524,2528';                                              |
|CATEGORY=4.2                                                              |
|CLIST='2550,2552,2554,2558';                                              |
|CATEGORY=4.3                                                              |
|QLIST='EQ,ER,ES,ET,EU,EV,EW'                                              |
|CLIST='2600,2604,2608,2612,2620,2624,2628,2632,2640,2644,2648,2670,       |
|  2674,2678,2682,2690,2694,2698,2714,2730,2750,2754,2758,2762,2766,       |
|  2770,2778,2786,2794';                                                   |
|CATEGORY=4.4                                                              |
|QLIST='EK,EL,EM,EX,EY,EZ'                                                 |
|CLIST='2800,2804,2812,2816,2820,2822,2824,2828,2840,2856,2860,            |
|  2864,2868,                                                              |
|  2870,2874,2878,2882';                                                   |
|CATEGORY=4.5                                                              |
|CLIST='3200,3202,3204,3206,3208,3230,3232,3234,3236';                     |
|CATEGORY=4.6                                                              |
|CLIST='3252,3254,3256,3270,3272,3274,3276,3278';                          |
|CATEGORY=5.0                                                              |
|CLIST='3150,3160,3170,3180';                                              |
|CATEGORY=5.1                                                              |
|CLIST='3000,3001,3020,3021,3022,3051,3070,3071,3005,3006,3025,3075';      |
|CATEGORY=5.2                                                              |
|CLIST='3030,3031,3032,3080,3081,3082,3110,3035,3085';                     |
|CATEGORY=5.3                                                              |
|CLIST='3010,3011,3012,3040,3041,3042,3043,3090,3091,3092,3093,3121,       |
|  3122,3045,3095';                                                        |
|CATEGORY=6.1                                                              |
|QLIST='LG,LH,LJ,LK,LL,LM,LN,LP,LQ,LR,LS,LT,LU,LV,LW,LX,LY,LZ,MA,MB,       |
|  MC,MD,ME'                                                               |
|CLIST='4500,4504,4508,4512,4516,4520,4524,4528,4532,4534,4536,4538,       |
|  4544';                                                                  |
|CATEGORY=6.3                                                              |
|QLIST='RS,RI';                                                            |
|CATEGORY=7.1                                                              |
|QLIST='MX,MY,MZ,NA,NB,NC'                                                 |
|CLIST='4550,4554,4558,4562,4564';                                         |
|CATEGORY=7.3                                                              |
|QLIST='QU,EG,MN';                                                         |
+--------------------------------------------------------------------------+
```

DATA STATEMENTS INPUT TO PROCEDURE IRWCATS, CONTINUED

```
+------------------------------------------------------------------------+
|CATEGORY=7.5                                                            |
|QLIST='KG,KH,KM';                                                       |
|CATEGORY=7.6                                                            |
|QLIST='SC,SL,SM,SN,SP,SQ,SR,SS,ST,SU,SV,SW,SX,SY,SZ,TA,TB';             |
|CATEGORY=8.1                                                            |
|QLIST='KR,KS,KE,KF,MM,MT,NF,NG,NJ,PD,PE,PF,PH,QH,QJ,QK,QL,QT,QX,RA,     |
|  RB,NH'                                                                |
|CLIST='4000,4004,4008,4012,4016,4020,4050,4062,4066,4580,4017,4018,     |
|  4584,4588,4596,4592';                                                 |
|CATEGORY=8.2                                                            |
|QLIST='KA,KB,KT,PV,PW,QF,QG'                                            |
|CLIST='4300,4320,4324,4328,4332,4354,4358,4362,4366,4368,4624,4462,     |
|  4600,4604,4608,4612,4616,4620';                                       |
|CATEGORY=8.3                                                            |
|QLIST='QY,QZ,QR,QS,QV,QW,RU,RZ,PB';                                     |
|CATEGORY=8.4                                                            |
|QLIST='MH,MJ,MK,ML,MP,MQ,MR,KD,KK,RX,RY'                                |
|CLIST='4468,4464';                                                      |
|CATEGORY=8.5                                                            |
|QLIST='MS,QC,PZ,QA,QB,QD,KJ,KN,KP,RZ';                                  |
|CATEGORY=8.6                                                            |
|QLIST='NK,NL,NM,NN,NS,NT,NU,NV,NW,NX,NY,MF,MG,KV,KW,KX,PL,PM,PN,PP,     |
|  PR,PS,PT,PU,PX';                                                      |
|CATEGORY=8.7                                                            |
|QLIST='FP,FQ,FR,FS,FT,FU,FV,FW,FX,FY,FZ,GA,GB,GC,GD,GE,GF,GG,GH,GJ,     |
|  GK,GL,GM,GN,GP,GQ,GR,GS,GT,GU,GV,GW,GX,GY,GZ,HA,HB,HC,HD,HE,HF,HG,    |
|  HH,HJ,HK,HL,HM,HN,HP,HQ,QQ';                                          |
|CATEGORY=8.8                                                            |
|QLIST='KL,KQ,KU,KY,KZ,LA,LB,LC,LD,LE,LF,ND,NE,NZ,PC,PJ,PK,PY,QE,RU,     |
|  RV,RW';                                                               |
|CATEGORY=8.9                                                            |
|QLIST='RC,RD,RE';                                                       |
|CATEGORY=9.1                                                            |
|QLIST='TN,TP,TQ,TR,TS,TT,TU,TV,TW,TX,TY,TZ,UA,UB,UC,UD,UE,UF,UG,UH,     |
|  UJ,UK,UL,UM,UN,UP,UQ,UR,US,UT,UU,UV,UW,UX,UY,UZ,VA,VB,VC,VD,VE,VF,    |
|  VG,VH,VJ,VK,VL,VM,VN,MU,MV,MW'                                        |
|CLIST='4108,4132,4455,4599';                                            |
|CATEGORY=9.2                                                            |
|QLIST='SJ,SK,TC,TD,TE,TF,TG,TH,TJ,TK,TL,SE,SF,SG,SH'                    |
|CLIST='5000,5600,2570';                                                 |
|CATEGORY=9.3                                                            |
|QLIST='SD,TM';                                                          |
|CATEGORY=9.4                                                            |
|QLIST='PA,QM,QN,QP,RG,SA';                                              |
+------------------------------------------------------------------------+
```

DATA STATEMENTS INPUT TO PROCEDURE IRWCATS, CONTINUED

```
+----------------------------------------------------------------+
|CATEGORY=0.0                                                    |
|QLIST='KC,NP,NQ,NR,RF,RL,SB,ZA,ZB,ZC,ZD,ZE,ZF,ZG,ZH'            |
|CLIST='4400,4472,4476,0637';                                    |
+----------------------------------------------------------------+
```

PROCEDURE NAME: IRWXUML, a procedure to extract data for sample cars from the NW and TT UMLER Files

AUTHOR: Robert W. Whitaker
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LANGUAGE: Procedure IRWXUML is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWXUML is to extract material pertaining only to sample cars from the UMLER file. Inputs are the sample profile and the entire UMLER file. A version of the UMLER file containig only data for sample records is output. The UMLER file must be in sort by car identification (columns 3-16). (Note: this program must be specially compiled to handle the particular UMLER in question. The version reported here is for the TT UMLER.)

PROCEDURE IRWXUML JCL STATEMENTS

Statement	Contents
EXEC	The purpose of the EXEC statement is to invoke procedure IRWXUML. The REGION and TIME parameters may be specified. A REGION of 140K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I execution time parameters. Example: //IRWXUML EXEC PGM=IRWXUML,REGION=140K,TIME=2
STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWXUML load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWXUML,DISP=(SHR,PASS)

PROCEDURE IRWXUML JCL STATEMENTS, CONTINUED

Statement	Contents
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWXUML may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSOUT DD	The purpose of the SYSOUT DD statement is to define a SYSOUT file where the SORT/MERGE procedure may place messages during execution. Its record characteristics are predefined. Example: //SYSOUT DD SYSOUT=A
SORTLIB DD	The purpose of the SORTLIB DD statement is to define a load library to which the SORT/MERGE procedure may link during execution. Example: //SORTLIB DD DSN=SYS1.SORTLIB,DISP=(SHR,PASS)
SORTWK01 DD thru SORTWK06 DD	The purpose of the SORTWK DD statements is to define from 3 to 6 scratch files for use by the SORT/MERGE procedure during execution. Example: //SORTWK01 DD UNIT=SYSDA,SPACE=(CYL,2,,CONTIG)
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a

PROCEDURE IRWXUML JCL STATEMENTS, CONTINUED

Statement	Contents
	physical sequential input file containing the sample car profile. Its assumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 80. Example: //SYSUT1 DD DSN=PMMCO.TT.UMLER.SAMPLE,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the entire UMLER file. Its assumed record characteristics are RECFM=FB and LRECL=198. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 198. Example: //SYSUT2 DD DSN=PMMCO.TT.DATA.CAR,DISP=(SHR,PASS)

SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a version of the UMLER file containing only sample cars may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=198 and BLKSIZE=4158.
	
	Example:
	//SYSUT3 DD DSN=PMMCO.TT.DATA.CAR.SAMPLED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

PROCEDURE NAME: IBWCARS, A procedure to convert NW UMLER data to the basic combined format.

AUTHOR: Robert W. Whitaker
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(202) 223-9525

LANGUAGE: Procedure IBWCARS is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IBWCARS is to convert the NW UMLER file to the basic combined format.

PROCEDURE IBWCARS JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IBWCARS. The REGION and TIME parameters may be specified. A REGION of 120K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IBWCARS execution time parameters.
	
	Example:
	//IBWCARS EXEC PGM=IBWCARS,REGION=120K,TIME=2,
	// PARM=('/ID=''CREATE COMBINED FORMAT''','PROB=C.C1')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IBWCARS load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IBWCARS,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IBWCARS may place messages

PROCEDURE IRWCARS JCL STATEMENTS, CONTINUED

Statement	Contents
	during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state- may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the NW UMLER data. Its assumed record characteristics are RECFM=FB and LRECL=213. Its BLKSIZE may be taken from the SYSUT1 DD statement, the file label or may default to 213. Example: //SYSUT1 DD DSN=PMMCO.SAMPLED.DATA.CAR,DISP=(SHR,PASS)

SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential output file containing records in the combined format with data extracted from the UMLER file. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.BASE.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

SYSIN DD	The purpose of the SYSIN DD statement is to define a physical sequential input file where data statements defining the relationship between PMM&Co. job codes and C.R.B. job codes and qualifiers may be placed. Its as-

PROCEDURE IRWCARS JCL STATEMENTS, CONTINUED

Statement	Contents
	sumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE is taken from the SYSIN DD statement, the file label or may default to 80. Example: //SYSIN DD *

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWCARS execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWCARS-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWCARS as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWCARS parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWCARS PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CREATE COMBINED FORMAT'''
PROB	The PROB parameter may be used to specify the probability that a particular output record be formatted. Its default value is 0. Example: 'PROB=0.01'

PROCEDURE NAME: IRWPAIR, A procedure to create a unit record for each repair record.

AUTHOR: Robert W. Whitaker
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LANGUAGE: Procedure IRWPAIR is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWPAIR is to create a basic combined format record for each repair record. Inputs are the freight car history file for sample cars and the basic combined data file. An updated version of the combined data file is output.

PROCEDURE IRWPAIR JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWPAIR. The REGION and TIME parameters may be specified. A REGION of 140K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWPAIR execution time parameters.
	
	Example:
	//IRWPAIR EXEC PGM=IRWPAIR,REGION=140K,TIME=2,
	// PARM=('/ID=''CREATE COMBINED RECORDS FOR PAIRS''',
	// 'PROB=0.01','CARID=''NW C89220''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWPAIR load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWPAIR,DISP=(SHR,PASS)

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PROCEDURE IRWPAIR JCL STATEMENTS, CONTINUED

Statement	Contents
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWPAIR may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statement may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSOUT DD	The purpose of the SYSOUT DD statement is to define a SYSOUT file where the SORT/MERGE procedure may place messages during execution. Its record characteristics are predefined. Example: //SYSOUT DD SYSOUT=A
SORTLIB DD	The purpose of the SORTLIB DD statement is to define a load library to which the SORT/MERGE procedure may link during execution. Example: //SORTLIB DD DSN=SYS1.SORTLIB,DISP=(SHR,PASS)
SORTWK01 DD thru SORTWK06 DD	The purpose of the SORTWK DD statements is to define from 3 to 6 scratch files for use by the SORT/MERGE procedure during execution. Example: //SORTWK01 DD UNIT=SYSDA,SPACE=(CYL,2,,CONTIG)
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a

PROCEDURE IRWPAIR JCL STATEMENTS, CONTINUED

Statement	Contents
	physical sequential input file containing the freight car history file for sample cars. Its assumed record characteristics are RECFM=FB and LRECL=130. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 130. Example: //SYSUT1 DD DSN=PMMCO.HISTORY.CAR.SAMPLED,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the basic combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 120. Example: //SYSUT2 DD DSN=PMMCO.BASE.DATA.COMBINED,DISP=(SHR,PASS)

SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a version of the combined data file containing records for repair pairs may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT3 DD DSN=PMMCO.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWPAIR execution time parameters. Its format is as follows:

    PARM=('PL/I-parameters/IRWPAIR-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWPAIR as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure

IRWPAIR parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWPAIR PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CREATE COMBINED RECORDS FOR PAIRS'''
SORT	The SORT parameter may be used to indicate the quantity of core to be allocated to the SORT/MERGE procedure. Its default value is 30000. Example: 'SORT=40000'
PROB	The PROB parameter may be used to specify the probability that any one combined record output will be printed. Its default value is 0. Example: 'PROB=0.01'
CARID	The CARID may be used to specify any car-id for which the combined record is to be printed. Its default value is a null string. Example: 'CARID=''NW 089220'''

PROCEDURE NAME: IRWPDST, A procedure to complete and sort the Per Diem Comparison data file.

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LANGUAGE: Procedure IRWPDST is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWPDST is to supply the car initials when they are missing and to sort the resulting file by month within year within car-id. The unsorted Per Diem Comparison data file is input and a sorted version of the same is output.

PROCEDURE IRWPDST JCL STATEMENTS

Statement	Contents
EXEC	The purpose of the EXEC statement is to invoke procedure IRWPDST. The REGION and TIME parameters may be specified. A REGION of 120K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I execution time parameters. Example: //IRWPDST EXEC PGM=IRWPDST,REGION=120K,TIME=2
STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWPDST load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWPDST,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWPDST may place messages

PROCEDURE IRWPDST JCL STATEMENTS, CONTINUED

Statement	Contents
	during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state-may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSOUT DD	The purpose of the SYSOUT DD statement is to define a SYSOUT file where the SORT/MERGE procedure may place messages during execution. Its record characteristics are predefined. Example: //SYSOUT DD SYSOUT=A
SORTLIB DD	The purpose of the SORTLIB DD statement is to define a load library to which the SORT/MERGE procedure may link during execution. Example: //SORTLIB DD DSN=SYS1.SORTLIB,DISP=(SHR,PASS)
SORTWK01 DD thru SORTWK06 DD	The purpose of the SORTWK DD statements is to define from 3 to 6 scratch files for use by the SORT/MERGE procedure during execution. Example: //SORTWK01 DD UNIT=SYSDA,SPACE=(CYL,2,,CONTIG)
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the unsorted Per Diem Comparison data. Its assumed record characteris-

PROCEDURE IRWPDST JCL STATEMENTS, CONTINUED

Statement	Contents
	tics are RECFM=FB and LRECL=72. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 72. Example: //SYSUT1 DD DSN=PMMCO.CCMP.PERDIEM,DISP=(SHR,PASS)

SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential output file where the sorted version of the Per Diem Comparison data may be placed. Its record characteristics are predefined as RECFM=FB and LRECL=72. Its BLKSIZE is set equal to the SYSUT1 BLKSIZE.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.SORTED.CCMP.PERDIEM,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

PROCEDURE NAME: IRWDIEM, A procedure to extract offline miles and days from the Per Diem Comparison data and to insert this information into the Combined data file.

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LANGUAGE: Procedure IRWDIEM is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWDIEM is to extract offline miles and days from the Per Diem Comparison file and to insert this information into the Combined data file. Inputs are the sorted and corrected version of the Per Diem Comparison file and a previous version of the Combined file. Output is an updated version of the Combined file. The Per Diem Comparison file must be sorted and updated by procedure IRWPDST.

PROCEDURE IRWDIEM JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWDIEM. The REGION and TIME parameters may be specified. A REGION of 120K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWDIEM execution time parameters.
	
	Example:
	//IRWDIEM EXEC PGM=IRWDIEM,REGION=120K,TIME=2,
	// PARM=('/ID=''EXTRACT OFFLINE MILES AND DAYS''',
	// 'PROB=0.01')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWDIEM load module.

PROCEDURE IRWDIEM JCL STATEMENTS, CONTINUED

Statement	Contents
	Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWDIEM,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWDIEM may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state- may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the updated Per Diem Comparison data. Its assumed record characteristics are RECFM=FB and LRECL=72. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 72. Example: //SYSUT1 DD DSN=PMMCO.SORTED.COMP.PERDIEM,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the Combined data file to which offline miles and days are to be added. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 120. Example: //SYSUT2 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)

PROCEDURE IRWDIEM JCL STATEMENTS, CONTINUED

Statement	Contents

SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a version of the Combined file containing offline miles and days may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT3 DD DSN=PMMCO.UPDATED.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWDIEM execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWDIEM-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWDIEM as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWDIEM parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWDIEM PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''EXTRACT OFFLINE MILES AND DAYS'''
PROB	The PROB parameter may be used to indicate the probability that a particular output record will be printed. Its default value is 0.

PROCEDURE IRWDIEM PARM PARAMETERS, CONTINUED

Parameter	Contents
	Example: 'PaCb=0.01'

PROCEDURE NAME: IRWINBO, A procedure to combine Merge and Jumbo data into a single output file.

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LANGUAGE: Procedure IRWINBO is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWINBO is to combine Merge and Jumbo data into a single output file. Merge data and Jumbo data for sample cars are input, both of which must be in sort by time within day within month within car-identification. A combined Merge-Jumbo file is output.

PROCEDURE IRWINBO JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWINBO. The REGION and TIME parameters may be specified. A REGION of 120K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWINBO execution time parameters.
	
	Example:
	//IRWINBO EXEC PGM=IRWINBO,REGION=120K,TIME=2,
	// PARM=('/ID=''COMBINE MERGE AND JUMBO''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWINBO load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWINBO,DISP=(SHR,PASS)

PROCEDURE IRWINBO JCL STATEMENTS, CONTINUED

Statement	Contents
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWINBC may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing sorted Merge data for the sample cars. Its assumed record characteristics are RECFM=FB and LRECL=65. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 65. Example: //SYSUT1 DD DSN=PAMCO.SORTED.BIG.MERGE,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing sorted Jumbo data for the sample cars. Its assumed record characteristics are RECFM=FB and LRECL=90. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 90. Example: //SYSUT2 DD DSN=PAMCO.SORTED.JUMBO.SAMPLE,DISP=(SHR,PASS)
SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a file containing appended Merge and Jumbo data may be placed. Its record

PROCEDURE IRWINBO JCL STATEMENTS, CONTINUED

Statement	Contents

	characteristics are predefined as RECFM=FB, LRECL=155 and BLKSIZE=3100.
	
	Example:
	//SYSUT3 DD DSN=PMACO.MERGE.JUMBO.APP,UNIT=3330,
	// VOL=SER=PMAPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWINBO execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWINBO-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWINBO as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWINBO parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWINBO PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''EXTRACT OFFLINE MILES AND DAYS'''
CARID	The CARID parameter may be used to specify the identification of a car whose output records are to be printed. Its default value is a null string. Example: 'CARID=''NW 08922C'''
STOPAFT	The STOPAFT parameter may be used to specify the maximum

PROCEDURE IBWINBO PARM PARAMETERS, CONTINUED

Parameter	Contents
	number of records to be read from file SYSUT1. When STOPAFT is greater than 0, file SYSUT1 is treated as though an end of file had occured after STOPAFT records have been read. Its default value is 0. Example: 'STOPAFT=5000'
PRINT	The PRINT parameter may be used to indicate whether or not output records may be printed. If CARID is also specified, it applies only to the car identified. PRINT is a 1-bit string parameter. Its default value is '0'B. Example: 'PRINT=''1''B'

PROCEDURE NAME: IRWMRBO, A procedure to add Merge and Jumbo data to the Combined file.

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LANGUAGE: Procedure IRWMRBO is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWMRBO is to add Merge and Jumbo data to the Combined file. Inputs are the combined Merge-Jumbo file and a previous version of the Combined file. Outputs are an updated version of the Combined file and a file containing abstracted Merge-Jumbo data for use in future processing.

PROCEDURE IRWMRBO JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWMRBO. The REGION and TIME parameters may be specified. A REGION of 160K and a TIME of 5 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWMRBO execution time parameters.
	
	Example:
	//IRWMRBO EXEC PGM=IRWMRBO,REGION=160K,TIME=5,
	// PARM=('ISA(38K)/ID=''ADD MERGE/JUMBO TO COMBINED''',
	// 'PROB=0.01','CARID=''NW 089220''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWMRBO load module. Example:

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PROCEDURE IRWMREO JCL STATEMENTS, CONTINUED

Statement	Contents
	//STEPLIB DD DSN=PMMCO.LOAD.IRWMREO,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWMREO may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statement may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing combined Merge-Jumbo data. Its assumed record characteristics are RECFM=FB and LRECL=155. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 155. Example: //SYSUT1 DD DSN=PMMCO.MERGE.JUMBO.APP,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing a previous version of the combined file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 120. Example: //SYSUT2 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)
SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a version of the

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PROCEDURE IRWMREC JCL STATEMENTS, CONTINUED

Statement	Contents

	combined data file containing updated records may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT3 DD DSN=PMMCO.UPDATED.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

SYSUT4 DD	The purpose of the SYSUT4 DD statement is to define a physical sequential output file where abstracted Merge-Jumbo data may be placed for further processing. Its record characteristics are predefined as RECFM=VBS and LRECL=4096. Its BLKSIZE may be specified in the SYSUT4 DD statement or may default to 4100.
	
	Example:
	//SYSUT4 DD DSN=PMMCO.ABSTRACT.MERGE.JUMBO.APP,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWMREO execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWMRBO-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWMREC as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWMRBO parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWMREC PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''ADD MERGE/JUMBC TO COMBINED'''
CARID	The CARID may be used to specify any car-id for which the combined record is to be printed. Its default value is a null string. Example: 'CARID=''NW 089220'''
PRCB	The PROB parameter may be used to specify the probability that any one combined record output will be printed. Its default value is 0. Example: 'PRCB=0.01'
STOPAFT	The STOPAFT parameter may be used to indicate how many recrods are to be read, at the most, from the SYSUT2 file. When STOPAFT is greater than 0, procedure IRWMRBC behaves as though an end of file had been encountered on file SYSUT2 after STOPAFT records have been passed. Its default value is 0. Example: 'STOPAFT=5000'

PROCEDURE NAME: IRWCTAB, A procedure to tabulate the Combined data file.

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LANGUAGE: Procedure IRWCTAB is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWCTAB is to tabulate the Combined data file. Tables are by PMM&Co. repair category and show car type by age.

PROCEDURE IRWCTAB JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWCTAB. The REGION and TIME parameters may be specified. A REGION of 182K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWCTAB execution time parameters.
	
	Example:
	//IRWCTAB EXEC PGM=IRWCTAB,REGION=182K,TIME=2,
	// PARM=('/ID=''EXTRACT REPAIR-TYPE TABLES''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWCTAB load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWCTAB,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWCTAB may place messages

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PROCEDURE IRWCTAB JCL STATEMENTS, CONTINUED

Statement	Contents
	during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statement may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the Combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMRCO.DATA.COMBINED,DISP=(SHR,PASS)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWCTAB execution time parameters. Its format is as follows:

```
PARM=('PL/I-parameters/IRWCTAB-parameters')
```

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWCTAB as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWCTAB parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWCTAB PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''EXTRACT REPAIR-TYPE TABLES'''
TYPE	The TYPE parameter may be used to select the PMM&Cc. repair category to be tabulated. All repair categories are tabulated when it is less than or equal to 0. Its default value is 0. Example: 'TYPE=23'

PROCEDURE NAME: IRWWAY2, A procedure to prepare combined records for paired C.R.B. repair codes.

AUTHOR: Robert W. Whitaker
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LANGUAGE: Procedure IRWWAY2 is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWWAY2 is to prepare combined records for paired C.R.B. repair codes. An old version of the Combined data file is input. An updated version of the Combined data file is output.

PROCEDURE IRWWAY2 JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWWAY2. The REGION and TIME parameters may be specified. A REGION of 100K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWWAY2 execution time parameters.
	
	Example:
	//IRWWAY2 EXEC PGM=IRWWAY2,REGION=100K,TIME=2,
	// PARM=('/ID=''CREATE 2-RECORDS''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWWAY2 load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWWAY2,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a

PROCEDURE IRWWAY2 JCL STATEMENTS, CONTINUED

Statement	Contents
	SYSOUT file where procedure IRWWAY2 may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state- may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing an old version of the Combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)

SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential output file where an updated version of the Combined data file may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.UPDATED.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWWAY2 execution time parameters. Its format is as follows:

```
PARM=('PL/I-parameters/IRWWAY2-parameters')
```

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWWAY2 as REPCRT and ISA(10K), are adequate, and they may be omitted. Procedure IRWWAY2 parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWWAY2 PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CREATE 2-RECORDS'''
CARID	The CARID parameter may be used to specify the identification of a car whose output records are to be printed. Its default value is a null string. Example: 'CARID=''NW 089220'''
PROB	The PROB parameter may be used to indicate the probability that a particular output record will be printed. Its default value is 0. Example: 'PROB=0.01'
LIST	The LIST parameter may be used to indicate whether or not output records may be printed. If CARID is also specified, it applies only to the car identified. LIST is a 1-bit string parameter. Its default value is '0'B. Example: 'LIST=''1''B'

PROCEDURE NAME: IRWWAYX, A procedure to prepare combined records for paired PMM&Co. repair codes.

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LANGUAGE: Procedure IRWWAYX is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWWAYX is to prepare combined records for paired PMM&Co. repair codes. An old version of the Combined data file is input. An updated version of the Combined data file is output.

PROCEDURE IRWWAYX JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWWAYX. The REGION and TIME parameters may be specified. A REGION of 100K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWWAYX execution time parameters.
	
	Example:
	//IRWWAYX EXEC PGM=IRWWAYX,REGION=100K,TIME=2,
	// PARM=('/ID=''CREATE 2-RECORDS''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWWAYX load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWWAYX,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a

PROCEDURE IBWWAYX JCL STATEMENTS, CONTINUED

Statement	Contents
	SYSOUT file where procedure IBWWAYX may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing an old version of the Combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)

SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential output file where an updated version of the Combined data file may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.UPDATED.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWWAYX execution time parameters. Its format is as follows:

```
PARM=('PL/I-parameters/IRWWAYX-parameters')
```

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWWAYX as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWWAYX parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWWAYX PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CREATE 2-RECORDS'''
CARID	The CARID parameter may be used to specify the identification of a car whose output records are to be printed. Its default value is a null string. Example: 'CARID=''NW 089220'''
PROB	The PROB parameter may be used to indicate the probability that a particular output record will be printed. Its default value is 0. Example: 'PROB=0.01'
LIST	The LIST parameter may be used to indicate whether or not output records may be printed. If CARID is also specified, it applies only to the car identified. LIST is a 1-bit string parameter. Its default value is '0'B. Example: 'LIST=''1''B'

PROCEDURE NAME: IRWFMAT, A procedure to tabulate records for selected repair codes from the Combined data file.

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LANGUAGE: Procedure IRWFMAT is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWFMAT is to tabulate records for selected repair codes for the Combined data file.

PROCEDURE IRWFMAT JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWFMAT. The REGION and TIME parameters may be specified. A REGION of 100K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWFMAT execution time parameters.
	
	Example:
	//IRWFMAT EXEC PGM=IRWFMAT,REGION=100K,TIME=2,
	// PARM=('/ID=''PRINT SELECTED COMBINED RECORDS''',
	// 'CLIST=''00,99''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWFMAT load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWFMAT,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a

PROCEDURE IRWFMAT JCL STATEMENTS, CONTINUED

Statement	Contents
	SYSOUT file where procedure IRWFMAT may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the Combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWFMAT execution time parameters. Its format is as follows:

    PARM=('PL/I-parameters/IRWFMAT-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWFMAT as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWFMAT parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWFMAT PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''EXTRACT REPAIR-TYPE TABLES'''
CLIST	The CLIST parameter may be used to specify a list of repair codes for which Combined data records are to be tabulated. It is a character string whose default value is null. Example: 'CLIST=''00,99'''

PROCEDURE NAME: IRWXTAB, A procedure to tabulate the Combined data file as prepared by procedure IRWWAYX.

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LANGUAGE: Procedure IRWXTAB is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWXTAB is to tabulate the Combined data file as prepared by procedure IRWWAYX. Tables are by PMMCo. repair category and show car type by age. A selected subset of the Combined data file is output for use in other procedures.

PROCEDURE IRWXTAB JCL STATEMENTS

Statement	Contents
EXEC	The purpose of the EXEC statement is to invoke procedure IRWXTAB. The REGION and TIME parameters may be specified. A REGION of 100K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I execution time parameters. Example: //IRWXTAB EXEC PGM=IRWXTAB,REGION=100K,TIME=2
STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWXTAB load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWXTAB,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWXTAB may place messages

PROCEDURE IRWXTAB JCL STATEMENTS, CONTINUED

Statement	Contents
	during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state- may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the Combined data file. Its assumed record characteristics are RECFM= FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)

SYSUT2	The purpose of the SYSUT2 DD statement is to define a physical sequential output file where a special subset of the Combined data file may be placed. Its record characteristics are RECFM=FM, LRECL=120 and BLKSIZE=4200.
	
	Example:
	//SYSUT2 DD DSN=PMMCO.SUBSET.DATA.COMBINED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(19C,190),RLSE),
	// DISP=(,CATLG,DELETE)

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PROCEDURE NAME: IRWRESS, A procedure to create regression records from the Combined data file.

AUTHOR: Robert W. Whitaker
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LANGUAGE: Procedure IRWRESS is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWRESS is to create regression records from the Combined data file. Inputs are UMLER data for sample cars and the Combined data file. The Regression data file is output.

PROCEDURE IRWRESS JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWRESS. The REGION and TIME parameters may be specified. A REGION of 120K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWRESS execution time parameters.
	
	Example:
	//IRWRESS EXEC PGM=IRWRESS,REGION=120K,TIME=2,
	// PARM=('/ID=''CREATE REGRESSION DATA''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWRESS load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWRESS,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a

PROCEDURE IBWRESS JCL STATEMENTS, CONTINUED

Statement	Contents
	SYSOUT file where procedure IBWRESS may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statement may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing UMLER data for sample cars. Its assumed record characteristics are RECFM=FB and LRECL=213. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 213. Example: //SYSUT1 DD DSN=PMMCO.SAMPLED.DATA.CAR,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the Combined data file. Its assumed record characteristics are RECFM=FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT2 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)
SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where the regression data set may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=145 and BLKSIZE=4205. Example:

PROCEDURE IRWRESS JCL STATEMENTS, CONTINUED

Statement	Contents

	//SYSUT3 DD DSN=PMMCO.DATA.REGRESS,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWRESS execution time parameters. Its format is as follows:

PARM=('PL/I-parameters/IRWRESS-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWRESS as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWRESS parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWRESS PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''CREATE REGRESSION DATA'''
CARID	The CARID may be used to specify any car-id for which debugging information is to be printed. Its default value is a null string. Example: 'CARID=''NW 089220'''
PROB	The PROB parameter may be used to specify the probability that debugging information be printed for any car-id. Its default value is 0. Example: 'PROB=0.01'

PROCEDURE IRWRESS PARM PARAMETERS, CONTINUED

Parameter	Contents
CARGO	The CARGO parameter is a 1-bit string which indicates whether or not the cargos carried by each car are to be listed. Its default value is '0'B. Example: 'CARGO=''1''B'

PROCEDURE NAME: IRWSLST, A procedure to generate a detailed repair listing on a shop basis.

AUTHOR: Robert W. Whitaker
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LANGUAGE: Procedure IRWSLST is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWSLST is to generate a detailed repair listing on a shop basis. Inputs are the UMLER data for sample cars, the freight car history data and data statements relating PMM&Co. repair codes to C.R.B. repair codes. A sorted version of the freight car history file is output.

PROCEDURE IRWSLST JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWSLST. The REGION and TIME parameters may be specified. A REGION of 180K and a TIME of 4 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWSLST execution time parameters.
	
	Example:
	//IRWSLST EXEC PGM=IRWSLST,REGION=180K,TIME=4,
	// PARM=('/ID=''TABULATE REPAIR DATA''','YEAR=76',
	// 'LOW.MONTH=1','HIGH.MONTH=7')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWSLST load module. Example:

PROCEDURE IRWSLST JCL STATEMENTS, CONTINUED

Statement	Contents
	//STEPLIB DD DSN=PMMCO.LOAD.IRWSLST,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWSLST may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger is desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state-may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSOUT DD	The purpose of the SYSOUT DD statement is to define a SYSOUT file where the SORT/MERGE procedure may place messages during execution. Its record characteristics are predefined. Example: //SYSOUT DD SYSOUT=A
SORTLIB DD	The purpose of the SORTLIB DD statement is to define a load library to which the SORT/MERGE procedure may link during execution. Example: //SORTLIB DD DSN=SYS1.SORTLIB,DISP=(SHR,PASS)
SORTWK01 DD thru SORTWK06 DD	The purpose of the SORTWK DD statements is to define from 3 to 6 scratch files for use by the SORT/MERGE procedure during execution. Example: //SORTWK01 DD UNIT=SYSDA,SPACE=(CYL,2,,CONTIG)

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PROCEDURE IBWSLST JCL STATEMENTS, CONTINUED

Statement	Contents
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing UMLER data for sample cars. Its assumed record characteristics are RECFM =FB and LRECL=213. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 213. Example: //SYSUT1 DD DSN=PMMCO.UMLER.SAMPLE,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing the freight car history data for sample cars. Its assumed record characteristics are RECFM=FB and LRECL=130. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 130. Example: //SYSUT2 DD DSN=PMMCO.HISTORY.CAR.SAMPLED,DISP=(SHR,PASS)

SYSUT3 DD	The purpose of the SYSUT3 DD statement is to define a physical sequential output file where a sorted version of the freight car history file containing only sample cars may be placed. Its record characteristics are predefined as RECFM=FB, LRECL=130 and BLKSIZE=4160.
	
	Example:
	//SYSUT3 DD DSN=PMMCO.HISTORY.CAR.SORTED,UNIT=3330,
	// VOL=SER=PMMPAK,SPACE=(TRK,(190,190),RLSE),
	// DISP=(,CATLG,DELETE)

SYSIN DD	The purpose of the SYSIN DD statement is to define a physical sequential input file where data statements defining the relationship between PMM&Co. job codes and C.R.B. job codes and qualifiers may be placed. Its assumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE is taken from the SYSIN DD statement, the file label or may default to 80. Example: //SYSIN DD *

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWSLST execution time parameters. Its format is as follows:

    PARM=('PL/I-parameters/IRWSLST-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWSLST as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWSLST parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWSLST PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''TABULATE REPAIR DATA'''
YEAR	The YEAR parameter may be used to indicate the year to be associated with tabulated data. Its default value is 0. Example: 'YEAR=76'
LOW.MONTH	The LOW.MONTH parameter may be used to indicate the lower in a range of months to be associated with tabulated data. Its default value is 0. Example: 'LOW.MONTH=1'
HIGH.MONTH	The HIGH.MONTH parameter may be used to indicate the higher in a range of months to be associated with tabulated data. Its default value is 0. Example: 'HIGH.MONTH=7'
SIZE	The SIZE parameter may be used to specify the quantity of core to be allocated for execution of the SORT/MERGE procedure. Its default value is 30000.

PROCEDURE IBWSLST PARM PARAMETERS, CONTINUED

Parameter	Contents
	Example: 'SIZE=44000'

PROCEDURE NAME: IRWVIVE, A procedure to generate survival curves for NW data.

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LANGUAGE: Procedure IRWVIVE is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWVIVE is to generate survival curves for NW data. The Combined data file and control statements indicating which repair codes are to be considered are input.

PROCEDURE IRWVIVE JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWVIVE. The REGION and TIME parameters may be specified. A REGION of 160K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWVIVE execution time parameters.
	
	Example:
	//IRWVIVE EXEC PGM=IRWVIVE,REGION=160K,TIME=2,
	// PARM=('/ID=''TABULATE REPAIRS FOR 2.4''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWVIVE load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWVIVE,DISP=(SHR,PASS)
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a

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PROCEDURE IRWVIVE JCL STATEMENTS, CONTINUED

Statement	Contents
	SYSOUT file where procedure IRWVIVE may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE of 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD state-may be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSOUT DD	The purpose of the SYSOUT DD statement is to define a SYSOUT file where the SORT/MERGE procedure may place messages during execution. Its record characteristics are predefined. Example: //SYSOUT DD SYSOUT=A
SORTLIB DD	The purpose of the SORTLIB DD statement is to define a load library to which the SORT/MERGE procedure may link during execution. Example: //SORTLIB DD DSN=SYS1.SORTLIB,DISP=(SHR,PASS)
SORTWK01 DD thru SORTWK06 DD	The purpose of the SORTWK DD statements is to define from 3 to 6 scratch files for use by the SORT/MERGE procedure during execution. Example: //SORTWK01 DD UNIT=SYSDA,SPACE=(CYL,2,,CONTIG)
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing the Combined

PROCEDURE IRWVIVE JCL STATEMENTS, CONTINUED

Statement	Contents
	data file. Its assumed record characteristics are RECFM= FB and LRECL=120. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 120. Example: //SYSUT1 DD DSN=PMMCO.DATA.COMBINED,DISP=(SHR,PASS)
SYSIN DD	The purpose of the SYSIN dd statement is to define a physical sequential input file where control statements may be placed indicating which repair codes are to be included. The SYSIN file is optional. All repair codes are included when it is omitted. Its assumed record characteristics are RECFM=FB and LRECL=80. Its BLKSIZE in taken from the SYSIN DD statement, the file label or may default to 80. Example: //SYSIN DD *

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWVIVE execution time parameters. Its format is as follows:

    PARM=('PL/I-parameters/IRWVIVE-parameters')

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWVIVE as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWVIVE parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWVIVE PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is

PROCEDURE IRWVIVE PARM PARAMETERS, CONTINUED

Parameter	Contents
	a null string. Example: 'ID=''TABULATE REPAIRS FOR 2.4'''
SORT	The SORT parameter may be used to indicate the quantity of core to be allocated to the SORT/MERGE procedure for execution. Its default value is 30000. Example: 'SORT=44000'
XDAYS	The XDAYS parameter indicates a number of days for which and below which repair intervals are not to be consid- ered. Its default value is 0. Example: 'XDAYS=5'

CONTROL STATEMENTS

Control statements may be placed in the SYSIN file to indicate which repair codes are to be considered. Their format is as follows:

```
OP='operation';
  LIST='repair-code-list';
```

The 'operation' may be:

```
INCLUDE
EXCLUDE or X
ALLIN
ALLOUT
```

and the 'repair-code-list' is any list of repair codes and ranges of repair codes. The operations ALLIN and ALLOUT do not have associated repair code lists.

As an example:

```
OP='ALLIN';
OP='EXCLUDE';
  LIST='2.3,4.5-5.7';
```

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indicates that all repair codes other than 2.3 and 4.5 through 5.7 are to be considered.

PROCEDURE NAME: IRWVIVA, A procedure to generate survival curves for TT data.

AUTHOR: Robert W. Whitaker
Peat, Marwick, Mitchell & Co.
1025 Connecticut Avenue, N.W.
Washington, D.C. 20036
(202) 223-9525

LANGUAGE: Procedure IRWVIVA is written to be compiled and executed at an installation supporting the PL/I Optimizing Compiler, Version 1, Release 2.3, PTF 61, or later.

PURPOSE:

The purpose of procedure IRWVIVA is to generate survival curves for TT data. The UMLER file for sample cars, the TT interval data and control statements indicating which repair codes are to be considered are input.

PROCEDURE IRWVIVA JCL STATEMENTS

Statement	Contents

EXEC	The purpose of the EXEC statement is to invoke procedure IRWVIVA. The REGION and TIME parameters may be specified. A REGION of 140K and a TIME of 2 minutes have been found to be adequate for a 360/65. The PARM parameter may be used to specify PL/I and procedure IRWVIVA execution time parameters.
	
	Example:
	//IRWVIVA EXEC PGM=IRWVIVA,REGION=140K,TIME=2,
	// PARM=('/ID=''TABULATE REPAIRS FOR 2.4''')

STEPLIB DD	The purpose of the STEPLIB DD statement is to define a load library containing the procedure IRWVIVA load module. Example: //STEPLIB DD DSN=PMMCO.LOAD.IRWVIVA,DISP=(SHR,PASS)

PROCEDURE IRWVIVA JCL STATEMENTS, CONTINUED

Statement	Contents
SYSPRINT DD	The purpose of the SYSPRINT DD statement is to define a SYSOUT file where procedure IRWVIVA may place messages during execution. Its default record characteristics are RECFM=VBA, LRECL=125 and BLKSIZE=129. The user may specify a BLKSIZE or 129 or larger if desired. Example: //SYSPRINT DD SYSOUT=A
PLIDUMP DD	The purpose of the PLIDUMP DD statement is to define a SYSOUT file where a core management report may be placed by the PL/I housekeeping procedures and where an ABEND dump may be placed if required. The record characteristics of the PLIDUMP file are predefined. This DD statemay be omitted. Example: //PLIDUMP DD SYSOUT=A
SYSUT1 DD	The purpose of the SYSUT1 DD statement is to define a physical sequential input file containing UMLER data for sample cars. Its assumed record characteristics are RECFM=FB and LRECL=198. Its BLKSIZE is taken from the SYSUT1 DD statement, the file label or may default to 198. Example: //SYSUT1 DD DSN=PMMCO.IT.SAMPLED.DATA.CAR,DISP=(SHR,PASS)
SYSUT2 DD	The purpose of the SYSUT2 DD statement is to define a physical sequential input file containing IT interval data. Its assumed record characteristics are RECFM=FB and LRECL=26. Its BLKSIZE is taken from the SYSUT2 DD statement, the file label or may default to 26. Example: //SYSUT2 DD DSN=PMMCO.IT.DATA.INTERVAL,DISP=(SHR,PASS)
SYSIN DD	The purpose of the SYSIN dd statement is to define a physical sequential input file where control statements may be placed indicating which repair codes are to be included. The SYSIN file is optional. All repair codes are included when it is omitted. Its assumed record charact-

PROCEDURE IRWVIVA JCL STATEMENTS, CONTINUED

Statement	Contents
	eristics are RECFM=FB and LRECL=80. Its BLKSIZE in taken from the SYSIN DD statement, the file label or may default to 80. Example: //SYSIN DD *

THE PARM PARAMETER

The PARM parameter of the EXEC statement may be used to specify PL/I and procedure IRWVIVA execution time parameters. Its format is as follows:

```
PARM=('PL/I-parameters/IRWVIVA-parameters')
```

The formats of the PL/I execution time parameters may be found in the PL/I Programmers' Guide. Their defaults, set by procedure IRWVIVA as REPORT and ISA(10K), are adequate, and they may be omitted. Procedure IRWVIVA parameters are keyword and may be supplied in any order. Omitted parameters have default values. Their formats may be found in the following table.

PROCEDURE IRWVIVA PARM PARAMETERS

Parameter	Contents
ID	The ID parameter may be used to specify any character string to be used as identification. Its default value is a null string. Example: 'ID=''TABULATE REPAIRS FOR 2.4'''
XDAYS	The XDAYS parameter indicates a number of days for which and below which repair intervals are not to be considered. Its default value is 0. Example: 'XDAYS=5'
STOPAFT	The STOPAFT parameter may be used to indicate the maximum number of records to be read from the SYSUT2 file. When

PROCEDURE IBWVIVA PARM PARAMETERS, CONTINUED

Parameter	Contents
	STOPAFT is assigned a value which is greater than 0, file SYSUT2 is treated as though an end of file had been encountered after STOPAFT records have been processed. Its default value is 0. Example: 'STOPAFT=5000'
QLIST	QLIST is a character string parameter which may be used to select which interval records are to be included by indicating a list of qualifiers. Its default value is '0,1'. Example: 'QLIST=''1'''

CONTROL STATEMENTS

Control statements may be placed in the SYSIN file to indicate which repair codes are to be considered. Their format is as follows:

```
    OP='operation';
      LIST='repair-code-list';
```

The 'operation' may be:

```
    INCLUDE
    EXCLUDE or X
    ALLIN
    ALLOUT
```

and the 'repair-code-list' is any list of repair codes and ranges of repair codes. The operations ALLIN and ALLOUT do not have associated repair code lists.

As an example:

```
    OP='ALLIN';
    OP='EXCLUDE';
      LIST='2.3,4.5-5.7';
```

indicates that all repair codes other than 2.3 and 4.5 through 5.7 are to be considered.

APPENDIX D

A STUDY TO INVESTIGATE AND ASSESS DATA COLLECTION ALTERNATIVES FOR USE IN RAILROAD REPAIR SHOP ENVIRONMENTS

CONTENTS

LIST OF TABLES

APPENDICES

I. BACKGROUND

The objective of this report is presentation of CI findings in investigating and assessing data collection alternatives for use in the repair shop environment. The report discusses various data collection devices as well as associated data conversion methods for communications purposes. Evaluation includes criteria for estimating the per message cost from source through conversion for each alternative. Results are developed in such a way as to permit general comparison of the advantages of each approach.

The breadth of equipment covered by the general term "Data Collection" requires a precise definition of the scope of this report and associated research. In that our objective was to identify and evaluate equipment and techniques suitable for the shop environment, we focused on those classes of equipment designed for operator interaction. We excluded all automatic (or sensor-based) data capture equipment and the range of equipment classified as process control instrumentation. The latter generally is an element of a closed-loop feedback system rather than a data collection technique. Their job-specific nature precludes meaningful application in broad terms in the shop environment.

Three terms are useful in distinguishing between the primary methods of data collection for computer processing:

- Key Entry: Batch data entry, normally from manually transcribed records, by an operator using keypunch equipment;
- Source Data Automation: Data capture as a by-product of a conventional business transaction; (for example, character readers or bar code readers employed at the point of sale to eliminate the need for manual data recording for later batch processing of transaction data).
- Factory Data Collection: Recording of data on events as they occur in the plant environment. (The industrial equivalent of source data automation).

This report dwells primarily upon techniques that have been employed in the plant environment, but does consider other methods both for purposes of perspective and their potential if packaged for industrial use.

In narrowing the field for investigation, a number of important considerations were established:

- The need to function reliably and with minimal maintenance in adverse environments.
- Simplicity of design and function to promote ready comprehension and use by non-clerical shop personnel.
- Performance characteristics that complement rather than stymie operator execution of primary tasks.

The foregoing considerations - environment and personnel - are as important in the development of a data collection system as the information to be collected.

(As an aside, although beyond the scope of this report, the technique ultimately selected must be implemented in a fashion that serves an immediately visible, useful purpose in the eyes of the operators. Neglect of this consideration may have a negative impact upon operator performance).

Further definition of general requirements for work station operator data entry in the shop environment suggests the following general equipment classes:

1. Portable devices that can be carried to the data entry location.
2. AC-powered, stand-alone devices that record and store data for batch transfer to the computer on a routine or polled basis;
3. AC-powered, stand-alone devices that collect and transfer data on a real-time basis to a central recorder or directly to the computer.

The balance of this report describes and evaluates equipment selected from the above general categories, in terms of the following criteria:

CRITERION	COMMENT
• DATA MEDIUM	The information carrier and data format
Environmental Suitability	Resistance to dirt, abrasion, humidity, etc.
Data Capacity	Number of characters accommodated per square in
Redundancy	Format integrity, probability of error
Operator Convenience	Ease of use
Provision for Back-Up	Alternative entry method if damaged
Product Suitability	Is medium physically compatible with product?
Sources	Suppliers
Costs	---
• COLLECTION DEVICE	The data entry device
Environmental Suitability	Accommodation of temperature variance, humidity etc.
Operator Convenience	Ease of use, operator guidance, feedback
Error Checking/Correction	Device editing capability
Interface Characteristics	Nature of link to data processing system
Buffering Capability	Ability to store data
Reliability	Failure modes and frequency
Back-Up Provisions	Power-fail provision, alternative entry methods
Sources	Suppliers
Costs	---
• DATA MEDIUM/DEVICE:SYSTEM PER MESSAGE TIME & COST	Identification of criteria for estimate of system cost per data entry

II. APPROACHES TO DATA COLLECTION

On the basis of general analysis of the range of equipment now offered for factory data collection and the broad criteria described in Section I of this report, the following techniques were selected for detailed evaluation:

- **Bar Coding** - Optical coding, similar to the Uniform Product Code incorporated in grocery packaging, now read by automatic and handheld scanners.
- Magnetic Coding - Coding similar to that incorporated in the dark tape stripe found on many credit cards, toll road tickets, parking garage tickets, etc.
- Punched Cards - The classical data entry vehicle and approach for non-variable information input.
- Optical Character Recognition (OCR) - Stylized encoding of human-readable characters suitable for machine processing (e.g. bank checks, oil company charge slips) now in use for retail POS transaction recording.
- Voice Recognition - Electronic recognition and processing of spoken operator input.
- Key Entry - Operator use of keyboard terminal for data entry.

Of the techniques selected, the first four rely to varying degrees upon operator performance. Data can be encoded in machine-readable form and the operator simply assists in presentation for transcription by an essentially automatic 'reader'. The latter, key entry and voice recognition are more dependent upon operator performance in that he or she must make the transfer from the document to the data processing system by reading, interpreting and manually or vocally entering the data. We will examine these methods first in our discussion and comparison of the five techniques.

A. KEY ENTRY

Key Entry has one major advantage and one major disadvantage over the other four methods. The major advantage is that from a pure hardware point of view, it is the least expensive. Terminal costs range between $1,000 and $3,000 depending upon the features desired. Key Entry does not require any coding medium such as coding labels, specially printed tags, cards or forms. Its major disadvantage is the high degree of error which is possible with only moderate data volume. For example, if each input item is 10 characters and 500 items are required to be input each work shift, there is a total of 5,000 characters that must be input without error. This is virtually impossible even for the most experienced operator. At the beginning of this report, we stated that the primary job function of the operator was not data entry. Therefore, even with its low cost, this method must be given a low priority when accuracy is important in the data collection process.

- Data Medium: Key entry systems are dependent upon operator interpretation of printed or other visually captured information. Accordingly, the only constraint on medium selection is that it permit ready operator recognition; i.e., be prominently located and legible.

    1. Environmental Suitability. See above. Generally permits the widest latitude in medium selection.

    2. Capacity. Ten characters/inch is normally reasonable.

    3. Redundancy. More a function of the device/system. If the supplier offers check-digit verification (see paragraph 3 under Data Collection Device, below), the addition of a specially calculated suffix for each data record will enhance integrity. Check digit calculation and provision for its inclusion with other data carried by the selected medium are generally one-time costs which can be amortized over the life of the system. If the medium is generated under computer control (e.g. labels, cards), such costs are nominal. Less common media (metal plates, permanent tags, etc.) may require substantial costs for check digit incorporation.

    4. Operator Convenience. Dependent upon medium selected, location and accessibility.

    5. Provision for back-up. Design should

address possibility of damage and replacement alternatives.

6. Product Compatibility. Maximum flexibility.

7. Sources/Costs. Current methods of product or task identification may be adequate. Without specific application detail, and in that no special encodation is required, we attach no incremental costs (except for suggestion of the probable cost of check-digit employment) for the data medium element of key entry systems.

- Data Collection Device: Data Entry is required by an experienced operator in a field-by-field mode on a keyboard usually associated with an output display.

  1. Environmental Suitability. Several manufacturers supply equipment which will meet the most rugged environments. The keyboard is usually mounted in a sealed enclosure that may have heating or cooling.

  2. Operator Convenience. Data input is via a numeric or alpha-numeric keyboard by an experienced operator. Special function keys may be employed if the application requires repeated dedicated input. Normal operator training can be accomplished in a few days. Most devices include audio and visual display characteristics for operator guidance.

  3. Error Checking/Correction. Normal operation does not include error checking in the key entry device itself. This editing of the input data is normally accomplished at the computer. This is a serious drawback of this method of data collection. (As an option, however, some manufacturers will provide for local verification of a check-digit added as a suffix to the encoded data and entered by the operator at the end of the message. This feature which is designed to filter

out operator transcription errors would not only add to device cost, but also to the cost of the input media whose preparation for inclusion of the check digit would become a factor in overall technique assessment).

4. Interface Characteristics. The distance between the key station and computer is usually limited to 1,000 feet. However, greater distance may be accommodated if communication driving methods are employed such as modems. In this event, the distance is virtually unlimited.

5. Buffering Capability. Typical applications employ data buffering in the computer to which the terminal is linked. This would be the simplest and least expensive application. If buffering is required at the key station, small solid state memories with capacity of up to 8,000 characters may be purchased as an option. This could add as much as $3,000 to the cost of the key entry station.

6. Reliability. Published data on equipment performance varies for each manufacturer. It is safe to say, however, that meantime between failure exclusive of mechanical abuse would be in the range of 20,000 hours.

7. Back-up Provision. Since key entry is the most primitive form of Data Collection, no direct provision for key station failure is incorporated. The likely alternative is a spare key station.

8. Sources, Costs. Typical equipment is available from the following companies:

   IBM Corporation
   (Dayton, New Jersey)
   Azurdata Corporation
   (Richland, VA)
   Electra/General Corporation
   (Minnetonka, MN)

   Other suppliers are listed in Appendix II.

9. <u>Estimated Per Message Time & Cost</u>. It is estimated that data fields should be under seven (7) characters in length for best operator performance. At this rate, an effective message input would be 7 to 10 per minute, with the need to re-enter one message in 50.

The per message cost, aside from that associated with device cost, would, therefore, not normally be significant in the shop environment.

B. VOICE RECOGNITION

For several years now, a number of companies have worked on the development of devices which would respond to spoken control commands in the process environment where operators were required to use their hands for product or package manipulation. IBM, RCA, Philco-Ford and Cutler-Harrison were among the pioneers in voice or spoken pattern recognition. More recently, micro-processor based units have been installed for data entry in the factory environment for quality control and material handling applications. System components typically include:

- A wireless or cable-linked operator headset and microphone which feeds operator commands to a:
- Rack- or bench-mounted input terminal which processes the commands through a spectral analysis technique and formats them for transfer to the data processing system;
- In some systems, a visual display device for operator feedback and/or guidance.

Additional information on these systems is referenced in Appendix I. Our evaluation of their suitability is outlined below:

- Data Medium: Voice recognition systems are also dependent upon operator interpretation of printed or other visually captured information. Accordingly, not unlike key entry, they permit considerable flexibility in data medium selection including, but not limited to, labels, tags, metal plates, work station task "menus", etc.

    1. Environmental Suitability. See above. Product or task identification method can be developed to meet the demands of the environment.

    2. Capacity. More a function of operator convenience. How many characters per inch can be readily seen and correctly interpreted in the environment? Ten (10) characters/inch appears reasonable.

    3. Redundancy. A variety of approaches are available for enhancement of data integrity. The addition of a check character similar to that described for key entry is absolutely essential for voice entry of multi-character records.

4. Operator Convenience. Dependent upon carrier (medium) type, location and accessibility.

5. Provision for back-up. Data carrier design should address possibility of damage and replacement alternatives.

6. Product Compatibility. Considerable flexibility here.

7. Sources/Costs. In that voice recognition systems do not require special data encodation, current methods of product or task identification may well suffice. Accordingly, we attach no incremental costs for the data medium component of this data entry technique (except as they may relate to special one-time costs associated with incorporation of a check character).

- Data Collection Device: Our discussion here relates to the operator headset and voice recognition terminal.

1. Environmental Suitability. Manufacturers' specifications indicate the systems will operate in industrial areas within a temperature range of 32°F to 122°F and 10-95% relative humidity. Directional microphones permit speaker recognition in areas where the noise level reaches 90db.

2. Operator Convenience. Except for individual preference which may render the headset undesirable, it appears that the system is well suited to operator mobility. A visual display may be incorporated in the system to permit operator audit of device recognition of input prior to transmittal to the computer. The display can also be used for operator 'prompting' or guidance. Operator training is normally accomplished in a half-day or less depending upon task complexity.

3. Error Checking/Correction. Voice recognition systems are 'programmed' to recognize individual operator speech patterns. An operator 'trains' the system by repeating each word in the application vocabulary ten times. Once 'trained', the information is stored for use when that operator is on the job. Most systems will recognize 98-99% of the unverified information entered. Each recognized word is displayed for verification by the operator before entering. To enter the data after verification, the operator says "go" or "OK". Specific data on error rates are not available, although it would appear that they would be directly linked to message size, volume and the latter's impact upon operator performance.

4. Interface Characteristics. Interface distance between the headset and the terminal can be up to 1000 feet. Output from the terminal conforms to current industry standards for computer communications.

5. Buffering Capability. Typical voice recognition terminals accommodate a vocabulary of 32 isolated words or phrases with provision for expansion up to 220 words. Data buffering or storage would normally be handled by the mini-computer to which the terminal is linked.

6. Reliability. Published data on equipment performance is not available but may be obtained from system users who include:

   Olin-Winchester Corporation
   S.S. Kresge & Company (Sparks, Nevada)
   United Airlines (Chicago O'Hare)
   United Parcel Service (Baltimore)
   Continental Can Co. (Milwaukee)
   Owens Illinois (Pittston, PA)
   Reynolds Metals (Bristol, VA)

7. Back-up Provision. No direct provision for micro-phone failure is incorporated in typical systems aside from replacement. Manual data transcription or key entry would appear to be the likely alternatives.

8. Sources, Costs. Commercially available equipment is offered by the following companies (See Appendix II):

   Threshold Technology, Inc.
   (Delran, New Jersey)
   Scope Electronics, Inc.
   (Reston, Virginia)
   Dimension, Inc.
   (Reston, Virginia)

   Terminal pricing is in the $10,000 range.

9. Estimated Per Message Time & Cost. All speech recognition equipment is based upon isolated word recognition requiring, therefore, a short (100 millisecond) pause between each spoken input. Manufacturers indicate normal inputs of 60-70 per minute after training. Assessment of these parameters for application in the shop environment would depend upon the nature of the input data. If a typical message were composed of ten characters (e.g., a product serial number), the effective message input rate would be 6-7 per minute, with the need to reenter one message per 100 for lack of initial recognition. This would appear to be quire satisfactory for the shop environment.

   Accordingly, device cost would be the primary factor in analysis of per message costs for the voice data entry technique.

C. BAR CODES

Considerable visibility for bar coding as a source data entry technique has been achieved through grocery industry adoption of the Uniform Product Code for product identification at the check-out counter. More pertinent to this report is the rapidly growing use of bar codes for industrial material handling, production and inventory control. Objectives in these applications include minimization of labor involvement in material control and data collection activities, error reduction and control system sensitivity to anomalies in production or warehousing operations.

Initial applications of bar code technology were developed in the mechanized environment where conveyorized product flow permitted the use of automatic code readers (e.g., laser scanners). The success of these systems created demand for application of the technology in those areas where either the nature of the product or the handling method precluded automatic scanning. It is the handheld code reader developed to meet this demand in non-mechanized operations that we'll assess here in connection with their suitability for the shop environment.

The fundamental elements of code reading systems are:

1. The product, its physical characteristics, the amount of data required to identify it, the characteristics of the environment in which it is handled and the handling method.

2. The code, which is developed on the basis of required data content (number of characters, alphanumeric or numeric only), code area which is a function of product size and the area available for coding, analysis of that method of code preparation and application to the product best suited to the needs of the user and determination of that code medium which will provide the best performance in the actual application environment.

3. The code reading method, automatic or handheld, which will permit ready integration of the system with on-going operations and enhance rather than inhibit data entry task execution.

4. Decoding electronics which process reader input, validate and format it for on-line transfer or buffering for batch transfer to a data processing system.

Appendix I contains the reference material on code reading systems which was reviewed in preparation of the following evaluation.

- Data Medium: Code reading technology is based upon machine capture of encoded data typically carried by a label, printed directly on product packaging, incorporated in employee badges, incorporated in work station task "menus", etc.

  1. Environmental Suitability. Labeling materials are available for application to a broad variety of substrates. A broad range of stock and adhesive permits use in subzero to high temperature environments. Laminates and overlays are available to minimize the impact of mechanical abrasion and enhance overall durability as required.

  2. Capacity. Current coding formats permit encoding at densities of up to 10 characters per lineal inch.

  3. Redundancy. Bit substitution error probability for most coding formats is less than 1 in 10^6.

  4. Operator Convenience. Labels are normally human as well as machine-readable and can be located in readily accessible positions.

  5. Provision for Backup. Label design should address possibility of damage and replacement alternatives (e.g., in-shop label printer).

  6. Product Compatibility. Labels are generally the most flexible method for product identification. If data collection activities include identification of events (e.g., task completion), personnel, etc., coding can be incorporated in "task menus" or related job shop documents as well as employee badges, etc.

  7. Sources, Costs. A variety of sources for labels, printers, pre-printed forms, etc., is contained in Appendix II. Costs range from \$.001 per square inch of adhesive-backed, bar code label stock to \$.05 per square inch of plastic laminated stock.

- **Data Collection Device:** The use of code reading technology in the shop environment would involve handheld "Lightpens" and associated decoding, processing and communications formatting electronics.

  1. Environmental suitability. Typical industrial code reading equipment is designed for operation in the plant environment at temperatures ranging from 32°F to 122°F and non-condensing humidity up to 90%. Packaging to accommodate broader extremes as well as possible mechanical abuse is available.

  2. Operator convenience. Typical Lightpens are slightly larger than conventional felt tip pens and are manipulated in the same fashion. Normal operator training can be accomplished in less than ten minutes. Lightpen cord length can be as much as 40 feet. Many users mount the devices on overhead retractors which keep the pens within reach, but clear of the work area. Labels may be read bi-directionally (i.e. left to right or right to left) at speeds from 3 to 30 or 40 inches per second. Pens typically permit 30 to 40 degrees misalignment with respect to the perpendicular to the coded message

     Code length, of course, will impact operator performance in that he or she must sweep through the entire code on a single pass. In this connection, bar height may be increased for longer codes to accommodate the normally curved motion observed during typical operator "wanding".

     Although features vary, most devices incorporate both audio and visual display characteristics for operator feedback and guidance.

  3. Error checking/correction. Decoding electronics typically compare code input against known dimensional, format and content parameters. They accommodate variations in pen speed through the code by measuring dimensional tolerances on a relative basis. Upon completion of a successful 'read', the operator is given an audio acknowledgement signal (and, in most cases, the code is displayed). In the event of an unsuccessful reading attempt or an unreadable code, no audio signal is provided.

     Lightpen-associated electronics do not normally provide error correction.

4. Interface Characteristics. Most code reading devices provide current loop and EIA RS-232C outputs. Normally, asynchronous Serial ASCII messages are transmitted at standard rates up to 9600 baud. Line drivers are available for transmission over long distances and a number of manufacturers provide multiplexers and acoustic couplers. EBCDIC (IBM-compatible) ouput is available on some models.

   A variety of options for communications handshaking is available.

5. Buffering capability. Most devices, with the exception of fully portable units, are used in an on-line configuration. Manufacturers do, however, offer both solid state and cassette memory options for data storage in an off-line mode. Capacities vary from 200 16-character records to 8000 records.

6. Reliability. Published data on equipment mean-times-between failure is not readily available. Analysis of component characteristics, however, leads us to project the following figures:

   a) Lightpens: 20,000 hours (exclusive of mechanical abuse).

   b) Basic Electronics: 15,000 hours maintained within environmental limits.

   c) Solid State Memory: 10,000 hours maintained within environmental limits.

   d) Cassette Transport: 5,000 hours maintained within environmental limits.

7. Back-up Provision. In most units, unreadable labels or Lightpen failure are handled through data entry via keyboard. Total device failure would require standard manual data transcription.

8. Sources, Costs. Code reading equipment suppliers are listed in Appendix II. Device costs will be a function of features selected, but would normally range between $1,300 and $3,000.

9. Per Message Time & Cost. Comments here are based exclusively on structured testing of operator performance and actual field experience.

   a) Depending upon the work station configuration, code accessibility and operator performance, as many as 60 ten-digit codes can be entered in one minute by a non-clerical operator.

b) Typical first-pass read rates in the industrial environment exceed 97%. The balance are normally captured on a second pass.

c) Properly integrated in the work station, code reader per message costs in terms of operator time will be negligible.

d) Actual cost of identification labels coupled with device costs, therefore, are the primary factors to be analyzed in developing projected costs for specific applications.

D. MAGNETIC CODING

There are two primary varieties of magnetic systems now used for source data entry: Magnetic ink character recognition (MICR) and magnetic stripe sensors. MICR systems have stiff constraints on font design and form layout and, as in the case of bank checks, rely heavily upon centralized, tightly controlled preprinting of the data. The magnetic stripe technique, however, is more flexible and, accordingly, deserves consideration in this report.

The magnetic stripe is used in some retail systems for POS transaction recording and is accepted as a standard for credit cards by the airline and banking industries.

- Data Medium: Magnetic stripe encoding is covered by an ANSI standard which calls for data recording (serial by bit) in a three-track format.

  1. Environmental Suitability. Labeling materials are generally magnetic medium that is adhered permanently to a card or form. The medium is sensitive to temperature extremes beyond 50^{o} and $80^{o}F$. It goes without saying that the medium is very sensitive to even the smallest magnetic fields.

  2. Capacity. Current coding formats permit encoding at densities of normally 15 characters per linear inch.

  3. Redundancy. Bit substitution error probability is less than 1 in 10^{6}.

  4. Operator Convenience. Data is not human readable and therefore, can not be verified by an operator.

  5. Provision for back-up. Replacement alternatives should be available. Special equipment is required to generate the labels. This equipment is usually expensive.

  6. Product Compatibility. If activities include identification of events, this method of on-line generation of encoding would be difficult to incorporate.

7. Sources, Costs. Costs range from $.05 per inch to $.15 per inch of plastic laminated stock.

- **Data** Collection Device: The use of magnetic stripe **encoding** in the shop environment would involve an **operator** inserting a code similar to a credit card **into a** reading device. This device would decode, **process** and communicate the data to a central **computer**.

1. Environmental Suitability. Typical equipment is designed for operation at temperatures of 50°F to 100°F and non-condensing humidity up to 90%.

2. Operator Convenience. Normal operator training can be accomplished in less than 10 minutes. Although features vary, most devices incorporate both audio and visual display characteristics for operator feedback and guidance.

3. Error Checking/Correction. Decoding electronics typically compare code input against **known** dimensional, format and content parameters. Upon completion of a successful "read", the operator is given an acknowledgement.

4. Interface Characteristics. Most devices provide current loop and EIA R2-232C output. Normally, asynchronous serial ASCII messages are transmitted at standard rates up to 9600 baud. However, several methods of handshaking protocol may be required between the computer and the code reading station. The specific method of handshaking will depend on the computer manufacturer selected.

5. Buffering Capability. These devices are used in an on-line configuration. They do not supply buffering other than a single message which may be retransmitted if the host computer requests.

6. Reliability. Data on equipment meantime between failure, exclusive of mechanical abuse, is 10,000 to 20,000 hours. This assumes the environmental specifications previously mentioned.

7. Back-up Provision. Total device failure would require standard manual data transcription.

8. Sources, Costs. Device costs are a function of features selected. The most primitive device has a price in the range of $800. A more sophisticated device, with manual keyboard and display would cost in the range of $2,000.

9. Per Message Time & Cost. A non-clerical operator could be expected to achieve a 99% first read rate in the shop environment. It would appear that the impact of operator time on per message costs would be negligible. Specific per message cost is a function of the volume of encoded cards. Typical vendor quantities are in the 1,000 unit quantity. The price per unit is a function of the stock to which the encoding is applied and the cosmetic features which accompany the encoding, such as a picture on an employee identification badge.

E. PUNCHED CARDS

The most commonly used punched card is covered by the American National Standard Institute (ANSI) 80-column standard. This method has been used for many years in the computer field for inputting stored programs to a computer. The data medium itself is inexpensive and is less subject to the environmental constraints on such media as magnetic tape. However, the data reading devices (card readers) are generally expensive and, because of their mechanical nature, are subject to reliability problems. The cards themselves are also subject to handling restrictions, such as "do not fold, spindle or mutilate". This must be considered when in the repair shop environment.

- Data Medium: Data input is based upon mechanical reading of holes punched in the card.

   1. Environmental suitability. Cards are paper stock that may be stored at any temperature. Relative Humidity should be kept at 70% for best results to reduce static change on the cards.

   2. Capacity. Standard and fixed at 80 characters per card in most cases. 51 and 96 character systems are offered.

   3. Redundancy. Standard cards can accommodate a one-character check digit.

   4. Operator Convenience. Cards normally have human readable information printed on the card in addition to the punched holes.

   5. Provision for Back-up. System design should address possibility of and replacement of cards (i.e., local card punch).

   6. Product Compatability. Cards may include part numbers, employee number and other shop data. The card may be stored for record keeping. However, affixing the card to the product may be difficult in some cases.

7. Sources, Costs. Cards are available from any data processing supplier. Typical costs range from $.001 to $.003 per card unpunched. Card punching devices and related operating costs must be considered in overall assessment of this approach. In most cases, card punching is accomplished by the user's processing department.

- Data Collection Device: Card readers are manufactured by a variety of suppliers, many of whom are listed in Appendix II. These manufacturers supply many different models with various features. However, the main difference is the card reading rate specified in cards per minute (C.P.M.). In the shop environment, cards would normally be singly rather than batch processed and CPM is relatively unimportant. In the event, however, of the simple collection of cards in the shop for later batching, one should be aware of the fact that increased CPM requires more sophisticated devices whose prices rise sharply.

  1. Environmental suitability. Typical equipment is designed for operation at temperatures around 70°F and non-condensing humidity up to 90%. The environment must be dust and oil free.

  2. Operator Convenience. Operation is simple. Single cards or a "deck" (stack of cards) is placed in the reader or a hopper and a button is pushed.

  3. Error checking/correction. Error checking is done on each card for a parity check on the entire card. No correction method is supplied.

  4. Interface Characteristics. Most card reading devices provide current loop and EIAR2-232C output. Normally, asynchronous Serial ASCII data are transmitted at standard rates up to 9600 baud. EBCDIC (IBM-compatible) output is available on some models.

  5. Buffering capabilities. All devices are used in an on-line configuration. Buffering is confined to one 80 character card.

6. Reliability. Published data on equipment is generally specified at 6,000 hours assuming routine preventive maintenance is regularly performed.

7. Back-up Provision. Device failure would require manual data transcription.

8. Sources, Costs. Card reading equipment suppliers are listed in Appendix II. Device costs will be a function of reading speed. Single card devices can be obtained for less than $1000. Both devices with rates up to 300 C.P.M. is in the range of $6000. At 1200 C.P.M., the cost can rise to $20,000.

9. Per message time & cost. This is a function of the reader selected and the reading rate.

F. OPTICAL CHARACTER RECOGNITION (OCR)

OCR has been available for document processing in the office environment for over 25 years and yet fewer than 2000 sites now employ it. Primary constraints relate to tight specifications on document preparation, document reject rates and reprocessing costs and the relatively high costs associated with starting up. Primary successes have been in oil company credit slip processing and health insurance from processing.

More recently, lower cost, handheld OCR scanners have been introduced for data collection at the retail (non-grocery) point of sale. It is this class of device that is examined in the following paragraphs.

- Data Medium: In its analysis of alternatives for machine-readable encodation of merchandise tickets, the National Retail Merchants Association (NRMA) was particularly concerned with minimizing ticket size, employment of both low cost, low speed ticket encoders as well as high speed devices, and ticket content modification (i.e., adding or deleting information). Their selection of the OCR-A Size 1 character set was based upon these and other criteria.

   1. Environmental suitability. Employment of OCR in the shop environment would require machine readable encoding of labels or tags for product identification and the use of preprinted forms for repetitive data input. As with bar codes, a wide range of materials is available to meet the performance requirements dictated by the specific shop environment. However, the relatively small size of individual OCR characters could be a problem if the tag or label were subjected to mechanical abuse and portion or all of a character obliterated.

   2. Capacity. Character density ranges from eight to eleven .094-inch high characters per lineal inch.

   3. Redundancy. Standard techniques for ensuring data integrity include special characters for identifying field (message) length, 'protection' characters, etc. Although not specifically addressed in supplier literature, check characters could more than likely be added to enhance integrity. Character substitution error rates are quoted as being less than 1 in 10^4.

4. Operator Convenience. A primary virtue of OCR is that the media are both human and machine-readable. Minimal training is required to familiarize operators with the rather stylized nature of the OCR font.

5. Provision for Backup. Tag or form design should address possibility of damage and replacement alternatives (e.g. in-shop label printer).

6. Product Compatibility. Labels, tags, task 'menus' can be readily obtained to accommodate the needs of the shop environment, but strict attention to printing specifications is essential. Also, irregular surfaces generally unsuitable for OCR applications (e.g. labels on rough castings).

7. Sources, Costs. A variety of firms specialize in the supply of OCR tags, labels, forms, etc. The best source of information on these suppliers would be the OCR device manufacturer. (See Appendix II). Costs are similar to those outlined for bar coding.

- Data Collection Device: The use of OCR technology in the shop environment would involve handheld 'readers' and associated decoding and output electronics.

1. Environmental Suitability. OCR readers are available for use in environments where temperature ranges from 35°F to 105°F with relative humidity of 5 to 90%.

2. Operator Convenience. Typical readers are approximately four-inches long, three or four inches high and one-inch thick with a pistol-like grip. Weight without cable varies from three to five ounces. Cable length varies from six to ten feet. Features vary, but most OCR systems provide audio acknowledgement of valid entries. OCR readers permit operator wanding speeds of three to thirteen inches per second, reader misalignment of up to 8-degrees in any single plane with respect to the perpendicular to the coded message and cumulative misalignment of not more than 20 degrees in all planes. Encoded labels may be read in either direction.

   Longer messages may prove somewhat more difficult to handle in that character height of approximately 1/10th of an inch may not be increased to facilitate operator handling.

3. Error Checking/Correction. Decoding electronics compare message input with known dimensional and content parameters, editing same prior to transfer to the output interface. In the event of a valid read, an audio tone is provided to the operator. In the event of an unsuccessful reading attempt, no tone is provided and the operator rescans. Visual display of input data is provided with some models and, in any case, could be fed back from the user's data processing system to a display device.

   Reader electronics do not incorporate error correction capability.

4. Interface Characteristics. Normal OCR electronics provide a ten-line parallel ouput to the user's processor. Cable length is currently limited to 15 feet. One supplier offers an RS232C serial interface option.

5. Buffering Capability. Current OCR devices buffer reader input from a single line of copy prior to outputting. Buffer capacity ranges from 25 to 63 characters. Data storage for batch transfer to a business system would require additional user-supplied equipment. (A recently introduced portable unit incorporates a mini-cassette with 8000 character storage capacity.)

6. Reliability. The following information was drawn from published material of a single supplier and may not be typical.

   - Handheld reader: Desgined to provide 5000 hour mean-time-between failure exclusive of lamp and fuses. Lamp MTBF design goal is 1000 hours. Mean-time-to-repair (via replacement) is quoted at 15 minutes.

   - Associated electronics: No data published.

7. Back-up Provision. The basic OCR system consists of a reader and decoding electronics. Device failure would require manual data transcription. The user could, of course, add a manual entry back-up such as a keyboard.

8. Sources, Costs. Appendix identifies current OCR system suppliers. Equipment costs, depending upon volume, range between $1800 and $3000 for on-line devices. Portable units with appropriate telecommunications interface hardware are priced near $5000.

9. Estimated Per Message Time & Cost. Comments here are based upon observation of equipment in operation and interpretation of manufacturer claims.

   a) Depending upon message length and accessibility, a non-clerical operator could be expected to achieve a 95% first read rate in the shop environment. Further, input of 30 to 50 ten character records per minute would appear to be an achievable rate.

   b) Although operator training would require more attention than for bar code reading, it would appear that the impact of operator time on per message costs would be negligible.

   c) Label, tag or forms cost, then, along with basic device and necessary user supplied keyboards, displays, etc. cost are the primary factors to be analyzed in assessing specific application costs.

III. SUMMARY & CONCLUSIONS

Tables I and II on the following page summarize our general findings. Essentially, they illustrate surprising, albeit superficial, similarity between device characteristics. With the exception of magnetic stripe and punched card, for example, each technique permits considerable flexibility in media selection. Each data encoding approach packs roughly ten characters per inch. There is little difference in packaging for industrial applications (ignoring price variations). Equipment reliability appears to be generally good and, with the possible exception of voice recognition, pricing generally falls below $3000 per device.

BUT - There are differences. Let's briefly examine them:

A. Neither key entry nor voice recognition requires specialized data media. However, without addition of a check digit suffix or elaborate central computer message validation, the probability of operator error is high.

B. Bar codes and OCR use high integrity media which can be made an integral part of the product (be it labels on parts or pages in a catalog), but these media do represent an element of continuing system cost. The latter is also true of magnetic stripe and punched cards with the additional drawback of the need for developing a method for attaching them securely to the product.

C. None of the approaches considered requires elaborate operator training, but there are subtle and important differences in terms of technique impact upon operator performance of other tasks at the work station. He or she has to give some thought to key or voice data entry. With the other approaches, they need only perform a mechanical function.

D. None of the systems covered provide for back-up in the event of device failure although most bar code systems include a keyboard for manual entry of non-coded information. In the event of Lightpen failure, the keyboard would be used until the pen is replaced.

TABLE 1

DATA COLLECTION TECHNIQUE COMPARISON SUMMARY: MEDIA

DATA MEDIUM CRITERIA	KEY ENTRY	VOICE RECOGNITION	BAR CODING	MAGNETIC CODING	PUNCHED CARDS	OCR
Environmental Suitability	Widest Latitude	Widest Latitude	Multiple Alternatives	50° to 80°F Sensitive to magnetic fields	Damage possibility in harsh environments	Multiple alternatives sensitive to damage
Data Capacity	10 chars/ inch	10 chars/inch	10 chars/ inch	10-15 chars/inch	Standard 51 to 160 chars/card smaller cards available	8 to 11 chars/ inch
Redundancy	None without check digit	None without check digit	Error rate less than 1 in 10 4. Check digit enhances	Error rate less than 1 in 10 4. Check digit enhances		Error rate less than 1 in 10 4. Check digit enhances
Operator Convenience	Application Dependent	Application Dependent	Reasonable with minimal training.	Reasonable (locating and manipulating may inhibit)	Reasonable, although cumbersome	Some care required although reasonable
Back-up Provision	Manual	Manual	Manual	Manual	Manual	Manual
Product Compatibility	Widest Latitude	Widest Latitude	Some Constraints	Not integral to product. Unsuitable for task menus.	Not integral to product. Unsuitable for task menus.	Some Constraints
Sources	Application Dependent	Application Dependent	Appendix II	Appendix II	Appendix II	Appendix II
Costs (Estimates only)	Application Dependent*	Application Dependent*	$.0002 to .005 per character depending upon carrier	$.005 to .015 per charcter depending upon carrier	$.002 per card not including cost of punching	Similar to bar coding

* Excluding costs associated with check digit incorporation.

TABLE II

DATA COLLECTION TECHNIQUE COMPARISON SUMMARY: EQUIPMENT

EQUIPMENT CRITERIA	KEY ENTRY	VOICE RECOGNITION	BAR CODING	MAGNETIC CODING	PUNCHED CARDS	OCR
Environmental Suitability	Many industrial packages	32°F to 122°F 10-95% relative humidity	32°F to 122°F to 90% relative humidity	Industrial Packages available	Industrial Packages available	35°F to 105°F to 90% Relative Humidity
Operator Convenience	Some skill required. Relatively easy to use with training	Well suited to operator mobility. Some potential inconvenience with headset.	Easy to use with minimal training. Feedback good.	Convenience a function of card accessibility and work station layout.	Convenience a function of card size, accessibility & work station layout.	Some skill required. Longer messages may require greater care.
Error Checking & Correction	Not without check digit Error rated 2 to 4%	Likely 98% 1st read rate. Not self-correcting.	Format checking. 97% or better first read rate. Not self correcting.	Format checking. Read rate dependent upon card condition. Not self correcting.	Read rate dependent upon card conditon. Not self correcting.	Format checking. No error correction. 95% first read rate.
Interface Characteristics	Current industry standards	Current industry standards	Current Industry Standards.	Current Industry Standards	Current Industry Standards	Moving towards industry standards
Buffering Capability	Optional	Requires additional device	Optional	Requires additional device	Requires additional device	Normally done by host computer
Reliability (estimates)	MTBF: 20,000 Hours	Reference user list	MTBF: 16,000 hours	MTBF: 15,000 hours		Lamps: 1,000 hours MTBF Devices: 5,000 hours MTBF
Back-up Provisions	Manual	Manual	Manual Human readable normally parallels bar code.	Manual Difficult unless data also shown in human readable format on carrier	Manual Difficult unless data also shown in human readable format on carrier	Manual
Sources	Appendix II	Appendix II	Appendix II	Appendix II	Appendix II	Appendix II
Costs (Estimates/Unit)	$1000-$5000	$10000	$1300-$3000	$800-$2000		$1800-$5000
CRITERIA FOR ESTIMATING SYSTEM COSTS						
• Medium	None, except check digit if used	None, except check digit if used	See medium. Continuing cost.	See medium. Continuing cost.	See medium. Continuing cost.	See medium. Continuing cost.
• Device	See costs & MTBF	See costs	See costs/MTBF	See costs/MTBF	See costs/MTBF	See costs/MTBF
• Training	Message length dependent 1-5 days		1 day or less	Minimal	Minimal	1 day or less
• Operator Time	Application specific (Use 7-10/minute)	Application specific (Use 6-7/minute)	Application specific (Use 60 records/minute)	Application specific	Application specific	Application specific (Use 30 to 50 records/minute maximum

The foregoing tables allow for generalized comparison of the various data collection techniques covered in this report. Evaluation for purposes of selection of that technique best suited for a specific application must be based upon more detailed criteria developed on the basis of actual operating requirements. Particularly pertinent in this connection are:

- Operating personnel qualifications (skilled, unskilled, clerical, non-clerical, etc.)
- Personnel workload (nature, complex or simple, and amount of manual work to be performed)
- Work Station Layout (can the data entry device be readily integrated with the operator's station?)
- Input Message Source (travel document, label, station 'task menu', operator judgment, etc.?)
- Input Message/Length (number of characters, content, relationship of input to employee performance i.e., incentive-link or merely an additional task?)
- Input Message Frequency (number of entries per day, per hour?)

We have selected a few of these criteria for further comparison of the techniques presented. Although somewhat arbitrary, the categories defined in Table III are not atypical of the shop environment. It is the technique as much as the content that should serve as a useful guideline for data entry system selection. It should be understood that the following exercise would normally be undertaken subsequent to preliminary screening on the basis of criteria outlined in the preceding pages.

TABLE III

DATA COLLECTION TECHNIQUE COMPARISON CHART (In application, only criteria specific to a given application need be considered)

CRITERIA / TECHNIQUE	KEY ENTRY	VOICE RECOGNITION	BAR CODING	MAGNETIC CODING	PUNCHED CARDS	OCR
Personnel Qualifications: Skilled, Unskilled, Clerical	Although related to message length, workload, etc, key entry requires certain dexterity and is normally best suited for skilled personnel	Best with reasonably skilled workers	Minimal training required	Minimal training required	Minimal training required	Some training required
Personnel Workload						
Simple, low volume	OK	OK	OK	OK	OK	OK
Simple, high volume	Questionable	OK	OK	OK	Questionable	OK
Complex, low volume	Questionable	OK	OK	OK	OK	OK
Complex, high volume	Questionable	OK	OK	OK	Questionable	Questionable
Work Station Layout						
Tight quarters	Could be a problem	OK	OK	OK	OK	OK
Ample space avail.	OK	OK	OK	OK	OK	OK
Input Message						
• Source						
Document	OK	OK	OK	OK	OK	OK
Label	OK	OK	OK	OK	OK	OK
Task Menu	OK	OK	OK	NO	NO	OK
Judgment	OK	OK	NO	NO	NO	NO
• Length						
5 characters	OK	OK	OK	OK	OK	OK
15 characters	Questionable	OK	OK	OK	OK	OK
20 characters	NO	Questionable	OK	OK	OK	Questionable
30 characters	NO	NO	OK	OK	OK	Questionable
• Frequency						
10 per hour	OK	OK	OK	OK	OK	OK
30 per hour	OK	OK	OK	OK	OK	OK
40 per hour	Questionable	OK	OK	OK	OK	OK
60 per hour	Questionable	OK	OK	OK	OK	OK
120 per hour	NO	OK*	OK*	OK*	OK*	OK*

* May begin to impact efficiency on other tasks. Accordingly, utility a function of value or criticality of data entered. It may, indeed, be appropriate to assign full-time personnel.

The report set out to assess alternative methods of data entry on the basis of their suitability for the shop floor. Primary considerations included:

- The need to function reliably and with minimal maintenance in adverse environments.
- Simplicity of design and function to promote ready comprehension and use by non-clerical shop personnel.
- Performance characteristics that complement rather than stymie operator execution of primary tasks.

In our opinion, none of the methods examined should be ignored in preliminary analysis of specific data entry requirements.

Final recommendations, of course, cannot be made without specific application characteristics and requirements. It may indeed develop for a given application that a hybrid device offers the best solution. In this connection, a number of suppliers offer equipment which permits not only key, but also magnetic stripe, punched card or bar code data entry.

APPENDIX I

Reference Materials

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APPENDIX II

Supplier Listings

Data included in this appendix is representative. It does not purport to cover either all suppliers or all possible equipment variations.

KEY ENTRY SYSTEMS

Key: 1. Fixed position devices
2. Portable devices

Supplier	Key
Azurdata, Inc. 1305 Mansfield, Richland, WA 99352	1+2
Computer Identics Corporation 31 Dartmouth Street Westwood, MA 02090 Numeric and full alphanumeric keyboard and 16 or 32-character displays	1
Datapathing, Inc. 370 San Aleso Ave. Sunnyvale, CA 94086	2
Digital Equipment Corporation 146 Main St. Maynard, MA 01754	1
Epic Data Corporation 12728 15th Place N.E. Bellevue, WA 98005	1
IBM Corporation Route 52 Dayton, NJ 01180	1
MSI Data Corporation 340 Fischer Avenue Costa Mesa, CA 92627	1+2
Norand Corporation, Subsidiary of Pioneer Hi-Bred International, Inc., P.O. Box 666 Cedar Rapids, IA	1+2
Panasonic, M.E.C.A. Industrial Apparatus Department, Industrial Division 2960 Hart Drive, Franklin Park, IL 60131	1+2

KEY ENTRY SYSTEMS cont'd

Supplier	Key
Perkin Elmer Corporation Randolph Park West Randolph, NJ 07801	1
Sierra Research Corporation P.O. Box 222 Buffalo, NY 04225	1
Telxon Systems Division Ghent Square Bath, OH 44201	1+2
Termiflex Corporation P.O. Box 1123 Nashua, NH 03060	1+2
TRW Data Systems, 12911 Simms Avenue, Hawthorne, CA 90250	1+2

VOICE RECOGNITION

1. Threshold Technology, Inc., 1829 Underwood Blvd., Delran, NJ 08075

2. Scope Electronics, Inc., 1860 Michael Faraday Drive, Reston, VA 22090

3. Dimension, Inc., 1860 Michael Faraday Drive, Reston, VA 22090

BAR CODE

Key:
1. Handheld Code Readers
2. Automatic Code Readers
3. Fixed position data entry terminals
4. Portable data entry terminals
5. Labels, label printers
6. Forms printers

Supplier	Key
Accu-Sort Systems 601 Lawn Avenue Sellersville, PA 18960	1, 2, 3, 4, 5
Avery Label 777 E. Foothill Boulevard Azusa, CA 91702	2, 5, 6
Azur Data Corporation 1305 Hansfield Avenue Richland, WA 00352	1, 3, 4
Bergen Brunswig Corporation 22351 S. Wilmington Avenue Carson, CA 90745	1, 3, 4
Centronics Data Computer Corporation One Wall Street Hudson, NH 03051	5, 6
Computer Identics Corporation 31 Dartmouth Street Westwood, MA 02090	1, 2, 3, 5
Courier Citizen Company 339 Harbor Way So. San Francisco, CA 94080	5, 6
Data Royal 235 Main Dunstable Road Nashua, NH 03060	5, 6
Epic Data Corporation 12728 15th Place N.E. Bellevue, WA 98005	1, 3
Ferranti-Packard, Ltd. 121 Industry Street Toronto, Ontario CANADA	1, 2, 3, 4

BAR CODE cont'd

Supplier	Key
IBM Corporation Route 52 Dayton, NJ 08810	1, 2, 5
Identicon Corporation 1 Kenwood Circle Franklin, MA 02038	1, 2, 3, 4
Interface Mechanisms 5503 232nd Street S.W. Mountlake Terrace, WA 98043	1, 3, 5
3M Company Special Enterprises Dept. 3M Center, Building 2232 St. Paul, MN	5
Markem Corporation 150 Congress Street Keene, NH 03431	5
Mead Corporation 1771 Springfield Street Dayton, OH 45401	5, 6
Monarch Marking Systems P.O. Box #608 Dayton, OH 45401	1, 2, 3, 5, 6
MRC Corporation 11212 McCormick Road Hunt Valley, MD 21031	2
MSI Data Corporation 340 Fischer Avenue Costa Mesa, CA 92627	1, 3, 4
NCR Corporation 950 Danby Road Ithica, NY 14850	2
Nixdorf Computer, Inc. 888 Worcester Street Wellesley, MA 02181	3
Norand Corporation 550 Second Street, SE Cedar Rapids, IA 52401	1, 3, 4
Panasonic 2960 Hart Drive Franklin Park, IL 60131	2, 3

Supplier	Key
Plessey Canada Ltd. 300 Supertest Road Dawnsview, Ontario 3Mj 2M2 CANADA	1, 4
Printronix 17421 Derian Avenue Irvine, CA 92714	5, 6
Skanamatic P.O. Box S or Route 5 West Elbridge, NY 13060	1, 3
Standard Register Co. Dayton, OH 45401	5, 6
Telxon Corporation 7280 Wynnwood Houston, TX 77008	1, 3, 4
Wallace Business Forms 237 Lancaster Avenue Devon, PA 19333	5, 6
Weber Marking Systems 711 West Algonquin Road Arlington Heights, IL 60005	5, 6

MAGNETIC STRIPE READERS

1. Synergistics, Inc., 10 Huron Drive, E. Natick, MA 01760
2. Sankyo Seiki, Inc., 149 5th Avenue, New York, NY 10010
3. Data Source Corporation
4. Epic Data Corporation, 12728 15th Place N.E., Bellevue, WA 98005
5. IBM Corporation, Route 52, Dayton, NJ 08810

PUNCHED CARD

1. Constal Data, 1592 N.W. 159th Street, Miami, FL 33169
   "Smart Clock": 16 digit hollerith code reader, numeric keyboard & display, clock

* 2. IBM 2790 Data Collection System using 2791 area stations and 2796 Data Entry Units incorporating card reader & Thumbwheels

3. Epic Data Corporation, 12728 15th Place N.E., Bellevue, MA 98005

4. Panasonic Models B & BT (10 to 22 characters)

5. Custom Terminals Corporation, 216 North Fehr Way, Bay Shore, NY 11706

6. Wright Line, Inc., Worcester, MA. 01606
   Portable Key Punches

* 7. IBM 5230 Data Collection System using 5235 Data Entry Station with status lights, keyboard, action/function keys, display, card and badge readers. Output to punched cards, diskettes or telecommunications link.

8. Decicom Systems, Inc., 857 Essex Street, Brooklyn, NY 11208 - Model D57 Optical Badge & Card Reader

* 9. Digital Equipment Corporation, Maynard, MA 01754
   Models RT803 and RT805 Work Stations incorporating badge and card readers, 32-character display, 12-position keypad operator guidance lights, and function keys.

* The IBM and DEC systems are typically marketed as packages including manufacturer-supplied central processing hardware.

OPTICAL CHARACTER RECOGNITION (OCR)

1. Caere Corporation, 345 East Middlefield Road, Mountainview, CA

2. Recognition Products, Inc., P.O. Box 5569, Dallas TX 75222

3. Key Tronic, P.O. Box 14687, Spokane, WA 99214

4. Data Source Corporation, 2350 Alaska Avenue, El Segundo, CA 90245

NOTE 1: Recognition Products has just introduced a portable OCR data entry device with keyboard, display and cassette memory.

NOTE 2: OCR media. Most of the manufacturers identified as suppliers of bar code printers, labels or forms can supply OCR media.

MISCELLANEOUS

1. Data Recognition Ltd (England) - Optical Mark Readers

2. Hewlett Packard
   P.O. Box #4207
   Huntsville, Al. 35802
   Model 7261A Optical Mark Reader

3. iCOM, Inc.
   6741 Variel Avenue
   Cagoga Park, Calif. 91303
   Model 60 Microperipheral card reader/printer (mark sense)

4. Motorola
   Room 2128, 8000 W. Sunrise Blvd.
   Fort Lauderdale, Fl. 33313

5. Optical Scanning Corp.
   Newtown, Pa. 18940
   OPSCAN 12/17 Source Document Readers (mark sense).

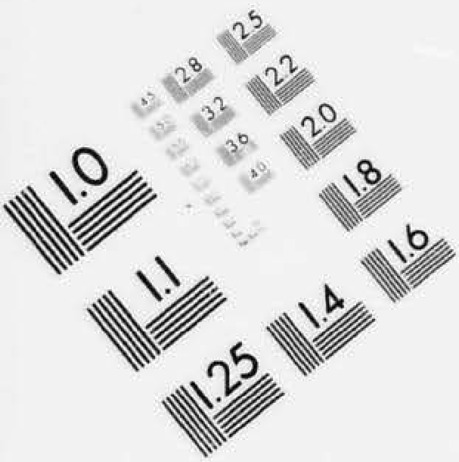
6. Quest Automation Ltd. (England):
   Datapad System recognizes handwritten data entry

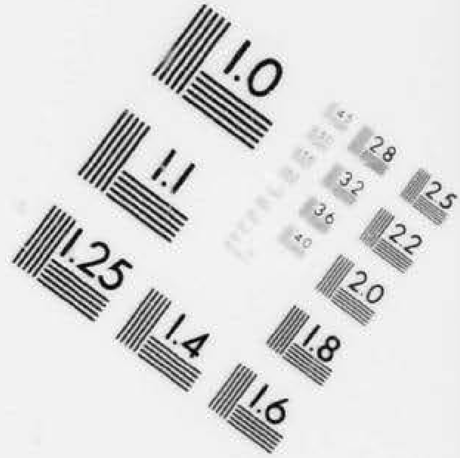
7. Sentracon Corp.
   Westwood, Mass.
   Non-magnetic, non-optical electronically encoded badges and badge readers with keyboard and display.

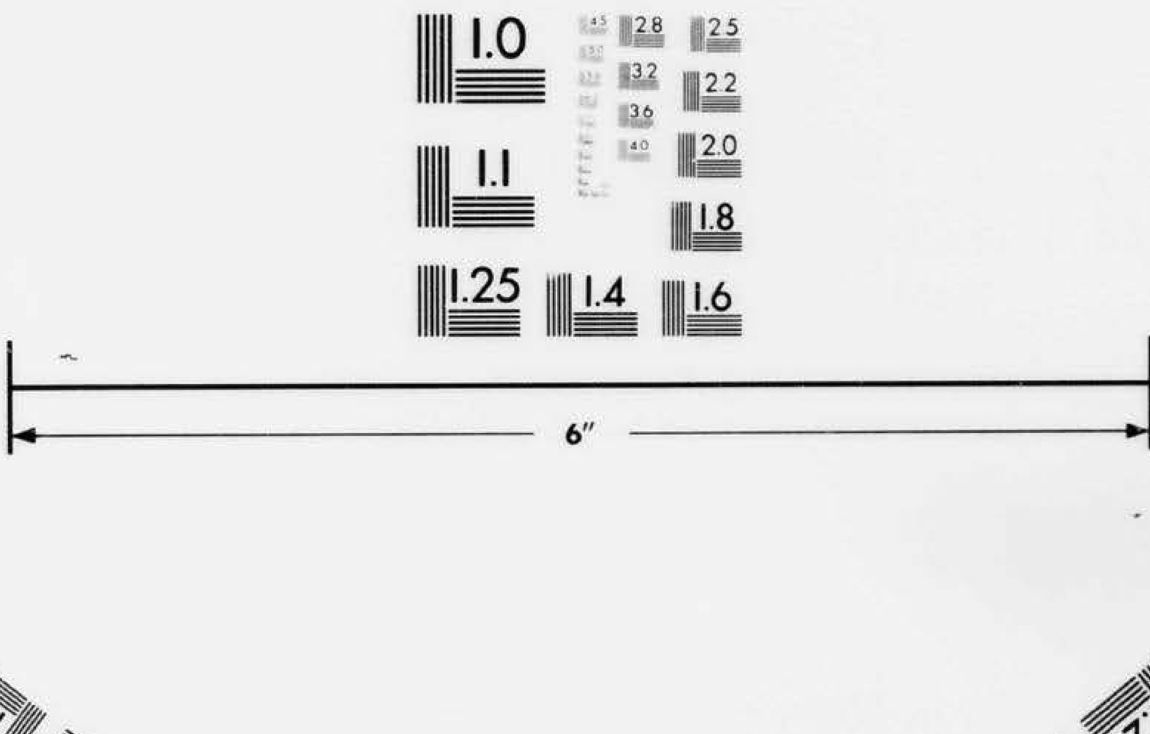
8. Sweda International
   Magnetic and punched hole encoding

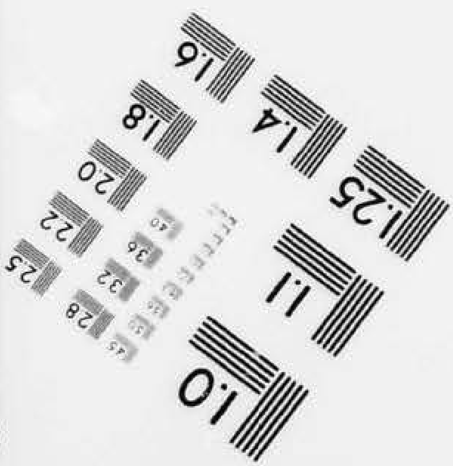
9. Wyle Computer Products
   Series 700 Optical Mark Readers

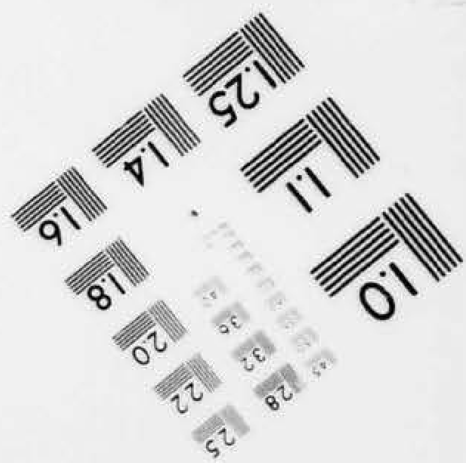
UNITED STATES OF AMERICA
GOVERNMENT PRINTING OFFICE











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July 14, 1981