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Transit Reliability Information Program

Reliability Verification Demonstration Plan for Rapid Rail Vehicles

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Final Report

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16. Abstract

The Transit Reliability Information Program (TRIP) is a government-initiated program to assist the transit industry in satisfying its need for transit reliability information. TRIP provides this assistance through the operation of a national Data Bank. This Data Bank collects, stores, and analyzes data generated by transit operators during the course of revenue service operation and equipment maintenance. The results of the periodic analyses of the stored data are distributed to TRIP participants and users.

This report provides a description of the utilization of TRIP as a tool for conducting a Reliability Verification Demonstration Plan for rapid rail vehicles.

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PREFACE

This document describes the utilization of the Transit Reliability Information Program (TRIP) as a tool for conducting a Reliability Verification Demonstration Plan for rapid rail vehicles. This document has been prepared by the Dynamics Research Corporation, (DRC), Wilmington, Massachusetts, under Contract Number DOT-TSC-1559, issued by the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC), on behalf of the Office of Safety and Product Qualification of the Urban Mass Transportation Administration (UMTA), Office of Technology Development and Deployment, U.S. DOT.

The purpose of this document is to provide the TRIP user with descriptions of the Data Bank capabilities, data requirements, operation pertaining to the conduct of a Reliability Verification Demonstration (RVD), RVD planning phases, and procedures for conducting and analyzing an RVD program.

The authors would like to acknowledge with gratitude the DRC personnel who have contributed to the production og this report:

Sal DeSalvo and Jonathan Frueh who performed the background research and development of the application of TRIP to an RVD plan.

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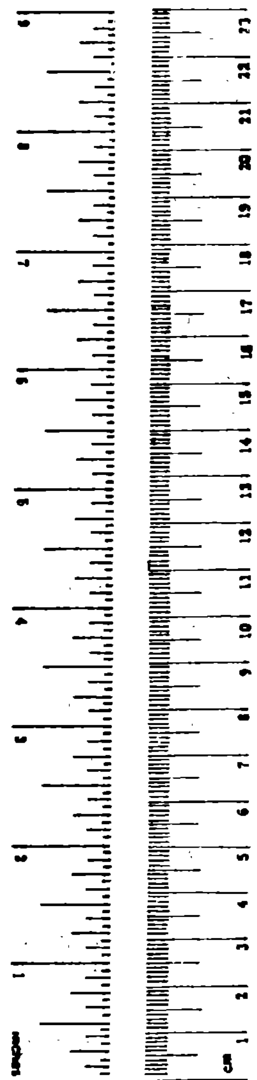
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

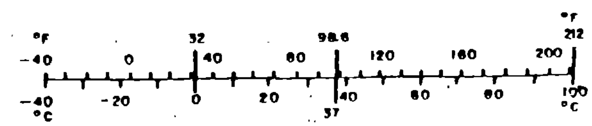
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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



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1 - INTRODUCTION

This is one of a set of documents which suggest applications and provide guidelines to current and potential participants in the Transit Reliability Information Program (TRIP). The "TRIP Reliability Verification Demonstration Plan for Rapid Rail Vehicles" has been prepared by the Dynamics Research Corporation (DRC) under Contract Number DOT-TSC-1559, issued by the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC).

TRIP is a government-initiated program to assist the transit industry in satisfying its need for transit reliability information. TRIP provides this assistance through the operation of a national reliability Data Bank. This Data Bank collects, stores, and analyzes data which is currently being generated by transit operators in the course of revenue service operation and equipment maintenance. The results of periodic analyses of the stored data are distributed to TRIP participants and users.

These Guidelines will be periodically revised and updated to reflect improvements in the TRIP Data Bank and experience gained by the transit industry as a result of TRIP. Comments on this document or questions concerning its latest revision should be submitted to:

U.S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
Transit Systems Branch
Kendall Square
Cambridge MA 02142

1.1 PURPOSE AND SCOPE

This document has been prepared as an applications manual for the TRIP Data Bank (TDB). The TDB is capable of storing and processing various operations and maintenance related data for rapid rail transit vehicles. This data is collected from participating transit authorities. After processing, reports are generated which provide information that may be used to assess the relative reliability and maintainability aspects of the transit vehicles.

The document provides the user with an overview of the TRIP and TRIP Data Bank. In Sections 2 and 3 it describes the Data Bank Capabilities, data requirements, and operation pertaining to the conduct of a Reliability Verification Demonstration, including:

- Data generation and recording;
- Data submission;
- Data formatting and storage; and
- Report generation.

The use of Reliability Verification Demonstration (RVD) is a relatively new concept in the transit industry, but it is becoming increasingly important as the costs of procuring and maintaining new equipment increases while seemingly, the useful life decreases. Thus, properties are recognizing the need to specify and evaluate reliability criteria as a part of the procurement process in order to obtain a high degree of cost effectiveness in their equipment. Accordingly, this document recommends procedures for planning, implementing and evaluating an RVD program. Section 4 is concerned with the RVD planning phases, including:

- Organization of the program;
- Setting up test facilities for the RVD;
- Establishing ground rules for conducting the RVD;
- Selection of an RVD sample set; and
- Estimating the duration of the program.

Procedures for conducting and analyzing the RVD program are discussed in Section 5 of this document. A variety of techniques for reliability evaluation are presented including ways in which the TRIP Data Bank may be used to collect and process the data collected during the program.

1.2 BACKGROUND

The Transit Reliability Information Program (TRIP) is a government initiated response to an acknowledged need to collect and analyze rail transit equipment reliability data on a national level. The goals of TRIP are to:

- Amalgamate current reliability efforts within the transit industry, and provide a focal point for a consolidated reliability effort;

- Promote uniform reliability related definitions for the transit industry;

- Provide a central repository for voluntary submittal of transit industry field failure data;

- Provide means for periodic distribution of reliability data to potential users;

- Provide data for factual comparison of reliability between related equipments;

- Provide substantive data for specifying new equipment procurements, justifying product improvement projects, and supporting system analysis programs.

TRIP has been designed as a three-phase program. Phase I consists of:

- Definition and scoping of the functional and operational requirements of the TRIP Data Bank;

- Design, implementation, operation, and enhancement of a Rail Rapid Vehicle (RRV) Experimental Data Bank (EDB) for the purpose of evaluating the design concepts of the (full-scale) TRIP Data Bank on a prototype scale;

- Design, implementation, operation, and enhancement of an EDB for Buses.

Phase II consists of merging the two EDBs into a single data bank and expanding the scope of the data bank to include all aspects of vehicles involved. Phase III will be the expansion of the TRIP Data Bank to include other classes of transit equipment.

TRIP is currently in Phase I. The initial TRIP support contract was issued to the Dynamics Research Corporation in September, 1978, by the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC) for the purpose of planning and establishing a program to collect and evaluate reliability information on new and existing transit vehicles. This contract focused on TRIP for Rail Rapid Vehicles (RRV TRIP) and included the definition and scoping of the full-scale TRIP Data Bank and establishment of the RRV Experimental Data Bank.

The American Public Transit Association (APTA), under separate contract to TSC, established the TRIP Liaison Board consisting of representatives from U.S. rail transit authorities and transit equipment manufacturers. The Liaison Board has provided continuous guidance for the development of TRIP and the EDB through a series of periodic meetings. From the Liaison Board membership, six transit authorities volunteered at the contract "Kick-off meeting" to participate in the development of TRIP by supplying data to the EDB. The six properties are:

BART	Bay Area Rapid Transit District
CTA	Chicago Transit Authority

GCRTA	Greater Cleveland Regional Transit Authority
NYCTA	New York City Transit Authority
PATCO	Port Authority Transit Corporation
WMATA	Washington Metropolitan Area Transit Authority.

The development of the TRIP Data Bank began with an investigation of existing reliability data banks and an analysis of the data collection and reporting approaches being used in the transit industry. Particular emphasis was placed upon the six EDB properties. The results of these investigations were used to formulate a functional definition of the TRIP Data Bank. Each of the required TRIP Data Bank functions was further defined into modular "elements" which were then translated into preliminary design requirements and specifications. A chronological summary of the TRIP Data Bank development is presented in DRC Report Number R-341U, "TRIP Phase I Report." See Section 1.3, herein, for a complete list of reference documents.

Part of the TRIP Data Bank design included the development of a uniform system of transit vehicle component identification. This parallel activity resulted in the formulation of the "Generic Part Number" (GPN), a code by which equipment of similar function is classified and grouped according to that function. The purpose of the GPN is to provide a common numbering system to which the individual part numbering systems used at the various transit properties can be cross-referenced. The GPN is the major "key" by which component data is stored in the TRIP Data Bank and, because of its orientation toward equipment function, provides a means for efficient data retrieval in support of analytical comparison of functionally similar equipment. Procedures were subsequently developed for preparing the "Generic Parts List" (GPL), the cross-reference table of transit property part numbers versus Generic Part Numbers.

The design and implementation of the Experimental Data Bank began early in 1979. The purpose of the EDB was to provide a model or prototype of the TRIP Data Bank so that the various aspects of the emerging Data Bank design could be tested and refined prior to full-scale implementation. The TRIP Liaison Board recommended three rail vehicle subsystems (doors and door controls, propulsion, and friction brakes) for use as "pilot equipment" in the EDB.

Following the successful completion of the Software Acceptance Test, the TRIP Experimental Data Bank began operation on August 6, 1979, with the input of July data from BART and WMATA. EDB refinement and expansion have been on-going activities since the initiation of operation. Expansion of the "input side" of the EDB continued with the inclusion of CTA and PATCO in November, 1979, and NYCTA in February 1980. (GCRTA will be brought on-line early in 1981.) The EDB currently contains data going back to August 1, 1979, for CTA and PATCO, and July 1, 1979, for BART, NYCTA, and WMATA.

The first EDB Output Report was published in September, 1979, and contained the July data from BART and WMATA. The TRIP Liaison Board reviewed the report and recommended several modifications to format and content. EDB Output Reports were subsequently published in November, 1979 (August and September data), March, 1980 (November, 1979, data) and July 1980 (March data).

It is on the "output side" of the EDB where emphasis on the "experimental" nature of the data bank has occurred. Each EDB Output Report has been a major revision of the previous report in terms of both format and content. Methods of presenting the data, level of detail, accuracy and validity, statistical significance, all of these, and more, are of concern to the Liaison Board members, and their concern is reflected in the high level of interest being expressed in the presentation of information from the EDB.

A Critical Design Review (CDR) of TRIP was held in April 1980. The CDR Committee, consisting of the TRIP Liaison Board representatives from the six participating properties and representatives from APTA, UMTA, and TSC, reviewed the past 24 months of TRIP activity; assessed TRIP benefits; listened to each participant's position on TRIP; and concluded that TRIP cannot be properly evaluated without 12 to 18 months of additional EDB experience.

The CDR recommendations impacted Phase I of the TSC TRIP Implementation Plan as follows:

- The operation and refinement of the RRV EDB by DRC with three major assemblies from 10 series of vehicles from 6 properties will be continued for an additional 21 months (15-month EDB operation and refinement with an additional 6-month EDB operation and merge transition period);

- The establishement and operation by TSC of an EDB for buses will begin during Phase I by monitoring a sample of assemblies from a limited number of buses.

Participation and interest in, as well as potential benefits from, Phase I indicate that TRIP EDB users (operating properties, consultants, Federal Government, and suppliers) want factual information from TRIP and are relying on TRIP's large quantity of readily available maintenance data to provide timely reports of equipment replacement experience.

Pending a favorable decision from the final Phase I CDR, Phase II will start a full-scale merged RRV and Bus TRIP Data Bank. It will be established and put on line starting with the transfer of data from the RRV and Bus EDBs. The number of equipments initially monitored will be small, but as the capability expands, additional equipments will be monitored until failure data on all vehicle components are contained in the data bank. A CDR of Phase II can then be performed to determine if Phase II accomplished its goals and if Phase III is justified. Phase III is envisioned as the expansion of the Data Bank and equipment monitored to cover UMTA responsibilities in Fare Collection, ATO/ATC, and track and structures. As other transportation equipments are incorporated, the TRIP Data Bank will become the UMTA National TRIP.

These guidelines and applications will continue to be revised as the TRIP Data Bank is refined and improved to reflect the latest procedures and uses of this system. As new examples of the use of information generated by the Data Bank are provided, they will be included in this and related documents to assist participants in the use of TRIP and the information which it produces.

1.3 REFERENCES

The following reports, issued by the Dynamics Research Corporation (DRC), collectively describe the development of the TRIP Experimental Data Bank. Except for references (6) and (7) below, these are "draft" reports which document the progressive development of the EDB. In some cases, the specific information contained in these reports has become obsolete. For the most part, however, the concepts remained valid as the EDB evolved and have been incorporated into one or more of the "final" reports, references (12) through (16), below.

(1) Report No. E-4852U - TRIP Task I Draft Report - (Data Bank/Source Investigation), December 18, 1978.

(2) Report NO E-4894U - TRIP Task 2 Draft Report - "TRIP Data Bank Scope and Definition," January 18, 1979.

(3) Report NO. E-4895U - TRIP Task 3 Draft Report - "Transit Vehicle Equipment Lists", January 18, 1979.

(4) Report No. E-4896U - TRIP Task 3 Draft Report - "Reliability Equipment List Operating Procedures", January 18, 1979.

(5) Report No. E-4998U - TRIP Task 4 Interim Report - "Rapid Rail Transit Vehicle guidelines for the Operation and Use of the TRIP Data Bank", April 16, 1979.

(6) Report No. R-284U - "TRIP Experimental Data Bank Acceptance Test Plan - Final", July 9, 1979.

(7) Report NO. R-285U - "TRIP Experimental Data Bank Acceptance Test Procedures - Final", July 9, 1979.

(8) Report No. E-5150U - TRIP Task 6 Draft Report - "Railcar Standardization Reliability Plan", August 20, 1979. (NOTE: This is the draft report upon which this "TRIP Reliability Verification Demonstration for Rapid Rail Vehicles" is based.)

(9) Report No. E-5234U - "TRIP Experimental Data Bank Program Maintenance Manual - Preliminary", October 19, 1979.

(10) Report NO. E-5235U - "TRIP Experimental Data Bank User's Manual - Draft", October 19, 1979.

(11) Report No. E-5361U -"TRIP Generic Maintenance Action Codes", February 5, 1980.

The following reports also issued by DRC, are companion documents to this "TRIP Reliability Verification Demonstration For Rapid Rail Vehicles." Collectively, these reports document the configuration, operation, use, application, and development of the TRIP Experimental Data Bank. This report is included in the following set of references to provide correspondence with the five themes mentioned above.

(12) Report No. R-337U - "TRIP Experimental Data Bank Program Maintenance Manual", September 30, 1980.

(13) Report No. R-338U - "TRIP Experimental Data Bank Operating Procedures Manual", September 30, 1980.

(14) Report No. R-339U -"TRIP Participants Guidelines", September 30, 1980.

(15) Report No. R-340U - "TRIP Reliability Verification Demonstration Plan for Rapid Rail Vehicles", September 30, 1980.

(16) Report No. R-341U - "TRIP Phase I Final Report for Contract Number DOT-TSC-1559", October 31, 1980.

2 - TRIP OVERVIEW AND APPLICABILITY TO RELIABILITY VERIFICATION DEMONSTRATION

The Transit Reliability Information Program (TRIP) is a government initiated effort to provide "real-world" reliability data for rapid rail transit vehicles, together with a Data Bank which can provide information and reports tailored to the needs of the transit industry. TRIP is the response to an acknowledged need not only for collection and storage of baseline, industry-wide reliability information, but also for a system in which to analyze this data in order to support the activities and interests of the industry which it serves.

In addition to its capability of providing industry-wide analysis of transit data, TRIP can support the specific requirements of individual Reliability Verification Demonstration programs. It is with this application in mind that this document has been prepared. The following subsections contain a description of the TRIP Data Bank (TDB) and its operation in order to provide the potential user of TRIP with an overview of TDB capabilities in support of a Reliability Verification Demonstration.

2.1 TRIP DESCRIPTION

The TRIP Data Bank is a computerized system for the collection, processing, storage, retrieval, analysis and reporting of reliability-related information pertaining to rapid rail transit vehicles. Information covering the configuration, operations, maintenance, and repair of transit vehicles is submitted to the TDB by TRIP participants. The Data Base within the TDB acts as a central source of operation and maintenance history data for these vehicles. The collected data is analyzed to determine equipment reliability levels and trends. The results of these analyses are reported to both TRIP participants and other interested users.

The TRIP Data Bank is most accurately described as an "integrated" data base. Its primary characteristics are:

- All data is stored in one central storage location allowing easy access to any data item;

- The data base consists of different types of data all logically related by Generic Part Number and chronological order to permit rapid and efficient reporting;

- A wide variety of data, including reference, operating, inspection, and unscheduled maintenance data, can be stored efficiently by Generic Part Number to organize data which is related to the same equipment.

Detailed descriptions of TDB operation, including use of the Generic Parts List, Generic Part Numbers and the Data Dictionary referred to in this report, may be found in the referencs listed in Section 1.3.

The centralized storage of all data permits the efficient analysis of different types of data and standardization of data content. For example, static and dynamic data are stored side-by-side under a given Generic

Part Number in the data base. This storage method permits analysis of reference data, based on various dynamic data parameters such as vehicle series mileage.

Information in the TDB is stored in chronological order by Generic Part Number and Generic Serial Number. This logical arrangement of the data can be viewed as providing a "filing cabinet" of data with a "folder" for each unique serialized part. All "folders" are in part number sequence and for a given part all serialized occurrances are grouped together. The data in the "folder" is in most-recent chronological order for each serial number to provide quick access to more recent data.

This data organization method provides a data base that contains a complete history of all data stored in a format that can be used in a wide variety of analyses. For example, all traction motors that failed or required maintenance during a given month would be stored together in the Data Base. The most recent failures and associated repairs would be the first accessed and retrieved, resulting in a "last-in-first-out" retrieval procedure.

Each unique data type is identified and stored in the integrated Data Base using an "index key", which permits the direct access and retrieval of each of these groups of data. This so called "indexed sequential" organization allows "random" access to the specific data of interest without having to read all stored data to locate the desired item. This direct-access capability is provided by the Data Dictionary which describes the type, content, and relationship of all data stored in the Data Base.

Figure 2.1-1 presents a functional overview of the TRIP Data Bank. The input side of the TDB consists of several separately-executed programs which collectively perform the functions of input data conversion, formatting, standardization and editing and Data Base update. These functions include:

- Conversion of hard-copy (i.e., forms, documents) input data into computer-readable format;

- Conversion of computer-readable (i.e., magnetic tape) input data into the input format of the host computer;

- Extraction and reformatting of all input data in computer readable format into Data Base format;

- Assignment of generic "index keys" and other generic codes to provide uniform data storage format, including;

  - Generic Part Numbers;
  - Generic Serial Numbers;
  - Generic Maintenance Codes;

- Data verification of all data input to the TDB, including:

  - Verification of processed input data for accuracy;
  - Checking of data prepared for Data Base input for validity by comparison with data element

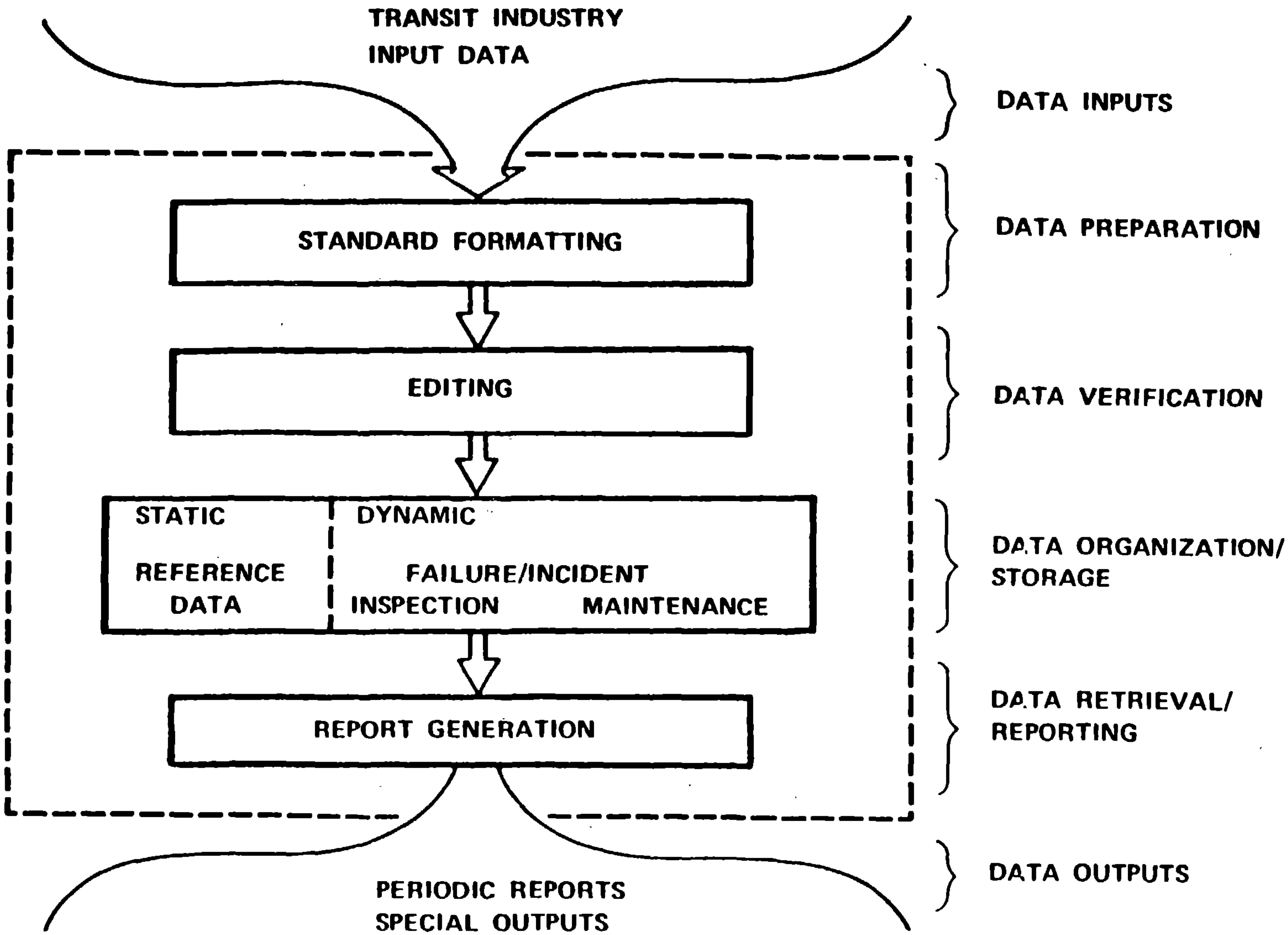

Figure 2.1-1 - TRIP DATA BANK FUNCTIONAL OVERVIEW

acceptable ranges and/or tables of values as defined by the submitting transit property; Checking for redundant entries on the Data Base.

The generation of output reports from the TRIP Data Bank is accomplished through the use of several functional procedures, including:

- Re-ordering and reformatting of data retrieved from the Data Base;

- Automated analyses of the retrieved data utilizing standard as well as special analytical techniques;

- Production of routine periodic reports to present the information in both tabular and graphical format;

- Production of special-request reports to meet the individual needs of TRIP users.

Periodic reports are produced on a scheduled basis by the TDB operating staff. All reports are reviewed for data content and validity of analysis prior to distribution to TRIP users.

Special requests are processed on an individual basis in order to accommodate the specific information needs of the requestor. Special requests may require special analytical algorithms and report formats. In order to minimize the necessary turn-around time tp produce special reports, the TDB utilizes an independent, system-standard report generator to satisfy these requests.

2.2 OPERATIONAL APPLICATION OF TRIP TO RELIABILITY VERIFICATION DEMONSTRATION

Reliability Verification Demonstration (RVD) might be used as a part of warranty assurance for new vehicles and for evaluating hardware replacement needs. The TRIP Data Bank provides a valuable tool for use in an RVD program. Such a program would normally consist of four major activities.

- Data Generation and Recording
  - Failure Reporting
  - Maintenance Records
  - Utilization Records.
- Data Submission (to the TDB)
  - Regular Intervals
  - Consistency of Content
  - Consistency of Format.
- Data Storage (within the TDB)
  - Integrated Data Base
  - Logically Structured.
- Report Generation (from the TDB)
  - Timely

- Relevant
- Flexible.

The preceding section addressed the capabilities of the TRIP Data Bank as a generalized system to accept and store rail transit vehicle operating and maintenance data and to produce reliability reports based upon that data. The purpose of this section is to provide an overview of how the TRIP Data Bank can be used to support a Reliability Verification Demonstration program in the context of the four major activities outlined above.

2.2.1 Data Generation and Recording

The primary source of data for a Reliability Verification Demonstration program is the transit property at which the demonstration is being conducted. The ability to successfully evaluate the results of a demonstration is dependent upon both the quantity and quality of the data provided. Some of the typical source documents for data to support an RVD might include:

- Operation Logs which contain the basic data necessary to compute vehicle utilization, such as scheduled and/or completed revenue service trips;

- Incident Reports which contain the information pertinent to the discovery of an equipment problem or malfunction during revenue service such as:

    - when, where and how the problem was discovered;
    - observed symptoms which led to the discovery;

- resultant consequence to service, such as delay or train removal;
- preliminary estimate of the affected hardware or system;

- Repair Records which contain a detailed description of:

  - actual defects found;
  - resultant repairs;
  - subsequent tests to verify the repair;

- Scheduled Maintenance and Inspection Records which contain the data necessary to support compliance with the equipment manufacturer's preventative maintenance requirements.

It is recognized that the degree of detail available from these data source documents may vary between transit properties. In the context of a Reliability Verification Demonstration, however, it is assumed that a mutual agreement exists between the transit property and the organization evaluating the results concerning the required quantity and quality of the data to be provided. It is further assumed that the transit property recognizes the need to maintain the quality of the data throughout the entire duration of the RVD program.

2.2.2 Data Submission

The TRIP Data Bank is capable of accepting data through either of two input media:

- Data Entry Terminal - that is: the hard-copy forms used by the transit property to record data which are directly input to the TDB. This could be accomplished either at the property via telephone data links or at the TDB site.

- Magnetic Tape - that is: a transcription onto magnetic tape of data generated by the property and collected, stored and/or pre-processed by the transit property's own or leased computer facility.

Magnetic tape is, of course, the most efficient method of data submission to the TDB if the property is not directly inputting data locally since hard-copy data entry is a labor-intensive process. Data would be submitted at regular intervals consistent with the reporting requirements of the Demonstration Program.

The TRIP Data Bank can accommodate a relatively wide range of data formats. A complete content description of the data, along with a sample set of data, should be provided to the TDB operating personnel in advance of the initial data submission in order to allow adequate time to develop and test the necessary algorithms and programs/procedures to extract the required data elements for input to the Data Bank. The information which is required in order to "initialize" the TDB is described in detail in Section 3.

2.2.3 Data Storage

As described in Section 2.1, the TRIP Data Base is the central repository for the data submitted by the transit property for use in the various analyses to support the Reliability Verification Demonstration. Each record in the Data Base consists of an "index key" followed by the individual data elements. The "index key" provides a "name and address" for the record within the Data Base and consists of:

- Generic Part Number - the component to which the data applies and which may range from "vehicle" to "thumb-screw;"

- Generic Serial Number - the transit property, vehicle series and vehicle (car) number on which the component resides;

- Date - the date on which the data was generated, for example:

  - The date (from the transit property data) on which a maintenance action was completed;
  - The date on which life-cumulative-mileage for a vehicle was recorded for submission to the TDB;

- Subdate - used to differentiate between two or more Data Base records having the same values in the other four fields of the "index key", but different values in the data fields (for example: two different maintenance actions on the same component on the same duty);

- Record Type (see below).

  - Dynamic Data
  - Reference Data.

Fifteen record types have been defined in the TRIP Data Bank. They are divided into two categories as shown below:

- Dynamic Data

  - Utilization Data (vehicle)
  - Incident Data (vehicle)
  - Scheduled Maintenance Data (vehicle)
  - Repair Data (vehicle)
  - Component Repair Data (bench)
  - Scheduled Maintenance Narrative
  - Repair Narrative
  - Component Repair Narrative.

- Reference Data

  - System Configuration Data
  - Route Configuration Data
  - Route Operating Data
  - Vehicle Series Information
  - Specification Data (vehicle)
  - Configuration Data (vehicle systems)
  - Specification Data (component).

Dynamic data is produced as a result of vehicle operation, maintenance and repair. It is from the analysis of the dynamic data that reliability and reliability growth determinations are made. Reference data describes the characteristics of the equipment and the environment in which it operates and, thus, provides a basis for the interpretation of the reliability analyses. These characteristics might include the expected or predicted baseline reliability parameters which will be verified/evaluated in the RVD.

2.2.4 Report Generation

Routine (i.e.: periodic) reports can be produced by the TRIP Data Bank in accordance with the requirements of the Reliability Verification Demonstration program. The transit property and contractor assisting in the evaluation should investigate and determine the frequency, purpose and content of each report to be produced. (Potential output report definitions requirements are discussed more fully in Section 3.) TDB operating personnel will provide assistance in defining report formats and algorithms necessary to achieve the desired results.

The Generic Part Number (GPN) and Generic Serial Number (GSN) together provide several possible ways in which the data can be sorted for analysis due to the logical structure of these numbers. By specifying the appropriate fields of the GPN and GSN to be used as sort criteria, reliability analyses can be performed at virtually any level of vehicle equipment detail. Some examples of the possible reports are shown in Table 2.2-1 in terms of a description of the report and the GPN and GSN fields required for sorting.

Table 2.2-1 POSSIBLE DATA SORTS FOR REPORT GENERATION

REPORT DESCRIPTION	FIELDS REQUIRED TO PERFORM SORT					
	GPN			GSN		
	Functional Hierarchy	Equipment Breakdown	UCEC	Property ID	Vehicle Type	Car Number
Vehicle reliability	x					
OPTIONS: • by Property	x			x		
• by Vehicle Series	x			x	x	
• by Car Number	x			x	x	x
Vehicle reliability by System	x					
OPTIONS: • by Property	x			x		
• by Vehicle Series	x			x	x	
• by Car Number	x			x	x	x
System reliability by Vehicle Series	x			x	x	
OPTIONS: • by Subsystem	x			x	x	
• by Major Assembly	x	x		x	x	
• by Component	x	x		x	x	
Component reliability by Vehicle Series	x	x		x	x	
OPTIONS: • by Component Class	x	x	x	x	x	
Vehicle Utilization	x					
OPTIONS: • by Property	x			x		
• by Vehicle Series	x			x	x	
• by Car Number	x			x	x	x

3 - RELIABILITY VERIFICATION DEMONSTRATION PLAN

The TRIP Data Bank (TDB), as a generalized transit vehicle reliability information and analysis system, contains all of the features necessary to support the data processing requirements of a Reliability Verification Demonstration (RVD) program. As an operating data system designed specifically to meet the needs of the transit industry, the TDB can be readily adapted to provide reliability information support services. Use of the TDB can eliminate the cost and lead-time required by an individual transit property to develop a specialized data processing system to support RVD programs.

The purpose of this section is to provide the potential user of TRIP with an outline of the types and content of the information which should be provided in order to:

- define the reports to be produced by the TDB in support of a RVD program;
- characterize the data to be supplied as input to the TDB;
- initialize the TDB to accept, store and process the data.

3.1 OBJECTIVES

One primary objective of a Reliability Verification Demonstration program is to demonstrate that new transit vehicles, and especially selected subsystems, comply with the reliability requirements set forth in the vehicle specification documents. Such a program usually involves the first 50-100 vehicles delivered under contract and may last for one or more years.

The RVD program is accomplished by operating the vehicles in a revenue service environment while maintaining a careful accounting of the data elements which assist in evaluating reliability criteria such as:

- Operating Hours of Mileage;
- Unscheduled maintenance, repair or replacement;
- Scheduled maintenance and inspections;
- Relevant versus nonrelevant failures.

Mean time (or miles) between (relevant) failures (MTBF) is computed from the above data and is used as a measure of equipment reliability. The resultant MTBF may be used as an absolute measure of reliability at a given time, and may be plotted (log-log) as a function of accumulated operating hours in order to determine reliability growth trends.

The purposes of the TRIP Data Bank are to provide an efficient and economical means of storing data, once generated, and to provide the analytical "tools" necessary to support the demonstration.

3.2 OUTPUT REPORTS DEFINITION

The TRIP Data Bank can provide a wide range of analytical techniques for information presentation. Within the bounds of practicality, however, the primary questions to be answered for an RVD are:

- Does the equipment, as delivered, perform in accordance with the specified reliability?

- If not, does the data indicate a suitable growth in reliability performance, such that the specified reliability will be achieved?

Assuming that the transit property directs its data collection for the RVD toward answering these questions, the property can assist the TRIP Data Bank operating personnel in defining the appropriate TDB output requirements that will support the answers. This may be accomplished if the transit property provides the following information on its data collection documents/reports:

- Document Title or Number;

- Frequency or Date of Document, for example:

  - weekly;
  - monthly;
  - 10th day of each month;

  NOTE: The document frequency or date is dependent upon the frequency of data submission.

- Description of Purpose of Document;
- Content of Document
  - Detailed listing of data elements (e.g. car number; cumulative mileage; period mileage; etc.);
  - Summary requirements (e.g., column totalization; averaging; etc.);
- Sequence of Presentation
  - Key data elements (e.g., car number);
  - Primary, secondary and tertiary sorting requirements;
  - Columnation;
- Data Element Source Document(s) (e.g., Incident Report; Vehicle Service Report; etc.).

It would be of further assistance if the property provided sample copies of its data collection documents to TDB operating personnel not only for clarification of the above information, but also so that they may be reviewed to determine that the necessary information will be available for TDB input. The information will be reviewed to determine if the output requirements can be met by a standard TDB report format. If not, new algorithms and report formats will be developed as necessary. Standard procedures and report formats will be used wherever possible, however, to minimize output production costs. (It should be noted that the above information must normally be provided when requesting special reports.)

3.3 INPUT DATA REQUIREMENTS

Once the TDB output reports have been defined which will satisfy the requirements for reliability evaluation, the next step in this part of the RVD program is to identify the input data requirements. Requirements both for data format and data type must be determined. After this, procedures for collecting the data at the property and submitting it to the TDB for storage and processing may be established.

Whether data will be submitted to the TRIP Data Bank as hard-copy forms, as formatted records on a magnetic tape, or through direct data entry terminal telephone links, a complete description of the data should initially be provided to TDB operating personnel so that procedures for the input processing of the data and, in the case of a magnetic tape, utility software for data extraction may be defined and developed. The information necessary to define input data requirements includes:

- Purpose of the data record or form - that is: what type of information is conveyed? (Inspection data, scheduled maintenance data, repair data, etc.);

- Content of the data record or form - that is: what are the individual data elements? (car number, cumulative mileage, part number, repair code, etc.);

- Format of the data record or from - that is:

  - length of each data element;

- sequence of data elements;
- sequence of data records, if more than one record of form must be combined to completely describe a single maintenance transaction;

- Relevant data elements - that is: which data elements provide information meaningful to the RVD program? or, conversely: which data elements are "for company use only?" (e.g., employee number).

3.3.1 Data Types

Reliability analysis of the vehicle systems for the RVD will be based on two basic types of data to be submitted by the transit property to the TRIP Data Bank for processing. These are:

- Reference (Static) Data; and

- Dynamic (Operations and Maintenance) Data.

Static, or reference, data is information which describes the configuration, characteristics and operating procedures of a transit system, vehicle, or equipment on a vehicle. This type of reference data is used to interpret and understand the outputs and reports generated by the TRIP Data Bank. Uses of reference information include: interpretation of differences in reliability values by vehicle based upon passenger loads and route assignment; or, interpretation of reliability values of a class of equipment based upon the characteristics and intended application of each equipment type within that class. The sources of this type of reference data include:

- Transit System Route Maps;
- Station Platform and Power Substation Separation Data;
- Vehicle Maintenance Manuals;
- Operating Schedules;
- Car Assignment by Routes;
- Vehicle Specifications.

Pertinent data from these sources are stored in the TRIP Data Base as Reference Data Records for potential use or comparison in the analyses.

A second type of useful reference data is information which is necessary for the input processing of dynamic data, as derived from:

- Component Code Books;
- Vehicle Parts Catalogs;
- Transit Property Stock Catalogs;
- Maintenance and Repair Manuals;
- Vehicle Rosters (car numbers by vehicle series);
- Code definitions for all encoded data, such as:

- symptom codes;
- defect codes;
- repair codes;
- test codes.

Because maintenance activity codes are different at each transit property, a set of standard "generic" codes and definitions has been incorporated into the TRIP Data Bank. All transit property codes are cross-referenced to the generic codes based upon the code type, definition and application.

Vehicle rosters are used to define the set of Generic Serial Numbers (Property ID/Vehicle Type/Car Number) that will be assigned to the dynamic data records in the TRIP Data Base. The vehicle parts catalogs and maintenance manuals are used to develop the Generic Parts List (list of Generic Part Numbers) for the vehicle.

Dynamic data is that information which is generated while the vehicles, or particular system(s) are operated and maintained for revenue service during the RVD program. Sources for this type of data will include:

- Operators Incident Reports;
- Vehicle Defect/Discrepancy Reports;
- Unscheduled Maintenance Reports;
- Parts/Material Requisitions.

Dynamic data will be filed in the Data Base by Generic Part Number.

3.3.2 Generic Parts List Development

A Generic Parts List (GPL) is developed for the vehicle or equipment series for which the Reliability Verification Demonstration is being conducted. The GPL is a cross-reference table consisting of:

- Generic Part Number;
- Maintenance Information System (MIS) Code;
- Property Stock Number;
- Manufacturer's Part Number;
- Part Name/Description.

The TDB user must designate which of three (MIS, stock or manufacturer) numbering systems is used in the data to identify components. That property identification system would then be used in the Generic Mapping input process where GPNs, GSNs, and generic maintenance activity codes are assigned to the data records. The entire GPL is maintained in the TRIP Data Bank, however, as reference data.

The development of the GPL is the most time-consuming activity of TDB initialization. For this reason, the reference information required to develop the list should be provided to the TDB operating personnel as soon as possible.

The assigning of Generic Part Numbers could, in theory, be carried down to the last nut, bolt and washer on the vehicle. It is recommended, however, that GPN assignment terminate at the lowest-replacement-unit level consistent with (primary) maintenance practices. Repair or replacement of the so-called "miscellaneous hardware" should be accommodated in repair codes which may be applied to the repair of the component of which the "miscellaneous hardware" is a part.

3.3.3 Data Submission Requirements

A major requirement for data submission to the TRIP Data Bank is that the data be submitted at regular intervals so that data entry and report generation can be scheduled on a continuing production basis. For example, hard-copy data may be submitted weekly; magnetic tape data may be submitted less frequently (for example: monthly) depending upon the volume of the data and capacity of the magnetic tape. Neither of the above data submission intervals are mandatory, however, and suitable alternate arrangements may be made to coincide with the data reporting requirements of the Reliability Verification Demonstration program.

All data submitted to the TRIP Data Bank is normally copied and retained for archival storage at the TDB facility as a permanent record of submission. Hard-copy forms are usually stored on microfiche. Original forms can be returned upon request to the source; otherwise, they will be destroyed thirty days after being put on microfiche. Data from magnetic tapes can be copied onto TDB facility tapes, and then the tapes are returned to the source within thirty days of receipt.

4 - RELIABILITY VERIFICATION DEMONSTRATION PROCEDURES

4.1 PURPOSE AND SCOPE

The purpose of this section is to describe a detailed plan recommended for conducting a Reliability Verification Demonstration (RVD) Program. This description is aimed towards a program performed by operating vehicles in revenue service on a property's transit network with the objective of verifying specification reliabity standards or requirements. The necessary interface between the transit authority (property) and the TRIP Data Bank (TDB) operating personnel (contractor) will be defined with respect to the data collection and support services requirements.

The plan described herein includes a detailed description of the objectives, requirements, conditions and procedures necessary for a property to verify that its equipment meets the reliability requirements spelled out in the contractual specifications. The plan is arranged so that the specifics of program conduct and analysis may apply to either the vehicle as an entity or to specific system or subsystem requirements as the occasion may demand.

Upon completion of test arrangements and the availability of vehicles identified for testing, the RVD program should commence at the earliest convenient time. The program should continue until such time that the requirements have been met or that the test has been terminated for noncompliance.

Conduct of an RVD program can best be achieved through implementation of the procedures recommended for the following activities:

- Organization of the program;
- Setting up a test facility;
- Establishing ground rules;
- Selection of an RVD sample set;
- Conduct of RVD; and
- Analysis of results.

The following subsections will discuss these activities, the procedures and criteria for successful accomplishment of the program, and the program interface with the TRIP Data Bank. The procedures outlined are intended to describe a rigorous and controlled program of reliability verification. Depending upon circumstances, properties may wish to deviate from these procedures. This should only be done with a full understanding of the potential effects of such a deviation(s).

4.2 PROGRAM ORGANIZATION

After the decision has been made to conduct a reliability verification demonstration and prior to its commencement, a meeting between property management personnel who serve their respective engineering groups and additional interested parties, such as the TDB operating personnel and the equipment manufacturers, should be held to define organizational responsibility, program conduct, and to generate RVD schedules and activities. It is intended that a program organization to direct and perform the RVD be identified consisting of the following: test director who will manage, coordinate and schedule the test program; test engineer who will monitor and direct test personnel in their activities according to specific procedures; test operators who will operate the vehicles throughout the demonstration test; repairmen who will be selected for performing maintenance on the vehicles throughout the demonstration; data collection personnel who will collect and log in data; data processing and analysis personnel for TDB support. In a small test program it may be practical to combine some of the active functions under the responsibility of a single individual.

In addition to assigning program responsibility at this initial meeting, a set of observers should be designated to act as official witnesses throughout the program. These observers may review data logs, operations and maintenance procedures and routines to insure that the test is being performed as the property and other interested parties originally agreed upon. Any deviation noted by such witnesses should be brought to the attention of the test director. However, such observers may not be permitted to act, alter, participate or interfere in any manner with the conduct of the RVD.

In the initial meeting the property and support personnel should establish the goals and procedures for the program. The goals should focus upon the particular criteria that are to be evaluated and the potential results of the program and the expected effects of these results. Program reviews should be scheduled at periodic intervals so that the progress of the RVD may be reviewed. Procedures to be used should be agreed upon by all parties at this meeting. Of a special importance are the maintenance procedures. If the vehicle or subsystems being evaluated are new and the property and manufacturer have previously agreed upon a set of maintenance procedures, these procedures should be followed rigorously throughout the RVD.

4.3 TEST FACILITY

The operating system and facility to be used for the RVD should normally be the property's own operating track system. Similarly the repair and data collection facilities should also be those employed at the property. Facilities and equipment to be used should be sufficient for complying with the reliability requirements for testing. Consequently, tools and test equipment necessary to maintain the equipment should be made available and be in place prior to the test commencement. Documents or manuals describing maintenance procedures for detecting faults, performing repairs and check outs should not only be available for use by the participating personnel, but it is suggested that they use these documents so that the repairs may be made in accordance with prescribed standards. The manuals should be made available prior to the test so that they may be reviewed if necessary by maintenance personnel or observers.

It is recommended that a specific bay be set aside for maintenance on RVD vehicles during the program. This bay should be designated as the test bay area and should exclude those personnel who are not part of the test from working in that area. The reason for this is so that the same personnel, facilities, and equipment will be available for conducting maintenance without interference. This arrangement permits a consistent baseline for measuring the effectiveness of the demonstration. Varying personnel and/or equipment would lead to inconsistencies in measurement and might require additional instruction for each new repairman as he may be added to the test group. No maintenance should be started until all equipment and personnel are available. Data collection and logging facilities should be set aside for the test also. It is advantageous to have collection facilities in a close proximity to the bay to facilitate any transactions and verifications which may have to be made during the course of the test.

4.4 GROUND RULES

In order to meet the requirements of the RVD its specific goals should be established for each vehicle, system, or subsystem under consideration for the program. These goals are stated in terms of failure rates (MTBF or MDBF) or some other operating parameter and are often specified in procurement documents. The objective of the RVD program is to evaluate a units real performance relative to these goals (reliability requirements). Typical goals for a rapid transit vehicle might be those listed for a vehicle system as follows:

TABLE 4.4-1. TYPICAL RELIABILITY REQUIREMENTS FOR A RAPID TRANSIT VEHICLF

Systems	MTBF (hours)
Propulsion	600
Auxiliary Electrical	1,650
Truck and Suspension	1,900
Friction Brake	1,100
Door	1,850
Communications	2,350
Car Body	650
Heating and Air Conditioning	2,700
Spin Flash Slide	27,000
Coupler	6,900

The above values yield total vehicle MTBF of approximately 150 hours. In addition to the specified values the property should determine minimum values which you would find acceptable. In many cases these minimum values may be the original specified value. When these goals have been identified, it will be possible to determine the expected time length of the RVD program as the function of the expected reliability and the RVD sample size.

Once the units (vehicle, system, subsystem) to be evaluated have been selected and their reliability goals identified each unit should be listed with its assembly breakdown structure, car spotting part numbers, and component failure rates. As a matter of policy generic part numbers should be structured in the format used by the TDB. In this structure the generic part number is related to a component and range from the vehicle itself down to minute hardware, such as "nuts and bolts." The use of this format provides a consistent and readily useable scheme for tracking component failures and processing them through TRIP.

Prior to the initiation of the demonstration test, test procedures and plans need to be formulated and distributed to all parties involved. These procedures should reflect the requirements of the contract, its specifications and standards. At a minimum the procedures should include the following:

- A list of all the components in each system to be monitored with corresponding part numbers, failure rates and function;
- Identification of the tools and test equipment to be employed during repairs;
- The test cycle that will be used (length of run per day and schedule of these runs);
- Procedures for preventive maintenance;
- The method for data recording, collection and submittal to TRIP for processing and analysis;
- The performance parameters to be measured, such as MTBF or MDBF;
- Failure classifications to be used for the test;
- Sample of data recording forms and logs; and
- Method of performing configuration control.

In addition, appropriate specification, standards, guidelines and maintenance practices which will affect the conduct of the demonstration shall be distributed for use during the RVD.

It is important to note that once a property has established a set of procedures for the RVD program these procedures should be followed for the programs duration. Whether or not the procedures used are those recommended in this plan, the failue to adhere to a change in these procedures could affect the results of the program.

4.5 SELECTION OF AN RVD SAMPLE SET

A representative sample of vehicles, systems, or subsystems indicative of the total population to be acquired for use should be selected for the reliability verification demonstration. The quantity of units should also be taken at random so the sample set is unbiased in its representation of the total population. Table 4.5-1, following, lists recommended quantity of units to be selected for the RVD program based on the anticipated total population.

For example, if a transit authority were to procure 300 vehicles the suggested minimum number of vehicles to be tested would be 30 or 10 per cent. The vehicle population would not likely be delivered at once but rather over a period of months. In general, deliveries are based on a monthly production rate. Vehicles out of every population lot should be selected at random from that lot until the recommended sample size for a test program is reached. A lot if not defined by contract consists of at least one month's production. The actual quantity to be negotiated

Table 4.5-1 - VEHICLE SELECTION SAMPLE

Population	Recommended Sample Size
100	15% = 15
200	12% = 24
300	10% = 30
400	10% = 40
500	10% = 50
over 500	10%

with the procuring property. It is recommended that selection should start with the first lot produced and continue until the total demonstration sample is reached. For example, if the procured population is 100 then 10 vehicles will be delivered each month and 3 out of every month's lot should be selected at random for testing until the designated sample size (approximately 15) is achieved. Table 4.5-2 following suggest possible sample sizes for each lot delivered. For an RVD this selection process may be applied to either the vehicle in its entirety or to those systems within the vehicle which have been selected for reliability evaluation .

It should be understood that a property may define what it considers to be an adequate lot, the end objective being to obtain a reasonable sample which is representative of the vehicle population to be evaluated. Tables 4.5-1 and 4.5-2 are intended as guidelines but constraints such as time or availability may direct the property to make its own selection policies. For example, a property may procure 500 vehicles which are produced at a rate of 25 per month. From Table 4.5-1, 500 vehicles would require a sample of 50 for the RVD. The sample selection interval and the number of vehicles to be evaluated at any one time may vary as the property sees fit for its purposes. In the special circumstance where reliability verification demonstration is to be used as part of qualification for preproduction unit, it is recommended that at least two of these units be used depending upon availability of the units, schedule, and allowable test duration for the program duration requirements.

Table 4.5-2 - SAMPLE SIZES FOR EACH LOT

Lot Size	Recommended Lot Sample Size	Maximum Lot Sample Size
1–3	all	all
4–16	3	9
17–52	5	15
53–96	8	19
96–200	13	21
over 200	20	22

4.6 TEST PROCEDURES

In this section, the various procedures for selecting and criteria for performing the appropriate RVD program are discussed. There are a number of inter-related variables relating to the properties' needs and requirements that must be determined as a part of the RVD. These variables include:

- number of units available for testing;
- amount of time available for testing;
- levels of confidence needed in test results;
- the specified failure rates and associated tolerance limits.

As the property decides on this information, it will be better prepared to select and plan the RVD program most suited to its requirements.

There are three basic types of RVD programs that a property may select, each of which is reflected in Figure 4.6-1. The first type of RVD program is one in which reliability testing is conducted on the unit sample set until a predetermined number of failures (r_0) have occurred. The second program requires testing of the sample set until an established time (τ_0) has elapsed. The third RVD program is a sequential procedure in which the test time and number of failures are continuously monitored, and at any given moment the decision can be made to continue testing or accept/reject the units based on their reliability

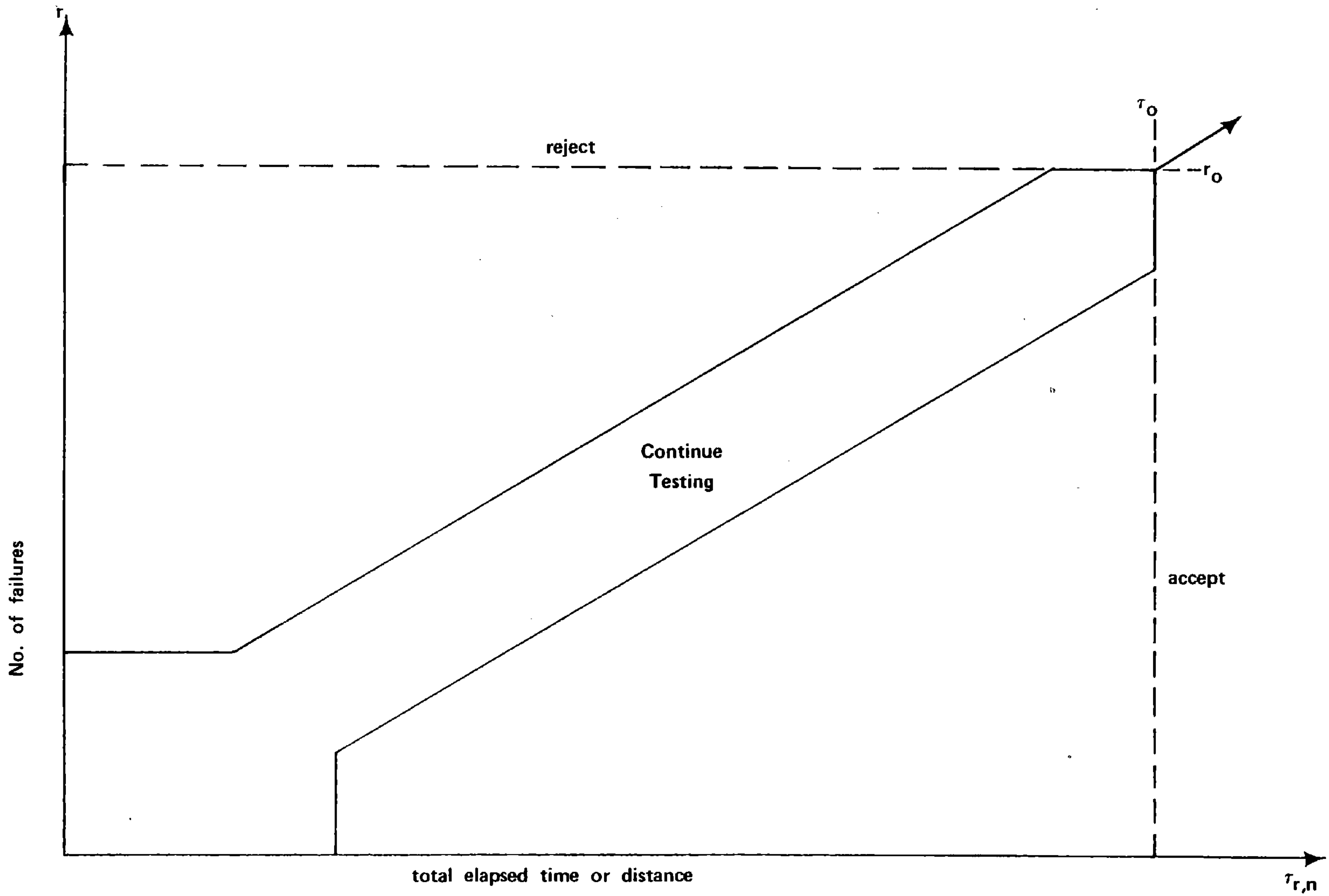

Figure 4.6-1. SAMPLE RVD TEST EVALUATION PLOT

performance. Any one of these three RVD programs may be used separately or in any combination with the others; the decision will probably be a factor of the variable constraints as well as the desires of the property.

The following subsections will discuss the procedures for conducting each of the three RVD program types mentioned above. These procedures derive from several assumptions which must be made to reduce the complexity of both the mathematics involved and the RVD program itself. The assumptions include:

- The mean time (distance*) between failures, θ, or the failure rate, λ, given in the reliability equation

  $$R(x) = e^{-x/\theta}, \ \theta = \frac{1}{\lambda} \quad (1)$$

  is constant for the RVD program period.

- Failures are random and are distributed exponentially as described in the equation above.

- Failed units are returned to the test program immediately after replacement or repair, i.e.; the number of samples under test remains constant for the program.

* Note: Although time is generally used for a reliability basis in this report, distance may be easily substituted where it is the measure for reliability.

If the units to be evaluated are new, then it is quite possible that the failure rate will not be constant until some burn-in period has been completed. This is due to the likelihood of some "infant mortality" in various components of the new units. Consequently, it is recommended that some burn-in period be accomplished prior to commencement of the test program for all new equipment. This period (distance or time) should be sufficiently great that the probability of unacceptable reliability due to "infant mortality" is low. The purchasing property may wish to consult the car builder when determining a suitable burn-in period. All units to be tested should undergo the same burn-in, and have the same condition and configuration. Similarly, there is also some doubt as to the true randomness of the failures occurring in a sample set of new units. If, indeed, the units to be tested are all new, then some care will be necessary in evaluating the tradeoffs between test time, sample size and failure count.

The algorithms presented in the following paragraphs are derived from statistical mathematics for life testing. Some of the derivations are presentd in the text, where necessary, and the remainder may be found in references.

4.6.1 Failure Rate, Tolerance and Confidence

Historically, transit equipment reliability has been specified in terms of mean time between failure (MTBF); a minimum acceptable MTBF has been assigned to each system or major component as appropriate. In many cases, the bases for these reliability assignments are questionable, especially since the detailed collection and analyses of reliability data as performed by the TRIP are relatively uncommon in most transit properties. A single valued MTBF specification is, in itself, inadequate for new equipment specification when anything beyond a general design goal is desired. Suffice it to say that it is doubtful that an MTBF obtained at one property will be duplicated at another for identical equipments. Obviously, properties should provide car builders with sufficient information that each property will see its desired MTBF goal achieved. There are numerous ways of providing this information, most of them beyond the scope of this report, but with respect to specifying reliability numerically it is recommended that certain parameters should be provided in future specifications for new transit equipment. Specification of these parameters will not only make the property's RVD program easier, but will assist the car builder in developing equipment having an operating life that the property will find acceptable. These parameters include:

- θ_0 - some acceptable (high) mean life, $\overline{\text{MTBF}}$;
- θ_1 - some unacceptable (low) mean life; $\underline{\text{MTBF}}$;
- α - producer's risk;
- β - consumer's risk.

Traditional reliability specifications as discussed above, provide single valued reliability criteria data such as that listed in Table 4.4-1. In developing and evaluating the RVD programs recommended herein, it will be necessary to identify both a θ_0 and a θ_1 value. These two values should be separated by at least a fifty percent factor ($\theta_0/\theta_1 \geq \frac{3}{2}$) in order to keep costs of the RVD program down. As the selected ratio of θ_0 to θ_1 decreases, the length of the test program is likely to increase in order that the property may make its accept/reject decison with confidence. Selection of these two MTBF values should be done with care. With new equipment, the specified MTBF should be established as θ_1 if it is indeed the minimum acceptable value; otherwise, the specified MTBF should be bracketed with θ_0 and θ_1 values (tolerances on the MTBF) such that the ratio between the two is adequate. If the equipment to be tested has been used in other vehicles, then there may be some established data base from which appropriate θ_0 and θ_1 values may be drawn. Similarly, with older equipment to be tested, existing reliability data may be used for one or both of the values.

Evaluation of information collected on equipment evaluated during an RVD must be performed with some definable degree of confidence. This is achieved through assigning values for producer's risk (α) and consumer's risk (β); where α is the probability of rejecting equipment having a true MTBF (θ) equal to or less than θ_0, and where β is the probability of accepting equipment having a true MTBF (θ) equal to or less than θ_1. Another way of looking at this is that there will be a confidence level of $1-\alpha$ that the consumer's decision at the conclusion of the RVD program will be accurate. It follows logically that as α decreases (or the confidence level increases) the time and or number of units required for the RVD will increase. While a property may wish for 100% confidence in its decision, other economic factors must be considered, so consequently levels of 80% to 95% ($0.05 < \alpha < 0.20$) are normally selected. Similarly for β, values between 0.05 and 0.50 are recommended, depending upon the RVD program planned. The forthcoming sections will discuss how α, β, θ_0, and θ_1 are used to plan and evaluate an RVD. For the sample programs presented, values of $\alpha = \beta = 0.10$ and the ratio $\theta_0/\theta_1 = \frac{3}{2}$ will be used, but properties

planning an RVD should thoroughly evaluate their requirements before selecting the appropriate values.

4.6.2 RVD Testing To A Fixed Number Of Failures

Regardless of the type of program selected, an RVD need never be conducted beyond a predetermined maximum number of failures or a maximum time limit. In this section focus is placed on calculating the failure limit and evaluating the results of the demonstration at this limit. In performing the calculations presented herein, the assumptions relating to failure distribution, randomness, and replacement, etc. presented here should be reviewed as they form a basis for the equations.

In setting up the RVD procedure, it will be necessary to establish two test hypotheses (H_0 and H_1) about the true MTBF (θ_T). They are $H_0 : \theta_T = \theta_0$ and $H_1 : \theta_T = \theta_1 < \theta_0$, such that the probability of accepting $\theta_T = \theta_0$ given that θ_0 is true equals $1-\alpha$, and the probability of accepting $\theta = \theta_0$ given that θ_1, is true is less than or equal to β. Thus the confidence levels are set and criteria for selection/rejection of the tested equipment chosen. The test MTBF value ($\hat{\theta}$) will be determined at the conclusion of the RVD such that

$$\hat{\theta} = \frac{\tau_{r,n}}{r};\qquad (2)$$

where τ is the total time (distance) operated by all test units (n) whether they failed or not up until the time (distance) when the r-th failure occurred $(\tau = \sum_{j=1}^{n} \tau(n))$

When testing to a fixed number of failures, r_0, the equation (2) then becomes:

$$\hat{\theta} = \frac{\tau_{r,n}}{r_0}$$

where r_0 is determined as follows.

It has been assumed that the probability distribution function for failures, f(t), may be represented as:

$$f(t) = \frac{1}{\theta} e^{-t/\theta}\qquad (3)$$

an exponential distribution. As a result, the variable τ/θ is proportional to $\chi^2(2r)/2$ (chi-squared distribution with 2r degrees of freedom); that is:

$$2t/\theta \sim \chi^2(2r).$$

From equation (2), this may be shown as:

$$2r/\theta \sim \chi^2(2r). \tag{4}$$

It may further be shown that the region of acceptance, H_0, for $\theta_t = \theta_0$ must be of the form

$$\hat{\theta} > \theta_0 \, \chi^2_{1-\alpha}(2r)/2r \tag{5}$$

where r is the smallest integer, r_0, such that:

$$\chi^2_{1-\alpha}(2r_0)/\chi^2_{\beta}(2r_0) > \theta_1/\theta_0. \tag{6}$$

Thus the inequality (6) will determine that failure limit, r_0, which insures that an accept/reject decision may be made within the confidence levels desired. This is not to say that a valid decision cannot be made with fewer failures($r < r_0$); indeed, the value r_0 is a maximum beyond which no further testing is required. Table 4.6-1 shows some failure limits for given values of α, β and θ_0/θ_1. It should be noted that the number of failures is independent of the specified MTBF or the number of units to be evaluated.

<u>Example 1:</u> Assume that $\alpha = .10$, $\beta = .10$, $\theta_0 = 2200$ hrs. and $\theta_1 = 1100$ have been assigned for an RVD on a friction brake system. From Table 4.6-1 it can be determined that

Table 4.6-1.

RVD TEST TO FAILURE LIMITS (r_o) FOR

PRESELECTED VALUES OF α, β, AND θ_o/θ_1

θ_o/θ_1	α=.05				α=.10				α=.20			
	β=.05	β=.10	β-.20	β=.50	β=.05	β=.10	β=.20	β=.50	β=.05	β=.10	β=.20	β=.50
3/2	67	55	40	19	52	41	29	12	37	27	18	6
2	23	19	15	8	18	15	11	5	13	10	7	3
5/2	14	11	9	5	11	9	7	2	8	6	4	2
3	10	8	7	4	8	6	5	2	5	4	3	2

the test may be concluded when 15 failures have occurred. Use of the tables in Appendix A verifies that:

$$\chi^2_{.90}\ (30)\ /\chi^2_{.10}\ (30) = 20.60/40.26 = .51 > .50 = \theta_1/\theta_0.$$

At the end of the RVD program; that is after r_0 failures have occurred, a $\hat{\theta}$ may be calculated using equation (2) and an accept/reject decision made using equation (5). Continuing with Example 1, for r_0 = 15, then the test MTBF must be equal to or greater than 1511 hours, i.e.:

$$\hat{\theta} > \theta_0\ \chi^2_{1-\alpha}(2r)/2r = 2200\ (20.60)/30$$
$$= 1511.$$

If the 15th failure had occurred after 22,500 hrs ($\hat{\theta} \approx 1500$) of testing then the friction brake system would have been unacceptable. On the other hand, if the 15-th failure had not occurred until the 24,000th hour ($\hat{\theta}$ = 1600), then the system would be accepted with a minimum 90% confidence that the true MTBF is greater than θ_1. Figure 4.6-2 represents these results graphically.

4.6.3 Time Truncated RVD

It is difficult to plan the time requirements for the failure limited type of demonstration just discussed. Even when the confidence levels and reliability tolerances have been determined and, from that, the accept/reject criteria calculated, it is difficult to estimate the time length of the program. As this test type may not be concluded until

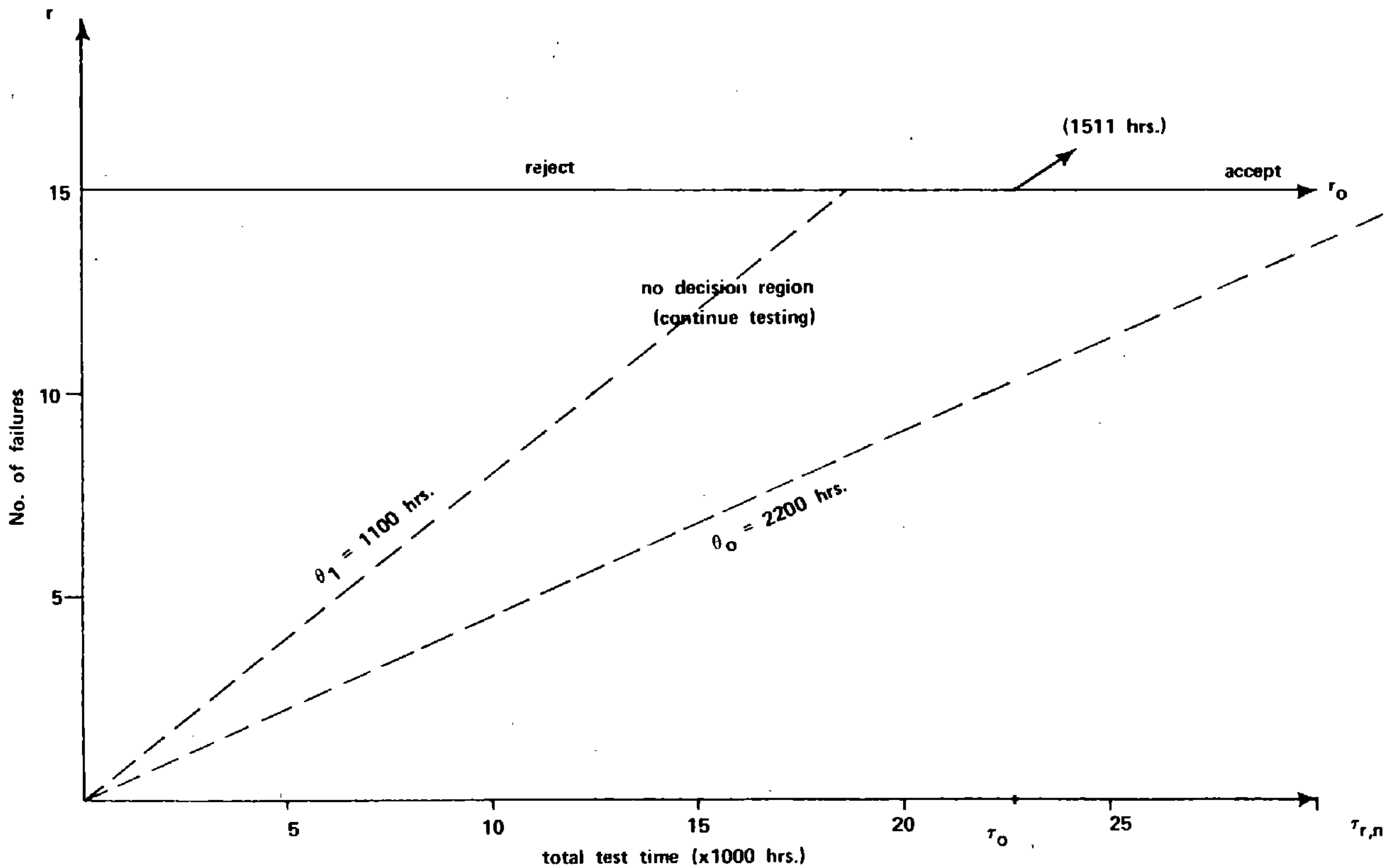

Figure 4.6-2. EXAMPLE 1: RVD TEST TO FAILURE LIMIT

the r_0-th failure has occurred, it presents definite problems to transit properties where the availability and scheduling of time, facilities and personnel is important. From Figure 4.6-2, it may be seen that all decisions made prior to τ must result in a reject decision. Furthermore, if r_0 failures have not occurred by time τ_0 then the RVD must terminate in an accept decision as the test concludes exactly at the r_0-th failure. Thus, τ_0 must represent the maximum time for which the test must run before a decision can be made with the required confidence. That is (from equations (2) and (5))

$$\tau_0 = \theta_0 \chi^2_{(1-\alpha)} (2r_0)/2 \tag{7}$$

where r_0 has been determined in the manner described in Section 4.6.2.

To this point, there has been little discussion of the impact that the number of samples (n) being tested have on the RVD duration. As mentioned the failure limited RVD is independent of n, which is to say that regardless of the number of samples tested, the RVD terminates at the r_0-th failure and the total test time for all samples tested is the aggregate sum of the test times for each of the samples. The maximum required test time given by equation (7) is achieved through reducing the number of samples tested to one. When more than one equipments are tested in the RVD, the real test time $\tau_{r,n}$, is a function of τ_0 and n, i.e.:

$$\tau_{r_0,n} = \tau_0/n = \theta_0 \chi^2_{(1-\alpha)} (2r_0)/2n.$$

Consequently, in planning an RVD, the property may fix $\tau_{r_0,n}$ based on any time constraints they may have within the limitations imposed by the number of equipments available for testing and the τ_0 requirements. The accept/reject decision for a time truncated RVD is identical to that calculated for the r_0th the failure for the failure limited RVD using equation (5).

Example 2: Assume that a property is purchasing new air conditioning units for 150 of its subway cars. The testing must be conducted in revenue service operation over a ninety day period. The property has specified α and β risk levels of 10% with θ_0 = 4050 hrs and θ_1 = 2700 hrs. Assuming that each car averages 16 operating hours per day, then there are 1440 real hours of testing ($\tau_{r_0,n}$) available. Referring to Table 4.6-1, it will be seen that the maximum number of failures (r_0) that must be accumulated is 41. From equation (7) we find that:

$$\tau_0 = \theta_0 \chi^2_{(1-\alpha)} (2r_0)/2$$

$$= (4050)\ (66)/2 = 133{,}650 \text{ hours.}$$

The minimum number of units to be tested becomes:

$$n = \tau_0/\tau_{r_0,n}$$

$$= 133{,}650/1440 = 92.81 \rightarrow 93.$$

That is a minimum of 93 air conditioning units must be installed on the subway cars in order to complete the RVD within the 90-day timeframe.

Now, using equation (5), it may be determined that if the mean time between failures, $\hat{\theta}$, is greater than 3260 hours at the end of the ninety day RVD, then the units will be accepted:

$$\hat{\theta} > \theta_0 \chi^2_{(1-\alpha)} (2r_0)/2r_0$$

$$> (4050)\ (66)/2\ (41)$$

$$> (3260).$$

These results are illustrated in Figure 4.6-3.

It is important to recall that replacement of failed units was assumed for these test. Therefore, when a failure occurs, the clock is stopped for that unit and restarted again when repairs are made and the unit is back in operation. The RVD is completed after τ_0 , aggregate hours of operation by the units. It is not important that each unit operate the same amount of time; indeed, when equipment is delivered in lots, it may be neither practical nor possible for this to occur. If, as in the case of Example 2, the minimum number of units possible are tested in a time truncated RVD, then the test time for each unit will normally be about equivalent.

4.6.4 Sequential Testing

The two previous RVD test types have provided the user with maximum time and failure limits beyond which no further

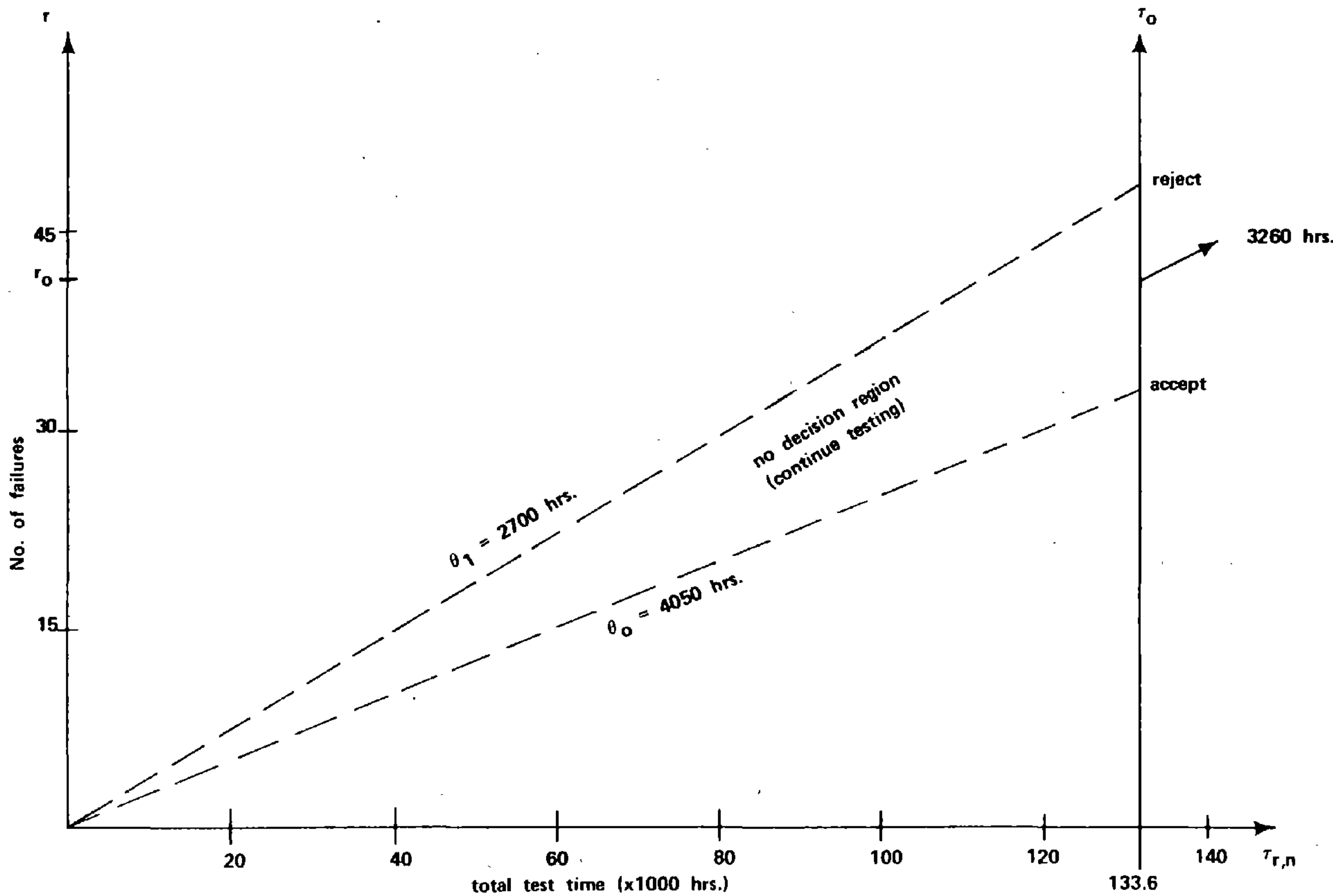

Figure 4.6-3. EXAMPLE 2: RVD TIME TRUNCATED TEST

testing is required. For those tests, no judgement is possible until the RVD terminates at the limit. Intuitively, it seems that there should be certain circumstances in which an early decision might be made, and there are. These early decisions may often be made through the use of sequential testing; at any time in the RVD, the testing organization can measure $\hat{\theta} = \frac{\tau_{r,n}}{r}$ and make an accept, reject or continue testing decision. This type of test illustrated in Figure 4.6-1, could, of course, be continued until the maximum time/failure bound is reached before a reject/accept judgement is made. The following paragraphs discuss the procedures for sequential testing.

For sequential testing, we again start with two hypotheses:

$$H_0: \theta = \theta_0$$

$$H_1: \theta = \theta_1 < \theta_0$$

and the probabilities (risks) =

$P(H_1/H_0) = \alpha$: probabililty of accepting H_1 when H_0 is true, and

$P(H_0/H_1) = \beta$: probability of accepting H_0 and H_1 is true.

Next, a likelihood ratio is developed with the following rules:

(1) If $L_{1,r}/L_{0,r} < A$, accept H_0

(2) If $L_{1,r}/L_{0,r} > B$, reject H_0

(3) If $A < L_{1,r}/L_{0,r} < B$, continue observations.

The likelihood function, $L_{R,r}$, is defined as:

$$L_{R,r} = \prod_{j=1}^{\tau} \frac{1}{\theta} e^{-t/\theta} \tag{8}$$

for the exponential failure distribution that has been assumed. The bounds, A and B, are ratios related to the risk levels such that:

$$A = \frac{\beta}{1-\alpha}, \text{ and } B = \frac{1-\beta}{\alpha} .$$

Thus, the inequality for the continued observation region becomes (based on the initial assumption):

$$\frac{\beta}{1-\alpha} < \left(\frac{\theta_0}{\theta_1}\right)^r \exp\left[-\left(\frac{1}{\theta_1} - \frac{1}{\theta_0}\right) \tau_{r,n}\right] < \frac{1-\beta}{\alpha} . \tag{9}$$

Taking the natural logarithm of (9) and rearranging yields:

$$\frac{-\ln\left(\frac{\beta}{1-\alpha}\right)}{\frac{1}{\theta_1} - \frac{1}{\theta_0}} + \frac{r \ln(\theta_0/\theta_1)}{\frac{1}{\theta_1} \quad \frac{1}{\theta_0}} < \tau_{r,n} < \tag{10}$$

$$\frac{-\ln \frac{1-\beta}{\alpha}}{\frac{1}{\theta_1} - \frac{1}{\theta_0}} + \frac{r \ln (\theta_0/\theta_1)}{\frac{1}{\theta_1} - \frac{1}{\theta_0}} .$$

The inequality of equation (10) provides the equations of the upper and lower bounds for the decision regions shown in Figure 4.6-1. Additional boundries are further provided by the r_0 and τ_0 limits calculated previously. Also shown in the figure are some preliminary boundaries inside of which no decision can be made. These are strictly arbitrary and may be used at the discretion of the test directors. Basically, the preliminary boundaries are included so that some minimum time or number of failures will pass before any decision may be made, allowing some stabilization of the reliability data base.

Example 3: Assume that an RVD is planned for a new fleet of 255 rapid transit cars to be delivered soon for which the following reliability data has been specified for the car systems:

System	θ_o	θ_1	α	β
Propulsion	900	600	.10	.10
Auxiliary Electrical	2475	1650	.20	.20
Truck & Suspension	2850	1900	.10	.05
Friction Brake	2200	1100	.10	.10
Door	3700	1850	.10	.10
Communications	4700	2350	.20	.50
Carbody	1300	650	.10	.10
Heating & Air Conditioning	4050	2700	.10	.10

Spin/Slide	54,000	27,000	.05	.10
Coupler	10,350	6900	.10	.10

In order to evaluate all of the systems, a quick calculation shows that the spin/slide system is the high driver with a required τ_0 = 669,600 hours.

For the given scenario, assume that the property is capable of performing acceptance testing and burn in at a rate of 15 car per month; thus the last cars will be ready for operation at 18 months from the initial delivery. The property will operate the cars in the RVD program for an average of 480 hours/month. If the entire lots (15 cars) are used, then the RVD will require a maximum of about 13 months for evaluation of all systems. If only 10 cars from each lot are used, then the RVD will require a maximum of about 16 months.

For the sequential RVD program, a test graph should be constructed for each system or equipment to be evaluated. For this example, we will construct graphs (Figure 4.6-4 and 4.6-5) of the propulsion and communications systems. Looking first at the propulsion system, the inequality for the decision lines becomes from equation (10):

$$\frac{-\ln(.1/.9)}{\frac{1}{600}-\frac{1}{900}} + \frac{r\ln(3/2)}{\frac{1}{600}-\frac{1}{900}} < \tau_{r,n} <$$

$$\frac{-\ln(.9/.1)}{\frac{1}{600}-\frac{1}{900}} + \frac{r\ln(3/2)}{\frac{1}{600}-\frac{1}{900}}$$

$\theta_0 = 900 \quad \theta_1 = 600 \quad a = .10 \quad \beta - .10 \quad r_o = 41 \quad \tau_o = 29{,}700$ hrs.

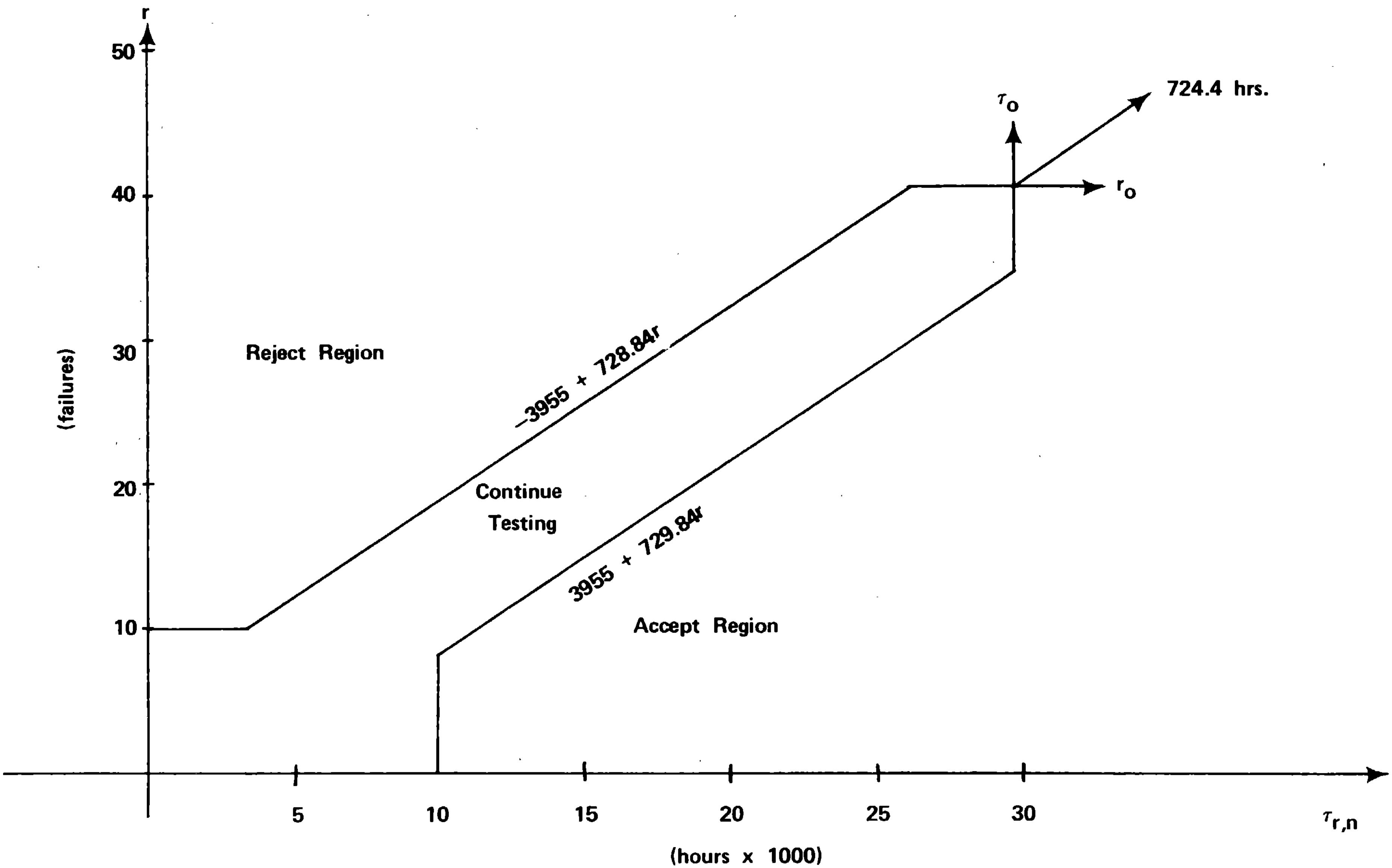

Figure 4.6-4. SEQUENTIAL RVD GRAPH FOR PROPULSION SYSTEM

$\theta_o = 4700 \quad \theta_1 = 2350 \quad \alpha = .20$

$\beta = .20 \quad r_o = 3 \quad \tau_o = 7214.5$

$\beta = .50 \quad r_o = 7 \quad \tau_o = 22247.5$

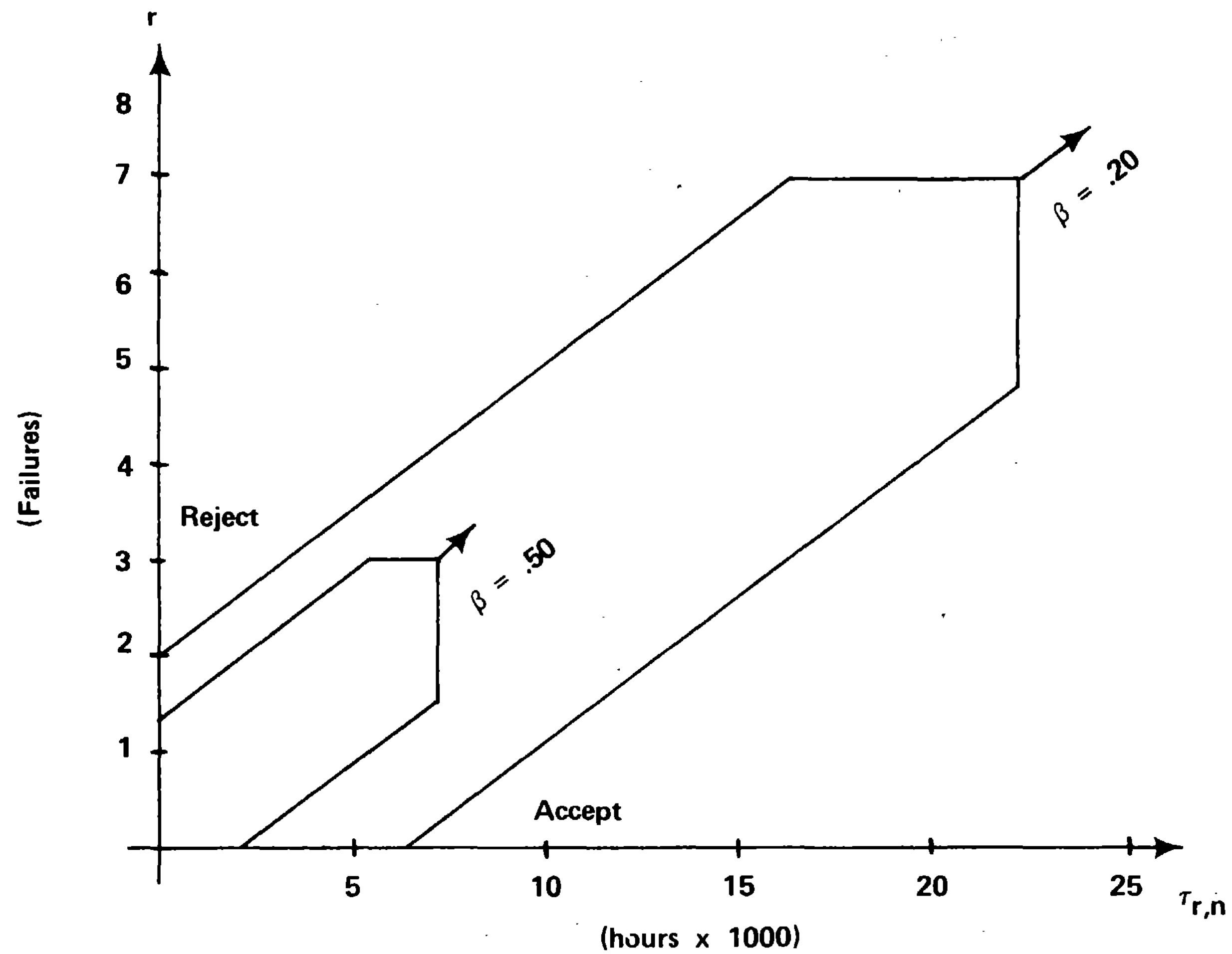

Figure 4.6-5. SEQUENTIAL RVD GRAPHICAL COMPARISON FOR COMMUNICATIONS SYSTEM

and simplified

$$3955 + 729.84r < \tau_{r,n} < -3955 + 729.84r.$$

For the graph, the maximum limits become

$r_0 = 41$, and
$\tau_0 = 29700$ hrs,

with the decision criterion of:

$\hat{\theta} > 724.4$ hours.

at these limits. In addition, since the propulsion system is of importance, the property arbitrarily decides that it will make no decision before 10 failures or 10,000 operating hours have occurred. These decisions and calculations are illustrated in Figure 4.6-4. Now the property can periodically determine and decide, at any time, to reject or accept the equipment, or to continue testing. If, for example, at 20,000 hours an MTBF is calculated, the decisions will be as follows:

for; $r \leq 21 \rightarrow$ accept system
$22 \leq r \geq 32 \rightarrow$ continue testing, and
$r \geq 33 \rightarrow$ reject system.

The sequential RVD graph for the communications system is calculated in a similar manner. The decision bounds are given by the inequality:

$$2209.0 + 3257.8r < \tau_{r,n} < -4306.6 + 3257.8r.$$

The boundaries and decision criterion are:

$r_0 = 3,$

$\tau_0 = 7214.5$ hours, and

$\hat{\theta} > 2404.83$ hours.

The primary objective of this example is to demonstrate the effects of changing the risk levels. If the consumer's risk were reduced to $\beta = .20$, the decision bounds would become:

$$6515.6 + 3257.8r < \tau_{r,n} < - 6515.6 + 3257.r,$$

and the boundary decision criteria:

$r_0 = 7,$

$\tau_0 = 22{,}247.5,$ and

$\hat{\theta} = 3173.21$

The effects of changing β are shown graphically in Figure 4.6-5. The differences become obvious when presented in this manner.

- In most cases a decision will be made and the test terminated for the β = .50 condition before a decision is possible in the β=.2 case.

- Although the reliability criteria are identical for the two cases, it is possible to accept the equipment with a lower reliability. The consumer's risk is 50%.

- As β increases, the symmetry about the origin shifts so that equipment that is on the borderline of rejection will, at least, be tested further before a decision is made.

The conclusion to be drawn is that properties should carefully evaluate their decison risks (α and β) and perhaps investigate the selected values graphically before settling upon the values to be used. These risks can have considerable effect on the length and success of the program. Literally, they will reflect the property's confidence in the demonstrated equipment reliability.

4.7 FAILURES

One of the most important aspects of an RVD is that of failure reporting. Recording of failure data serves a two-fold purpose. First, in order to determine the acceptability of the equipment evaluated, it is critical that failure data, such as failure type and time/distance to failure be logged so that accurate test reliability may be calculated. Second, it is assumed that an underlying purpose of an RVD is to provide an opportunity for evaluating the causes of equipment failures under controlled conditions, so that appropriate corrective action through procedural changes, engineering modifications, or component redesign may be accomplished to increase reliability.

During the RVD, all failed equipment and/or related incident data should be recorded on forms. Serialized units which must be replaced should be documented appropriately, and identical part numbered units used for replacement. Any replacement or repair which could effect a change in the equipment reliability should not be performed during the RVD; otherwise, previously collected data on the system or subsystem, etc. are voided. Furthermore, deteriorated parts which are still within specified tolerance limits should not be replaced during the test.

4.7.1 Definitions and Categories

Reliability criteria are expressed in terms of some mean interval between failures. Usually, the interval is either time, in hours, or distance, in miles or kilometers. It is important that in specifying reliability and planning an RVD program that a property take care in its selection of a reliability interval. Certain systems, such as air conditioning or auxiliary electrical, tend towards a time rather than distance reliability as they are used regardless of whether the vehicle is moving or not. On the other hand, brake and propulsion systems are distance dependent. Another important aspect of reliability specification is the meaning of failure. In its most general sense, a failure is that occurance or circumstance which prevents the vehicle, system, subsystem or component, etc. from functioning in its normal or intended manner. It hardly seems reasonable that accidents, acts of vandalism, or natural disasters should be considerd as failures in a reliability evaluation for transit equipment; so consequently, this general category as defined above is termed incident. Failures, then, are understood to be those incidents which are not caused by a source external to the vehicle or equipment. An attempt is made herein to define some of the terms used in the RVD programs relating to reliability.

- Incident - Any occurance which causes a disruption to service or operational capabilities, i.e., failures, vandalism, accidents, national disasters.

- Failure - Any detected inability of a component or equipment to function or perform in accordance with the indicated requirements, not caused by vandalism, accident, natural disaster.

- Failure, Primary - A failure which is responsible for a system or equipment malfunction,. (Independent Failure).

- Failure, Secondary - A failure which occurs as the consequence of another failure (Dependent Failure).

- Failure, Relevant - A failure which has as its cause an inherent weakness in manufacture or design or an inability of equipment to operate satisfactorily in interface with the remainder of the system.

- Failure, Non-relevant - A failure which has as its cause an out of tolerance (incorrect) condition external to the failed unit.

The above definitons must unfortunately depend upon individual interpretations of the language. It is therefore imperative that all personnel involved in an RVD program understand and agree upon the evaluation criteria to be used. For example, there are certain vehicle systems, such as the brakes, where redundancy is built in for reasons of safety or availability. A single failure in such a system may have little or no affect on the vehicle's ability to function successfully in its normal manner. None-the-less, the failure occurred and should be recorded. This leads to the definition of reliability which is to be evaluated in the RVD. Generally there are understood to be two primary categories which are defined as follows:

- Mean Interval Between Failures - the arithmetic mean of the interval (time, distance, cycles, etc.) between successive failures.

- Mean Interval Between Service Failures - the arithmetic mean of the interval between successive failures which interrupt or impact service operations.

Obviously, a single brake system failure may have no short-term impact on service operation, but it will in time, if no repair is performed. Finally, in the above definitions no clarification of the type of failure has been provided; relevant, primary failures are the normally accepted criteria, but it is the responsibility of the property performing the RVD to provide the appropriate distinction.

4.7.2 Failure Verification

All failures observed during the RVD program should be confirmed by the test director or test engineer and initialed on the failure report. It is the responsibility of the test director or engineer to review each failure report and determine the type of classification that applies to the failure. More critical to the classification is the determination that the failure is relevant, at least to the RVD. Any additional comments or observations that the test director or engineer may find useful to qualify the event should be included in the report. The test director or engineer should insure that the failure report is complete and contains all the data necessary to the maximum extent possible for providing a complete description of the event.

4.7.3 Verifying Repairs

Following a repair or corrective action prior to resumption of test, it shall be permissible to operate equipment for the purpose of proper operational checkout. This will insure that the repair made did indeed correct the problem and that the vehicle, system or equipment is ready for operation. The test director or engineer will supervise that the prescribed procedures for checking out equipment have been followed. Fault indicators, proper operation, and safety features shall be checked to verify that the repair made did indeed correct the fault found.

4.7.4 Analysis of Failures

It is desired that the cause of each equipment failure shall be determined by investigation and analysis. Such investigation and analysis should consist of any applicable method necessary to determine the cause of failure. As the failures are recorded, the test engineer should indicate the suspected cause of failure on the failure report under his comments section. Those failures for which there is insufficient information to indicate the apparent cause can be set aside for investigation at a later time.

4.8 SUMMARY

4.8.1 Planning

When a property has determined the desirability of a Reliability Verification Demonstration for its equipment, it should establish an organization or committee responsible for test administration and conduct. This organization should develop a schedule for the RVD including review intervals in order to discuss RVD progress and problems. Other responsibilities of the RVD test committee should include:

- Establishing ground rules for RVD conduct
- Identifying maintenance facilities and procedures.

- Ensuring proper reporting and recording of failures.

- Analyzing RVD results.

As a part of the planning, the property or test committee should verify the reliability criteria against which it plans to evaluate the equipment. The type of RVD test should be selected and procedures for accomplishing the test defined.

4.8.2 Installation and Burn-in

All vehicles, systems, test equipment and instrumentation to be used in the RVD should be calibrated and checked out prior to the RVD to ensure that they meet minimum safety and performance standards. This action will serve to insure that the vehicles and the facilities will function properly under test conditions, and without hazard. Fundamentally, the installation period requires that each vehicle be run for a brief period (500 miles or 50 hours) to permit familiarization and acquaintance with operating procedures. Minimum safety standards are those standards prescribed by the transit authority for operating the vehicle without hazard. For example, warning lights, signals, proper operator training, brakes, and controls should be verified prior to operation. Any failures found during this period will be recorded and replaced by a good component. However, such failures will not count towards the demonstration test. Furthermore, if the vehicles or equipment are new, the property should allow some burn-in period (about 2500 miles or 200 hours) in order to reduce the possibility of test degradation due to "infant mortality" of the equipment.

Maintenance and data collection personnel should be given the opportunity to familiarize themselves with their duties and procedures to insure that a smooth transition of data from maintenance action to data recording and processing will follow. Maintenance personnel should also exercise the repair routines to be employed using the tools, test equipment, and manuals provided for such purposes. Where procedures are found to be deficient in performing a repair, such steps will be reviewed and corrected to the satisfaction of all parties involved in the RVD. The basic data flow should adhere to the following steps. A failure report should be initiated by the operator when a failure occurs. This report should be sent with the vehicle to the maintenance shop where the report should be completed by maintenance personnel performing the repair. Next, the test engineer should review the repair information for completeness and verify the failure. After this, a copy of the failure report should be collected, logged in, and stored as necessary for shipment on a periodical basis to TRIP for processing.

4.8.3 Testing

Once the RVD procedures have been determined and all prior conditions have been met, the test may be started. Regardless of the number of simulataneous RVD's (one for each system or equipment type having its own reliability specification) each program should be evaluated in accordance with the criteria of the test plan such as discussed in Section 4.6.

Test time or mileage is understood as meaning equipment operating time or mileage for purposes of determining equipment reliability. It is assumed that during the test, vehicles may be removed from service due to failures of one kind or another. Barring vehicles which may not be returned to service (i.e., accident), such interrupted time will not count as test time or mileage nor cause the test time/mileage to be extended by the period interrupted. If a vehicle is removed from service due to an accident, the remaining demonstration fleet may run for an additional period to account for the lost vehicle time or mileage due to its removal.

Determination of compliance is measured against failures occurring during the demonstration test itself; all data pertinent to the test will be logged and recorded. As the data is accumulated and evidence shows that the criteria for acceptance or rejection have been met, the test may be terminated and the results summarized. Depending upon the RVD plan selected, one of three decisions may be made at any given time: (1) continue testing, (2) discontinue testing because criteria for rejection are met, and (3) discontinue testing because criteria for acceptance are met.

During the RVD, each vehicle odometer or equipment elapsed time meter should be checked periodically to insure its proper operation. The odometer or time meter should be replaced immediately if defective without counting it as a failed item for demonstration purposes. If not already installed, hub odometers should be installed on vehicles and/or timers added for operators to clock time expended during operation. As a last resort, daily time of operation, miles traveled, number of runs made may be logged to provide data for operational measurement.

Preventive maintenance procedures as specified by manuals for maintaining the equipment during normal operation should be used during the reliability test. No additional preventive maintenance is allowed during the reliability test or during actual equipment repair. Readjustment of operator controls, periodic calibration, and checkout is not to be considered preventive maintenance. Preventive maintenance may be performed on test equipment and the maintenance facility as necessary.

4.8.4 RVD Results

If the RVD program for an equipment is terminated in an accept decision, the general conclusion is that the equipment meets an intended (specified) reliability goal with a definable level of confidence. It is possible that certain design changes or modifications which improve equipment reliability might be identified as a consequence of the RVD. It may also be discovered that certain procedures followed during the RVD result in a definable difference in reliability or availability. In either case the equipment has met its reliability objectives and further improvements await further decisions. The other cause for termination, rejection or failure to meet the reliability goals, requires definite follow-on action for obvious reasons. When a demonstration test is halted due to a failure, a procedure for correcting the causes of the deficiency should be initiated. The corrective procedure should incorporate an evaluation which will consider the historical trend of the test, the number of kinds of failures, and the point at which the reject decision was made. From the data evidence gathered, the corrective action should follow a plan where the failure, design deficiencies, or procedures which have caused the decision can be corrected but not degrade the equipment as a result. The specified performance and design characteristics of individual equipment should not be changed sot that reliability requirements can be achieved. If it is determined that a failure is due to operation of a component beyond its design limits, it shall not count as a demonstration failure and a replacement will be made with a like component. Such corrective action should be reported in detail with supporting data and does not count as a failure towards the reliability requirements. All such failures shall be reviewed by engineering analysis for final evaluation.

When enough failures have occurred that an RVD is terminated in a reject decison, detailed analysis by the property and the equipment manufacturer should be performed, especially if the causes for the poor reliability are in question. It will be necessary at this point to review past RVD and appropriate historical data in order to select the proper course of action. In this circumstance, the TRIP data bank is likely to be a valuable resource.

5 - TRIP DATA SUPPORT FOR AN RVD PROGRAM

5.1 INTRODUCTION

TRIP is a government-initiated program to assist the transit industry in satisfying its needs for rapid rail transit vehicle reliability information. This assistance is provided through the operation of a national reliability data bank to collect, store and analyze data generated by transit operators in the course of transit vehicle revenue operation and maintenance. Summary results of periodic analysis of the data are distributed to TRIP participants and users.

The TRIP data bank has been designed specifically to meet the needs of the transit industry for timely reporting of reliability information from a variety of perspectives including:

- Fleet Performance;
- Individual Vehicle Performance;
- System Performance;
- Component Performance.

The data bank design is based upon a modular concept to provide wide flexibility in the various functions of data entry, data verification/editing, data base update, data retrieval and data analysis. Input data processing programs are custom-tailored to read and reformat transit authority data into system standard formats. This approach enables the data bank to accept data in a wide variety of formats and minimizes the programming effort required to initialize the system to accept data on new transit vehicles and equipment.

TRIP is ideally suited to support a Reliability Verification Demonstration and provide the data services necessary. TRIP is designed to provide such services; it can process, summarize and analyze data in an impartial manner, and respond with data output in a timely fashion.

5.2 DATA INPUT

Throughout the RVD program, operations, maintenance activities and incidents related to the performance of the equipment(s) under test should be documented in detail, and submitted to the TRIP Data Bank for storage and processing. Later, outputs formatted in a manner that will facilitate evaluation of the equipment(s) performance can be produced on demand. The generation of output data (discussed in Section 5.3) requires input data which TRIP can utilize for processing. To serve this purpose, expedite data collection and minimize problems during the demonstration, extensive use of TRIP codes and generic part numbers should be used for classifying the test data. This use will futher facilitate uniformity in tracking, processing and evaluating the data so that the outputs can be presented in a timely manner. For purposes of component or vehicle comparison uniformity of classification becomes an essential characteristic.

To streamline and reduce the data load for those performing the RVD, input records for supplying data to TRIP have been limited to those which will provide only that data which is essential to making the appropriate accept/reject or continue testing decision. For this effort, only a daily log and failure reports are required.

5.2.1 Daily Log

A daily log record should be maintained throughout the RVD. At a minimum, vehicle number, route, date and mileage/hours accumulated should be recorded by the vehicle or equipment operators. In the comment column, as appropriate, the number of runs per day performance of scheduled maintenance or any other pertinent information, such as the occurance of an incident, should be recorded (See Figure 5.2-1 for an example of the type of form that might be used). This log will be an input to TRIP.

5.2.2 Failure Report

A failure report should be prepared each time a reportable failure (relevant, primary, etc.) occurs during the RVD as defined or agreed upon by the test organization. This report will describe the symptoms and effects of each failure as well as the resultant maintenance actions required to correct the malfunction. Such a report should include, but not be limited to, presentation of the following information:

- A failure report number;

- Vehicle Number ____________
- Route ____________

Date	Accumulated Mileage/Hours	Oper. Initials	Comments	Date	Mileage/Hours	Oper. Initials	Comments

Figure 5.2-1 - SAMPLE DAILY LOG (TRIP INPUT)

- Date of event, hours/mileage accumulated to that date;
- Vehicle number, specific route (if practicable)
- System, subsystem, assembly, and component name and part/serial number;
- Narrative description of the fault symptoms, maintenance action taken and resulting correction checkout. Narration should include any related characteristics which would fully describe the event, especially the cause of failure;
- Coded description of the symptoms, failure type and maintenance actions taken. (It is intended that all the coded failure information recorded should make use of the TRIP code schema whenever possible.

A representative example of the type of failure report format that might be used for an RVD is illustrated in Figure 5.2-2. In many cases, those failure report formats used by individual transit properties may be used with only minor modifications.

5.3 DATA OUTPUT

In order that the conduct and results of an RVD may be clearly and easily interpreted and analyzed, a variety of outputs from TRIP may be obtained. These outputs are derived from both the evaluation criteria determined prior to the start of the program and the operations/maintenance

- Vehicle Number ____________ • Date ____________ • Mileage/Hours ____________
- Report Number ____________ • Route ____________
- Failure Symptoms (describe) ________________________________

____

____

________________________________ • Operator ____________

Check Section A B

AIR

1. Low, High/Leaks*

AIR COMFORT

2. Blowers
3. Body heat/cooling*
4. Cab heater/windshield demist*

BRAKES

5. Abnormal emergency braking
6. Erratic braking
7. Poor braking
8. Sander failure
9. Track brake failure

BRAKING SYSTEM WARNING LIGHTS

10. Friction brake on train
    a. light comes on abnormally
    b. light does not come on
11. Friction brake on car
    a. light comes on abnormally
    b. light does not come on
12. Pass. emerg. stop failure
13. Track brake on-light
    a. comes on abnormally
    b. does not come on

CARBODY

14. Body damage
15. Cab door/divider/curtain*
16. Console
17. Destination sign(s)
18. Door centre/LR*
19. Door front
20. Equipment access doors
21. Exterior lights
22. Farebox
23. Fire extinguisher
24. Floor covering
25. Grills and vents
26. Handrail(s)
27. Headlight(s)
28. Horn/gong*
29. Interior lights
30. Interior panels/trim/covers*
31. Leaks
32. Locks
33. Mirrors—Doors/interior*
34. Operator's seat
35. Passenger seat(s)
36. Passenger stop request
37. Tools
38. Warning panel lights
39. Windows
40. Windshield
41. Wiper/washer*

COMMUNICATIONS

42. Radio does not function properly
43. Intercom does not function properly
44. PA does not function properly

COUPLER

45. Fails to engage

*circle appropriate trouble

Check Section A B

COUPLER (continued)

46. Fails to disengage
47. Fails to center
48. Fails to extend
49. Fails to retract
50. Electrical head failure

DOORS

51. Abnormal door speed
52. Door close green light will not come on
53. Door(s) out of service—by passed
54. Emergency door release failure
55. External door switch(s) failure
56. Internal center door switch failure
57. Manual door release failure
58. Sensitive edge inoperative

PANTOGRAPH

59. Foot pump failure
60. Manual control valve failure
61. Will not raise from cab
62. Will not lower from cab
63. Will not lock down

PROPULSION SYSTEM

64. Blown fuses/circuit breakers
65. Dead car
66. Erratic operation
67. Master controller(s)
    a. bad detents
    b. deadman control
    c. locks up
    d. sticking
68. Spins/slide failure*
69. Track switch failure
70. Traction motor blower(s)

PROPULSION SYSTEM WARNING LIGHTS

71. Battery over voltage
72. Battery under voltage
73. Dynamic brake off-light
    a. comes on
    b. does not come on
74. LVPS failure
75. Overspeed indicator/alarm abnormal*
76. Propulsion disabled
77. Speed sensor failure

TRUCKS — TRUCK A B C

78. Flat wheel(s)
79. Hard ride
80. Lifeguard
81. Locked wheel(s)
82. Spring brake wound off
83. Track brake cradle
84. Truck cut out

MISCELLANEOUS — A B

85. Accident
86. By pass switch thrown
87. Dragging equipment
88. Noise
89. Smoke or fire

Figure 5.2-2 · SAMPLE FAILURE REPORT (TRIP INPUT)

- Vehicle Number ________________
- Report Number ________________
- Maintenance Work Performed (describe)

	Part Number	Codes	
• System ________			
• Subsystem ________			
• Assembly ________			
• Component ________			

- Repairman ________________

Failure Verification (check at least one)

- Relevant ________
- Non-Relevant ________
- Redundant ________
- Multiple ________
- Incident ________

- Comments

- Test Engineer ________________

Figure 5.2-2 - SAMPLE FAILURE REPORT (TRIP INPUT) data collected during the program. Potential outputs, described in the following paragraph, include:

- Test Data Logs - Provide a history of operations, maintenance and incidents for each vehicle, system or equipment during the RVD.

- Equipment Failure Records - Provide a failure history of each unit on test. It can be used to identify trends and, in summary format, to plot the test's progress with respect to time.

- Test Criteria Plots - Provide a continuous plot of a test's progress for each unit with respect to its accept/reject criteria.

- Duane Plots - Provide a means for measuring the reliability growth of a system. Can be of assistance in determining the valiidity of an RVD program.

5.3.1 Test Data Logs

A complete record of accumulated input data for each individual vehicle/system under test will be provided during the test. The record format shall permit ready reference to test history of each vehicle/system in the program. At a minimum, the test log will report the vehicle number, system/vehicle name/model number, hours of operation/mileage accumulated for a specified period (bi-weekly) date, number of failures for the period, number of incidents for the period. Figure 5.3-1 presents a sample of one output format

- Hardware - ID ____________
- Mileage/Hours Accumulated ____________

Date	Failure Report	Failure Type		Incident	Code		Comments
		Relevant	Non-Relevant		Symptom	Fault	

Figure 5.3-1 - SAMPLE DATA LOG (TRIP OUTPUT)

that might be used. Other formats are also possible, depending upon the availability of data.

5.3.2 Equipment Failure Record

A failure report will be provided for each equipment participating in the RVD. The record is designed to permit reference to the test history of each tested equipment so that widely divergent differences, trends, or patterns in test behavior for equipments may easily be recognized. At a minimum, the failure record will note the component, its next higher assembly, system, date of failure, hours or mileage at the time of failure, and, where applicable, vehicle number. This record can serve to detect failure trends and identify high failure rate items requiring action as a result of data analysis. In a summary form, this record is intended to contain all the information necessary to reach an accept/reject decision on the test. It shall include all failures considered relevant on all equipments under test. On a periodic basis, the summation of the failure data will be measured against the RVD evaluation criteria to determine whether an accept/reject decision is imminent. Figure 5.3-2 illustrates a potential format for presenting the necessary output data from TRIP.

5.3.3 Test Criteria Plots

Test data for each system will be plotted against the system's accept/reject test plan graph. The continuous plotting will determine the progress being made with regard to a system's accept/reject decision during the RVD. The test criteria plots will be output by TRIP periodicallv.

- Unit Nomenclature ____________________
- Part Number ____________________

Vehicle Number	System	Failure Report	Date	Mileage/Hours (as applicable)	Symptom Fault	Failure Description (brief)	Data Recorder Initials

Figure 5.3-2 - SAMPLE EQUIPMENT FAILURE RECORD (TRIP OUTPUT)

Although the derivation and application of test criteria plots has been detailed in Section 4.6, their use will be summarized briefly herein. Three test types have been recommended for an RVD:

- Test to a failure limit;
- Test to a time limit;
- Sequential testing.

In all cases, the number of failures having occurred on the equipment being evaluated is plotted against the total test time that has passed. For the first two tests mentioned, the RVD is continued on the particular equipment until the failure or time limit has been met, after which a reject/accept decision may be made with some predetermined level of confidence.

The most commonly used test is the sequential type since this test may be terminated more quickly than the other two. In the sequential test, a property may continuously monitor the elapsed time and number of failures that have occurred; at any time they may determine whether the test may be terminated in a accept/reject decision, or if it must be continued. Figure 5.3-3 illustrates a sequential test on which actual failure data would be plotted by TRIP. As an alternate to the test criteria plot, the actual failure data may be compared with a table of criteria, such as presented in Table 5.3-1, and the decision to terminate or continue testing made accordingly.

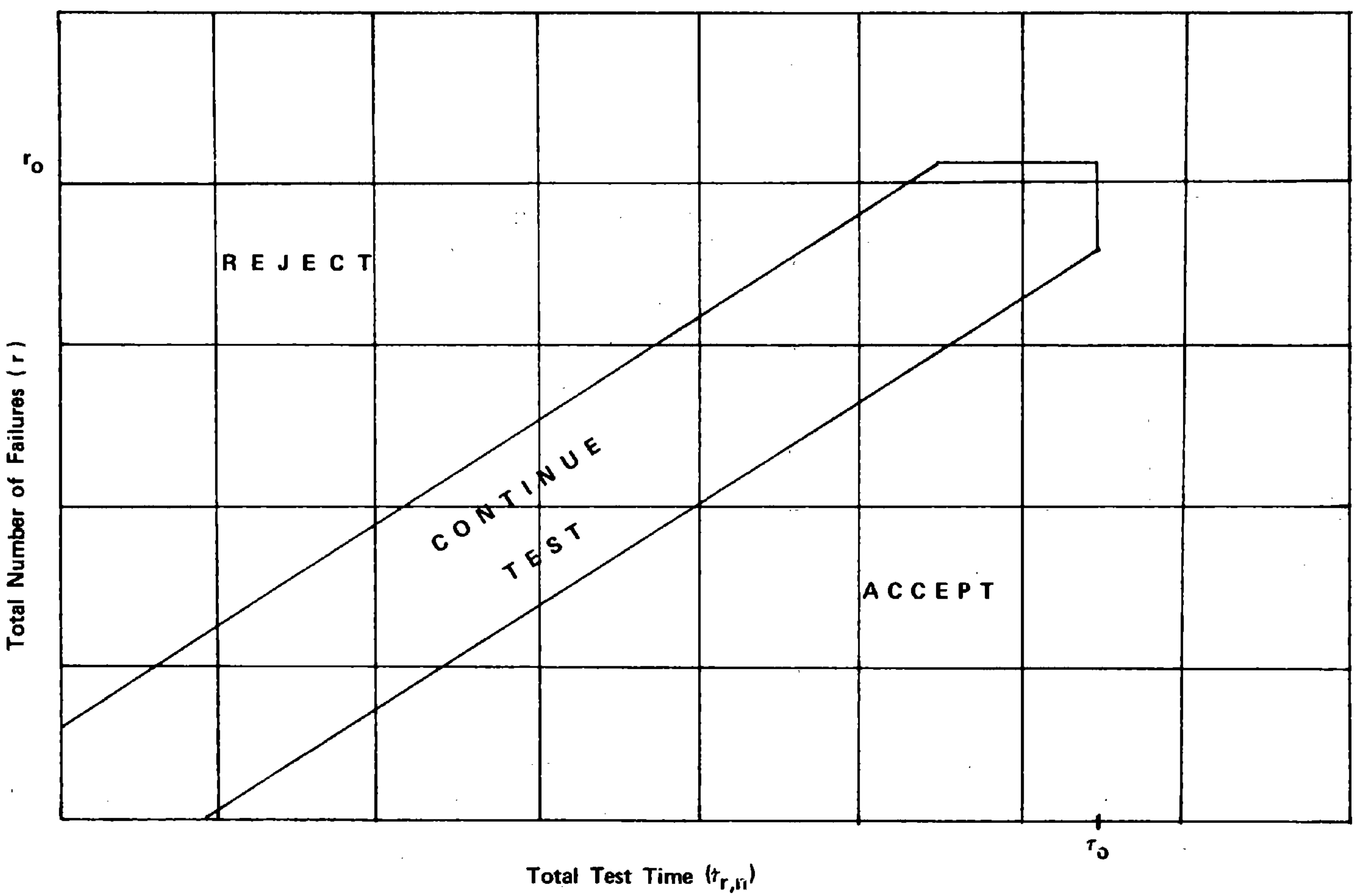

Figure 5.3-3 - SAMPLE SEQUENTIAL TEST PLAN (TRIP OUTPUT)

Table 5.3-1

SAMPLE SEQUENTIAL TEST DECISION CRITERIA

No. Failures	Total Test Time (multiples of θ_1) Reject (Equal or Less)	Accept (Equal or More)
0	N/A	5.89
1	N/A	7.28
2	N/A	8.66
3	N/A	10.05
4	N/A	11.43
5	1.04	12.82
6	2.43	14.21
7	3.82	15.59
8	5.20	16.98
9	6.59	18.37
10	7.97	19.75
11	9.36	21.14
12	10.75	22.52
13	12.13	23.91
14	13.52	25.30
15	14.91	26.68
16	16.29	28.07
17	17.68	29.46
18	19.06	30.84
19	20.45	31.40
20	21.84	31.40
21	23.22	31.40
22	24.61	31.40
23	26.00	31.40

given: $\alpha = .05$, $\beta = .05$, $\theta_0/\theta_1 = 2$

$(-5.89 + 1.39r < \tau_{r,n} < 5.89 + 1.39r)$

5.3.4 Duane Plots

A Duane plot is a graphical representation of a units reliability plotted against cumulative time. Such a plot should be maintained for each equipment to be evaluated in an RVD, as one of the assumptions made in the recommended RVD test procedures is that the reliability measure (MTBF or MDBF) remains constant for the test duration. A change in reliability may affect the validity of the RVD results, and so a Duane plot will be useful in monitoring an equipment's reliability, stability and any trends.

Reliability for complex equipment, such as a rapid transit car or one of its major systems typically follows what is known as a "bathtub" curve (shown in Figure 5.3-4 below). If a RVD is performed on new equipment before the period of "infant mortality" has ended, then it is apparent that the test MTBF calculated at the completion of the RVD may not be a true representation of the equipment's true reliability during its useful operating life. The Duane plot will be used in the RVD to demonstrate that the RVD results truly represent the equipments' design reliability. This plot will be an output published periodically by TRIP.

Duane plots are also useful in certain types of pre-production and warranty programs in which a reliability growth is planned between some initial low MTBF value and another pre-defined MTBF goal. Such a growth is normally due to modification improvements as well as some improvement in operations or maintenance procedures. For these types of programs and expcted growth of between 0.3 and 0.5 has been historically demonstrated as acceptable. This growth range is illustrated in the plot in Figure 5.3-5.

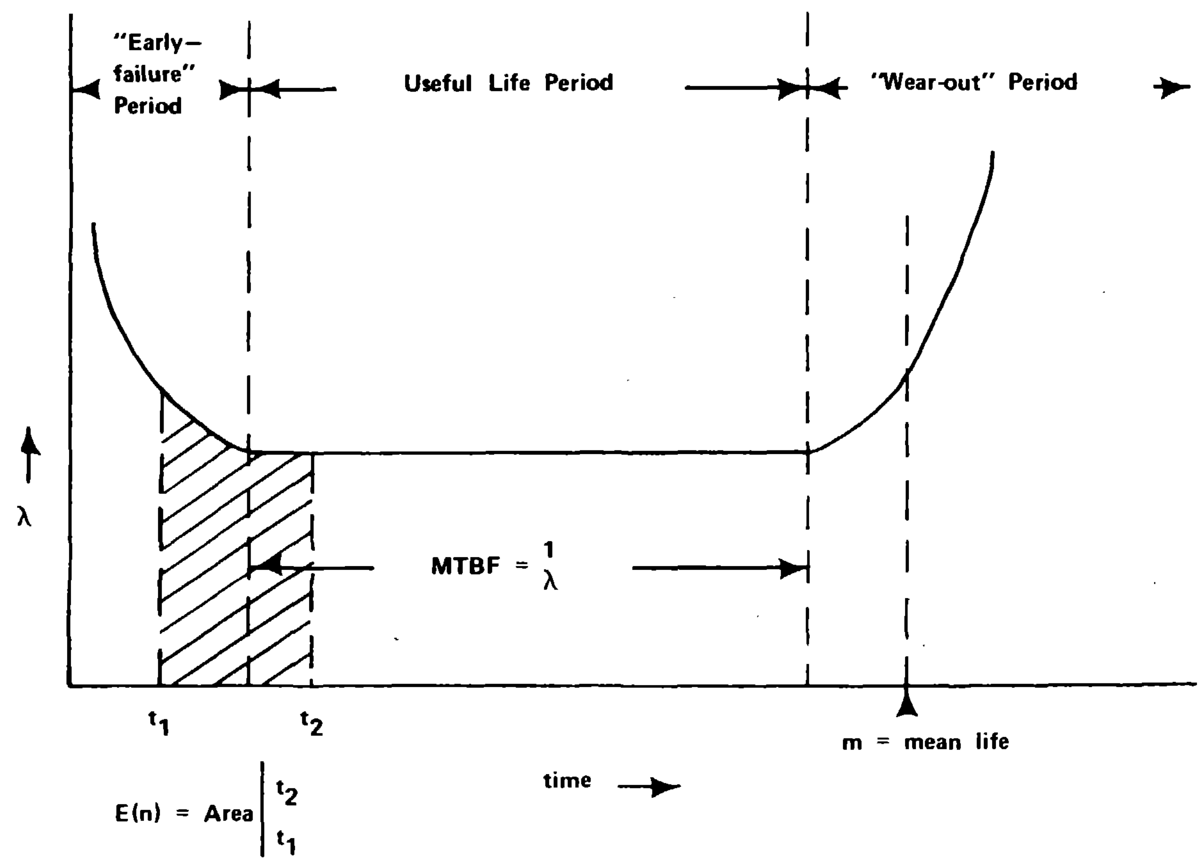

Figure 5.3-4. STANDARD RELIABILITY CURVE

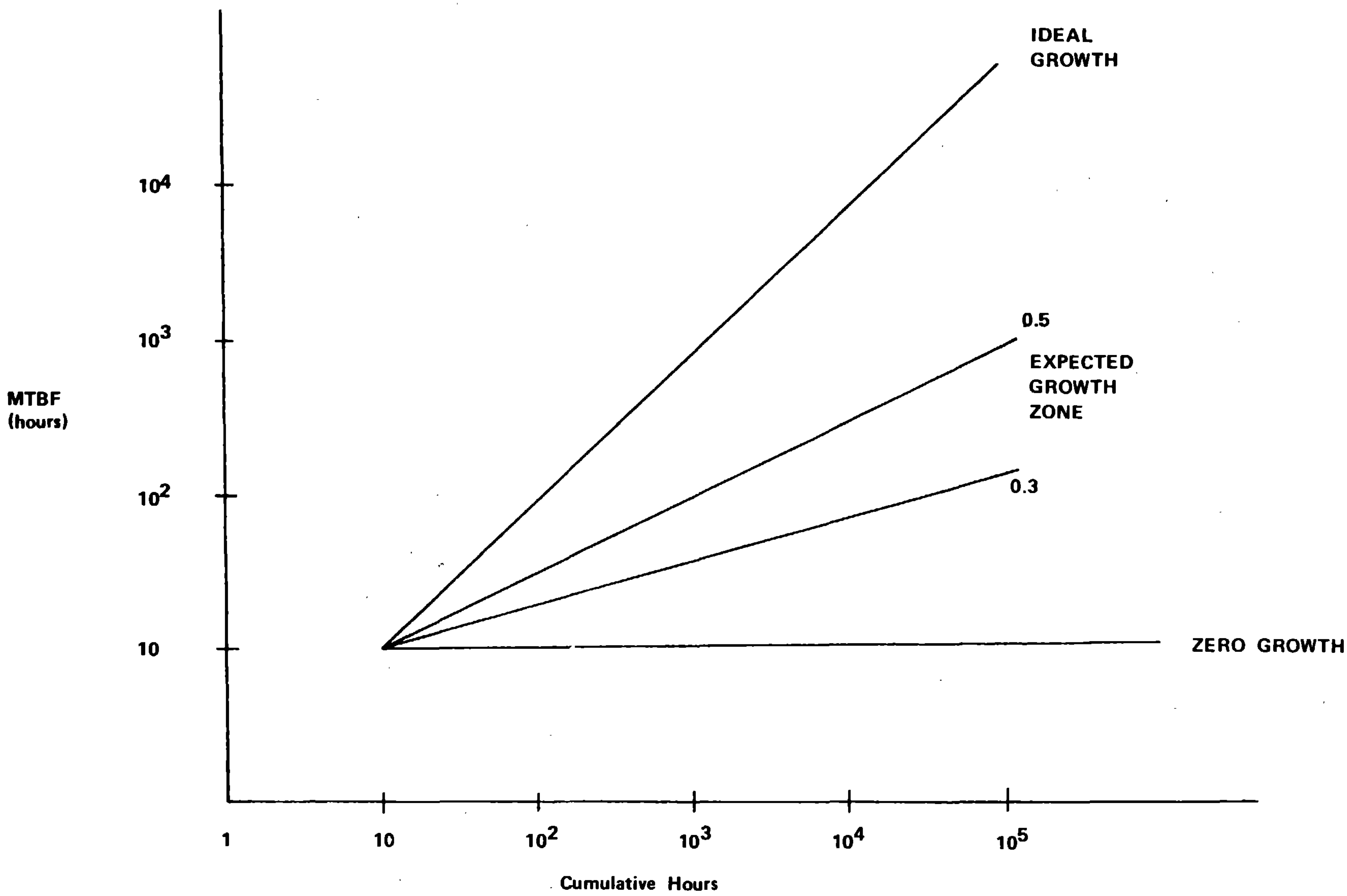

Figure 5.3-5. - SAMPLE DUANE PLOT (TRIP OUTPUT)

5.4 RVD RESULTS

In support of the demonstration test, TRIP will be instrumental in providing analysis so that failure data characteristics may be evaluated to provide useful results for rectifying operational and design problems. Ultimately such analysis will contribute to reducing failures and improving overall reliability of the vehicles. In conjuction with the test, TRIP will provide special reports, as requested, to highlight equipment problems. Typical of such reports and analysis are the following:

- Analysis of data trends, patterns, evaluations;
- Special evaluations of significant contributors to vehicle failure rates (high drivers);
- Comparison analysis for system MTBF accept/reject criteria;
- Impact of vehicle removal from test; and
- Changes in test policies and procedures.

5.4.1 Reliability Calculations

Before an accept/reject decision may be made, it is first necessary to determine the failure rate (λ) or mean interval between failures (θ) of the equipment being tested. The procedures for this determination is as follows:

1) Identify these failures (r) which have occurred and which shall be counted against the equipment reliability:

$$r = \sum_{i=1}^{n} r_2, \qquad (11)$$

where r_2 is the number of failures for each of the n equipments of one type under test.

2) Determine the total time (or distance) on test $(\tau_{r,n})$ for the equipment on test:

$$\tau_{r,n} = \sum_{j=1}^{n} \sum_{i=1}^{r} t_{i,j}, \qquad (12)$$

where $t_{i,j}$ is the time (or distance) to each accountable failure (r_i) for each equipment (n_j) of a type.

3) Calculate mean interval between failures (θ) :

$$\hat{\theta} = \frac{\tau_{r,n}}{r} = 1/\hat{\lambda}$$

5.4.2 Analysis

When the failure rate for an equipment type under test has been calculated, the test organization may then decide upon the appropriate action to take at any given time.

Regardless of the decision, there are a variety of analytical techniques that may be used to assist in the decision and analyses that follow. Some of these techniques are discussed briefly below. Further detailed explanations of these techniques may be found in the references or numerous other documents of statistical analysis and reliability evaluation.

- Least squares: To examine data trends and correlation, we may take data from a group of vehicles on test (selected from the first production lot) and data from a later group on test (a later production lot) and determine if the data has changed or remained the same. The results may show that the failures are fewer due to improved maintenance procedures or that design changes have been incorporated. Also, the application may well show how well the later data relates to the first group of data (i.e., is there any influence or are we really taking information from the same kind of data base?).

- Difference between two means: To examine how data from two different groups correlate. Take data from two different systems or vehicle groups. Data may be extracted from different operational periods or during the same operational period. The application will determine if failures in one group influence and relate to failures in the other group. Is there a substantial difference in the data groups? Is one system being maintained in a different way from another system? Is this due to better P.M. and/or tools and test equipment for one system versus the other system?

- Chi Square Test: To determine if the data follows a normal or log normal distribution by test. Electrical equipment failures and repairs usually follow a log normal distribution while mechanical equipment leans toward a normal distribution. By examining the data we may determine how far and biased the failures are with regard to their distribution of the data being reported and point out significant failure concentrations.

- Histograms: To plot the basic distribution of the data. We can show the failure frequency with regard to mileage/hours period interval and/or total cumulative mileage/hours. This application can also point to failure concentration where we can answer when do most failures occur?

- Standard deviation: To show the variance, spread in the data. We can show how much the data itself varies from its own mean as a way of illustrating consistency or lack of consistency in the failures experienced by a system or vehicle. It can also reflect the accuracy and quality of the data being generated.

- Run test: To predict overall system/vehicle expectation. Using system MTBF plotted over an extended period of time, estimate the projected trend such data will suggest for a future period.

- System prediction: To evaluate redundant systems taking into account the redundancy. Evaluate system and vehicle MTBF to indicate its performance and advantage due to its incorporated redundancy. What benefit does redundancy provide? Do we need more redundancy for better performance or can we live with less?

APPENDIX A

PERCENTAGE POINTS OF THE CHI-SQUARE DISTRIBUTION

χ^2_a

υ	$\chi^2_{.50}$	$\chi^2_{.30}$	$\chi^2_{.25}$	$\chi^2_{.20}$	$\chi^2_{.10}$	$\chi^2_{.05}$	$\chi^2_{.025}$	$\chi^2_{.01}$	$\chi^2_{.005}$	υ
1	0.455	1.074	1.323	1.642	2.706	3.841	5.024	6.635	7.879	1
2	1.386	2.408	2.733	3.219	4.605	5.991	7.378	9.210	10.597	2
3	2.366	3.665	4.108	4.642	6.251	7.815	9.348	11.345	12.838	3
4	3.357	4.878	5.385	5.989	7.779	9.488	11.143	13.277	14.860	4
5	4.351	6.064	6.626	7.289	9.236	11.070	12.832	15.086	16.750	5
6	5.348	7.231	7.841	8.558	10.645	12.592	14.449	16.812	18.548	6
7	6.346	8.383	9.037	9.803	12.017	14.067	16.013	18.475	20.278	7
8	7.344	9.524	10.219	11.030	13.362	15.507	17.535	20.090	21.955	8
9	8.343	10.656	11.389	12.242	14.684	16.919	19.023	21.666	23.589	9
10	9.342	11.781	12.549	13.442	15.987	18.307	20.483	23.209	25.188	10
11	10.341	12.899	13.701	14.631	17.275	19.675	21.920	24.725	26.757	11
12	11.340	14.011	14.845	15.812	18.549	21.920	23.337	26.217	28.300	12
13	12.340	15.119	15.984	16.985	19.812	22.362	24.736	27.688	29.819	13
14	13.339	16.222	17.117	18.151	21.064	23.685	26.119	29.141	31.319	14
15	14.339	17.322	18.245	19.311	22.307	24.996	27.488	30.578	32.801	15
16	15.338	18.418	19.369	20.465	23.542	26.296	28.845	32.000	34.267	16
17	16.338	19.511	20.489	21.615	24.769	27.587	30.191	33.409	35.718	17
18	17.338	20.601	21.605	22.760	25.989	28.869	31.526	34.805	37.156	18
19	18.338	21.689	22.718	23.900	27.204	30.144	32.852	36.191	38.582	19
20	19.337	22.775	23.828	25.038	28.412	31.410	34.170	37.566	39.997	20
21	20.337	23.858	24.935	26.171	29.615	32.671	35.479	38.932	41.401	21
22	21.337	24.939	26.039	27.301	30.813	33.924	36.781	40.289	42.796	22
23	22.337	26.018	27.141	28.429	32.007	35.172	38.076	41.638	44.181	23
24	23.337	27.096	28.241	29.553	33.196	36.415	39.364	42.980	45.558	24
25	24.337	28.172	29.339	30.675	34.382	37.652	40.646	44.314	46.928	25
26	25.336	29.246	30.434	31.795	35.563	38.885	41.923	45.642	48.290	26
27	26.336	30.319	31.528	32.912	36.741	40.113	43.194	46.963	49.645	27
28	27.336	31.391	32.620	34.027	37.916	41.337	44.461	48.278	50.993	28
29	28.336	32.461	33.711	35.139	39.087	42.557	45.722	49.588	52.336	29
30	29.336	33.530	34.800	36.250	40.256	43.773	46.979	50.892	53.672	30
35	34.338	38.860	40.221	41.802	46.034	49.798	53.207	57.359	60.304	35
40	39.337	44.166	45.615	47.295	51.780	55.755	59.345	63.706	66.792	40
45	44.337	49.453	50.984	52.757	57.480	61.653	65.414	69.971	73.190	45
50	49.336	54.725	56.333	58.194	63.141	67.502	71.424	76.167	79.512	50
55	54.336	59.983	61.665	63.610	68.770	73.309	77.384	82.305	85.769	55
60	59.336	65.229	66.982	69.006	74.370	79.080	83.301	88.391	91.970	60
65	64.336	70.466	72.286	74.387	79.946	84.819	89.181	94.433	93.122	65
70	69.335	75.693	77.578	79.752	85.500	90.530	95.027	100.436	104.230	70
75	74.335	80.912	82.860	85.105	91.034	96.216	100.843	106.403	110.300	75
80	79.335	86.124	88.132	90.446	96.550	101.879	106.632	112.338	116.334	80
85	84.335	91.329	93.396	95.777	102.050	107.521	112.397	118.244	122.337	85
90	89.335	96.529	98.653	101.097	107.536	113.145	118.139	124.125	128.310	90
95	94.335	101.723	103.902	106.409	113.008	118.751	123.861	129.980	134.257	95
100	99.335	106.911	109.145	111.713	118.468	124.342	129.565	135.814	140.179	100
105	104.335	112.095	114.381	117.009	123.917	129.918	135.250	141.627	146.078	105
110	109.335	117.275	119.612	112.299	129.355	135.480	140.920	147.421	151.956	110
115	114.335	122.451	124.838	127.581	134.782	141.030	146.574	153.197	157.814	115
120	119.335	127.623	130.059	132.858	140.201	146.568	152.215	158.956	163.654	120

$\chi^2 a$

υ	$\chi^2_{.995}$	$\chi^2_{.99}$	$\chi^2_{.975}$	$\chi^2_{.95}$	$\chi^2_{.90}$	$\chi^2_{.80}$	$\chi^2_{.75}$	$\chi^2_{.70}$	υ
1	0.0000393	0.000157	0.000982	0.00393	0.0158	0.0642	0.102	0.148	1
2	0.0100	0.0201	0.0506	0.103	0.211	0.446	0.575	0.713	2
3	0.0717	0.115	0.216	0.352	0.584	1.005	1.213	1.424	3
4	0.207	0.297	0.484	0.711	1.064	1.649	1.923	2.195	4
5	0.412	0.554	0.831	1.145	1.610	2.343	2.675	3.000	5
6	0.676	0.872	1.237	1.635	2.204	3.070	3.455	3.828	6
7	0.989	1.239	1.690	2.167	2.833	3.822	4.255	4.671	7
8	1.344	1.646	2.180	2.733	3.490	4.594	5.071	5.527	8
9	1.735	2.088	2.700	3.325	4.168	5.380	5.899	6.393	9
10	2.156	2.558	3.247	3.940	4.865	6.179	6.737	7.267	10
11	2.603	3.053	3.816	4.575	5.578	6.989	7.584	8.148	11
12	3.074	3.571	4.404	5.226	6.304	7.807	8.438	9.034	12
13	3.565	4.107	5.009	5.892	7.042	8.634	9.299	9.926	13
14	4.075	4.660	5.629	6.571	7.790	9.467	10.165	10.821	14
15	4.601	5.229	6.262	7.261	8.574	10.307	11.306	11.721	15
16	5.142	5.812	6.908	7.962	9.312	11.152	11.192	12.624	16
17	5.697	6.408	7.564	8.672	10.085	12.002	12.792	13.531	17
18	6.265	7.015	8.231	9.390	10.865	12.857	13.675	14.440	18
19	6.844	7.633	8.907	10.117	11.651	13.716	14.562	15.352	19
20	7.434	8.260	9.591	10.851	12.443	14.578	15.452	16.266	20
21	8.034	8.897	10.283	11.591	13.240	15.445	16.344	17.182	21
22	8.643	9.542	10.982	12.338	14.041	16.314	17.240	18.101	22
23	9.260	10.196	11.688	13.091	14.848	17.187	18.137	19.021	23
24	9.886	10.856	12.401	13.848	15.659	18.062	19.037	19.943	24
25	10.520	11.524	13.120	14.611	16.473	18.940	19.939	20.867	25
26	11.160	12.198	13.844	15.379	17.292	19.820	20.843	21.792	26
27	11.808	12.879	14.573	16.151	18.114	20.703	21.749	22.719	27
28	12.461	13.565	15.308	16.928	18.939	21.588	22.657	23.647	28
29	13.121	14.256	16.047	17.708	19.768	22.475	23.567	24.577	29
30	13.787	14.953	16.791	18.493	20.599	23.364	24.478	25.508	30
35	17.156	18.484	20.558	22.462	24.812	27.820	29.058	30.181	35
40	20.674	22.142	24.423	26.507	29.067	32.326	33.664	34.874	40
45	24.281	25.880	28.356	30.610	33.367	36.863	38.294	39.586	45
50	27.962	29.687	32.348	34.762	37.706	41.426	42.944	44.314	50
55	31.708	33.552	36.390	38.956	42.078	46.011	47.612	49.055	55
60	35.510	37.467	40.474	43.186	46.478	50.614	52.295	53.808	60
65	39.360	41.427	44.595	47.448	50.902	55.233	56.991	58.572	65
70	43.253	45.426	48.750	51.737	55.349	59.868	61.698	63.344	70
75	47.186	49.460	52.935	56.052	59.815	64.515	66.416	68.125	75
80	51.153	53.526	57.146	60.390	64.299	69.174	71.144	72.913	80
85	55.151	57.621	61.382	64.748	68.799	73.843	75.880	77.707	85
90	59.179	61.741	65.640	69.124	73.313	78.522	80.623	82.508	90
95	63.963	65.886	69.919	73.518	77.841	83.210	85.374	87.314	95
100	67.312	70.053	74.216	77.928	82.381	87.906	90.131	92.125	100
105	71.414	74.241	78.530	82.352	86.933	92.610	94.894	96.941	105
110	75.536	78.448	82.861	86.790	91.495	97.321	99.663	101.761	110
115	79.679	82.672	87.207	91.240	96.067	102.038	104.437	106.585	115
120	83.839	86.913	91.567	95.703	100.648	106.762	109.216	111.413	120

For large values of r,

$\chi^2_{a,2r}$ may be approximated using the

CUMULATIVE NORMAL DISTRIBUTION FUNCTION

such that:

$$\chi^2_{a,2r} = \begin{cases} (-\sqrt{2(2r)-1} - Z_a)^2/2 , & a > .5 \\ (-\sqrt{2(2r)-1} + Z_a)^2/2 , & a < .5 \end{cases}$$

	$a_{.50}$	$a_{.70,.30}$	$a_{.75,.25}$	$a_{.80,.20}$
Z_a	0.00	0.524	0.675	0.842

	$a_{.90,.10}$	$a_{.95,.05}$	$a_{.975,.025}$	$a_{.99,.01}$	$a_{.995,.005}$
Z_a	1.282	1.645	1.900	2.326	2.576

example: $\chi^2_{.95,120} = (-\sqrt{239} - 1.645)^2/2 = 95.422$

$\chi^2_{.05,120} = (-\sqrt{239} + 1.645)^2/2 = 146.284$

(accuracy will improve with increasing r)

APPENDIX B
REPORT OF NEW TECHNOLOGY

A significant amount of rail transit equipment reliability data was collected which aided in the establishment of a national transit reliability Data Bank. The Data Bank will promote the amalgamation of current reliability efforts within the transit industry; provide a focal point for a consolidated reliability effort; and assist the transit industry in creating, developing, and improving revenue service operations.

85 copies