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Contract No. 3136

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT

RELIABILITY AND MAINTAINABILITY DEFINITIONS

July 1984

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1.0 INTRODUCTION

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The primary goal of the Metro Rail Project is to operate a cost-effective rail rapid transit system that provides an acceptable level of service dependability. System dependability can be achieved by emphasizing the achievement of reliability, maintainability, and quality assurance requirements. The SCRTD is therefore implementing a comprehensive program for managing the systems assurance disciplines of reliability, maintainability, and quality assurance. These requirements include:

- Utilizing equipment which has proven reliability in similar applications on other rail rapid transit systems
- Applying the principles of redundancy in designs so that the failure of a single component will not be critical to safety or operational service
- Applying maintainability principles in all subsystem designs to ensure convenient maintenance operations
- Establishing appropriate maintenance procedures to improve maximum operational service with minimum equipment downtime
- Establishing well defined quality assurance procedures to ensure that materials, components and equipment delivered by contractors and subcontractors are inspected and conform to functional and performance requirements.

The Metro Rail systems or subsystems will use hardware that is primarily transit-proven. The hardware will be designed in a manner similar to that used at other contemporary rail rapid transit systems. However, use of proven equipment does not lessen the necessity for emphasizing system assurance.

A System Assurance Program Plan has been developed which identifies the management and technical tasks and activities directed at the disciplines of reliability, maintainability and quality assurance. As outlined in the System Assurance Program Plan, the first step in the reliability and maintainability programs is to select measures or indices from which reliability and maintainability objectives can be established for the system, each subsystem and major equipment components. This report represents the first part of a four-step process for identifying the reliability and maintainability numerical goals and requirements that will be incorporated into various contract specifications. These steps are to:

- Establish clear, precise definitions for suggested measures or indices
- Develop realistic goals and requirements for major system elements (vehicles, train control, etc.) to meet Metro Rail System dependability goals
- Allocate the top-level requirements to the major subsystems (propulsion, HVAC, brakes, etc.)
- Incorporate the requirements into the appropriate contract specifications.

The present report is confined to the first of these steps. However, it was recognized that the wide variety of definitions and measures that exist within the transit industry in part reflect some fundamental problems in relating the characteristics of individual equipments to the behavior of complex systems. Specifications necessarily are written at the equipment level, while the property's operational concerns arise largely at the system level. Consequently, the level-to-level linkages are very important. Also, most attempts to demonstrate equipment reliability and maintainability must be carried out in the presence of interactions with other elements of the system. Efforts to alleviate these problems were made in the course of the selection of reliability and maintainability measures and are also described in this report.

2.0 SUMMARY OF DEFINITIONS AND RECOMMENDATIONS

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This report presents recommendations and definitions with respect to measures of reliability and maintainability for application on the Metro Rail Project. The definitions represent selection and refinements from a wide variety of definitions used elsewhere. The approaches to specification and demonstration of maintainability and of the maintenance-related aspects of reliability also follow precedent.

2.1 DEFINITIONS

The following definitions are excerpted from the body of this report, where the background, rationale, and application of the definitions are discussed. Because the definitions are intended for contractual purposes, an effort has been made to minimize ambiguities and some explanatory text has been incorporated.

DEFINITION: FAILURE

The event, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.

NOTES:

- To be regarded as the failure of a specific item, the event or state must arise as a result of the properties of that item and must not be attributable to external factors that exceed specification limits.
- The failure of an item does not always imply the failure of the function or higher-level items with which the failed item is associated.
- When the failure of an item is addressed in a specification or in an analysis, that item should be identified clearly.

DEFINITION: INDEPENDENT FAILURE

A failure that occurs without being caused by the failure of another item.

NOTES:

- A failure that is induced by errors in testing procedures, or by stresses induced improperly by test equipment or instrumentation, should not be regarded as an independent failure.

- If two or more failures are induced concurrently by the same cause, not more than one of the failures should be regarded as an independent failure.

DEFINITION: DEPENDENT FAILURE

A failure that is not independent.

DEFINITION: REPRODUCIBLE FAILURE

A failure that can be duplicated.

NOTE:

- Questions as to whether a failure is reproducible should not arise when the failed state is evident from physical examination of the item, but only when a functional failure has been indicated as a transient event in operation. In such cases, verification of the failure should be possible by duplicating it in the shop or in operation.

DEFINITION: CONTRACTUAL FAILURE

A failure with respect to a contractual requirement, whether due directly to an independent, reproducible failure or to any resulting dependent failures.

NOTE:

- Only one contractual failure shall be counted in connection with the combination of any one independent failure and its dependent failures, if any. However, when this requires a choice among several contractual requirements, the selection shall be made by the District.

DEFINITION: LIFE UNITS

A measure of use duration applicable to the item (e.g., operating hours, clock hours, revenue hours, cycles, car-trips, car-miles).

DEFINITION: FAILURE RATE

The measure of the rate of decrease in item population or survival probability, expressed mathematically as:

$$\lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{R(t)}$$

NOTES:

- Depending on the circumstances and on requirements, the magnitude of the failure rate may be:
  - Derived from a specific model of the item's life distribution,
  - Predicted from prior information, including handbooks, or
  - Estimated by dividing the total number of observed failures in an item population by the corresponding number of accumulated life units
- The source or method for determining the failure rate value should be identified.

DEFINITION: MEAN TIME TO FAILURE (MTTF)

The arithmetic average of the times to failure of a population of items, measured in life units.

NOTES:

- The magnitude of the mean time to failure may be derived from specific models or predicted from prior information as in the case of the failure rate.

- When the constant-failure-rate assumption is appropriate, the mean time to failure is equal to the reciprocal of the failure rate and may be evaluated accordingly.
- The mean time to failure is an appropriate measure for non-repairable items.

DEFINITION: MEAN TIME BETWEEN FAILURES (MTBF)

The arithmetic average of the times between successive failures of an individual item or of each of the members of a population of items, measured in life units.

NOTES:

- MTBF may be derived, predicted, or estimated as in the case of MTTF.
- The mean time between failures is an appropriate measure for repairable items, but is numerically equal to the MTTF when the constant-failure-rate assumption is appropriate.

DEFINITION: MAINTAINABILITY

The collective properties of an item that determine consumption of resources, including time, per maintenance event. Maintainability generally is improved by design policies that facilitate access and diagnosis, especially for the most common failures, and by maintenance policies that provide adequate facilities, replacement parts, and staffing.

DEFINITION: BASELINE TIME TO REPAIR

The net active repair time, excluding the effects of any extraneous interruptions, from the beginning of fault location to the successful completion of functional checkout.

DEFINITION: MEAN BASELINE TIME TO REPAIR (MBTTR)

The arithmetic average of the baseline times to repair for a defined item and class of repairs.

NOTES:

- MBTTR may be determined directly from observations of actual repairs.

- Alternatively, when specified or when agreed to by the parties, MBTTR may be determined from a theoretical model (distribution) fitted to observations or from estimates based on maintenance analysis.

DEFINITION: MAXIMUM BASELINE TIME TO REPAIR (MAXMBTTR)

The 90th percentile of the distribution of baseline time to repair for a defined item and class of repairs, determined as in the case of MBTTR.

2.2 RECOMMENDATIONS

The maintenance demands generated by failure and by efforts to prevent failures also must be subjected to contractual control. Maintenance demands are determined jointly by reliability (failure frequency) and maintainability (resource consumption per failure). For some types of equipment, the total failure frequency for the operational consequence severity categories (explanation later in text) is an adequate reliability measure for maintenance demand purposes; for others, a separate requirement may be necessary. With respect to maintainability, the following steps are recommended in addition to the usual specifications of repair times.

For demonstrations:

- Define and require a maintainability demonstration program that:
  - Reflects the repair time requirements
  - Involves the performance of repairs on actual, deliberately introduced, or appropriately simulated failures
  - Assures an appropriate mix of failures within each class to which a specific requirement applies
  - Is performed under conditions (including skill levels, facilities, and equipment) that reasonably approximate the conditions expected in SCRTD facilities.

For preventive maintenance:

- Establish contractual post-delivery penalties for provable inadequacies in the supplier-defined preventive maintenance program.

- Verify that the supplier-defined preventive maintenance activities can be accomplished within the projected clock- and man-hours

For spares provisioning:

- Require each prospective supplier to submit, as part of his bid or proposal, a preliminary provisioning list and corresponding cost estimate

- Require an updated provisioning list at a time no later than the maintainability demonstration

- Establish contractual penalties for:

  - Nontrivial cost growth from the preliminary provisioning list to the updated list

  - Multiple or severe shortages resulting from spares consumption in excess of provisioning

  - Excessive inventory costs associated with spares consumption that is less than one-fourth of the consumption predicted for provisioning purposes for any item

- Require consistency between reliability predictions and spares provisioning.

3.0 BACKGROUND

3.0 BACKGROUND

When a rail rapid transit system operates without performance degradation, accidents, and equipment shortages, it provides patrons with a definable level of service. Under these conditions, the transit property realizes maximum revenues for a given fare structure, and minimum variable costs. Unfortunately, the system can be subject to perturbations caused by failures of equipment and inefficiencies. The type of perturbation of interest for purposes of this report involves equipment failure and its consequences.

From the patron's standpoint, the consequences of equipment failure are delays and/or discomfort. Sometimes, only patrons in a specific transit vehicle or train or at a specific location are affected. Sometimes many trains are affected and occasionally (e.g., when too many vehicles become unavailable or when an important track segment is unusable), all patrons are affected. Although a typical occurrence many directly affect only a small number of patrons, frequent occurrences are likely to affect the perceptions of the riding public.

When equipment fails, the transit property incurs the cost of repair and, possibly, the costs of providing substitute transportation such as bus bridges. Additional capital costs may be incurred in providing spare vehicles or equipments or in improvements, such as pocket tracks, needed to enhance failure management capabilities. There may also be opportunity costs such as foregone revenues due to reduced system capacity and/or patron dissatisfaction.

The frequency of failure is largely determined by equipment characteristics and is measured in terms of reliability. The duration of delays due to a failure depends strongly on the ability to correct or bypass the on-line problem. This ability is determined by equipment characteristics measured in terms of maintainability and by recovery provisions and operating strategies and rules. The cost of repair is also heavily influenced by other aspects of maintainability. The time required to restore equipment to a serviceable condition, and the requirements for spare parts and spare vehicles, are also heavily influenced by maintainability design. In addition, time and spares requirements are affected by factors such as maintenance facility sizing and layout and staffing levels.

The analysis of equipment failure and the subsequent effect on the transit system and its patrons is complex. It involves issues that are normall eyond the scope of any specification of the reliability and maintainability of any individual piece of equipment. However, such specifications are important for two reasons:

- Reliability and maintainability measures are elements of the more complex issues of dependability and availability
- The quantification of such measures allows overall system dependability and availability to be estimated and allows individual equipment performance to be assessed. The latter is particularly important because it can be contractually enforced in order to achieve the system dependability goals.

The purpose of this report is to present clear and precise definitions of reliability and maintainability measures so that they can be uniformly applied on the Metro Rail project and allow numerical indices to be derived.

3.1 HISTORICAL BACKGROUND

Quantitative definition and evaluation of reliability, availability and maintainability (RAM) began in the 1940's as a result of the increasing complexity of military hardware. The development and exploitation of RAM techniques were fostered by the defense and aerospace industries. It was not until more complex, new transit systems began to be developed in the 1960's that any serious attempt was made to apply those techniques to the transit industry.

RAM definitions and procedures in the transit industry are derived from their military counterparts but there are some special problems which are noteworthy:

- In fixed-guideway systems, the interactions among system elements (vehicle-to-vehicle, train-to-train, train-to-guideway) are strong; therefore, failure effects tend to be closely coupled.
- There is a strong interaction between the system and its patrons.
- Most suppliers are not thoroughly experienced with RAM requirements, concepts and analytical tools.

Rail rapid transit thus combines complexity in RAM relationships with an unavoidable reliance on suppliers who are inexperienced in RAM disciplines. This may help to account for the diversity in RAM measures and definitions among different transit properties. However, it must be acknowledged that basic differences--e.g., between the commuter-rail-like characteristics of BART and the close station spacing of NYCTA--can result in real differences in RAM needs.

3.2 SOURCES

To provide a background for the selection of suitable reliability and maintainability indices for the Metro Rail Project, definitions from several sources are included in this report. Exhibit 3-1 identifies these sources:

- MIL-STD-721C is the primary source of military definitions, and thus reflects the historical antecedents.
- The APTA-Glossary and APTA-RAM specification guidelines represent the transit industry's attempt to provide definitions for industry-wide use.
- TRIP definitions, while not in general use, are associated with the program to establish a common data base for the industry.
- BART and SEMTA definitions are associated with current procurements and thus indicate contemporary practice.

RAM definitions are provided for numerous areas and have been grouped as follows:

Reliability	Maintainability
Failures	Maintenance
Failure Accountability	Maintenance Time Elements
Failure Consequences	Mean Repair Times
Failure Rates and Mean Times	

In each area, a variety of definitions is presented, recommended appropriate measures and their definitions are listed, and the rationale for their choice is explained.

EXHIBIT 3-1
SOURCES OF DEFINITIONS

ACRONYM	FULL TITLE
721C	MIL-STD-721C, 12 June 1981: Military Standard: Definitions of Terms for Reliability and Maintainability
APTA-G	Glossary of Terms Prepared for The American Public Transit Association by the Reliability, Availability, Maintainability (RAM) Task Force
APTA-RAMS	Guideline for Rail Rapid Transit Equipment Reliability, Availability and Maintainability Specification, May 1981, published by The American Public Transit Association
TRIP	Transit Reliability Information Program (TRIP) Participants Guidelines (Many of the definitions used in TRIP appear in the text rather than as distinct definitions. In view of this, definitions attributed to TRIP often are paraphrased.)
BART	Bay Area Rapid Transit District, Agreement for Development, Procurement and Testing of Vehicle Automatic Train Control Equipment; Agreement No. 42CA-110
SEMTA	Southeastern Michigan Transportation Authority, System Contract for Central Automated Transit System

4.0 RELIABILITY

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The reliability of a transit system is affected by all kinds of failures, regardless of their causes. The causes of interest for purposes of this report are those which involve equipment failure and its consequences. The intent is to exclude perturbations which:

- Are externally caused by vandalism, strikes, most accidents, and out-of-design-range weather conditions
- Are induced by human error in operations or maintenance, unless directly attributable to the equipment supplier
- Result from planned, periodic activities such as preventive maintenance and overhaul.

4.1 FAILURES

Exhibit 4-1, Basic Failure Definitions, displays some definitions of failure and near-synonyms of failure. The multiple definitions may reflect attempts to distinguish among perturbations of differing severity or origins. Failures can, and sometimes must, be categorized in a number of different ways, and there are not enough near-synonyms available to accommodate all distinctions. The distinctions among definitions also often are not obvious. For example, the difference between anomaly, failure, and malfunction in the APTA-G definitions is not clear. For most purposes, it is easier to use a basic definition of failure and attach modifiers as needed. An expanded version of the 721C definition is appropriate:

DEFINITION: FAILURE

The event, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.

EXHIBIT 4-1
BASIC FAILURE DEFINITIONS

FAILURE (721C)

The event, or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified.

FAILURE (TRIP)

. . . incident where a component was found to be inoperative or exceeded its design limits and, therefore, did not perform its intended function.

REPAIR ACTION (TRIP)

Component repair due to catastrophic failure or operation beyond specified limits. (Implicitly, an action made necessary by a FAILURE.)

MAINTENANCE ACTION (TRIP)

A minor repair (as contrasted to REPAIR ACTION).

FAILURE (SEMTA)

An event which results in the inability of a system element to perform an intended function.

FAULT (SEMTA)

An event that produces a state or condition in a system element which contributes to the occurrence of an undesired event. A fault may be, but is not necessarily, a failure.

FAILURE (APTA-G)

An inability to perform an intended function.

EXHIBIT 4-1
BASIC FAILURE DEFINITIONS
(Continued)

<u>ANOMALY</u> (APTA-G)

Deviation from nominal performance which does not cause a significant affect on system performance but does warrant investigation and/or repair.

<u>DEFECT</u> (APTA-G)

A fault, imperfection, flaw, lack of completeness, or other conditions which do not comply with specified technical requirements.

<u>DISCREPANCY</u> (APTA-G)

Nonconformance of equipment or nonequipment items to stated standards exclusive of the external environment.

<u>MALFUNCTION</u> (APTA-G)

Any anomaly of failure wherein the system, subsystem or component fails to function as intended.

<u>INCIDENT</u> (APTA-G)

An unforeseen event or occurrence which does not result in injury or property damage.

NOTES:

- To be regarded as the failure of a specific item, the event or state must arise as a result of the properties of that item and must not be attributable to external factors that exceed specification limits.

- The failure of an item does not always imply the failure of the function or higher-level items with which the failed item is associated.

- When the failure of an item is addressed in a specification or in an analysis, that item should be identified clearly.

4.2 FAILURE ACCOUNTABILITY

To the extent that RAM indices are to be used by the SCRTD for contractual purposes, it is important to distinguish between those failures for which the equipment supplier can properly and effectively be held accountable and those for which he can not. In general, a supplier can properly be held accountable for failures that occur within the specified operating environment and that could, in principle, have been prevented by design, procurement, and production aspects reasonably within the supplier's control. He can effectively be held accountable if the transit system's failure data collection system is credible or if the contract places the burden of proof on the supplier.

Exhibit 4-2, Failure Accountability Definitions, displays some definitions related to assigning responsibility for the failure. The usual practice is not to hold the supplier accountable for secondary (dependent) failures. It can be argued that, while multiple counting involving primary and secondary failures should be avoided, the total cost of the consequences, including repair time and cost for secondary failures, should be taken into account.

The BART definitions appear appropriate with four exceptions:

- The definition of independent failure is exclusively test-oriented

- The definition of reproducible failure eliminates intermittent failures and failures that can only be duplicated under service conditions

EXHIBIT 4-2
FAILURE ACCOUNTABILITY DEFINITIONS

FAILURE, INDEPENDENT (721C)

Failure which occurs without being caused by the failure of any other item. Not DEPENDENT.

FAILURE, DEPENDENT (721C)

Failure which is caused by the failure of an associated item(s). Not INDEPENDENT.

FAILURE, NON-RELEVENT (721C)

(a) A failure verified as having been caused by a condition not present in the operational environment, or
(b) A failure verified as peculiar to an item design that will not enter the operational inventory.

FAILURE, NON-CHARGEABLE (721C)

(a) A non-relevant failure, or
(b) A relevant failure caused by a condition previously specified as not within the responsibility of a given organizational entity. (All relevant failures are chargeable to one organizational entity or another).

FAILURE, PRIMARY (APTA-G)

The failure which is responsible for a system malfunction.

FAILURE, SECONDARY (APTA-G)

A failure which occurs as the consequence of another failure (also dependent failure).

EXHIBIT 4-2
FAILURE ACCOUNTABILITY DEFINITIONS
(Continued)

<u>INDEPENDENT FAILURE</u> (BART)

A failure which occurs without being caused by the failure of a) other parts of the equipment under test, b) test equipment, c) instrumentation, or d) the test facility.

<u>REPRODUCIBLE FAILURE</u> (BART)

A failure which can be duplicated in the shop and for which, if the failure is corrected by replacing a part, the replaced part itself is failed.

<u>CONTRACTUAL FAILURE</u> (BART)

An independent, reproducible failure of supplier-furnished equipment under test, plus any non-independent failures caused thereby, classified as one failure and used to determine contractual compliance. All such failures are contractual failures unless and until determined to be otherwise by the Engineer. Failure requiring software modifications shall not be considered as contractual failures.

- Disposition of failures by the Engineer should be a contractual provision, but not a part of a definition

- Software-caused failures should be included unless and until resolved by successful modification--again, a contractual provision but not a part of a definition.

This leads to the following appropriate definitions:

DEFINITION: INDEPENDENT FAILURE

A failure that occurs without being caused by the failure of another item.

NOTES:

- A failure that is induced by errors in testing procedures, or by stresses induced improperly by test equipment or instrumentation, should not be regarded as an independent failure.

- If two or more failures are induced concurrently by the same cause, not more than one of the failures should be regarded as an independent failure.

DEFINITION: DEPENDENT FAILURE

A failure that is not independent.

DEFINITION: REPRODUCIBLE FAILURE

A failure that can be duplicated.

NOTE:

- Questions as to whether a failure is reproducible should not arise when the failed state is evident from physical examination of the item, but only when a functional failure has been indicated as a transient event in operation. In such cases, verification of the failure should be possible by duplicating it in the shop or in operation.

DEFINITION: CONTRACTUAL FAILURE

A failure with respect to a contractual requirement, whether due directly to an independent, reproducible failure or to any resulting dependent failures.

NOTE:

- Only one contractual failure shall be counted in connection with the combination of any one independent failure and its dependent failures, if any. However, when this requires a choice among several contractual requirements, the selection shall be made by the District.

4.3 FAILURE CONSEQUENCE

As indicated by the definitions in Exhibit 4-3, Failure Consequence Definitions, categorization of failures in terms of their consequences has been employed in military and transit contexts but in rather different ways. Except for safety, the greatest concern in rail transit systems almost always is with disruption of operations. This concern is reflected in requirements involving "service failures." Some properties include in the service failure category any failure which requires a train or vehicle to be removed from revenue service or precludes a train or vehicle from entering revenue service. The basic concept is delay to revenue service, as in the BART definition (six-minute delay in run time). Typical delay threshholds for service failure definition are four to six minutes. Some properties define a second threshhold, on the order of ten to fifteen minutes, for major delays, but this is used internally rather than in equipment specifications. In at least one case (a propulsion system development contract), schedule adherence has been defined in terms of not exceeding the loss of one-half of a peak period headway, or about 1 1/2 minutes.

The concept of service failure is applicable primarily to vehicles and vehicle-borne equipment. Whether a wayside failure interferes with train operation depends on design, system configuration, and operating rules. If such a failure does interfere, the time required to correct the problem is virtually guaranteed to exceed the service failure threshhold. For vehicles and vehicle-borne equipment, the allowed frequency of service failures typically is 1/4 of the allowed frequency of all failures, but the ratio may be as low as 1/10.

EXHIBIT 4-3
FAILURE CONSEQUENCE DEFINITIONS

FAILURE, CATASTROPHIC (721C)

A failure that can cause item loss.

FAILURE, CRITICAL (721C)

A failure, or combination of failures, that prevents an item from performing a specified mission.

FAILURE, SERVICE (APTA-G)

A failure which not only prevents the unit from performing its intended function, but it also disrupts or delays scheduled service.

CONTRACTUAL REVENUE (CR) FAILURE (BART)

A contractual failure that is reported in contractual revenue operation.

CONTRACTUAL SERVICE (CS) FAILURE (BART)

A contractual revenue failure which is documented by BART Central to have delayed scheduled terminal zone to terminal zone run time of a train by at least six minutes, or a vehicle which consistently fails to transmit its I.D. to wayside reader equipment.

MALFUNCTION (SEMTA)

Any anomaly that occurs in a component or subsystem that adversely affects its intended performance. Malfunctions may be classified as:

a. Class I malfunctions are those that pose a threat to passenger safety and integrity of the vehicle and hence, the entire system.

b. Class II malfunctions are failures of vehicles or wayside equipment which does not present immediate danger to passenger safety. It does cause an interruption or degradation in system revenue service.

c. Class III malfunctions are failures that do not endanger passenger safety nor interrupt nor degrade service, but do cause inconvenience to passengers.

While service failure is a valid and important concept, its use as a contractual requirement with measured conformance presents very serious difficulties:

- Delay times are variable and the choice of a threshold value must account for that variability. If the threshold value is close to the typical delay time, then the incidence of failures may be erratic with many failures which cause delays marginally less than the average not being included.

- Because delay duration depends on factors such as train length and crew response as well as equipment characteristics, responsibility for exceeding the threshhold often is subject to dispute. At a minimum, this places a heavy burden on the recordkeeping system in terms of providing detail and assuring integrity.

- Because the allowed frequency of service failures will be low, especially for individual items such as vehicle-borne Automatic Train Control (ATC) equipment, sufficient operating time for high-confidence verification is not likely to be available during the reliability demonstration program.

For such reasons, acceptance decisions often must, and usually should, be based on design reliability analyses rather than on actual measurement of service failure frequency. If that is to be the case for Metro Rail, alternative approaches to failure categorization should be considered.

An alternative failure categorization approach is presented in Section 4.4 below for consideration by Metro Rail management.

4.4 AN ALTERNATIVE APPROACH TO FAILURE CATEGORIZATION

A truly comprehensive scheme for failure categorization would be complex to the point of defying mathematical analysis; at best, it might be implementable by computer simulation. Even if such an approach were feasible, its purposes would be defeated by uncertainties about patron perception and, for that matter, differences in views among transit managers.[1]

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1. See pp. 3-5 through 3-11 in Vol. II of The Development of Measures of Service Availability, Report No. UMTA-MA-0048-78-3, June 1978, for a good discussion of problems of this kind.

Exhibit 4-4, Failure Categorization Matrix, suggests an approach that might be used to categorize failures in more detail than is permitted by the "service failure/revenue failure" definitions, without incurring prohibitive complexity. This matrix is based on the notion that, for any given type of equipment failure, it is possible to determine the typical direct results (status after failure) and assess the relative severity of those results based on the vehicle's pre-failure activity (assignment at time of failure). For example, assume that a failure involves a brake lock-up requiring mechanical disabling of the brake mechanism before movement can resume. If the vehicle is in revenue service at the time of failure, the operating rules almost certainly will require offload followed by self-propelled removal (assuming there are enough good cars in the consist). A major delay also would occur, especially if speed restrictions are involved. The corresponding cell in the matrix presumably would be labeled as implying severe consequences. The same equipment failure on a vehicle in a terminal spare assignment would result in a dispatch-prohibited status, and the consequences associated with that cell would be considered much less severe.

Because the severity of the operational consequences associated with any given combination of "Assignment at Time of Failure" and "Status After Failure" is independent of the cause, it can be assessed without knowledge of the details of the underlying equipment failure. In fact, the assessment can be made before the specifics of design are known. The assessment should be performed by SCRTD personnel with operational experience, and does require knowledge of system features, such as crossover locations, that affect the impact of blockages. Severities should be ranked on a scale with limited resolution; a scale of 1 to 6 is suggested.

Another part of the linkage between equipment failure and system consequences is determined by equipment design and configuration. (What must be done to effect cut-out of propulsion on one truck, and how long does it take to accomplish this?) The linkage is also determined in part by operating rules. For example, what speed or other restrictions are associated with x cut-outs in a consist of y cars?

Filling in such a matrix is a task for the SCRTD, not for equipment suppliers. Assistance from suppliers may be helpful in the related task of determining how specific equipment failures are to be associated with cells in the matrix. The objective of the task is to help provide a coherent basis for the subsequent setting of specification limits on the frequencies of failure at various severity levels.

EXHIBIT 4-4

FAILURE CATEGORIZATION MATRIX

Status After Failure	In Revenue Service	Deadhead	Terminal Spare	In Terminal Or Yard Awaiting Dispatch	In Yard Or Shop
	Assignment At Time of Failure (Discovery)				
Usable Without Restriction After:					
Minor Delay	☐	☐	☐	☐	☐
Moderate Delay	☐	☐	☐	☐	☐
Major Delay	☐	☐	☐	☐	☐
Remove From Service When Run Complete After:					
Minor Delay	☐	☐			
Moderate Delay	☐	☐			
Major Delay	☐	☐			
Offload Followed By Self-Propelled Removal From Service After:					
Moderate Delay	☐				
Major Delay	☐				
Assisted Removal From Service Required	☐	☐			
Nonoperational Inconvenience/ Discomfort Only	☐	☐	☐	☐	
Dispatch Prohibited		☐	☐	☐	

For purposes of specification and demonstration, it appears feasible and desirable to express the "delay" aspects of failure categorization in a form that doesn't require measurement of delay duration. This will help in avoiding some of the arguments about responsibility for delay--e.g., "that propulsion failure could have been corrected in less than four minutes if the maintenance supervisor hadn't been out on a coffee break." Delays due to equipment failure tend to be minor, moderate, or major depending on whether:

- The failure can by bypassed automatically (e.g., by line switch opening) or by action taken from the head-end cab by the train operator

- The failure can be bypassed by train operator action at the failed car

- Assistance must be brought to the scene.

For wayside equipment failures, the first category would consist of those correctible by action at Central, and the second of any failures susceptible to correction by non-maintenance personnel in the vicinity.

This approach simplifies the interface between those aspects that are largely operations-oriented and those that relate directly to equipment characteristics. The interface is represented by the failure categorization matrix. Implementation can be summarized as follows:

- As indicated above, severity of operational consequence should be assessed by operations-oriented SCRTD personnel

- The SCRTD's system safety specialists should define the rules that govern operation with equipment in degraded condition (e.g., speed restrictions and passenger offload criteria)

- The SCRTD's reliability and maintainability specialists should assign maximum allowable occurrence frequencies to each severity category for use in contract specifications

- Each supplier should be contractually responsible for conducting and documenting the necessary analyses, at the appropriate levels of detail, to predict equipment failure frequencies and to realte each equipment failure to the corresponing location in the matrix.

Of course, these aspects are not completely decoupled. For example, the supplier analyses must be subject to review and approval by the SCRTD, while the supplier must be permitted to make safety-related rules more restrictive where he considers this necessary for his protection from liability to third parties.

After verification and approval of the supplier's analyses of the linkages between equipment failures and the matrix, the need to measure delays and document operational impacts for contract specification enforcement no longer exists. Each type of equipment failure has become self-classifying. However, SCRTD may well wish to record and analyze delays and other operational problems for internal uses.

Equipment failures imply maintenance costs as well as operational perturbations. The maintenance burden is determined by maintainability as well as reliability, along with other factors such as spares provisioning, and requires separate specification and demonstration requirements.

4.5 FAILURE RATES AND MEAN TIMES

The term "failure rate" can have a number of definitions, depending upon the precision which is required. For many practical purposes, the failure rate is simply the number of failures which occur per unit of time. This definition assumes a unifrom population of equipment which has a constant failure rate. In reliability demonstration programs, the population is frequently undergoing retrofit programs so that both the state of the equipment and its failure rate are variable. Under these circumstances, the simple calculation is sometimes modified to become a moving average calculation. For example, the Toronto Transit Commission (TTC) uses a 12 month reliability demonstration period and a 12 week data collection period. Within the 12 week period the state of the equipment and its failure rate is assumed sufficiently constant to allow the sample calculation to be a reasonable estimate of the true reliablity. Because the moving average calculation is performed weekly, the method intrinsically accounts for equipment improvements which are being made to delinquent components.

Many aspects of reliability programs require quantitative estimates and analyses long before practical observations can be made. Reliability analyses allow these estimates to be made with the use of failure rate information drawn from historical data, either directly from comparable equipment or from sources such as MIL-HDBK-217. Both methods have their purposes. The analytical process can provide early estimates to support the design process, while practical demonstration programs can be used, and understood, without theoretical training in reliability.

Failure rate and subsidiary definitions are given in Exhibit 4-5. It can be seen that "time" may be any appropriate life unit. An item may be an individual component or an aggregate of components. To minimize the need for many definitions, the 721C definition of "time" should be adopted and the 721C definition of "life units" be adapted in the following modified form:

DEFINITION: LIFE UNITS

A measure of use duration applicable to the item (e.g., operating hours, clock hours, revenue hours, cycles, car-trips, car-miles).

Difficulties may arise because items differ with respect to their "natural" life units. For example, chopper propulsion failures are closely related to operating time, while door operator failures are linked to door cycles and therefore, indirectly, to station stops. To combine individual failure rates to higher level measures, such as vehicle MTBF, requires a transition to a common basis utilizing a conversion factor such as average schedule speed. Conversion factors differ widely among properties. For example, BART and NYCTA have substantially different average speeds, station spacing and numbers of doors per car. In using historical data from other properties, such differences must be considered.

The definition of failure rate can take various forms depending upon the purpose being served. The following combined mathematical and practical definition is suggested:

DEFINITION: FAILURE RATE

The measure of the rate of decrease in item population or survival probability, expressed mathematically as:

$$\lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{R(t)}$$

NOTES:

- Depending on the circumstances and on requirements, the magnitude of the failure rate may be:
  - Derived from a specific model of the item's life distribution,

EXHIBIT 4-5
FAILURE RATE AND SUBSIDIARY DEFINITIONS

TIME (721C)

The universal measure of duration. The general word "time" will be modified by an additional term when used in reference to operating time, mission time, test time, etc. In general expressions such as "Mean-Time-Between-Failure (MTBF)," time stands for "life units" which must be more specifically defined whenever the general term refers to a particular item.

LIFE UNITS (721C)

A measure of use duration applicable to the item (e.g., operating hours, cycles, distance, rounds fired, attempts to operate, etc.).

ITEM (721C)

A non-specific term used to denote any product, including systems, materials, parts, subassemblies, sets, accesories, etc.

ITEM (APTA-G)

A generic term to denote systems, element of a system, software, component, part, etc.

FAILURE RATE (721C)

The total number of failures within an item population, divided by the total number of life units expended by the population, during a particular measurement interval under stated conditions.

FAILURE RATE (APTA-G)

The number of failures of an item per unit time (cycles, hours, miles, events, etc., as applicable for the item).

FAILURE RATE (APTA-RAMS)

$$\frac{\text{observed unit failures during unit time}}{\text{cumulative unit-time (T)}}$$

or

$$\frac{1}{\text{Mean-Time-Between-Failures (MTBF)}}$$

FAILURE RATE (TRIP)

$$\frac{\text{number of failures}}{\text{number of miles}}$$

- Predicted from prior information, including handbooks, or

- Estimated by dividing the total number of observed failures in an item population by the corresponding number of accumulated life units.

• The source or method for determining the failure rate value should be identified.

While it is common practice to express reliability in terms of failure rates for components, for systems it is more common to specify the mean time between failures. Exhibit 4-6, 721C Mean Period Definitions, indicates the variety of ways which can be used. It is important to note that the distinctions among these definitions reflect differences in undesired events rather than the life units used. An exception is the distinction between Mean Time Between Failures (MTBF) and Mean Time To Failure (MTTF). This distinction comes about because some components can be repaired, while others cannot and must be discarded. MTBF refers to those components which can be repaired; MTTF refers to components which cannot be repaired. Exhibit 4-7, the APTA Mean Period Definitions, place more emphasis on differences in life units. The APTA MTTF definition may be somewhat misleading because it can be interpreted to mean that all components in the population must fail before the MTTF calculation can be made. The APTA definition also includes the concept of mean life as distinct from MTBF and MTTR. The mean life concept is introduced to recognize that some components wear to the point that the cost of repair is greater than the replacement cost. Accordingly, mean life is an estimate of the economic life of a component. For completeness, Exhibit 4-8, Other Mean Period Definitions, provides information from other sources.

The following definitions are appropriate for MTTF and MTBF:

DEFINITION: MEAN TIME TO FAILURE (MTTF)

The arithmetic average of the times to failure of a population of items, measured in life units.

NOTES:

• The magnitude of the mean time to failure may be derived from specific models or predicted from prior information as in the case of the failure rate.

EXHIBIT 4-6
721C MEAN PERIOD DEFINITIONS

MEAN-TIME-BETWEEN-FAILURE (MTBF) (721C)

A basic measure of reliability for repairable items: The mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions.

MEAN-TIME-TO-FAILURE (MTTF) (721C)

A basic measure of reliability for non-repairable items: The mean number of life units of an item divided by the total number of failures within that population, during a particular measurement interval under stated conditions.

MEAN-TIME-BETWEEN-MAINTENANCE-ACTIONS (MTBMA) (721C)

A measure of the system reliability parameter related to demand for maintenance manpower: The total number of system life units, divided by the total number of maintenance actions (preventive and corrective) during a stated period of time.

MEAN-TIME-BETWEEN-REMOVALS (MTBR) (721C)

A measure of the system reliability parameter related to demand for logistic support: The total number of system life units divided by the total number of items removed from that system during a stated period of time. This term is defined to exclude removals performed to facilitate other maintenance and removals for product improvement.

MEAN-TIME-BETWEEN-MAINTENANCE (MTBM) (721C)

A measure of the reliability taking into account maintenance policy. The total number of life units expended by a given time, divided by the total number of maintenance events (scheduled and unscheduled) due to that item.

MEAN-TIME-BETWEEN-DEMANDS (MTBD) (721C)

A measure of the system reliability parameter related to demand for logistic support: The total number of system life units divided by the total number of item demands on the supply system during a stated period of time. e.g. Shop Replaceable Unit (SRU), Weapon Replaceable Unit (WRU), Line Replacement Unit (LRU), and Shop Replaceable Assembly (SRA).

EXHIBIT 4-6
721C MEAN PERIOD DEFINITIONS
(Continued)

MEAN-TIME-BETWEEN-DOWNING-EVENTS (MTBDE) (721C)

A measure of the system reliability parameter related to availability and readiness. The total number of system life units, divided by the total number of events in which the system becomes unavailable to initiate its missions(s), during a stated period of time.

MISSION-TIME-BETWEEN-CRITICAL-FAILURES (MTBCF) (721C)

A measure of MISSION RELIABILITY: The total amount of mission time, divided by the total number of critical failures during a stated series of missions.

EXHIBIT 4-7
APTA MEAN PERIOD DEFINITIONS

MEAN TIME BETWEEN FAILURES (MTBF) (APTA-G)

The arithmetic mean of the time between successive failures.

MEAN TIME TO FAILURE (MTTF) (APTA-G)

The arithmetic mean of time to failure of all items in the sample or population.

MEAN DISTANCE BETWEEN FAILURES (MDBF) (APTA-G)

The arithmetic mean of the distance traveled between successive failures of a repairable vehicle.

(MTBF) X (MILES/HOUR) (APTA-RAMS)

Where the miles/hour is an average speed defined in the specification.

MEAN CYCLES BETWEEN FAILURES (MCBF) (APTA-G)

The arithmetic mean of the number of cycles between successive failures of a repairable device.

MEAN TIME BETWEEN UNSCHEDULED MAINTENANCE ACTIONS (APTA-G)

The arithmetic mean of the time between malfunctions requiring corrective maintenance action.

MEAN CYCLES BETWEEN SERVICE FAILURES (MTBSF) (APTA-G)

The arithmetic mean of the time between failures which interrupt or impact service operations.

MEAN TIME BETWEEN SERVICE INTERRUPTING FAILURES (MTBSIF) (APTA-G)

(See MTBSF)

MEAN LIFE (APTA-G)

The arithmetic mean of time to wearout of all items in the sample or population.

EXHIBIT 4-8
OTHER MEAN PERIOD DEFINITIONS

MEAN TIME BETWEEN FAILURES (MTBF) (TRIP)

Derived from MMFB by dividing the latter by average miles per hour (operating speed).

MEAN MILES BETWEEN FAILURES (MMBF) (TRIP)

... the average operational mileage between equipment (vehicle, system etc...) interruptions (i.e. miles between failures); the reciprocal of the failure rate.

MEAN MILES BETWEEN MAINTENANCE ACTIONS (MMBMA) (TRIP)

Analogous to MMBF, but restricted to MAINTENANCE ACTIONS.

MEAN MILES BETWEEN REPAIR ACTIONS (MMBRA) (TRIP)

Analogous to MMBF, but restricted to REPAIR ACTIONS. (Ed.: Given the TRIP definition of FAILURE and REPAIR ACTION, MMBF and MMBRA appear to be synonymous.)

MEAN TIME BETWEEN FAILURE (MTBF) (SEMTA)

The average equipment operating time per independent equipment failure. MTBF is the reciprocal of failure rate and is expressed mathematically as:

$$\frac{\text{Equipment Operating Time}}{\text{Independent Failures}}$$

MEAN TIME BETWEEN FAILURES (MTBF), GENERAL DEFINITION (BART)

MTBF is a general term. For it to have meaning the concept of pertinence must be defined for a particular kind of time, a particular period, a particular item and a particular class of failures for that item.

$$\frac{\text{Total Pertinent Time}}{\text{Total Pertinent Failures}}$$

EXHIBIT 4-8
OTHER MEAN PERIOD DEFINITIONS
(Continued)

<u>CONTRACTUAL REVENUE MEAN TIME BETWEEN FAILURES (CR-MTBF)</u> (BART)

$$\frac{\text{Total Contractual Revenue Operating Time (for the period)}}{\text{Total Contractual Revenue Failures (for the period \& item)}}$$

<u>CONTRACTUAL SERVICE MEAN TIME BETWEEN FAILURES (CS-MTBF)</u> (BART)

$$\frac{\text{Total Contractual Revenue Operating Time (for the period)}}{\text{Total Contractual Service Failures (for the period \& item)}}$$

- When the constant-failure-rate assumption is appropriate, the mean time to failure is equal to the reciprocal of the failure rate and may be evaluated accordingly.

- The mean time to failure is an appropriate measure for non-repairable items.

DEFINITION: MEAN TIME BETWEEN FAILURES (MTBF)

The arithmetic average of the times between successive failures of an individual item or of each of the members of a population of items, measured in life units.

NOTES:

- MTBF may be derived, predicted, or estimated as in the case of MTTF.

- The mean time between failures is an appropriate measure for repairable items, but is numerically equal to the MTTF when the constant-failure-rate assumption is appropriate.

It should be understood that a repairable system may be composed of nonrepairable subsystems. In such cases, an MTBF value at one level may be determined by MTTF values at lower levels of aggregation.

It also should be understood that the constant-failure-rate assumption cannot apply to a function performed by redundant items. It may be appropriate to assign an "equivalent" failure rate, but such a rate must be derived from careful analysis. The equivalent failure rates or MTBF's in such cases are very sensitive to failure detection capabilities and to operating rules and repair policies.

When more than one kind of life unit is used, it is important to distinguish among them, such as by using MDBF (as in the APTA-G definition, Exhibit 4-7) to denote miles as the life unit. In the absence of other indications, the life unit implied by MTBF and MTTF is the operating hour, but failure rate usually is stated in events per million operating hours. This must be taken into account in equating the one to the reciprocal of the other. Specific failure categories or other undesired events also can be covered by these measures, but must be defined and indicated clearly. A common approach is to emphasize "service failures", as in the BART definitions of "contractual service failure" and CS-MTBF. As indicated in Section 4.4 previously, a more detailed categorization of failures which distinguishes among several levels of severity of consequences, and avoids the need to measure delay durations, is recommended. The preferred procedure is to specify an MTBF requirement for failures having consequences of the highest rank; the highest and the second-highest combined; the highest, second-highest, and third-highest combined; and so on until all ranks are considered jointly in the last requirement. This procedure automatically gives credit for over-achievement in MTBF in any of the lower ranks.

5.0 MAINTAINABILITY

5.0 MAINTAINABILITY

Exhibit 5-1, Maintainability Definitions, displays several definitions used in the industry. None is completely satisfactory. The 721C definitions are somewhat vague because the term "measure" is confusing. The APTA-G definition provides a close parallel to the standard definitions of reliability, but measurement of maintainability in terms of probabilities is virtually never encountered in practice. The SEMTA definition has some appropriate characteristics, but seems poorly phrased.

There is no pressing need to define "maintainability" as such, because specification is done in terms of specific measures such as averages of repair times. For the sake of completeness, the following definition is offered:

DEFINITION: MAINTAINABILITY

> The collective properties of an item that determine consumption of resources, including time, per maintenance event. Maintainability generally is improved by design policies that facilitate access and diagnosis, especially for the most common failures, and by maintenance policies that provide adequate facilities, replacement parts, and staffing.

There always is competition for available funding among physical and human resource demands, within maintenance and between maintenance and other necessary activities. There also is "competition" among hardware items in the sense that not all items can be made equally accessible, and often there are trade-offs between maintainability and reliability. Priorities will vary among properties and individuals.

Definitions suggested below are limited to those characteristics that are likely to be specified and measured. Related definitions that have been used elsewhere are shown in Exhibit 5-2, Maintenance Definitions.

EXHIBIT 5-1
MAINTAINABILITY DEFINITIONS

<u>MAINTAINABILITY</u> (721C)

The measure of the ability of an item to be retained or restored to specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.

<u>MAINTAINABILITY, MISSION</u> (721C)

The measure of the ability of an item to be retained in or restored to specified condition when maintenance is performed during the course of a specified mission profile. (The mission-related system maintainability parameter.)

<u>MAINTAINABILITY</u> (APTA-G)

A characteristic of design and installation which is expressed as the probability that an item will be restored to a specified condition in a given period of time, when maintenance is performed in accordance with prescribed procedures and resources.

<u>MAINTAINABILITY</u> (SEMTA)

(1) The combined qualitative and quantitative characteristics of material design and installation which enable the accomplishment of operational objectives with minimum maintainability expenditures including manpower, personnel skill, test equipment, technical data, and facilities under operational environmental conditions in which the scheduled and unscheduled maintenance will be performed.

(2) (Same as APTA-G definition).

EXHIBIT 5-2
MAINTENANCE DEFINITIONS

MAINTENANCE (721C)

All actions necessary for retaining an item in or restoring it to a specified condition.

MAINTENANCE, CORRECTIVE (721C)

All actions performed as a result of failure, to restore an item to a specified condition. Corrective maintenance can include any or all of the following steps: Localization, Isolation, Disassembly, Interchange, Reassembly, Alignment and Checkout.

MAINTENANCE, PREVENTIVE (721C)

All actions performed in an attempt to retain an item in specified condition by providing systematic inspection, detection, and prevention of incipient failures.

MAINTENANCE, UNSCHEDULED (721C)

Corrective maintenance required by item conditions.

MAINTENANCE, SCHEDULED (721C)

Preventive maintenance performed at prescribed points in the item's life.

SERVICING (721C)

The performance of any act needed to keep an item in operating condition, (i.e. lubricating, fueling, oiling, cleaning, etc.), but not including preventative maintenance of parts or corrective maintenance tasks.

MAINTENANCE (APTA-G)

All actions necessary for retaining an item in or restoring it to an operable condition.

MAINTENANCE, CORRECTIVE (APTA-G)

An action taken to restore a failed item of equipment to an operable state.

EXHIBIT 5-2
MAINTENANCE DEFINITIONS
(Continued)

MAINTENANCE, PREVENTIVE (APTA-G)

The actions performed in an attempt to retain an item in a specified condition by providing systematic inspection, detection, and prevention of incipient failure.

MAINTENANCE, UNSCHEDULED (APTA-G)

Maintenance action (unscheduled maintenance) initiated by the malfunction of equipment.

MAINTENANCE, SCHEDULED (APTA-G)

Programmed preventive maintenance.

SERVICING (APTA-G)

The replenishment of consumables needed to keep an item in operating condition, but not including any other preventive maintenance or any corrective maintenance.

REPAIR (APTA-G)

The maintenance activity which restores a failed item to an operable state.

5.1 MAINTENANCE AND MAINTAINABILITY MEASURES

The 721C and APTA-G definitions of various elements of maintenance parallel each other rather closely. The additional 721C definitions in Exhibit 5-3 are provided because they are sometimes used in connection with measures of more direct interest. They appear ambiguous, however. For example, the value obtained for MEAN-MAINTENANCE-TIME (defined in Exhibit 5-5) depends on whether a shop visit during which corrective, scheduled preventive, and servicing activities are performed is counted as one, two, or three maintenance events. Exhibit 5-4 provides commonly used maintenance time element definitions.

Before selecting definitions, the purposes of specifying maintainability measures must be considered. When maintenance is performed:

- There may be direct effects on operations. These are effects considered in the categorization of failures and the recommended reliability specifications based on such categorization. With that approach, these effects need not be considered again under the heading of maintainability.

- There may be indirect effects on operations due to inadequate availability of equipment--especially railcars--due to excessive maintenance times or to saturation or exhaustion of maintenance resources.

- There will be expenditures of maintenance resources.

Maintainability measures are specified to control these effects and expenditures. One aspect of control involves the limiting of maintenance times and costs. Another involves the achievement of good balance among such factors as maintenance facilities, manning, provisioning, and fleet size. Unfortunately, the credible measurement of maintenance time elements and the apportionment of responsibility for other resource imbalances under real-life conditions in the maintenance shop involve extreme difficulties. There are some realistic possibilities for useful specification provisions; before examining these, it may be useful to examine some existing definitions.

EXHIBIT 5-3
ADDITIONAL MAINTENANCE DEFINITIONS

MAINTENANCE, EVENT (721C)

One or more maintenance actions required to effect corrective and preventative maintenance due to any type of failure or malfunction, false alarm or scheduled maintenance plan.

MAINTENANCE ACTION (721C)

An element of a maintenance event. One or more tasks (i.e., fault localization, fault isolation, servicing and inspection) necessary to retain an item in or restore it to a specified condition.

EXHIBIT 5-4
MAINTENANCE TIME ELEMENT DEFINITIONS

<u>MAINTENANCE TIME</u> (721C)

An element of down time which excludes modification and delay time.

<u>TIME, DELAY</u> (721C)

That element of down time during which no maintenance is being accomplished on the item because of either supply or administrative delay.

<u>TIME, SUPPLY DELAY</u> (721C)

That element of DELAY TIME during which a needed replacement item is being obtained.

<u>TIME, ADMINISTRATIVE</u> (721C)

That element of delay time, not included in the supply delay time.

<u>TIME, CHECKOUT</u> (721C)

That element of MAINTENANCE TIME during which performance of an item is verified to be a specified condition.

<u>TIME, TURN AROUND</u> (721C)

That element of MAINTENANCE TIME needed to replenish consummables and check out an item for recommitment.

<u>TIME TO RESTORE</u> (APTA-G)

See TIME TO REPAIR.

<u>TIME, ACTIVE REPAIR</u> (APTA-G)

That portion of down time during which one or more repairmen are working on failed equipment.

<u>TIME, FAULT LOCATION</u> (APTA-G)

The length of time used in discovering the cause(s) of equipment malfunction.

EXHIBIT 5-4
MAINTENANCE TIME ELEMENT DEFINITIONS
(Continued)

<u>LOGISTIC TIME</u> (APTA-G)

That portion of down time associated with waiting for one or more replacement parts.

<u>TIME, ADMINISTRATIVE</u> (APTA-G)

That portion of the down time not included in logistic and active repair time.

<u>TIME, CHECK OUT</u> (APTA-G)

Time used to verify that a repair action has restored a discrepant component or equipment.

EXHIBIT 5-5
MEAN REPAIR TIME DEFINITIONS

MEAN-TIME-TO-REPAIR (MTTR) (721C)

A basic measure of maintainability: The sum of corrective maintenance times at any specific level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

MEAN-MAINTENANCE-TIME (MMT) (721C)

The measure of item maintainability taking into account maintenance policy. The sum of preventive and corrective maintenance times, divided by the sum of scheduled and unscheduled maintenance events, during a stated period of time.

MISSION-TIME-TO-RESTORE-FUNCTIONS (MTTRF) (721C)

A measure of MISSION MAINTAINABILITY: The total corrective critical failure maintenance time, divided by the total number of critical failures, during the course of a specified mission profile.

MEAN-TIME-TO-RESTORE-SYSTEM (MTTRS) (721C)

A measure of the system maintainability parameter, related to availability and readiness: The total corrective maintenance time, associated with downing events, divided by the total number of downing events, during a stated period of time. (Excludes time for off-system maintenance and repair of detached components.)

MEAN-TIME-TO-SERVICE (MTTS) (721C)

A measure of an on-system maintainability characteristic related to servicing that is calculated by dividing the total scheduled crew/operator/driver servicing time by the number of times the item was serviced.

MEAN-TIME-TO-REPAIR (MTTR) (APTA-G)

The arithmetic mean of active repair time.

MEAN TIME TO REPAIR (MTTR) (APTA-RAMS)

$$\frac{\text{Total repair time in hours}}{\text{Total number of repair actions}}$$

EXHIBIT 5-5
MEAN REPAIR TIME DEFINITIONS
(Continued)

MEAN TIME TO RESTORE SERVICE (APTA-G)

The arithmetic mean of time required to restore service after a failure has occurred.

MEAN MAINTENANCE TIME (APTA-G)

The arithmetic mean of the time required to perform a maintenance action.

M_{90} (APTA-RAMS)

The value of repair time which, out of a ranked statistical sampling of repairs, is not exceeded 90 percent of the time.

MEAN TIME TO REPAIR (MTTR) (TRIP)

The average time it takes to perform a number of repairs, usually expressed as:

$$\frac{\text{Active Repair Times}}{\text{Number of Repairs}}$$

(TRIP suggests that the inclusion of waiting and idle time in the MTTR, or the substitution of actual out-of-service time, would be more realistic.)

MEAN LABOR HOURS TO REPAIR (MLHTR) (TRIP)

A substitute for MTTR which uses total labor hours (man-hours) in place of active repair times (clock hours).

TRIP also suggests that "while this calculation more closely represents the actual time spent on repairing a vehicle, the addition of waiting and idle time would result in an estimate of elapsed repair time for a vehicle. Thus, a vehicle's out-of-service time can be approximated." (Ed.: The last sentence is invalid.)

MAINTENANCE LOAD FACTOR (MLF) (TRIP)

A measure reflecting the repair load experienced in maintaining a vehicle/component. This factor is indicative of the unavailability of a vehicle due to maintenance, and is determined by multiplying the vehicle/component's failure rate and MTTR.

EXHIBIT 5-5
MEAN REPAIR TIME DEFINITIONS
(Continued)

<u>MEAN TIME TO REPAIR (MTTR)</u> (BART)

Used to measure the secondary repair time of a defective subassembly of the ATC.

<u>MEAN TIME TO RESTORE SERVICE (MTTRS)</u> (BART)

Used to measure the primary repair time to restore a car with a defective ATC to normal operation.

<u>REPAIR RATE</u> (TRIP)

The reciprocal of MTTR:

$$\mu = 1/MTTR$$

(Ed.: This implies a negative exponential distribution of repair times--a model much less widely accepted for repair than for failure times.)

With one exception, the 721C and APTA definitions in Exhibit 5-5, Mean Repair Time Definitions, are straight-forward extensions (taking averages) of previously defined time elements and combinations of elements. The exception is APTA-RAMS definition of M_{90}, which defines a percentile of the distribution of repair times and is sometimes identified inaccurately as a maximum time to repair (e.g., $MMAX_{90}$). The two BART definitions make a clear and important distinction. Repairs performed on a railcar or other significant operational element of the rail system, such as a track circuit, usually by the replacement of a line replaceable unit (LRU), differ in impact and usually in duration from repairs performed in a component shop.

To minimize problems and disputes in connection with the measurement of maintenance times, it is necessary to conduct the measurement under controlled conditions. For both primary and secondary repairs (as in the BART definitions), the following approach is recommended:

- Identify items subject to primary and/or secondary repair. (At a minimum, all LRU's except throwaway items are subject to secondary repair and the items at the next higher level of aggregation are subject to primary repair.)
- Establish requirements (upper bounds) on mean repair times (primary and secondary, as appropriate) based on active repair time.
- Establish requirements (upper bounds) on the 90th percentile of the repair time distributions only for those items that:
  - Appear likely to have long and highly variable repair times, and
  - Can reasonably be subjected to at least ten trials in the course of maintainability demonstration.
- Define and require a maintainability demonstration program that:
  - Reflects the repair time requirements
  - Involves the performance of repairs on actual, deliberately introduced, or appropriately simulated failures
  - Assures an appropriate mix of failures within each class to which a specific requirement applies

- Is performed under conditions (including skill levels, facilities, and equipment) that reasonably approximate the conditions expected in SCRTD facilities.

Identification of items/repairs, prediction of relative frequencies, level of detail in the specification vs. detail to be provided by the supplier, and some other aspects of maintainability demonstration may depend on the supplier's skills and on details of the equipment configuration. It therefore must be anticipated that the contract specifications as initially issued will require subsequent elaboration.

The following definitions, applicable to both primary and secondary repairs, are suggested for specification and demonstration purposes.

DEFINITION: BASELINE TIME TO REPAIR

The net active repair time, excluding the effects of any extraneous interruptions, from the beginning of fault location to the successful completion of functional checkout.

DEFINITION: MEAN BASELINE TIME TO REPAIR (MBTTR)

The arithmetic average of the baseline times to repair for a defined item and class of repairs.

NOTES:

- MBTTR may be determined directly from observations of actual repairs.
- Alternatively, when specified or when agreed to by the parties, MBTTR may be determined from a theoretical model (distribution) fitted to observations or from estimates based on maintenance analysis.

DEFINITION: MAXIMUM BASELINE TIME TO REPAIR (MAXMBTTR)

The 90th percentile of the distribution of baseline time to repair for a defined item and class of repairs, determined as in the case of MBTTR.

The above demonstration addresses only repair times associated with corrective maintenance. Two other aspects of maintainability should also be addressed:

- Spares provisioning
- Preventive maintenance.

5.2 SPARES PROVISIONING

It is customary to require equipment suppliers to submit provisioning lists, but this usually occurs late in the acquisition phase and is not subject to effective incentives. The following is recommended:

- Require each prospective supplier to submit, as part of his bid or proposal, a preliminary provisioning list and corresponding cost estimate

- Require an updated provisioning list at a time no later than the maintainability demonstration

- Establish contractual penalties for:

  - Nontrivial cost growth from the preliminary provisioning list to the updated list

  - Multiple or severe shortages resulting from spares consumption in excess of provisioning

  - Excessive inventory costs associated with spares consumption that is less than one-fourth of the consumption predicted for provisioning purposes for any item

- Require consistency between reliability predictions and spares provisioning.

5.3 PREVENTIVE MAINTENANCE

It also is common practice to prescribe upper bounds on preventive maintenance and to require the supplier to define a preventive maintenance program complying with those bounds. To aid in assuring that a realistic and effective program is defined, the following is recommended:

- Verify that the supplier-defined preventive maintenance activities can be accomplished within the projected clock- and man-hours

- Establish contractual post-delivery penalties for provable inadequacies in the supplier-defined preventive maintenance program.

SCRTD METRO RAIL SYSTEM DESIGN CRITERIA

Volume 1, Section 3

SAFETY

JUN 30 1983

SCRTD METRO RAIL SYSTEM DESIGN CRITERIA

Volume 1, Section 3, Safety

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3.1 INTRODUCTION

The success of a rapid transit system depends primarily upon public acceptance, and acceptance can only be achieved by providing safe, dependable service. In this manner the public's confidence is gained and held. This is an important factor as the public, consumer groups, and the Government focus on the safety of products and services.

A modern transit system is a combination of complex elements in an operating relationship. As there is always a possibility that an element may not operate as intended or may fail safety problems can result.

In recent years the system safety approach has been accepted more readily as a preferred means to reduce safety problems. The system safety approach stresses hazard identification, evaluation and resolution in the design phase. It is at this point that the greater cost and safety benefits can be realized. The approach also emphasizes the use of analysis of the critical physical and functional interfaces between systems and subsystems.

It is planned that the SCRTD will continue to use the experience and knowledge gained at other properties in these areas and that system safety will continue to be applied in a systems engineering manner.

3.1.1 SCRTD Safety Policy

Safety is of foremost concern in the design, construction and operation of the Metro Rail system. All applicable codes and regulations, augmented by modern system safety engineering technology and industry standards, will be used to ensure that the system achieves a level of safety that equals or exceeds that of other rail transit systems. Safety requirements include hazards elimination and/or control, and provisions for emergencies.

3.1.2 Purpose

This document presents the Preliminary Engineering safety criteria. The purpose of the safety criteria is to provide sufficient definition and description of all facets of the safety approach and concept so design engineers and architects have guidance for the proper selection of equipment and design of facilities. Through these criteria, safety considerations will be integrated into all aspects of the design specification prepara- tion, equipment selection, construction, architectural concepts, procedures and operations.

3.1.3 Program Objective

The objectives of the safety program are the elimination or control of Category I and II hazards (as defined in MIL-STD 882A) and the assurance that no single point failure in a dynamic system results in an unsafe condition.

To achieve these objectives and provide a level of safety that equals or exceeds that of other rapid transit systems requires a comprehensive and complete system safety program. The program commenced with the firm positive attitude and position of the SCRTD. The next step is the implementation of the criteria and eventually the completion of the to-be-developed program elements and analyses.

3.1.4 Scope

Three documents have been prepared to define the safety, system assurance and security criteria for the Preliminary Engineering phase. This document outlines the safety criteria in the following areas:

- Station and Site
- Communications
- Passenger Vehicle
- Train Control

- Traction Power and Distribution
- Central Control
- Ways and Structures
- Operations and Maintenance

Material that meets stringent fire, smoke and toxicity requirements are essential to the safety and well-being of the public and SCRTD personnel. These factors are addressed in a separate fire/life safety criteria document.

3.2 (RESERVED)

3.3 STATION AND SITE

3.3.1 Station and Site Layout

A well planned site safely integrates vehicular and pedestrian traffic. Pedestrian exposure to vehicular traffic needs to be minimized and the potential for vehicle collisions caused by cross- and counter-flow reduced. Open lines of sight and clear graphics also contribute to traffic flow and management.

The recommended criteria are:

- Site access points are to be located to preclude traffic congestion, and traffic patterns for vehicles and pedestrians are to be clearly marked.
- Vehicle patterns that cross or result in counter-flow are to be minimized, as are common bus and auto lanes.
- Patron drop-off zones and taxi stands are to be conveniently located to minimize patron exposure to traffic. Patrons are to be able to move directly to the station entrance without crossing traffic lanes.
- If public parking is provided, special space is to be set aside for the handicapped at the closest point to the station entrance to minimize their exposure to traffic.
- Bus loading and unloading zones are to be located so that patrons do not have to cross traffic lanes.
- Clearly defined and well-marked crosswalks and sidewalks are to be provided with nonslip surfaces.

3.3.2 Station Architectural Features

3.3.2.1 Signage

Distinct, legible and correctly located signage is critical to improved patron safety, circulation and movement. Signage can reduce the potential for confusion, interference, bumping and jostling, and possible tripping and falling.

The recommended criteria are:

- Clear, legible and well-illuminated signing and graphics are to be provided in stations. The signing and graphics are to be located in a manner which enhances the safety and convenience of patrons.
- Consideration is to be given to utilizing a bilingual format on signs; the second language to be determined as a result of further study.
- Right-hand traffic is to be maintained where possible through signing.

3.3.2.2 Architectural Psychology

Some falls occurring on escalators and stairs are due to what is termed architectural psychology. The common interpretation is that as a person prepares to board an escalator or descend/ascend the stairs he/she should not be distracted from securing a hand- hold and establishing a footing by a vista that catches the eye. (The vista could be a piece of sculpture, elaborate advertise- ment, or architectural treatment.)

The recommended criterion is:

- Any design features or vistas which can distract patrons at the head or foot of stairs and escalators are to be avoided.

3.3.2.3 Platform

3.3.2.3.1 Safety Strip: Falls from the platform edge to the trainway are among the most serious hazards to be encountered in a rail transit system. Falls could occur when an individual stands too close to the edge and is jostled, or slips, or loses balance and falls onto the trainway. Therefore, it is important that the platform edge surface should be safe and distinctive in a manner that would alert patrons when they are close to the edge.

The recommended criteria are:

- The platform edge material is to be nonslip and different in color and texture to distinguish it from the main platform area.
- A narrow tactile strip which contrasts with the platform edge and the main platform area is to be part of the design to improve the probability of the safety strip being sensed by the blind.
- The width of the safety strip is to be comparable to those found in new transit system stations (approximately 2 feet).

3.3.2.3.2 Underplatform Refuge Area: If a patron falls from the platform to the trackway, a space should be available where one can crouch and avoid being struck by the oncoming train. In this space the patron should also be safe from the third rail and the hazards associated therewith.

The recommended criterion is:

- The underplatform design is to incorporate an area where one can crouch and not be struck by the collector shoe or other parts of the train. The third rail is to be located on the opposite side of the tracks from the underplatform refuge.

3.3.2.3.3 Vehicle/Platform Interface: The horizontal and vertical misalignment between the vehicle doors and the platform edge should be minimized to reduce the tripping hazard and the possibility for an object or limb to be caught between the vehicle and platform. Alignment would also reduce the potential for catching and trapping the wheels of a wheel chair.

The recommended criterion is:

- The platform design is to be coordinated with the track layout and the vehicle dynamic profile to provide an acceptable interface between the platform and vehicle. This interface is to minimize horizontal and vertical gaps at the vehicle door threshold.

3.3.2.3.4 Bumping Hazards: Pedestrians should not be exposed to bumping hazards on the platforms or public ways.

The recommended criterion is:

- Sufficient clear space is to be provided around overhead and side projections and corners to reduce the potential for bumps and walking into these protuberances.

3.3.2.4 Station Walking Surfaces

To reduce the potential of slipping, tripping and falling, all walking surfaces including the public areas and the auxiliary spaces are to be constructed of non-slip materials.

The recommended criterion is:

- All walking surfaces within the station are to have non-slip surfaces.

3.3.2.5 Walkway Screening

Station designs often incorporate passarelles and pedestrian overpasses in non-paid areas which connect other areas of the station or businesses to the mezzanine. If the potential exists for patrons to accidentally or deliberately drop objects onto the trackway, the walkway should be screened.

The recommended criterion is:

- When passarelles or pedestrian walkways are provided over the trackway, the walkways are to be screened.

3.3.2.6 Top of Balustrade

The architectural treatment of stairs, escalators and visual openings may include the use of balustrades. Patrons awaiting trains could place objects upon the top of the balustrade. The objects could slide or be knocked off and fall onto the patrons below.

The recommended criterion is:

- The top of the balustrade is to be sloped away from the vertical circulation elements and visual openings to prevent objects being placed upon them.

3.3.2.7 Railings/Guardrails

Railings, when used, need to meet the applicable codes regarding height and loadings. Additionally, the design should not permit dropped objects to roll underneath and fall to the next lower level(s).

The recommended criteria are:

- Railings are to extend to the floor.
- Railings are to comply with the requirements of the Life Safety Code NFPA-101 and the applicable local codes.
- When glazing is used in a railing, it is to be of sufficient strength to meet the National Bureau of Standards' recommended loadings for unique or unusual materials (NBSIR 76-1139, Investigation of Guardrails for the Protection of Employees from Occupational Hazards).

3.3.3 Elevators/Escalators

A comprehensive standard exists for the design of elevators and escalators. However, additional practical requirements have evolved for their use in transit stations.

3.3.3.1 Elevators

Federal and state legislation requires elevators in stations to accommodate the elderly and the handicapped. The elevators should also be sized to meet the requirements of emergency teams.

The recommended criteria are:

- Elevators are to meet the safety requirements in the elevator/escalator codes. ANSI A17.1, and the handicapped requirements in ANSI A117.1-1980.
- Two way communication is to be provided between the patron and the station attendant/Central Control.
- Elevators are to be sized to accommodate a horizontally positioned stretcher which is carried in emergency vehicles.

- Remote elevator indicators and controls are to be provided at Central Control for emergency operation, and in station attendants' booths, if provided.

3.3.3.2 Escalators

Escalators are an essential part of the patron circulation elements and the emergency evacuation route. Also, to minimize patron confusion and improve circulation, the direction of the escalators should be obvious to the patrons.

The recommended criteria are:

- Escalators are to meet the safety requirements in the elevator/escalator code, ANSI A17.1.
- Signing and graphics are to be provided to enable patrons to determine the direction of escalator motion prior to their arrival at the landing plate.
- Status indicators and remote controls are to be provided for emergency operations.
- Adequate queuing space will be provided at both the top and bottom of escalators.

3.3.4 Stairs

Stairs are a primary vertical circulation element between levels and are the main means of movement when escalators are inoperative. The tread-riser relationship should be one that easily accommodates travel in both directions, is usable under all types of weather, and minimizes the hazard of tripping or falling.

The recommended criteria are:

- There is to be a minimum of one class A stair connecting all levels in the public area.
- The tread-riser relationship is to meet the requirements of NFPA-101, Life Safety Code.
- The stairs are to be of a non-slip material with an eased nosing that is distinct and meets the requirements of ANSI A117.1.

- When runnels are provided, they are to meet the Life Safety Code requirement and are to be protected by the handrails.
- Handrails are to be continuous and meet the requirements of ANSI A117.1.

3.3.5 Fare Collection

The fare collection array acts as a barrier between the free and paid areas. It is designed to meter and control flow. However, in an emergency, such as platform overloading, controls should be provided that prevent an excessive number of people from entering the station and descending to the platform. Conversely, a situation may warrant that patrons exit as quickly as possible.

The recommended criteria are:

- Remote operation from Central Control is to be provided to permit control of inbound patrons passing through the fare collection array.
- In the event of a power loss the fare collection array is to permit free exiting.
- Remote controls are to be provided to permit free exiting.
- Provisions are to be incorporated to permit access by the handicapped using wheelchairs.
- Sufficient exit gates are to be provided to allow rapid and complete discharge of trains.

3.3.6 Vehicle Approach System

In order to prevent unnecessary crowding at the platform edges and to alert all patrons of a train's arrival, including those with conditional handicap, a warning system should be provided.

The recommended criterion is:

- A visual and audible method is to be provided to alert patrons of the impending arrival of a train.

3.4 COMMUNICATIONS

3.4.1 Closed Circuit Television (CCTV)

Each station will be designed to function with or without an attendant present. Therefore, electronic surveillance should be required so that Central Control can monitor selected station areas. If an attendant is present, there should be the capability within the attendant's booth to monitor those safety critical areas covered by CCTV. CCTV will permit the attendant (if present) and Central Control to monitor the station and platform to prevent overcrowding.

The recommended criterion is:

- As a minimum, platform edges, elevators and escalators are to be covered by CCTV. (For additional criteria, see Security Criteria, paragraph 4.1.)

3.4.2 Public Address (PA) System

The PA System is the primary means for making announcements and directing people in an emergency situation.

The recommended criteria are:

- The PA system is to provide the attendant and Central Control full station coverage at a level sufficient to be heard over normal train, equipment and public noise.
- The PA system installation is to be designed so that the loss of an amplifier or one loop will not leave any public area without a public address capability. The PA system is to be on an uninterrupted power source.
- Central Control is to be able to communicate with all the stations either singly or as a group.

3.4.3 Patron Assistance Phones and Emergency Phones

Emergency telephones and patron assistance phones should be provided at several locations in the stations to permit direct patron communications with the station attendant, if present, or

Central Control. On some transit properties the emergency phone replaces the fire department manual pull stations.

The recommended criteria are:

- Separate phones for emergency and assistance are to be located at each level and in the paid and free areas.
- Phones are to be routed through the attendant's booth to Central Control.
- All emergency calls answered at Central Control are to be recorded and retained.
- A call from an emergency phone is to generate a priority alarm at Central Control.

3.4.4 Radio Communications

Radios are the most commonly used method of communications between transit personnel and have significant usage in safety critical situations.

The recommended criteria are:

- A base station system is to be set up.
- Separate communication capabilities are to be provided, as a minimum for:
  - train operation
  - maintenance
  - security
  - emergency
- Emergency radio communications are to be on a separate channel and compatible with local emergency equipment.
- An antenna system is to be provided to permit use of local police force handy-talkies.
- A redundant capability is to be provided for emergency transmission in case of base station transmitter failure.

3.5 PASSENGER VEHICLE

3.5.1 Doors

3.5.1.1 Door Interlocks

A very serious safety condition would exist if doors should open on a moving train or if a train should start moving while the doors are still open.

The recommended criteria are:

- Automatic train protection (ATP) summary logic is to prevent side doors from opening until the train is properly berthed and stopped at the platform, and to prevent the train from starting until all side doors are closed and locked.
- The train operator's door controls are to be on the same side as the doors being operated.
- Door edges are to be designed with appropriate stiffness to prevent fingers from being inserted between fully closed leaves, yet permit the withdrawal of trapped clothing or articles.
- A door circuit is to be provided to recycle doors open when an obstruction is met.
- A positive door control device is to be provided to prevent side doors from sliding open.
- The design is to prevent doors on the side opposite the platform from being opened.

3.5.1.2 Door Warning Signal

Patrons should be alerted when doors are ready to close so they may avoid being struck or caught by the doors and be seated or obtain a handhold before the train starts moving.

The recommended criterion is:

- Warning chimes or bells are to sound inside the vehicle before the doors are closed.

3.5.1.3 Manual Releases

In an emergency it is essential that patrons have the capability to open the doors manually if the train operator is unable to do so. Also, it is important that emergency teams outside the vehicle be able to enter the vehicle under these conditions.

The recommended criteria are:

- Interior manual door controls are to be provided for use by the patrons.
- Exterior manual door controls are to be provided for use by emergency teams with the correct tools/equipment.
- Exterior side door status lights are to be provided to indicate door failure.
- End doors capable of being locked are to have the capability of being opened from the outside.

3.5.1.4 Door Width

The primary method of training/detraining is through the side doors.

The recommended criterion is:

- Side door openings are to be wide enough to permit use by patrons in wheelchairs.

3.5.1.5 End Doors

End doors are a necessity for evacuating patrons through the train in an emergency. However, they represent a safety hazard to patrons who use them while trains are in motion.

The recommended criteria are:

- End doors will be provided but will only be used in emergency conditions.
- Signs are to be placed on end doors to discourage patrons from moving between vehicles.

- End doors are to be wide enough to permit emergency egress of a handicapped person with assistance from other passengers or SCRTD operating personnel.

3.5.2 Inter-Car Closure

In an emergency, patrons may be required to move between vehicles in order to reach an area of safety.

The recommended criterion is:

- Restraining devices are to be provided between adjoining cars of the train to prevent falling. The space between cars is to be kept to a minimum.

3.5.3 Lighting

The illumination inside a car needs to be maintained at a level which permits normal visibility. This can be considered to be the level that permits patrons to read and gives high visibility of other occupants. In addition, a backup source should be provided for emergency lighting in the event that primary power is lost.

The recommended criteria are:

- Interior lighting levels are to be consistent with "APTA Transit Security Guidelines" of 30 or more footcandles on the reading plane.
- Emergency lighting capabilities are to be provided by a backup system. The level and duration of the lighting will conform to general industry standards (3 foot-candles for one hour).

3.5.4 Communications

On-board patrons can be vulnerable to serious personal injury, or severe illness, or can observe a potentially serious hazard (fire, vehicle malfunctions, etc.). It is essential to provide an accessible, easily operated, and reliable means of communicating to alert the train operator should such an emergency arise.

Additionally, it is important to provide a reporting link between the train operator and Central Control so that an adequate response to emergencies can be accomplished.

The recommended criteria are:

- Each vehicle is to contain a telephone or other means to permit communication between a patron and the train operator. The device is to be suitably protected from vandalism.
- Communications between Central Control and the train operator and/or on-board patrons are to be provided.
- A means of identifying the origin of an alarm is to be provided for each vehicle; the alarm is to be located on the exterior of the vehicle (flashing light, alarm bell, etc.).
- All vehicles are to be uniquely numbered to provide for positive identification.

On-board communications are also discussed in the Security Criteria, paragraph 5.3.

3.5.5 Windows

A continuing problem on transit vehicles is the hazard caused by objects striking and shattering or penetrating side windows, end windows and cab windows. Such occurrences, intentional or accidental, place the patrons and the SCRTD personnel at risk.

The recommended criteria are:

- The cab window is to be capable of withstanding the impact of a heavy object at maximum speed without the windshield shattering, spalling or being penetrated.
- Side and end windows are to be made of clear, impact-resistant material capable of resisting a heavy object at high impact velocities without the window shattering, spalling or being penetrated.
- Glazings are not to hinder or prevent emergency ingress or egress.

3.5.6 Interior Design Features

Passenger comfort and convenience should be of major consideration. Seating and standing arrangement should enable patrons to move easily and safely within a moving or stopped vehicle. In addition, consideration should be given to priority seating for the elderly and physically disabled and to a location for a wheelchair.

The recommended criteria are:

- Anthropometrics are to be used in the design of the physical features, to include passenger and operator seats and the cab layout.
- Sharp edges and protrusions are to be avoided.
- Protective cushioning is to be provided as appropriate.
- Windscreens/vanity screens are to be provided at door openings.
- Stanchions are to be provided.
- Handholds are to be provided as part of the lateral seats.
- Within each car a location is to be identified for a wheelchair which is not to interfere with the other patrons' movements.
- Priority seating graphics are to be provided in vehicles.
- The seat design and its structural requirements are to be established in conjunction with crashworthiness requirements.
- Non-flammable materials are to be used in the interior car design to the maximum extent possible.

3.5.7 Cab Control/Indications

The train operator should always be aware of the status of the vehicle and its subsystems, particularly those which can impact upon the safety of the vehicle or the passengers. Also, provisions should be made whereby the operator can safely bypass specific functions in order to move a train to a location where patrons may be safely detrained or maintenance/emergency services are available.

The recommended criteria are:

- As a minimum, the following conditions or system failures/malfunctions are to be detected, annunciated and displayed:
  - overspeed
  - power/propulsion failures/malfunctions
  - program stop
  - door open
  - automatic train protection (ATP) and automatic train operation (ATO) failures/malfunctions
  - activation of critical cutouts and bypasses
  - braking failures/malfunctions
  - improper berthing at station platform.
- Cutouts and bypasses are to be provided for dynamic functions that upon failure or malfunction interrupt normal train operations.
- An external light is to indicate when the vehicle is being operated in manual mode (ATP cutout).

3.5.8 Power/Propulsion

Normal or abnormal/emergency conditions or operations should not result in unsafe conditions.

The recommended criteria are:

- The train controller handle in the manual mode is to have a "deadman" or equivalent capability.
- The mode selection switch and the manual controller are to be interlocked to assure that the manual controller's capability is locked out from the mode selection switch in the automatic or off position.
- Means are to be provided to isolate the collector assembly from vehicle power from inside the vehicle.

3.5.9 Braking

Braking failures or malfunctions should not result in unsafe operations or conditions.

The recommended criteria are:

- The emergency braking system is to be designed to be fail-safe. A vehicle equipment malfunction or failure which would result in unsafe conditions shall cause an automatic brake application that can only be reset after the train has been stopped.
- Emergency brakes are to be applied when the emergency brake trainline is deenergized or open circuited.
- Specifications for acceleration, deceleration and jerk are to conform to accepted transit standards and are to take into account the potential for passenger injury due to the loss of balance.

3.5.10 Auxiliary/Electrical

Failures or malfunctions should not result in unsafe operations or conditions.

The recommended criteria are:

- Circuit breaker protection is to be provided against short circuits and overloads.
- High voltage circuits are to be provided with the appropriate identifications in accordance with industry standards and codes.
- High voltage power is to be positively separated from communication circuitry.
- Temperature and overload sensors are to be provided with the HVAC system.

3.5.11 Other Design Features

Several other features should be considered for inclusion as part of the vehicle design to improve safety.

The recommended criteria are:

- Anticlimbers are to be located at each end of the vehicle.
- Emergency instructions are to be placed in each car.
- Emergency equipment to aid in evacuation from the vehicle is to be located within the car.
- Fire extinguishers are to be provided.
- Exterior lighting is to include vehicle head and tail lights and hostling lights.
- The capability for manual decoupling from within the car is to be provided.
- A means to electrically isolate a car from on board the train is to be provided.
- Vehicle electrical, electro-mechanical, hydraulic and/or mechanical systems are to be designed to fail in the safest manner possible.

3.6 TRAIN CONTROL

Of the three train control functions (train protection, train operation, and train supervision), train protection incorporates those functions to ensure the safety of the train movement by preventing collisions and derailments. The ATP system should contain those functions and requirements which override all others by equipment design or manually by operating rules and procedures.

3.6.1 Train Detection

The design should ensure that the track is continuously monitored to determine the presence and location of trains.

The recommended criteria are:

- Train protection shall be continuous and fail-safe so that any detection system failure is to furnish a block occupancy indication.
- Track circuits are to be such as to ensure reliable detection.
- Broken rail detection capability is to be provided.
- Vital circuits on the main line are to be fail-safe, operate on closed loop principles and meet the requirements of the AAR Signal Manual.
- Selection of train detection frequency is to preclude frequency interference by cross talk at an unsafe level.

3.6.2 Train Separation

The design should ensure that trains on the same track maintain a safe following distance to prevent collisions.

The recommended criteria are:

- Block design and safe braking distances are to be based upon "worst case" conditions (i.e., adverse track conditions, grade, vehicle loadings, and brake performance).
- Blocks on both sides of a crossover are to be indicated as occupied when a train is in a crossover.

3.6.5 Other Design Features

Other features should be considered to improve safety.

The recommended criteria are:

- The functional hierarchy of the train control system is to be:
  - train protection
  - train operation
  - train supervision.
- Manual mimic boards and controls are to be located in local train control rooms.
- All train control logic circuitry is to be designed to fail in the safest manner possible.

3.6.3 Route Interlocking

Route interlocking prevents unsafe moves that could result in collisions or derailments.

The recommended criteria are:

- Train direction and route interlocking through cross-overs are to be protected by automatic train protection.
- Trains on crossing/merging of branching routes are not to be permitted to make unsafe moves.

3.6.4 Overspeed Protection

The design should ensure that trains remain at or below commanded or posted speeds.

The recommended criteria are:

- The ATP system is not to generate false speed commands.
- Errors or false wayside speed commands are to cause automatic braking.
- The propulsion, brake and operator control system on the vehicles are to be interlocked to prevent undesired movement or excess speed.
- Signal malfunctions through Central Control are not to be capable of offsetting or overriding the ATP system.
- The speed command logic is to interpret erroneous or absent commands as more restrictive than intended, and both commanded and actual speeds are to be displayed in the cab to the train operator.
- The design of train control wayside and onboard vehicle equipment shall include provisions to prevent electromagnetic interference.

3.7 TRACTION POWER AND DISTRIBUTION

3.7.1 Emergency Trip Station (ETS)

Prompt action on the part of a patron or an employee could prevent an injury or a fatality. For this reason most of the newer transit properties have incorporated emergency trip stations (ETS) at selected locations, normally identified by a blue light.

The recommended criteria are:

- An ETS is to be located in the station attendant's booth.
- ETS(s) is (are) to be located at the platform level and the location identified by a blue light with appropriate signing. The location is not to be accessible to patrons under normal conditions.
- An ETS is to be located at each cross passage.
- ETSs are to be located in the yards and the yard towers.
- ETSs are to be easily opened without special tools.

3.7.2 Uninterruptable Power Supply (UPS)/Interruptable Power Supply

During power failures, emergency power should be available at certain station locations and for those functions considered critical. Analyses should be made to determine the location of uninterruptable or interruptable power within stations.

The recommended criteria are:

- Dual feeders are to be provided.
- As a minimum, emergency power is to be provided for the following functions and locations:

  <u>Functions</u>:

  - Public address
  - Automatic fire suppression systems
  - Fire sensing and alarming
  - Security sensing and alarming
  - Closed circuit television and monitors
  - Radio systems

- Displays depicting vertical circulation element directions
- Emergency lighting
- Emergency telephones.

Locations (for emergency lighting):

- Platform, other levels, entrances, booth
- Emergency exit routes
- Ancillary rooms and spaces.

3.7.3 Tunnel Electrification Requirements

The loss of a single substation or a tunnel feeder should not interrupt the functioning of safety critical systems, such as the ventilation system, ETS, telephones and lighting.

The recommended criterion is:

- Tunnel fans, lighting, ETS and telephones are to be fed from two substations.

3.7.4 Third Rail Coverboards

Coverboards are installed to reduce the possibility of patrons and employees inadvertently contacting the third rail. They also serve as a means of differentiating between the third rail and running rails.

The recommended criterion is:

- Rigid third rail coverboards that meet appropriate fire, smoke and toxicity requirements are to be provided.

3.7.5 Third Rail Location

It should be recognized that provisions for preventing patrons from contacting the third rail, under any foreseeable conditions, are necessary.

The recommended criteria are:

- The third rail is to be located away from the safety walk and the station platform.

- Patrons are to be alerted to the hazards of the third rail through signing.

3.8 CENTRAL CONTROL

Central Control should be the focal point for maintaining an overview of train operations, train supervision and station operation, and also for communicating directions and conditions to operators, maintenance, supervisory and emergency personnel, and patrons (as required). To accomplish these functions, the following capabilities should be incorporated into the design of the Central Control facilities.

3.8.1 Communications

Dependable, flexible and redundant communication networks should be provided to ensure continuous contact with required personnel and patrons.

The recommended criteria are:

- A dedicated radio communications system is to be provided for use of transit system personnel between various fixed facilities and locations. As a minimum, separate frequencies are to be provided for:
  - Operations
  - Maintenance
  - Security
  - Emergency.
- Central Control is to have a capability of communicating with patrons in stations via a public address system and also have two way communications with vehicle operators.
- The radio system between Central Control and the patrons, and between Central Control and transit personnel, is to have a priority/emergency channel.
- Central Control is to be able to communicate via an emergency telephone system to patrons and SCRTD personnel. The communications are to be recorded and retained.
- Central Control is to have the capability of multiple telephone and radio communications reception and call out.
- The radio system and emergency telephone systems are to be independent to prevent a single failure from causing the loss of both systems.

- The requirement for a backup/alternate Central Control is to be analyzed.

3.8.2 Displays

Sufficient displays should be installed to permit Central Control to continuously track the status of trains and other critical station functions.

The recommended criteria are:

- Incoming and outgoing safety related messages are to be visually displayed and an automatic, hard copy record maintained.
- A means to continuously monitor fire/life safety functions is to be provided.
- Mimic boards and switch panels for train control and traction power are to be provided.
- Closed circuit TV monitors are to be provided for all stations as described in the Security Criteria, paragraph 7.

3.8.3 Controls

Central Control should have the capability to institute positive commands under all conditions.

The recommended criteria are:

- Central Control is to be able to set up train routing, subject to ATP.
- Central Control is to be able to control traction power functions and isolate track sections.
- Central Control is to be able to initiate a systemwide fan regimen, yet have the capability to select directional fan control.

3.8.4 Alarm Systems

Audible alarms are necessary to alert central control personnel of emergency situations.

The recommended criterion is:

- Audible alarms are to be provided for problems such as:

    - fire
    - intrusion
    - substation power failures
    - toxic gas presence.

3.9 WAYS AND STRUCTURES

3.9.1 Yards and Shops

Certain design features should be provided to ensure the continuing safe performance of maintenance activities.

The recommended criteria are:

- Shops are to be provided with dual power feeders and/or an emergency power source. If an emergency power source is provided, it should have adequate reserve to bring all machinery to a safe, shutdown condition.
- The requirement of Cal OSHA and applicable local codes are to be met in the design of the yards, shops and equipment.
- Maintenance vehicles, including the hi-rail, are to have positive train protection capability for detection purposes and be compatible with the train detection system.
- The yard design is to have the capability to perform daily safety and operational checks on all trains entering revenue service.
- Isolated yard tracks are not to be powered inadvertently by bridging.
- Non-slip surfaces are to be provided in all maintenance facilities areas.
- The yard tower is to have the maximum view of the yard.
- Yard access for vehicular traffic by perimeter road is to be provided.

3.9.2 Tunnels

The tunnels should be sized to accept the dynamic profile of the vehicles and accommodate the other features that are to be incorporated, such as the safety walks, milestone markers, etc. In addition, the tunnels should also be designed to meet conditions imposed by emergencies.

The recommended criteria are:

- Continuous safety walks are to be provided throughout the underground system.
- If a double bore tunnel is used, cross passages are to be located as determined by fire/life safety requirements.
- Cross passage doors are to be capable of withstanding the transient pressures created by the trains as well as meeting fire protection requirements.
- Cross passages are to be considered as a standardized location for special equipment, such as emergency trip stations, emergency telephones and fire protection equipment.
- Code-conforming ramps or stairs are to be used between safety walks and the track level.
- Studies are to be performed to determine the means to control water infiltration and flooding, if required.
- Safety walks, cross passages, cross passage doors, ramps and stairs are to be of sufficient width to accommodate a wheelchair.
- Ventilation is to be provided to aid in the removal of potential gases, smoke and other toxic fumes.

3.10 OPERATIONS, MAINTENANCE AND TRAINING

3.10.1 Training

Rapid transit and local emergency personnel should be well trained in their area of responsibility on the safety features and their uses.

The recommended criteria are:

- The operations and maintenance manuals and procedures are to identify and discuss the safety features and their use.
- SCRTD personnel are to receive classroom and on-the-job training on safety features and their use.
- SCRTD personnel are to be scheduled for refresher courses periodically.

3.10.2 Emergency Training

SCRTD personnel should be trained to assume and/or fulfill responsibilities for the types of natural disasters and system emergencies that could occur.

The recommended criteria are:

- SCRTD personnel are to receive training to handle system emergencies.
- SCRTD personnel are to receive training in natural disasters.
- SCRTD personnel are to participate in simulated emergencies and disasters.
- SCRTD are to be rescheduled for refresher courses periodically.

RTD 37-11
REV 3/82

DEPARTMENTAL

Tom T Rummel
85-04132

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

DO NOT INCLUDE MORE THAN ONE SUBJECT IN THIS COMMUNICATION

DATE: May 24, 1985

TO: Distribution

FROM: William J. Rhine William J Rhine

SUBJECT: METRO RAIL SYSTEM DESCRIPTION - REVISION 1

The attached revised Metro Rail System Description replaces the system description distributed via my memorandum of April 17, 1985. This Revision 1 version now becomes the standard to be used when a general system description is required. Users may reduce the description as deemed appropriate to the specific application, but substitutions and revisions are not condoned.

Attachment

Distribution:

A. Dale - MRTC
L. Elliott - Booz-Allen
K. Rummel - MRTC

cc:

M. Becher
D. Gary
E. Pollan
J. Sandberg
R. Wood

SYSTEM DESCRIPTION - REVISION 1 (5-23-85)

The Metro Rail System is an 18-mile rail rapid transit line planned by the Southern California Rapid Transit District (SCRTD) from downtown Los Angeles via the Wilshire District, Fairfax, and Hollywood and to the San Fernando Valley. This line is planned to be the core element of a regional rail rapid transit system. In addition to the planned 18-mile line, two future extensions of the Metro Rail System have been identified as part of the regional rail rapid transit system. While the entire mainline portion of the 18-mile line is planned as subway, the future extensions may involve surface or aerial segments as determined by design development.

The first four miles of the line have been identified as the initial operating segment because there are currently insufficient federal funds to construct either the 18-mile Metro Rail System or the 8.8-mile minimum operable segment identified in the Federal Environment Impact Statement. This initial segment, identified as MOS-1, consists of double-track mainline subway from Union Station to Wilshire/Alvarado Station with additional subway and surface track connecting to the yard southeast of Union Station. It includes all yard and shop facilities planned for the 18-mile system with the exception of part of the yard storage tracks, which will be installed as warranted by system extension and fleet expansion.

The MOS-1 line has five stations. The mainline route begins at Union Station, northeast of the Los Angeles Civic Center, and runs through the central business district, terminating on the west side at the Wilshire/Alvarado Station. The rail line is entirely in subway with line segments constructed by tunnel boring machines and stations and crossovers excavated by cut and cover construction techniques. Three double crossovers are included in the subway portion of MOS-1, one at each side of Union Station and one at the east end of the Wilshire/Alvarado Station.

The vehicles for the system will be stainless steel, standard gauge, 75 foot long rail cars, which will be configured in dependent pairs. They will be capable of operating at speeds up to 70 miles per hour and will operate on 750 VDC power supplied via third rail. Metro Rail trains may consist of two, four, or six vehicles. The capacity of each single vehicle will be 59 seated passengers plus space for one wheelchair, up to 110 standing passengers at normal loads, and over 200 standing passengers at crush loads. The vehicle fleet for MOS-1 will consist of 30 vehicles.

MOS-1 trains will have Automatic Train Protection equipment to ensure safe speed and separation of trains. Automatic Train Operation (ATO) also will be included to regulate train speed and provide precision station stopping and train berthing verification for trains operating on the mainline in the ATO mode. System operation will be centrally controlled from the Rail Control Center, located in the Yard, using communication links with facilities and trains involving telephones, radios, CCTV and data transmission.

The five initial stations will be primarily of a double-ended design with two mezzanines, but one station, Wilshire/Alvarado, will be of the single-mezzanine design characteristic of the majority of the stations on the 18-mile line. Each mezzanine free area will have ticket vending machines and change machines and will be separated from the paid area by one or two arrays of entry/exit faregate barriers. The fare structure for MOS-1 will be based on a single zone, but fare collection equipment will have multi-zone capability to accommodate system extension. Escalators, stairs, and elevators will provide normal vertical circulation between surface, mezzanine, and platform levels. Stations will be equipped for both attended and unattended operation. Some stations will have adjacent parking facilities, pick-up/drop off areas and/or bus pull-in areas to accommodate patrons arriving by automobile or by bus.

Ridership on MOS-1 is projected to be approximately 54,000 per day. Service for MOS-1 is planned to consist of 4-car trains operating at headways of 5 minutes during peak hours, increasing to 20 minutes during evenings and weekends. However, 6-car trains operating at 2 1/2 minute headways will be required to serve projected demand for the 18-mile line.

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Rhine

M E M O R A N D U M

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT
SYSTEMS DESIGN AND DEVELOPMENT DEPARTMENT
SYSTEMS ENGINEERING AND ANALYSIS

****

DATE: April 17, 1985

TO: Distribution

FROM: William J. Rhine *William J. Rhine*

SUBJECT: METRO RAIL SYSTEM DESCRIPTION

****

The attached Metro Rail System Description has been developed as the standard to be used when a general system description is required as in the introduction to Metro Rail Project reports or systems specifications. Users may reduce the description by deletion of paragraphs or sentences that are deemed not needed for the specific application in question. However, in the interest of accuracy and consistency between documents, substitutions and editorial revisions will not be condoned. In other words, do not even think about making it "better".

Attachment

Distribution:

A. Dale - MRTC
L. Elliott - Booz-Allen
K. Rummel - MRTC

cc: M. Becher
D. Gary
E. Pollan
J. Sandberg
R. Wood

To: B. Chaliff
J: R... 85-06098

RTD

John A. Dyer
General Manager

RECEIVED
SEP 17 1985
D.C.C.

SEP 12 1985

TO: Board of Directors

FROM: John A. Dyer

SUBJECT: Policy Statement on the Safety of the Metro Rail Project

INTRODUCTION

Recently there has been considerable discussion regarding the potential hazard of constructing and operating the Metro Rail Project in areas known to have concentrations of methane gas. This report will discuss the relevant issues and provide the basis for the District's position regarding the safety of the Metro Rail Project.

RECOMMENDATION

It is recommended that the Board adopt the following Policy Statement regarding Metro Rail safety:

> It is the Policy of this Board that the construction and operation of the Metro Rail Project be conducted in a safe and secure environment. Therefore, all appropriate measures required to ensure the safe construction and operation of the Project will be incorporated into the project design and into the construction and operations procedures.

BACKGROUND

The existence of natural methane gas in the Los Angeles area has been well known and documented throughout the Metro Rail design process. An extensive geotechnical investigation of the route was conducted and documented in a "Geotechnical Investigative Report" dated November 1981. Additional information was obtained and documented in the "Report of Subsurface Gas Investigation" prepared by Engineering-Science.

Based upon this extensive technical data, specific safety design measures were incorporated into the Project. The following measures ensure that a potentially dangerous gas build-up will not occur in the tunnels or stations during revenue operations:

o Natural ventilation, ventilation created by train movements and under platform exhaust systems that will operate continuously during revenue service.

f. Ventilation systems shall exhaust gas or vapors, shall have explosion relief mechanisms, and shall be fireproof.

g. Refuse chambers or alternate escape routes shall be provided and equipped with equipment acceptable to the Division. Workers shall be provided with emergency rescue equipment and trained in its use.

h. The main ventilation flow shall be reversible.

i. Fresh air shall be delivered in adequate quantities to all underground work areas. The supply shall be adequate to prevent hazardous or harmful accumulations of dust, fumes, vapors or gasses, and shall not be less than 200 cubic feet per man per minute or a velocity of 60 feet per minute.

Attached is my letter dated September 9, 1985 to Congressman Julian C. Dixon, which presents 20 issues related to the safety of the Metro Rail Project. This information was provided to assist Congressman Dixon to clarify any misunderstandings related to the Project.

CONCLUSION

I believe that the provisions outlined herein, and the extensive review of the project safety provisions by technical experts, have appropriately and prudently addressed all the safety issues associated with the design, construction and operation of the Metro Rail Project in areas known to contain methane gas.

Respectfully,

John A. Dyer

By: Robert J. Murray
Assistant General Manager
Transit Systems Development

Attachment

KNM

METRO RAIL TRANSIT CONSULTANTS
DMJM/PBQD/KE/HWA

Howard J. Chaliff

September 18, 1985

The attached Policy Statement on the Safety of the Metro Rail Project was sent to me by Bob Murray. I have attached a copy for your information.

CIRCULATE

M. Kenney
G. Cafer
W. Armento
D. Logan
W. Wheeler
F. Fortunato
E. Berge
A. Smithson
R. Keenan
G. Takei
K.N.M

HJC:ss

Attachment

To: B. Chaliff
Fr: RJG 85-06038

RTD

John A. Dyer
General Manager

RECEIVED
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D. C. C.

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Based upon this extensive technical data, specific safety design measures were incorporated into the Project. The following measures ensure that a potentially dangerous gas build-up will not occur in the tunnels or stations during revenue operations:

- o Natural ventilation, ventilation created by train movements and under platform exhaust systems that will operate continuously during revenue service.

- o An emergency ventilation system of fans and controls that can bring in fresh air and exhaust gases when required.

- o A gas sensor system will detect the presence of gas. If the gas build-up approaches a predetermined concentration level the emergency ventilation system will be activated.

- o Steel tunnel liners will be installed to prevent gas infiltration in areas identified as having the potential for high gas concentrations and pressure.

- o Gas barrier membranes will be installed in all concrete tunnel sections and in the stations.

Construction safety of the Metro Rail Project must comply with the regulations of the State of California, Division of Occupational Safety and Health. The applicable controlling provisions of the California Administration Code, Title 8: "Industrial Relations", Chapter 4: "Division of Industrial Safety", Subchapter 20: "Tunnel Safety Orders" are the most stringent tunnel safety orders in the country.

Based upon information supplied by the District, Cal/OSHA has classified the Project as "Gassy" for tunnel construction purposes. That classification and additional requirements in the contract specifications require that the contractors follow the California Tunnel Safety Orders in all matters relating to underground construction, but especially in selecting equipment, in testing for gas, in providing ventilation, and in providing personnel safety. Cal/OSHA will be overseeing the construction safety to ensure compliance with the Cal/OSHA Safety Orders.

Because of the gassy classification, contractors will be required to meet the following minimum requirements:

a. Comply with Title 8, Part 3 (Electrical Regulations) and other special orders as may be issued by the Division of Industrial Safety (the Division).

b. Smoking and other sources of ignition will be prohibited.

c. Welding, cutting and other spark-producing operations shall only be done in atmospheres containing less than 20 percent LEL (lower explosive limit) and under the direct supervision of qualified persons.

d. Automatic and manual gas monitoring equipment shall be provided for the heading and return air of tunnels using mechanical excavators. The monitor shall shut down the equipment under specific defined conditions.

e. Records of gas tests and air flow measurements shall be available at the surface and to the Division.

f. Ventilation systems shall exhaust gas or vapors, shall have explosion relief mechanisms, and shall be fireproof.

g. Refuse chambers or alternate escape routes shall be provided and equipped with equipment acceptable to the Division. Workers shall be provided with emergency rescue equipment and trained in its use.

h. The main ventilation flow shall be reversible.

i. Fresh air shall be delivered in adequate quantities to all underground work areas. The supply shall be adequate to prevent hazardous or harmful accumulations of dust, fumes, vapors or gasses, and shall not be less than 200 cubic feet per man per minute or a velocity of 60 feet per minute.

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Respectfully,

John A. Dyer

By: Robert J. Murray
Assistant General Manager
Transit Systems Development

Attachment

RTD

John A. Dyer
General Manager

SEP 9 1985

The Honorable Julian C. Dixon
2400 Rayburn House Office Building
Member of Congress
Washington, D. C. 20515

Subject: Suggested Floor Statement Materials
Regarding Transit/SCRTD Appropriations Legislation
Before the United States Congress
House of Representatives

Dear Mr. Chairman:

As the appropriations bill for transportation -- legislation that includes funding for the Los Angeles Metro Rail project -- reaches the floor of the House of Representatives, a great deal of deliberate confusion is being created by Metro Rail opponents and some misunderstanding regarding the project exists. The sixteen issues presented below are designed to provide the basis for overcoming the confusion and clarifying any misunderstandings. Summary materials are attached regarding each of the twenty (20) issues as follows:

Issue 1: The Engineering Science report of January 1984 concludes that Metro Rail can be constructed and operated in a safe manner, throughout the entire extent of the Metro Rail alignment.

Issue 2: Examples abound in Los Angeles and elsewhere of safe, successful tunnel construction in hazardous gaseous environments.

Issue 3: C. Kenneth Orski naively uncouples viable urban growth and development of the Los Angeles region from the success of Metro Rail -- the backbone of the region's transit infrastructure.

Issue 4: The Los Angeles community has passed, with great effort, numerous significant milestones towards Metro Rail implementation -- planning, design, environmental, and financing milestones.

Issue 5: Statements of Dr. Ronald J. Lofy have been taken out of context, suggesting the opposite of his publicly stated conclusion that "...engineers can design to protect from (methane) hazards."

Issue 6: Testimony by witness Brown and others before Congressman Waxman's Subcommittee on Health and the Environment -- testimony having no direct bearing on Metro Rail methane issues -- has been improperly utilized to generate erroneous and confused conclusions regarding Metro Rail safety.

Issue 7: Bobbi Fiedler has viciously misrepresented Metro Rail on matters pertaining to:

a. Voter support
b. Diversion of bus fare subsidy funds
c. Construction costs
d. Ridership/patronage forecast levels
e. Methane gas hazards; and
f. Cost efficiency;

Issue 8: Notwithstanding the conclusions of experts that Metro Rail can be safely built and operated through known methane gas deposits, the House Appropriations Bill approved on September 5 mandates the study of alternative Metro Rail alignments to avoid tunneling through risk zones.

Issue 9: Lessons learned from the Ross methane incident serve to confirm Metro Rail tunneling design conclusions and to illustrate that drilling in a gaseous environment can be undertaken in a safe manner under precautions far less stringent than those upon which the Metro Rail design is based.

Issue 10: Additional comment on the Waxman Subcommittee testimony of Dr. Ronald J. Lofy.

Issue 11: Summary comment on the Metro Rail Environmental Impact Statement.

Issue 12: Summary comment on the Environment Assessment of Metro Rail construction from Union Station to Wilshire/Alvarado.

Issue 13: Engineering and regulatory experts (e.g., Principal Engineer Byron Iskanian of California Mining and Tunneling; Battalion Chief Donald Bartlett of the Los Angeles Fire Department; and Chairman of the Board T. R. Kuesel of PBQD, Inc.) reaffirm that Metro Rail can be constructed and operated safely through the methane environment which it will encounter, citing ample successful precedent, stringent Cal OSHA regulations, as well as Metro Rail's state-of-the-art design.

Issue 14: Currently planned Metro Rail construction in the Wilshire/Fairfax area would occur under design conditions far different from those encountered in MOS-1 construction -- construction of the initial downtown Metro Rail increment.

Issue 15: Tunneling in methane environments is successfully undertaken every day in current United States mining practice; Metro Rail design provides adequate safeguards regarding the methane hazard.

Issue 16: The state-of-the-art design of Metro Rail provides an exhaustive set of precautions to ensure safety during both the construction and operation phases.

Issue 17: The Los Angeles City Council Task Force, which investigated the Ross incident, produced a report showing the location of oil seepage areas and old oil fields (Plate 1); the initial Metro Rail segment (MOS-1) does not affect these areas.

Issue 18: The California Transportation Commission, which provides a large percentage of the funding for Metro Rail, has established a deadline of June, 1986 for start of Metro Rail construction.

Issue 19: The SCRTD has clearly committed to abandon plans for Metro Rail tunneling in either the "high potential risk zone" or the "potential risk zone" as identified by the Los Angeles City Task Force.

Issue 20: An SCRTD appointed Board of Review of nationally recognized authorities on the subject of tunnel construction in gaseous areas has initiated its review of the Metro Rail project. The background report being utilized by the Board of Review is enclosed.

Should additional information regarding this matter be required, please contact me.

Sincerely,

John A. Dyer

Attachments
Enclosure

ISSUE NO. 1:

THE ENGINEERING SCIENCE REPORT OF JANUARY 1984 CONCLUDES THAT METRO RAIL CAN BE CONSTRUCTED AND OPERATED IN A SAFE MANNER, THROUGHOUT THE ENTIRE EXTENT OF THE METRO RAIL ALIGNMENT.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

ENGINEERING-SCIENCE

125 WEST HUNTINGTON DRIVE • P. O. BOX 538 • ARCADIA, CALIFORNIA 91006 • 818/445-7560

CABLE ADDRESS ENGINSC
TELEX 67-5428

6 September 1985
ES File 56151.00

Honorable Julian C. Dixon
Member of Congress
Washington, D.C. 20515

Subject: Metro Rail Project - Methane Gas Presence
Congressman Waxman Letter to John Dyer dated
26 August 1985

Dear Congressman Dixon:

Engineering-Science is concerned over Congressman Waxman's conclusions expressed in the above referenced letter. His conclusions are based, in part, on our report dated January 1984, entitled "Report of Subsurface Gas Investigation" in which we documented the presence of subsurface methane gas in sections of the proposed alignment of Metro Rail. We believe this report has been misinterpreted.

Congressman Waxman's concern over the safety of construction personnel and his constituency during construction and operation of Metro Rail is understandable. It was RTD's similar concern that was the basis of the methane gas investigation conducted by Engineering-Science. Engineering-Science's findings are the basis for designing and constructing measures into the system for protection against the hazards identified. In our opinion the conditions identified do not preclude construction in zones where gas is present.

There would be no major construction in Los Angeles if building codes prohibited construction in Zone 3 seismic areas because of the earthquake hazards in Southern California. Facilities are designed with protection against such seismic hazards. Likewise, facilities located in areas of methane gas can be designed and constructed with protection against such methane hazards. The Metro Rail can be constructed and operated in a safe manner through the areas identified in our report.

Very truly yours,

Dennis R. Kasper

Dennis R. Kasper
Vice President

DRK/pg

<u>ISSUE NO. 2</u>:

EXAMPLES ABOUNO IN LOS ANGELES ANO ELSEWHERE OF SAFE, SUCCESSFUL TUNNEL CONSTRUCTION IN HAZARDOUS GASEOUS ENVIRONMENTS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. OIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

PREVIOUS TUNNELING EXPERIENCE

IN HAZARDOUS GASEOUS ENVIRONMENTS

A. Los Angeles Area

More than 60 tunnels, with a total accumulated length of over 50 miles, have been bored within the Los Angeles City limits. The history of local tunneling experience was reviewed in the Metro Rail Geotechnical Investigative Report, prepared by Converse, Ward, Davis, Dixon in November, 1981. Particular attention was given to tunnels excavated by tunnel boring machines (TBM) which had similar geologic formations or subsurface conditions as those expected to be encountered along the Metro Rail alignment and where gas and/or oil conditions were encountered. These tunnels included:

- o Metropolitan Water District of Southern California (MWD) San Fernando Tunnel
- o MWD Newhall Tunnel
- o Los Angeles County Floor Control District (LACFCD) Sacatella Tunnel
- o MWD Tonner Tunnel

Geologic conditions, overall excavation progress and construction methods were summarized in the report for each case history. Similar geologic and excavation conditions were noted and compared to conditions expected to be encountered along the proposed alignment. These case histories indicate rapid and economical progress can be made by tunnel boring machines (TBM) on the Metro Rail alignment. For example, excavation experience in Old Alluvium at the San Fernando Tunnel resulted in record advances using a TBM with a digging spade. A total of 3,500 feet of tunnel was excavated in one month, and 277 feet during one three-shift day. When ground water was encountered, advance rates reduced to about 60 feet per three-shift day.

B. Rochester, New York

The experiences with methane gas design and construction on a sewer tunnel in gassy rock in Rochester, New York, are described in a paper written by John W. Critchfield and others. This paper was presented to the Rapid Excavation and Tunneling Conference held in New York City on June 16-20, 1985. Mr. Critchfield is Chairman of the Underground Technology Research Council, Technical Committee on Gassy Tunnels, and a member of the SCRTD Board of Review on Construction and Operation in Gaseous Areas. Mr. Critchfield has expressed confidence that with proper design and construction procedures, tunneling in the Los Angeles Area can be accomplished safely and economically.

ISSUE NO. 3:

C. KENNETH ORSKI NAIVELY UNCOUPLES VIABLE URBAN GROWTH AND DEVELOPMENT OF THE LOS ANGELES REGION FROM THE SUCCESS OF METRO RAIL -- THE BACKBONE OF THE REGION'S TRANSIT INFRASTRUCTURE.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNOING)
UNITED STATES HOUSE OF REPRESENTATIVES

The Future of Metro Rail is L.A. Area's Future

A September 5, 1985 Los Angeles Times article by C. Kenneth Orski contains many incredible assertions that do not withstand close examination. Mr. Orski suggests that Los Angeles Area can manage quite well without Metro Rail, and the loss of federal Metro Rail funds would matter very little.

Mr. Orski completely fails to recognize that Metro Rail is the backbone of an extensive 150 mile rail system approved by the voters in Los Angeles County on November 4, 1980. This system is designed to provide improved mobility to a large proportion of the Los Angeles population, and the argument that Metro Rail "...would benefit only a tiny fraction of the millions of people..." is clearly ludicrous. No single transportation project -- a freeway, a rail facility, a major realignment of an arterial, or traffic management measures -- is designed to stand alone. Improvement to the regional transportation system consists of a number of such projects, including more than ten proposed rail projects. Metro Rail is the beginning for these rail projects, the beginning of a 150 mile system that serves highly congested corridors in the region.

Mr. Orski argues that life will go on with congestion levels maintained at the level of "tolerability," but his reference to how other non-rail cities have fared is simple nonsense. The non-rail cities referred to by Mr. Orski are all a tenth or less the size of Los Angeles. Mr. Orski is oblivious to the fact that no other city in the Western World the size of Los Angeles is without a rail system. Nor do any of those cities exhibit the growth curve shown by Los Angeles, with an additional two million people (and their autos) anticipated by the year 2000. Simply put, Los Angeles will not be as desirable a place to live in the future without Metro Rail and the complementary 150 mile rail system.

Mr. Orski suggests that the Pasadena Freeway has, and that the Metro Rail will have, a significant effect on travel patterns and urban form. We agree. The evidence clearly shows that major transportation arteries such as freeways and rail transit systems influence the structure and development of an urban area. The additional transportation capacity offered by these transportation improvements is a major determinant for the location of urban development. If transportation systems such as the Metro Rail and complementary rail system are not built, the metropolitan area will become more dispersed, less centralized, ..d people will spend more time on congested streets and freeways in their cars traveling between home and a remote work place. Transportation improvements such as Metro Rail, coupled with sound urban development policies, will clearly enhance the area's quality of life.

Metro Rail provides a critical opportunity to increase the area's transportation capacity beyond that provided by the Los Angeles freeway system. The capacity of the proposed rapid transit system for Los Angeles is well in excess of 40,000 persons per hour each direction, while the space used is somewhat less than that needed for two freeway lanes. Yet, the maximum capacity of a freeway lane is about 2,000 vehicles per hour. Given the current average number of people in a car in Los Angeles, one freeway lane can carry only about 2,300 persons per hour. This is a mere five to ten percent of the capacity of the rail line which occupies less space! The Metro Rail project clearly offers major increases in transportation capacity, without consuming still more of the region's space needed for housing, workplaces, and related services.

In short, Mr. Orski's article is a thinly-veiled, apologetic argument for doing nothing. Traffic metering, freeway information systems, bus lanes and other similar projects all have a role to play in improving traffic, and they are all in use today in Los Angeles. They are nothing new. What are the alternatives to Metro Rail? Maybe more one-way streets, maybe more traffic signals, maybe replacing parking on major thoroughfares like Wilshire Boulevard with bus lanes, maybe running more buses, maybe allowing the region to spread more rapidly into agricultural and wilderness areas requiring each of us to spend more time traveling between places in the region. But are these alternatives cost-effective in the long run, and will they have a positive influence on the quality of life in Los Angeles? The answer is absolutely not. Together, these techniques cannot handle the scale of growth that is before us as an urban area. And community interests have recognized the need for leadership to substantially improve the area's transportation system. Metro Rail will clearly enhance the quality of life in Los Angeles, and will provide us with the opportunity to shape the region as we desire for years to come.

ISSUE NO. 4:

THE LOS ANGELES COMMUNITY HAS PASSED, WITH GREAT EFFORT, NUMEROUS SIGNIFICANT MILESTONES TOWARDS METRO RAIL IMPLEMENTATION -- PLANNING, DESIGN, ENVIRONMENTAL, AND FINANCING MILESTONES.

CHRONOLOGICAL LIST OF SIGNIFICANT EVENTS IN THE DEVELOPMENT OF THE METRO RAIL PROJECT

1)	Dec. 1971	California Senate Bill 325 signed -- provides transit subsidies.
2)	June 1974	Proposition 5 passes in State and LA County -- provides part of gas taxes for rail rapid transit.
3)	Mar. 1975	Rapid Transit Advisory Committee (RTAC) is created by RTD Board. Composed of RTD, local cities, County of LA, State and Federal government representatives.
4)	Dec. 1976	DOT funds $11 million for development of RTDP -- $2.5 million for the study of heavy rail.
5)	May 1977	Alternative Analyses/Environmental Impact Statement/Environmental Impact Report (AA/EIS/EIR) begun for heavy rail.
6)	Aug. 1977	Community Participation Program begins for AA/EIS/EIR.
7)	Oct. 1978	RTD Board adopts "Preferred Alternative" from AA/EIS/EIR (18.6 mile line, CBD to Valley)
8)	Feb. 1979	Public Hearings held for AA/EIS/EIR.
9)	Apr. 1980	Publication of Final AA/EIS/EIR.
10)	June 1980	$15.6 million approved for Preliminary Engineering (P.E.).
11)	Nov. 1980	Proposition "A" approved by Voters (54% majority) -- 1/2 cent sales tax for 150 mile rail system.
12)	Mar. 1982	Community Participation for 2nd Tier EIS/EIR begun. Milestone 1 (Preliminary System Definition and Operating Plan) and Milestone 2 (System Design Criteria) were published and community meetings held.
13)	May 1982	Public Hearings for Milestones 1 and 2 held. Milestone 3 (Route Alignment Alternatives) and Milestone 4 (Station Location Alternatives) were published and community meetings held.
14)	May 1982	$12.1 million approved for Phase III of P.E.
15)	July 1982	Milestone 5 (Right-of-way Acquisition and Relocation Policies and Procedures) was published and community meetings held.
16)	July 1982	$11.2 million approved for Phase III of P.E.
17)	July 1982	Public Hearings for Milestones 3 and 4 held.

18) Aug. 1982 — RTD Board adopts Milestones 1 and 2. RTD Board adopts Milestones 3 and 4. Public hearing on Milestone 5 held.

19) Sept. 1982 — RTD Board adopts Milestone 5. Milestone 6 (Land Use and Development Policies) was published and community meetings held.

20) Sept. 1982 — $18.7 million in continued funding for P.E. approved.

21) Nov. 1982 — Public hearing on Milestone 6 held. Milestone 7 (Safety, Fire/Life Safety, Security and Systems Assurance Policies) and Milestone 8 (System and Subsystems) were published and community meetings held.

22) Dec. 1982 — Public hearings on Milestone 7 and Special Alternatives Analysis held. RTD Board adopted route and station location recommendations from Special Alternatives Analysis.

23) Jan. 1983 — Public hearing on Milestone 8.

24) Mar. 1983 — RTD Board adopts Milestones 6 and 7. Milestone 9 (Supporting Services Plan) and Milestone 10 (Fixed Facilities) were published and community meetings held. Public hearing held on Milestone 9.

25) Apr. 1983 — Congress passes the Highway User Fee increase (5 cents additional charge on Federal gasoline tax) for construction of transit.

26) Apr. 1983 — $33.3 million funding approved for Phase II of P.E.

27) Apr. 1983 — RTD Board adopts Milestone 9. Milestone 11 (Cost Estimate) was published and community meetings held.

28) May 1983 — Public hearings on Milestone 9 and 10 held. Milestone 12 (Final System Definition) was published and community meetings held.

29) June 1983 — Public hearings on Milestones 11 and 12 held.

30) July 1983 — Public hearings held on Draft EIS/EIR.

31) Aug. 1983 — RTD Board adopts Milestones 9 and 10.

32) Aug. 1983 — President Reagan signs DOT appropriations bill containing a $117.2 million to start Metro Rail construction.

33) Aug. 1983 — Governor George Deukmejian signs into law Senate Bill 1159 authorizing SCRTD to engage in Joint Development ventures.

34) Sept. 1983 — $32.6 million approved by the State of California for acquisition of Santa Fe Rail Yard and $14.8 million approved for advanced land acquisition.

35) Sept. 1983 RTD Board adopts Milestones 11 and 12.

36) Oct. 1983 State passes Senate Bill 1238 allowing for creation of Benefit Assessment Districts.

37) Oct. 1983 RTD Board approves first Joint Development agreement between SCRTD and Park LaBrea Associates. This could provide a $30 million saving in construction cost for the Wilshire/Fairfax station.

38) Nov. 1983 Public hearing on $2.1 billion grant application for final design and construction held. RTD Board adopts EIS/EIR.

39) Dec. 1983 Final EIS/EIR published.

40) May 1984 $105 million federal grant approved for final design and "Pre-Construction" activities.

41) July 1984 UMTA reviews Preliminary Draft EA.

42) Aug. 1984 Public hearing on Draft EA held.

43) Sept. 1984 Final EA (Reprint) distributed.

44) Nov. 1984 UMTA issues Finding of No Significant Impact (FONSI) for MOS-1 EA.

45) Dec. 1984 Benefit Assessment Task Force(formed by RTD) provides recommendations to RTD Board. RTD Board Resolution of Intent to Establish Benefit Assessment Districts for first two districts (for MOS-1 segment) passed.

46) Jan. 1985 RTD Board hearing on Benefit Assessment Districts held.

47) Feb. 1985 RTD Board passes Resolution to Proceed with Establishment of Benefit Assessment Districts to provide $130 million in private sector contributions to the capital costs of MOS-1.

48) May 1985 Los Angeles City Council public hearing held. Council amends and approves Benefit Assessment District Resolution to provide $130 million in capital for construction of Metro Rail.

49) July 1985 RTD Board Resolution to Create Benefit Assessment Districts passed.

ISSUE NO. 5:

STATEMENTS OF DR. RONALD J. LOFY HAVE BEEN TAKEN OUT OF CONTEXT, SUGGESTING THE OPPOSITE OF HIS PUBLICLY STATED CONCLUSION THAT "...ENGINEERS CAN DESIGN TO PROTECT FROM (METHANE) HAZARDS.

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September 11, 1985

Honorable Henry A. Waxman, Chairman
Subcommittee on Health and Environment
of the Committee on Energy and Commerce
United States House of Representatives
2415 Rayburn House Office Building
Washington, D.C. 20515

Dear Congressman Waxman:

June 14, 1985 Methane Gas Testimony

I was pleased to have been invited to participate in the June 14, 1985 hearings on the Third and Fairfax fire and explosion, which was held here in Los Angeles. California. I have since had an opportunity to read over and edit my testimony, included herein, which I presented before you that day. I also refer you to my pre-prepared testimony which was submitted prior to the actual hearing.

I have followed the tangentially-related issue of the routing and protection design of the Metro Rail with considerable interest. My testimony before your Subcommittee dealt with the hazard to structures posed by naturally occurring methane in the West Los Angeles area. The proposed route of the Metro Rail passes through this area affected by methane and I am aware that my testimony may therefore have some effect on planning for the Metro Rail project. For this reason, I wish to take this opportunity to clarify my professional opinions on this matter.

I have reread my preprepared text and have come across my final concluding paragraph and feel that it may be a cause for misinterpretation. What the statement intended to say is that: "I do not 'personally' know if any of the present day conventional tunnelling equipment and safety procedures would be able to cope with the unexpected chance breakthrough of a large, greater than 5,000,000 cubic foot capacity, natural gas pocket under 8 psi pressure of the type that exists along the Wilshire Corridor". The word that was omitted was "personally" know. As I emphasized during my testimony, I am not a tunnelling expert, nor am I conversant with all of the various Federal and State tunnelling requirements.

What I have attempted to do is to alert those in responsible positions of authority about the methane gas danger, but at the same time, I have always been of the opinion that once responsible authorities and engineers are aware of the problem, that the problems can be resolved through application of valid physical and engineering principles. I feel that a fast, efficient, rapid transit system is desperately needed in Los Angeles and that the problems that are being presented can be satisfactorily resolved through responsible action after dealing with the facts.

Once again, I thoroughly enjoyed the experience in testifying before your Subcommittee and of having had the opportunity to meet you and your colleagues. If I can be of any further assistance, please do not hesitate to contact me at your convenience.

Very truly yours,

Ronald J. Lofy, Ph.D., P.E.
Vice President

RJL:hm

Enc.

ISSUE NO. 6:

TESTIMONY BY WITNESS BROWN AND OTHERS BEFORE CONGRESSMAN WAXMAN'S SUBCOMMITTEE ON HEALTH AND THE ENVIRONMENT -- TESTIMONY HAVING NO DIRECT BEARING ON METRO RAIL METHANE ISSUES -- HAS BEEN IMPROPERLY UTILIZED TO GENERATE ERRONEOUS AND CONFUSED CONCLUSIONS REGARDING METRO RAIL SAFETY.

WRITEN TESTIMONY SUPPLIED BY MR. BROWN AT FAIRFAX HEARING

NOT DIRECTLY RELEVANT TO METRO RAIL

THE WRITTEN TESTIMONY SUPPLIED BY MR. BROWN AT CONGRESSMAN WAXMAN'S HEARING WAS DIRECTED AT THE NEED FOR A LOW-COST GAS SENSOR FOR USE BY RESIDENCES AND, THEREFORE, DID NOT HAVE A DIRECT BEARING ON THE METRO RAIL METHANE-RELATED ISSUES.

ISSUE NO. 7A:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED METRO RAIL ON MATTERS PERTAINING TO VOTER SUPPORT.

THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 1: Voter rejection of an assessment on residential properties represents a no vote on Metro Rail.

Fact 1: The Los Angeles City Charter amendment to which this comment refers merely exempts residential property from an assessment program that the SCRTD has initiated to help fund the subway system. The amendment was virtually unopposed. The business community continues to support assessment of commercial property located in the vicinity of Metro Rail stations. Prior to the election, the SCRTD Board of Directors adopted an assessment program that specifically exempted residential property. While the voter-approved charter amendment disallows assessment of existing residential properties, it technically allows assessment of newly-built residential properties; but the SCRTD Board has formally excluded the assessment of all residential properties.

Metro Rail enjoys broad support from area citizens, elected officials, business and labor leaders and the media. In 1980, Los Angeles County citizens voted an increase in local taxes to build a rail system, the backbone of which is Metro Rail. A recent poll by the Los Angeles Times reported better than 2-to-1 support for construction of a mass transit system. An August, 1984 survey of San Fernando Valley residents indicated strong support for the project, and thousands of signatures on petitions in support of Metro Rail have been collected.

The willingness of the local business community to provide $170 million in private sector funds (collected via commercial property assessment) clearly demonstrates the level of local support and the recognition that Metro Rail will enhance the local business climate. The Executive Secretary of the Los Angeles County Federation of Labor, AFL-CIO has noted in public testimony that Metro Rail will enhance employee mobility and is supported by labor leaders. Moreover, Metro Rail will generate employment during construction and operation (some 3,000 jobs) and foster commercial activity near the system. A majority of the local media have also consistently maintained editorial support for the system.

ISSUE NO. 7B:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED METRO RAIL ON MATTERS PERTAINING TO DIVERSION OF BUS FARE SUBSIDY FUNDS.

THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
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UNITED STATES HOUSE OF REPRESENTATIVES

RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 2: Starting last July, thirty five cents of every ride is being diverted into the subway, imposing a hardship on the handicapped, students and elderly.

Fact 2: First, Metro Rail will provide improved accessibility and efficient transit service to a handicapped, student and elderly population. Second, when the Los Angeles County voters approved a 1/2 cent sales tax increase for transit in 1980, the proposition designated two phases for the distribution of funds.

Phase 1, which ended on July 1, 1985, mandated three uses for Propos[illegible]on A funds: (a) 25% for the 84 cities in the County, (b) whatever percen[illegible]e is needed to maintain a base bus fare of 50 cents, and (c) the remaining percentage for a Rail Transit Program. Phase 2 designates: (a) a continuation of 25% for the cities, (b) 35% (not 35 cents) for the Rail Program, and (c) the remaining 40% as discretionary.

The Rail Program funds are earmarked for rail projects only. When the voters approved Proposition A, they endorsed a network of 150 miles of transitways serving the entire region. Metro Rail is only one of several rail projects currently in the planning or design stages. Proposition A monies not spent on Metro Rail must, by law, be spent on other rail projects and could not be used for other purposes. The SCRTD is prepared to proceed with Phase 2 funds and build a cost-efficient Metro Rail system that, in concert with the bus and other rail systems, is designed to serve the elderly, handicapped and student populations of Los Angeles effectively.

ISSUE NO. 7C:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED

METRO RAIL ON MATTERS PERTAINING TO

CONSTRUCTION COSTS.

THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
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UNITED STATES HOUSE OF REPRESENTATIVES

RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 3: Since the first segment of the Metro Rail system will cost $250 million per mile to build, the full system will cost $4.7 billion.

Fact 3: The initial 4.4-mile segment includes costs that will not be experienced in future segments. These include: costs of an additional 1.1 miles of track for the main yard and shop; higher costs for each of the first segment downtown stations, which must have up to four entrances to service higher ridership levels; costs for a central control system and facility; higher construction and land acquisition costs in the central business district, and; the requirement to purchase nearly 50% of the total system vehicles in order to service the concentration of downtown passengers. It is incredibly naive, in view of these inevitably higher start-up costs for the system, to simply perform a linear extrapolation to determine the full system costs.

ISSUE NO. 7D:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED METRO RAIL ON MATTERS PERTAINING TO RIDERSHIP/PATRONAGE FORECAST LEVELS. THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
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(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 4: Los Angeles Times states that Metro Rail ridership will be a mere fraction of what SCRTD claims.

Fact 4: The July 2, 1984 Los Angeles Times article quotes one analyst, who suggests that ridership may be overstated by as much as 30%. Even under the assumption of a 30% reduction in ridership, it must be noted that seventy percent is not a "mere fraction." More importantly, the article states that, "even if Metro Rail ridership has been overstated by 30%, the line still would be considered cost-effective under criteria being used by the federal Urban Mass Transit Administration." It is significant that, as a result of this series of six articles (of which the July 2 article was one) which examined the pertinent issues concerning Metro Rail, the Los Angeles Times is on record as a clear and strong supporter of the project.

The SCRTD recognizes that ridership forecasting is not a precise science and some variation in actual ridership can be anticipated. However, the SCRTD has utilized standard forecasting techniques that are recognized by the UMTA and the transit industry as the best available means of forecasting ridership, a vital input to the proper planning of the project.

ISSUE NO. 7E:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED

METRO RAIL ON MATTERS PERTAINING TO

METHANE GAS HAZARDS.

THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
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RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 5: A methane explosion in the Metro Rail system is inevitable.

Fact 5: SCRTD engineers knew at the outset that the system would encounter some oil and gas-saturated sediments. For this reason, the SCRTD has worked closely with fire and safety officials, tunneling experts and its own consultants to incorporate safeguards in the design, construction and operation of Metro Rail, including steel lining for the tunnels, dense polyethylene sheets behind station walls, and backup gas detectors that will activate ventilation fans. (See additional materials contained herein.)

RESPONSES TO PRIOR FIEDLER COMMENTS

Fiction 6: The system is not cost-efficient on a per passenger basis.

Fact 6: This quote from the Final Environmental Impact Statement (FEIS) for Metro Rail is taken out of context, and the sentences immediately following are essential to judging the statement. The full quote is:

> "Under the predicted patronage levels (not reduced by 30 percent), none of the Project alternatives would be considered cost efficient on a per passenger basis. Similarly, under the reduced patronage levels, no alternative has marginal costs less than average costs. But, as noted earlier, this scenario assumes the worst case assumptions. This analysis represents only one perspective upon which to evaluate the project. If this worst case situation were to occur, system changes could be effected to reduce service and make them commensurate with the patronage levels." (Emphasis added)

The Urban Mass Transportation Administration (UMTA) issued its own version of cost-effectiveness calculations in the UMTA publication, "New Start Project Profiles," dated May 16, 1984. UMTA's calculations were based on UMTA's own procedures; and two cost-effectiveness indices were calculated by UMTA from the FEIS numbers: a Federal Cost-Effectiveness Index of $0.58 per new rider, and a Total Cost-Effectiveness Index of $1.46 per new rider. In the May 16 document, UMTA evaluates these indices in the following terms:

> "The LA Project, despite its high cost ... is cost-effective because of the additional ridership it attracts ... and the operating cost and travel time savings expected..."

UMTA ranked Metro Rail as the most cost-effective project in the nation out of all proposed new rail projects. UMTA Administrator Stanley has called Metro Rail one of the most cost-effective projects in the nation.

A basic flaw in the analysis of cost efficiency in the FEIS is the definition of the case against which to measure cost efficiency, i.e. the "No Project Alternative." The alternative used in the FEIS is a "do nothing" alternative that does not expand transit capacity to accommodate projected increases in travel demand due to population and employment growth through the year 2000. This is not a realistic alternative, because the existing street-dependent bus system is operating on a street system that is strained to capacity in the Metro Rail corridor. Unless a more realistic No Project Alternative is used that expands capacity to accommodate projected increases in demand, costs of not serving that demand on transit should be included in any cost-effectiveness calculations, or additional benefits should be ascribed to the Metro Rail project given that it allows the regional transit system to carry more riders than the No Project Alternative.

The SCRTD has operated by the rules in its efforts to obtain federal funds. Recognizing federal budget constraints, the 18.6-mile system has been segmented to allow for an orderly phasing of funds. Moreover, an unprecedented 52% of the cost for the first segment will be paid by sources other than UMTA Section 3 New Start funds.

ISSUE NO. 7F:

BOBBI FIEDLER HAS VICIOUSLY MISREPRESENTED

METRO RAIL ON MATTERS PERTAINING TO

COST EFFICIENCY.

THE TRUTH REGARDING THIS MATTER FOLLOWS.

HR 3244 FLOOR STATEMENT MATERIALS FOR
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ISSUE NO. 8:

NOTHWITHSTANDING THE CONCLUSIONS OF EXPERTS THAT METRO RAIL CAN BE SAFELY BUILT AND OPERATED THROUGH KNOWN METHANE GAS DEPOSITS, THE HOUSE APPROPRIATIONS BILL APPROVED ON SEPTEMBER 5 MANDATES THE STUDY OF ALTERNATIVE METRO RAIL ALIGNMENTS TO AVOID TUNNELING THROUGH RISK ZONES.

DRAFT LOS ANGELES TIMES OP-ED PIECE RE: METRO RAIL SAFETY

September 6, 1985

It is ironic that 11th hour concerns over environmental and safety issues threaten to undermine chances for Metro Rail funding, because no aspect of the subway project has been more thoroughly scrutinized.

A host of local, state, and federal laws mandated that a detailed study and review be undertaken over a period of the past five years. Among Metro Rail's Congressional critics are members who supported such legislation aimed at protecting the public from potential risks associated with construction of projects in environmentally sensitive areas.

Buttressing the federal environmental laws are Cal OSHA's state regulations governing tunnel construction that are the most stringent in the U.S. Los Angeles city and county fire safety officials also have painstakingly reviewed the Metro Rail plans. In fact, fire officials from both departments serve on the Metro Rail Fire, Life, Safety committee along with other experts.

From the start of Metro Rail planning in the late '70's, it has been well documented that the subway would encounter potential hazards including oil and gas. But RTD engineers have worked closely with Los Angeles fire officials, Cal OSHA, the federal Environmental Protection Agency and other regulatory agencies from the very beginning to address all environmental and safety issues.

The most knowledgeable tunneling and geology experts in the world are employed as Metro Rail consultants, including Lindvall, Richter & Associates. Heeding their advice, SCRTD has incorporated numerous safeguards and backup systems into the design of the subway system and in construction and operation plans.

The experts agree that Metro Rail can be built and operated safely. Cal OSHA reports that construction of Metro Rail "is feasible, and much less dangerous to excavate and build than many other projects constructed in the Los Angeles basin since 1972." In fact, 60 tunnels spanning 50 miles have been built in the Los Angeles Basin without incident. Many of these tunnels were built in methane gas areas.

I believe Metro Rail can be built safely along its present alignment. However, because there are still safety concerns in the Fairfax District, which is beyond the subway's initial 4.4 mile construction phase, I have offered a compromise to allay those lingering fears.

My amendment, which was approved Sept. 5 by the House Appropriations Committee, earmarks funds for a federally mandated study of alternative alignments to avoid tunneling through methane gas areas identified as "potential risk zones" and "high potential risk zones" by a City of Los Angeles task force.

Construction of the first four-mile-plus link (Union Station to Wilshire and Alvarado) of the eighteen-mile subway could get underway this winter. In the meantime, the alternative alignment study would be completed within nine months without causing a delay in completion of the remaining subway route out to Hollywood and the San Fernando Valley.

I believe this a fair compromise, one that reinforces our common desire that this vital transportation project be built and operated safely. Yet, others have urged that the project be sidetracked until still another exhaustive environmental analysis of the entire subway system is conducted.

That probe would tack on years to a project that has already been delayed too long, and would only duplicate previous studies. It would also be tantamount to killing Metro Rail because funding would be diverted this year to other cities whose transit needs pale in comparison to Los Angeles. It seems clear that methane gas isn't the only pitfall the subway must skirt -- politics poses an even greater risk.

ISSUE NO. 9:

LESSONS LEARNED FROM THE ROSS METHANE INCIDENT SERVE TO CONFIRM METRO RAIL TUNNELING DESIGN CONCLUSIONS AND TO ILLUSTRATE THAT DRILLING IN A GASEOUS ENVIRONMENT CAN BE UNDERTAKEN IN A SAFE MANNER UNDER PRECAUTIONS FAR LESS STRINGENT THAN THOSE UPON WHICH THE METRO RAIL DESIGN IS BASED.

LESSONS LEARNED FROM THE ROSS METHANE INCIDENT TO SERVE TO CONFIRM METRO RAIL TUNNELING DESIGN CONCLUSIONS AND TO ILLUSTRATE THAT DRILLING IN A GASEOUS ENVIRONMENT CAN BE UNDERTAKEN IN A SAFE MANNER UNDER PRECAUTIONS FAR LESS STRINGENT THAN THOSE ON WHICH THE METRO RAIL DESIGN IS BASED

__Comment:__ Has anything been learned from the explosion at the Ross Department store that would affect conclusions about the safety of Metro Rail design for gassy environments?

__Response:__ Protective devices being proposed for the Metro Rail would have prevented the type of disaster that occurred at the Ross Dress-for-Less Department Store if such devices had been installed when the building was constructed. Metro Rail designers have recognized the need for such protection and have taken the appropriate preventative actions.

With the specified construction and safety techniques, construction in gassy environments can be undertaken safely. An example of this is the drilling of the relief well to reduce the gas pressure at the Ross explosion site. The drilling was conducted without incident after the original disaster, under less stringent construction procedures than those specified for Metro Rail.

__Comment:__ On Page 1-3 discussing mitigation measures, it is stated that selection of mitigation measures for medium level hazards will be deferred until post construction conditions are determined.

__Response:__ As a result of the hazard-level designations in the Engineering Sciences (ES) report, SCRTD has included in the design specifications the installation of high density polyethylene barriers in the concrete tunnel in both low and medium hazard segments, and the use of a steel barrier in high hazard areas, when a pressure of 2 inches of water is present. In general, the polyethylene membrane is fully effective for all hazard levels, but steel is specified for the high hazard segments for its structural strength under seismic fault conditions as well as its barrier effects. This is not necessary or cost-effective in the lower hazard segments.

__Comment:__ On Pages 2-4 through 2-5, a description is provided of the potential effects of methane and hydrogen sulphide.

__Response:__ These descriptions are provided in order to indicate why there is a need for concern with either of these gases, and to indicate the nature of the gases themselves. Specifically, both are flammable or explosive; methane is lighter than air and is toxic through asphyxiation; while hydrogen sulphide is heavier than air and is toxic through other effects on the human system. Based on the measurements reported in the ES report, there are locations where methane exists in flammable concentrations and could be toxic. There are no instances of hydrogen sulphide at explosive or combustible concentrations, although there are instances of concentrations that exceed upper threshold limits for continued human exposure.

Comment: On page 2-6, under the section on Pressure Relief Systems, it says that special systems have been utilized on previous projects where flammable gases have been detected, but does not indicate where or on what projects.

Response: The Farmer's Insurance Building on Wilshire Blvd. in Los Angeles, not far from the Ross Dress-for-Less Store, encountered methane in the elevator shaft excavation. A gas utilization system was installed there and methane is currently being used to power the HVAC system.

Comment: On page 2-10, the report states that the construction conditions and service life may limit the long-range utility of barrier materials.

Response: For this reason, SCRTD requested a significant number of tests be run by Metrocon to determine the permeability, resistance to deterioration by hydrocarbons (liquid and gaseous), and deterioration from abrasion of a number of alternative barrier materials. Based on these tests, high density polyethylene was selected as the material that meets or exceeds all these requirements, thereby insuring a long service life.

Comment: On page 2-11, there is a discussion of construction by tunneling method rather than by "cut-and-cover" indicating that the latter would allow the use of a barrier on the exterior of the tunnel. What is the significance of this?

Response: The significance is that special construction techniques are specified in Metro Rail construction plans to provide for an exterior barrier. This is done by using a membrane applied to the outside of pre-cast concrete segments or by using cast-in-place tunneling, which allows the barrier to be placed outside the tunnel lining. Both of these construction methods are specified for Metro Rail tunnels.

Comment: How do the concentrations of hydrogen sulphide in Buffalo (NFTA) compare with those found in the ten borings in LA (and why were only ten of the 66 tested for hydrogen sulphide)? Is there any comparison that can be made to mitigation measures used for gasoline seepage in Baltimore and Washington, D.C. or to methane levels found in NYCTA.

Response: Information is not readily available for comparisons to these other systems. Gasoline seepage would also be a very localized phenomenon and is not directly comparable to methane. The only probes tested for hydrogen sulphide were those that had a positive "sniff" test, a negative sniff test being sufficient to indicate that the gas is not present. Of the 10 probes where a sniff test was positive, only four probes yielded a measurable concentration of hydrogen sulphide, all well below explosive or immediately toxic levels.

Comment: In Table 5.1, high concentrations of methane are registered at probes 11 and 15 (79% and 60%, respectively), and levels above 2.4 percent (the "acceptable" level) at probes 14, 16, and 21. Do these indicate that there will be similar problems on MOS-1 to the vicinity of Fairfax?

Response: Each of the high concentrations were measured at extremely low pressures. The highest concentration at probe 11 of 79 percent registered a pressure of only 0.1 inches of water, and the 60 percent concentration at probe 15 registered 0.2 inches of water. The other three also had very low pressure readings. Therefore, construction in the MOS-1 segment will not experience methane gas anywhere near the pressures found in the Fairfax area. Where methane at low pressure is detected during construction, activities will be halted. The methane will disperse by ventilation, after which construction can be resumed.

Comment: Chapter 6 appears to describe a situation in which explosive concentrations of methane could arise in a very short period of time. Is this indicative of a severe risk of explosion in the tunnels?

Response: Chapter 6 analyzes a range of conditions of diffusion of methane into the Metro Rail tunnel and proffers a worst case scenario in which all mitigation measures fail under the worst conditions identified in any probe, i.e. probe 39 with a concentration of 95 percent and a pressure of 193.9 inches of water column. It is important to note that the issue of significance in all the calculations in chapter 6 is the pressure of the gas. At flow rates of gas that can be expected from experimental data (rather than the conservatively-chosen 100 multiple of these rates), an explosive level of methane would not occur in less than about two days for pressures under 2 inches of water column. Such a concentration would require no ventilation systems operating and no trains operating throughout such a two-day period, which is a situation that will not exist. Only 4 of the 66 probes show a gas pressure equal to or greater than 2 inches of water column, emphasizing the fact that this analysis is clearly a worst case scenario.

Comment: Chapter 7 identifies high hazard situations and describes the measures that should be taken. Are all high hazard situations equally likely to result in risks to construction and/or operation?

Response: Table 7.1 shows how "hazard" levels are defined. More correctly, these should simply be defined as "design" levels 1, 2, and 3, indicating the types of design steps that need to be taken to mitigate gas problems. The "High hazard" level is defined as occurring if pressure of gas exceeds 2 inches of water column, or concentration exceeds 4.8 percent, or both. As noted in the previous response, pressure is far more critical than concentration. Methane occurrences in high concentrations at low pressure are likely to dissipate during construction and are unlikely to recur later as high concentrations. The significance of the "high hazard" designation is to indicate that it would be prudent to use design and construction procedures that will have maximum effect in preventing methane from penetrating the tunnels in these sections of the line.

The term "hazard" is standard engineering terminology used in numerous industrial and construction applications. For example, the California Administrative Code (Title 24, Part 3) defines hazardous situations relating to the State Electrical Code. These definitions relate to electrical devices in locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers. Specific requirements are defined for electrical devices under such conditions to render work areas safe. Clearly, the term "hazard" does not imply that it is unsafe to construct or install equipment under such conditions, and does not imply high risks of explosions or fires. Indeed, such conditions for electrical devices may occur in such areas as commercial garages and kitchens.

<u>Comment:</u> On page 8-4, a recommendation is made that pressure relief systems should be installed at six stations, including the three CBD stations. Does this indicate that serious methane problems exist for MOS-1?

<u>Resoonse:</u> These are highly conservative recommendations and indicate a considerable concern for safety. The three CBD stations will be constructed using cut-and-cover methods, which will allow for the dispersal of any gases encountered and also allow installation of a barrier membrane or a pressure relief system if required.

<u>Comment:</u> Figure 8.1 identifies several segments of the proposed Metro Rail alignment as being in high hazard areas.

<u>Response:</u> As noted under the responses on chapter 6 and chapter 7, a wide variation of exposure exists within the so-called high hazard segments. In fact, only that section of the line between Crenshaw/Wilshire and Fairfax/Beverly shows combinations of both concentration and pressure of methane that require the use of steel liners instead of concrete liners. In all other high hazard segments, the polyethylene barrier outside concrete liners will be more than adequate to deal with the methane present.

<u>Comment:</u> This report addresses gas safety issues related solely to operation of the system. Is there a similar safety report related to construction?

<u>Response:</u> Construction is completely regulated by state law as implemented by Cal-OSHA Tunnel Safety Orders. All construction will be undertaken in compliance with these orders, and the additional safety requirements specified in the construction contract documents by the SCRTD.

ISSUE NO. 10:

ADDITIONAL COMMENT ON THE WAXMAN SUBCOMMITTEE

TESTIMONY OF DR. RONALD J. LOFY.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. OIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNOING)
UNITED STATES HOUSE OF REPRESENTATIVES

Dr. Ronald J. Lofy is a noted expert in the design of methane control and building protection systems. At the Sub-committee Hearing investigating the fire and explosion at the Ross Dress-For-Less Store, Dr. Lofy continually stressed that he was not an expert in tunneling nor was he knowledgeable of tunnel techniques, Cal-OSHA tunneling safety procedures or equipment used in construction of gaseous tunnels. Dr. Lofy state, "I believe that once a well-designed, well-constructed tunnel, employing appropriately selected materials of construction, is in place, there is relatively little danger." "However, there ..e many dangers inherent in tunneling through these gas zones, particularly for the uninitiated or careless."

It is the conclusion of all the tunneling experts who have participated in the design and review of the Metro Rail plans, that the design and construction safeguards to be utilized will be very effective in ensuring the safety of construction persons and Metro Rail patrons.

ISSUE NO. 11:

SUMMARY COMMENT ON THE METRO RAIL ENVIRONMENTAL IMPACT STATEMENT.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

SUMMARY COMMENT ON THE METRO RAIL ENVIRONMENTAL IMPACT STATEMENT

The Final Environmental Impact Statement (FEIS) for the Metro Rail project was published in December, 1983. It shows clearly that the issue of methane gas was recognized at that time and that appropriate mitigation measures were proposed. Specific references are as follows:

Page 3-156 to 3-158: Chapter 11 on Geology and Hydrology notes the potential for gas to be found in the geologic formations of each segment of the Metro Rail alignment. The FEIS rated the CBD segment as potentially gassy to oily and gassy; the East-West section of the Wilshire Corridor segment is potentially gassy to oily and gassy, particularly west of La Brea; the Fairfax reach is oily and gassy from Wilshire north to Melrose Avenue, and nongassy north of Melrose Avenue. The Hollywood and North Hollywood segments are not rated for gas and oil, there being no evidence of any significant problems in these segments.

Page 3-161: Section 11.3.4 deals with mitigation measures proposed to deal with the issue of hydrocarbon accumulation in both liquid and gaseous form, under operating conditions. For liquid hydrocarbons, provision of drainage channels and sumps are indicated as being included in the design, where necessary. For gaseous hydrocarbons, special tunnel linings and gas collection and ventilation systems are indicated as the proposed mitigation measures. These measures are repeated on page 3-166, section 11.4.3.

Page 3-186: Chapter 13 discusses the construction impacts of Metro Rail, and Section 13.9.3 notes that natural gas is a matter of significant concern for construction, and notes also that natural gas can be released from tar sands as well as occurring in a free state in sedimentary strata. Over 50 percent of the alignment is identified as gassy or potentially gassy.

Page 3-188 to 3-189: Section 13.9.5 deals with mitigation of construction impacts and notes that "...avoidance of safety hazards from explosive gas in tunnels will be a major element in project planning and construction efforts." Five mitigation steps are proposed in that section:

a) Retention of Engineering Sciences Co. to study methane gas, and to install a series of probes for monitoring.

b) Constant gas monitoring during construction that will be used to shut down boring operations when gas concentrations rise toward danger levels.

c) Drilling small bore holes 20 feet ahead of the tunnel working face to relieve pressure pockets and to detect the existence of dangerous concentrations/pressures of gas.

d) Collection and ventilation systems to prevent gas build-ups.

e) Adherence to California Bureau of Mines' (Cal-OSHA) requirements for safe subsurface tunneling in hazardous environments.

Page 6-157: Comment 337 deals with the issue of construction in a gassy environment. The response reiterates the mitigation measures described in Section 13.9.5 and summarized above.

In summary, the FEIS shows that the issue of methane gas was recognized long before the explosion in the Fairfax area, and that the Engineering Sciences Co. report was requested as a further study of this issue. Furthermore, a set of appropriate mitigation measures for both construction and operation were proposed in the FEIS, which have been evaluated subsequently as appropriate and sufficient to deal with the issues.

ISSUE NO. 12:

SUMMARY COMMENT ON THE ENVIRONMENT ASSESSMENT

OF METRO RAIL CONSTRUCTION FROM UNION STATION

TO WILSHIRE/ALVARADO.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

SUMMARY COMMENT ON THE ENVIRONMENTAL ASSESSMENT OF METRO RAIL CONSTRUCTION FROM UNION STATION TO WILSHIRE/ALVARADO

The Environmental Assessment (EA) shows that the SCRTD has continued to recognize the issue of methane gas, and has added further precautions for both construction and operation as new information has become available. No significant new problems were identified for MOS-1, not already covered in the FEIS. The Environmental Assessment (EA) Report for the initial Minimum Operable Segment (MOS-1) deals with those impacts that can be expected to differ from the impacts described in the Final Environmental Impact Statement (FEIS) for the entire 18.6 mile project. The FEIS is therefore included by implied reference, and the EA becomes an addendum discussing the specific differences that would occur by building only this first segment of the project. The following are the specific references to this issue contained in the EA:

Page 90: This page makes reference in 3.9.9.3 to the issue of gas and oil in the construction environment. It is noted that the FEIS describes the environment with respect to gas and oil and points out further that oil is not likely to be found until points west of Wilshire/Alvarado.

Comments and Responses, Pages 11-13: Comment 5 raises the same question basically as Comments 337 and 338 on the FEIS, relating to old oil wells and potential methane gas problems. The response reiterates the mitigation measures proposed in the FEIS. Further, it discusses measures to detect old oil wells in advance of the tunneling, uncovering, and safely removing or recapping as necessary. Additional detail is also provided on measures against gas build-up during operations:

a) Natural ventilation and ventilation caused by train movements.

b) Emergency ventilation tied to computer controls and manual controls.

c) A sensor system to detect build-up of gases, followed by automatic train operation shutdown, if needed.

d) Impervious tunnel liners.

e) Barrier membranes, conduit seals, collars, and waterstops.

The response also notes that if these measures are not adequate, the District will install an extensive gas pressure reduction system. It also notes that Cal-OSHA safety requirements will be employed during construction.

ISSUE NO. 13:

ENGINEERING AND REGULATORY EXPERTS (E.G., PRINCIPAL ENGINEER BYRON ISKANIAN OF CALIFORNIA MINING AND TUNNELING; BATTALION CHIEF DONALD BARTLETT OF THE LOS ANGELES FIRE DEPARTMENT; AND CHAIRMAN OF THE BOARD T. R. KUESEL OF PBQD, INC.) REAFFIRM THAT METRO RAIL CAN BE CONSTRUCTED AND OPERATED SAFELY THROUGH THE METHANE ENVIRONMENT WHICH IT WILL ENCOUNTER, CITING AMPLE SUCCESSFUL PRECEDENT, STRINGENT CAL OSHA REGULATIONS, AS WELL AS METRO RAIL'S STATE-OF-THE-ART OESIGN.

RELEVANT QUOTES REGARDING METRO RAIL TUNNELING IN GASEOUS ENVIRONMENTS

Dennis R. Kasper, Vice President, Engineering Science, Inc.

-- September 6, 1985 letter to Congressman Waxman

"We believe this (1984 Engineering Science) report has been misinterpreted... In our opinion, the conditions identified (in the report) do not preclude construction in zones where gas is present... The Metro Rail can be constructed and operated in a safe manner through the areas identified in our rer -t."

Byron M. Ishkanian, Principal Engineer -- Mining and Tunneling, State of California, Division of Occupational Safety and Health.

-- June 26, 1985 letter to Congressman Waxman.

"...I am submitting this letter to clarify my position... tempered by almost 16 years experienced in soft ground tunneling in the Los Angeles and the Southern California area, much of it through gassy ground. Without appearing to be an advocate of the Metro Rail project, I nonetheless feel that it is feasible and much less dangerous to excavate and build than many other projects constructed in the Los Angeles Basin since 1972... We have learned a great deal about tunneling through gassy ground since the advent of the San Fernando tunnel disaster... The (1972 California Mine and Tunnel) Act has proven to be very successful and is used as guidelines for underground work throughout the nation and the world... I shoulder the ultimate responsibility for those workers underground who will build Metro Rail. I reiterate that I feel it is quite feasible."

Donald E. Bartlett, Battalion Chief, City of Los Angeles Department of Fire

-- June 26, 1985 letter to Congressman Waxman.

"At the outset, it was known that a portion of the Metro Rail project would traverse potentially gassy areas westerly along Wilshire Boulevard and northerly along Fairfax Avenue. With this fact in mind, criteria was developed to mitigate potential hazards during the project's construction phase and finally, during revenue operation... this construction will be performed pursuant to requirements by and under the direct on-site supervision of the State of California, Cal OSHA Mining and Tunneling unit (whose) orders are the most stringent requirements known world-wide. Because of our initial and ongoing involvement with the Metro Rail project, the Los Angeles City Fire Department feels that the Metro Rail alignment through potential gassy zones in and around the Wilshire/Fairfax area can and will be constructed and operated in a safe manner without adverse impact upon your constituents who live in the area."

T. R. Kuesel, Chairman of the Board, Parsons Brinkerhoff Quade & Douglas, Inc.

-- August 23, 1985 letter to Southern California Rapid Transit District.

"It is understandable that the Ross Clothing Store gas explosion and fire has generated public concern for the safety of SCRTD's Metro Rail construction against gas hazards during construction and operation, and RTD has been quite correct to engage in a thorough review of the design program conducted over the past two years, and the design recommendations for tunnel and station linings, ventilation systems, and gas detection and monitoring systems... With respect to construction, there is ample precedent for construction of tunnels in similar and more severe gas hazard conditions, both in Southern California and elsewhere...There should be no concern that construction of Metro Rail tunnels and other underground facilities will involve unprecedented hazards for either the general public or those engaged in construction... I believe that the Metro Rail transit consultant recommendations...are appropriate for dealing with the problems of gassy ground in Los Angeles."

Richard J. Proctor, Associate, Lindbal, Richter and Associates.

-- June 28, 1985 letter to Southern California Rapid Transit District.

"My experience includes being Chief Geologist during the excavation of several gassy tunnels in and near Los Angeles. The Newhall and San Fernando tunnels are located in the northern part of the City of Los Angeles. Both tunnels had oil seep into the tunnel and flow down the walls, where it was collected for disposal... It should be realized that hundreds of coal mines operate daily in levels of methane far greater than exists in Los Angeles... it is my opinion the LA Metro Rail subway can be safely completed and operated if the appropriate Cal OSHA requirements are met. Indeed, the subway atmosphere may be safer than the basements of some existing structures."

Melvin L. Polacek, PDCD, Joint Venture

-- July 2, 1985 letter to Southern California Rapid Transit District.

"A partner in the PDCD joint venture has constructed numerous high rise buildings along the SCRTD tunnel alignment, most recently at Wilshire Boulevard and Fairfax Avenue; the foundation for this building was excavated to a depth of 60 feet in the oil sands. Thus, the general geology is well known to us, as are the Cal-OSHA requirements and proper construction methods for the conditions to be encountered. Cal-OSHA has classified the SCRTD tunnels as 'gassy' in their entirety and tunnel safety will apply accordingly for 'gassy' tunnel operations... since the advent of Cal OSHA tunnel safety orders for gassy tunnels, there has not been an explosion in California tunnel construction resulting from the presence of gas... The construction manager monitoring/supervising personnel with 'previous-hands' on experience in tunneling operations, working in coordination with Cal-OSHA Tunnel Division, will assure a safe place of work."

David G. Hammond, Project Director, Metro Rail Transit Consultant

-- June 25, 1985 letter to Southern California Rapid Transit District.

"We have known from the inception of the project that the potential for gassy ground existed along the alignment and probes were installed to obtain measurements. The data generated has been shared with Cal OSHA who classified the tunnels 'gassy' and required that California tunnel safety orders (one of the best in the country) be applied during construction. Finally, we have provided an engineered system consisting of tunnel lining, membrane, ventilation, and gas sensors. The final design is current state-of-the-art and, properly executed in the field, will provide a safe, operable system... In conclusion, SCRTD, MRTC, and Cal OSHA are aware of the potential of having gas in the Metro tunnels. We have engineered the system to mitigate the gas by:

1. Installing probes to measure the gas in the field.
2. Providing concrete or steel lining for the tunnels.
3. Providing a membrane or coating to "back up" the concrete lining.
4. Providing ventilation to dilute and exhaust residual gas.
5. Providing sensors to monitor gas concentration in the exhaust air.

It is our belief that this combined approach represents the state-of-the-art in prudent design for the conditions expected and we are confident the design will provide a safe subway system."

ISSUE NO. 14:

CURRENTLY PLANNED METRO RAIL CONSTRUCTION IN WILSHIRE/FAIRFAX AREA WOULD OCCUR UNDER DESIGN CONDITIONS FAR DIFFERENT FROM THOSE ENCOUNTERED IN MOS-1 CONSTRUCTION -- CONSTRUCTION OF THE INITIAL DOWNTOWN METRO RAIL INCREMENT.

Traces of methane gas have been identified at various pressures and concentrations along the entire 18-mile route of the Metro Rail project. Based on this information, Cal-OSHA has classified the entire project as gassy. It is important to note, however, that the combination of gas, pressure and concentration varies greatly throughout the project.

In the MOS-1 area, concentrations of methane gas vary from 0 to a high of approximately 79% by volume near Civic Center Station. The gas pressures within MOS-1 are extremely low, varying from 0 to a high of 0.45 inches of water (where one inch of water equals 0.036 psi). As a comparison, the highest gas pressure measured along the Metro Rail route was 193.9 inches of water, or approximately 7 psi.

Engineering Science concluded that high hazard mitigation measures are needed only where high concentrations of methane gas are coupled with pressures of two inches of water. Based on the measured concentrations and pressures along the MOS-1 alignment, Engineering Science determined that the implementation of the design mitigation measures identified for high hazard areas was not needed in MOS-1.

Even though the need for high hazard mitigation measures was not established for MOS-1, system design in medium and low hazard areas located in MOS-1 incorporates the following features which will effectively mitigate gas migration into the transit facilities.

1. Installation of a high-density polyethylene (HDPE) barrier for the tunnel segments.

2. A high HDPE barrier around the stations.

3. The gas monitoring system which will detect methane and hydrogen sulfide.

4. Normal and emergency ventilation which can be activated to purge tunnels if methane reaches unacceptable levels.

These measures are in excess of the recommendations contained in the Engineering Science report dated January 1984 and in excess of the recommendations made by the City of Los Angeles Task Force for Construction in high potential risk zones.

ISSUE NO. 15:

TUNNELING IN METHANE ENVIRONMENTS IS SUCCESSFULLY UNDERTAKEN EVERY DAY IN CURRENT UNITED STATES MINING PRACTICE; METRO RAIL DESIGN PROVIDES ADEQUATE SAFEGUARDS REGARDING THE METHANE HAZARD.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

September 10, 1985

STATEMENT OF ROBERT H. KING, PH.D.

ASSOCIATE PROFESSOR OF MINING ENGINEERING

COLORADO SCHOOL OF MINES, GOLDEN, COLORADO

From my review of the project technical data, I have determined that portions of the Los Angeles Metro Rail tunnels will be driven through strata containing methane gases. Even though tunneling in such an environment could present a hazard, underground excavations can be and are accomplished safely under these conditions all the time. For example, underground coal miners work in similar environments every day, using techniques similar to those planned for the subway tunneling. Because of the additional explosive propagation hazard of coal dust, the geological conditions in these mines are much more dangerous than those that would exist in the Metro Rail subway tunnels. Even though over 300 million tons of coal are produced by 1600 underground mines each year, and 112,000 miners enter the mines each day, explosions are extremely rare. The explosion hazard in underground coal mines is reduced by strict enforcement of safety practices such as those required by the Cal OSHA standards adopted for the Metro Rail project. The extensive Cal OSHA regulations will establish the safety procedures that will be used on the Metro Rail project. I have been advised by Mr. Byron M. Ishkaniam, Principal Engineer, Mining and Tunneling, Cal OSHA, that since the revised Cal OSHA safety orders were issued in 1972, all tunneling in California subject to the orders has been completed without a serious incident. The application of the Cal OSHA safety orders to govern the Metro Rail tunneling operations should insure a safely constructed project.

Robert H. King, Ph.D., Member

Independent Panel of Experts

ISSUE NO. 16:

THE STATE-OF-THE-ART DESIGN OF METRO RAIL PROVIDES AN EXHAUSTIVE SET OF PRECAUTIONS TO ENSURE SAFETY DURING BOTH CONSTRUCTION AND OPERATIONS PHASES.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
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UNITED STATES HOUSE OF REPRESENTATIVES

METRO RAIL METHANE-RELATED SAFETY MEASURES
PRECAUTIONS PROVIDED FOR IN METRO RAIL DESIGN

Metro Rail design has been developed in strict compliance with all Cal OSHA tunnel safety orders, which include:

A. CONSTRUCTION

1. Use of tunnel ventilation to dilute and exhaust residual gas
2. Use of sensors in the tunnel to monitor gas concentrations in the exhaust air
3. Use of surface probes to measure gas pressure in the field
4. Training for all underground personnel
5. Use of explosive-proof electrical equipment
6. Elimination of smoking or other actions that could ignite gas
7. Control of any spark producing operations per Cal-OSHA requirements

B. OPERATIONS

1. Use of concrete or steel lining for the tunnels
2. Use of membrane or coating to "back-up" concrete lining and to wrap the passenger stations
3. Use of methane barrier hardware including conduit seals, collars on structure penetrations, and waterstops in expansion joints and selected construction joints
4. Frequent inspection of the inner steel liner
5. Use of sensor system and automatic monitoring system for methane gas and hydrogen sulfide gas which includes data transmission to Metro Rail Central Control and which includes triggering of emergency ventilation at very low presence levels.
6. Augmentation of normal ventilation and sensor systems at the passenger stations and purgation of tunnels with emergency ventilation.
7. Continue to monitor gas surface probes after construction

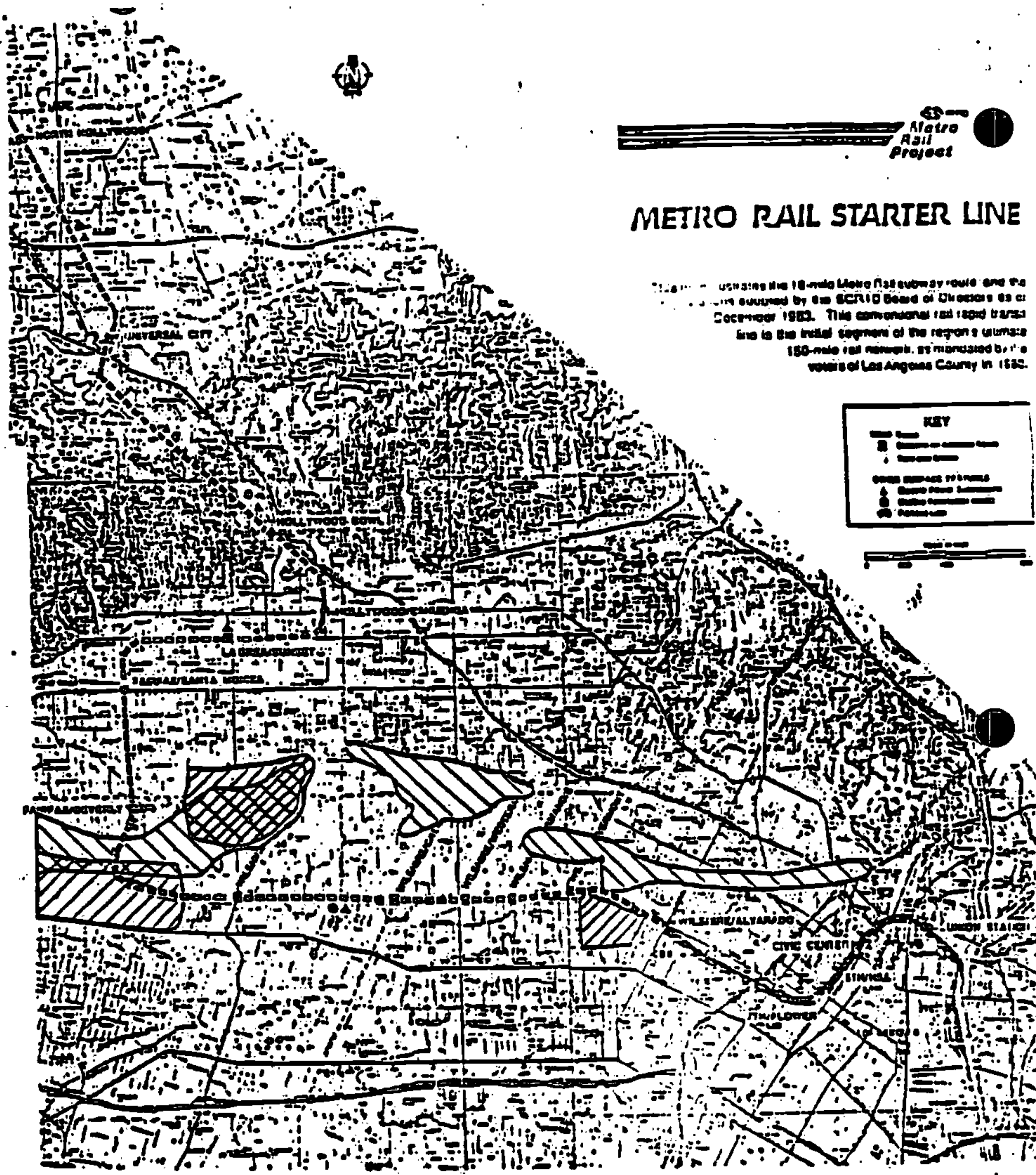
ISSUE NO. 17:

THE LOS ANGELES CITY COUNCIL TASK FORCE, WHICH INVESTIGATED THE ROSS INCIDENT, PRODUCED A REPORT SHOWING THE LOCATION OF OIL SEEPAGE AREAS AND OLD OIL FIELDS (PLATE 1); THE INITIAL METRO RAIL SEGMENT (MOS-1) DOES NOT AFFECT THESE AREAS.

Metro Rail Project

METRO RAIL STARTER LINE

This map illustrates the 18-mile Metro Rail subway route and the ... adopted by the SCRTD Board of Directors as of December 1983. This conventional rail rapid transit line is the initial segment of the region's ultimate 150-mile rail network, as mandated by the voters of Los Angeles County in 1980.



LEGEND: MOS-1 ALIGNMENT
LPA ALIGNMENT BEYOND MOS-1
OUTLINE OF [illegible] AREA
OUTLINE OF OIL FIELD
S.L. = Salt Lake; L.A. = Los Angeles; W = Western

ISSUE NO. 18:

THE CALIFORNIA TRANSPORTATION COMMISSION, WHICH PROVIDES A LARGE PERCENTAGE OF THE FUNDING FOR METRO RAIL, HAS ESTABLISHED A DEADLINE OF JUNE, 1986 FOR START OF METRO RAIL CONSTRUCTION.

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

STATE HIGHWAY ACCOUNT FOR LOCAL ASSISTANCE
MASS TRANSPORTATION PROGRAM

Resolution No. FMT-85-12

Program 30.20.020

Article XIX Guideway Funding

RESOLVED, that the following resolutions allocating funds to the Southern California Rapid Transit District be amended as described below;

That funds allocated by Resolutions FMT-83-10 and FMT-83-13, shall be available for encumbrance until June 30, 1985 rather than for liquidation until June 30, 1985 as presently stated;

That the June 30, 1985 deadline for start-up of Metro Rail construction presently included in Resolutions FMT-83-12 and FMT-84-7, shall be extended to June 30, 1986; and

That the $12,309,000 of Article XIX Guideway funding allocated from the 1983 Budget Act Item 2660-101-042 allocated by FMT-84-7, be reduced to $9,609,000.

PASSED BY
MAR 28 1985
CALIFORNIA TRANSPORTATION COMMISSION

ISSUE NO. 19:

THE SCRTD HAS CLEARLY COMMITTED TO ABANDON PLANS FOR METRO RAIL TUNNELING IN EITHER THE "HIGH POTENTIAL RISK ZONE" OR THE "POTENTIAL RISK ZONE" AS IDENTIFIED BY THE LOS ANGELES CITY TASK FORCE

HR 3244 FLOOR STATEMENT MATERIALS FOR
THE HONORABLE JULIAN C. DIXON
REGARDING TRANSPORTATION/SCRTD APPROPRIATIONS LEGISLATION
(INCLUDING METRO RAIL FUNDING)
UNITED STATES HOUSE OF REPRESENTATIVES

RTD

John A. Dyer
General Manager

September 9, 1985

The Honorable Julian C. Dixon
Member of Congress
Washington, D.C. 20525

Dear Mr. Chairman:

At your request, the House Appropriations Committee amended on September 5, 1985, the Transportation Appropriations Bill for Fiscal Year 1986 to include specific language related to the Los Angeles Metro Rail Project.

The first paragraph of that amendment requires the SCRTD to conduct a study of potential methane gas risk relating to the alignment of the Metro Rail Project beyond the Minimum Operable Segment (MOS-1). The second paragraph requires the development of "alternative alignments and appropriate environmental documents so that construction will not penetrate the 'potential risk zone' and the 'high potential risk zone' as defined by the City of Los Angeles Task Force..." Finally, the amendment language requires that the study be completed no later than nine months after the enactment of the legislation.

To the SCRTD this language is both mandatory and directive. The language means that no Metro Rail tunnels or stations can be constructed in the "potential risk zone" or the "high potential risk zone" as identified by the City of Los Angeles Task Force. Further, the language contained in the Bill establishes a process which requires a study to identify methane gas risk and to identify areas where there is least risk. In turn, this leads to the development of alternative alignments and the appropriate environmental documents which must preclude construction from penetrating either of the zones. Finally, based upon completion of the environmental process, a final decision is to be made on the alignment to be constructed which is not in the "high potential risk zone" or the "potential risk zone" as identified by the City of Los Angeles Task Force report.

Unfortunately, it is not possible to specify where the alignment of the system will be until the study of methane gas risk is completed and the

Southern California Rapid Transit District 425 South Main Street, Los Angeles, California 90013 (213) 972-6000

ISSUE NO. 20:

AN SCRTD APPOINTED BOARD OF REVIEW OF NATIONALLY RECOGNIZED AUTHORITIES ON THE SUBJECT OF TUNNEL CONSTRUCTION IN GASEOUS AREAS HAS INITIATED ITS REVIEW OF THE METRO RAIL PROJECT. THE BACKGROUND REPORT BEING UTILIZED BY THE BOARD OF REVIEW IS ENCLOSED.

appropriate alternative alignment and environmental studies are completed. This is due to the fact that those studies require a specific process in order to comply with the National Environmental Policy Act (NEPA), the UMTA regulations, and the California Environmental Quality Act (CEQA) legislation.

I hope that this letter responds adequately to your concerns. If you have questions, please contact me.

Sincerely,

John A. Dyer

RTD

FIRE/LIFE SAFETY COMMITTEE

September 11, 1985

FIRE/LIFE SAFETY COMMITTEE SUMMARY REPORT CONCERNING CONSTRUCTION AND OPERATION PLANS FOR THE METRO RAIL SYSTEM WITHIN A METHANE GAS ENVIRONMENT

The Fire/Life Safety Committee has completed a comprehensive review of all information related to the presence of methane gas along the Metro Rail alignment. The following information was reviewed in detail by the Committee in reaching its findings:

1. Geotechnical Investigation Report, Volumes 1&2, by Converse Ward Davis Dixon, dated November 1981.

2. Geotechnical Engineering Report for Design Unit A-250, by Converse Consultants, dated May 1984.

3. Geotechnical Engineering Report for Design Unit A-140, by Converse Consultants, dated October, 1983.

4. Methane Transmission Rates Through Various Barrier Materials for Tunnel Construction, by Miedema and Haxo, dated January 17, 1985.

5. Durability of Various Barrier Materials for Tunnel Construction, by Miedema and Haxo, dated June 6, 1985.

6. Swelling in Hexane of Various Barrier Materials for Tunnel Construction, by Miedema and Haxo, dated FEbruary 28, 1985.

7. Report of Subsurface Gas Investigation, by Engineering - Science, dated January 1984.

8. Report of Subsurface Gas Investigation, by Engineering - Science, dated May 1985.

9. Title 8 Tunnel Safety Orders, by CAL OSHA, revised August 23, 1973.

10. Task Force Report on the Methane Gas Explosion and Fire, by Department of Building and Safety of the City of Los Angeles, dated June 10, 1985.

11. Map locating Oil Wells, by Division of Oil and Gas, Department of Conservation, State of California, dated January 5, 1985.

12. Construction Safety and Security Manual, by PDCD, dated February, 1985.

13. Feasibility of Tunneling in Gassy Ground, by R.J. Proctor, dated June 28, 1985.

14. Route Alignment Drawings, Contract A-130, by Bechtel Civil & Minerals, Inc., dated April 8, 1985.

15. Route Alignment Drawings Contract A-141, A-146 and A-147 by Delon Hampton & Associates, dated July 9, 1985.

16. Gas Monitoring System Review & Design Recommendations, by MRTC, dated January, 1985.

17. Methane Control Program Theory of Operation.

18. Shield Driven Tunnels, Specification Section 02311, dated July 5, 1985.

19. Hydrocarbon - Resistant Membrane for Cast-In-Place Concrete, Specification Section 07101 dated June 10, 1985.

20. Hydrocarbon - Resistant Coating, Specification Section 07121, dated June 24, 1985.

21. Summary Letter, Hammond to Crawley, dated June 25, 1985.

22. Tunnel Liner Rationale Letter, Hammond to Murray, dated August 7, 1985.

23. Environmental Control System, by PBQ&D, dated July 1, 1985.

24. Study of methane and other combustible gases effect on underground operation of the Metro Rail Project - Kaiser Engineers, California and Gage-Babcock Associates, March 1983.

Our review indicates that all prudent and appropriate measures have been taken in the design of the Metro Rail System. Further, the Committee will continue to review the development of all designs on a continuing basis.

Accordingly, the Committee approves the Metro Construction and Operation Plans for implementation.

By the Fire/Life Safety Committee:

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CONTRACT NUMBER: DOTUM-60-80-C071004

FINAL DRAFT

January 1981

SYSTEM SAFETY ANALYSIS:

A Description of the Formats and Methodologies for System Safety Analysis of Fixed Guideway Transit Systems

Prepared for

Urban Mass Transportation Administration
Office of Safety & Product Qualification

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T A B L E   O F   C O N T E N T S

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1.0 INTRODUCTION

1.0 INTRODUCTION

The application of system safety analysis to fixed guideway transit systems is examined in this document. Chapter 1.0 presents the objective and scope of this document, defines system safety analysis and presents a brief history of its development. In Chapter 2.0, system safety analysis methods are discussed. Chapter 3.0 applies system safety analysis techniques to transit, and Chapter 4.0 presents the format and methodology of each technique.

1.1 OBJECTIVE

The objective of this document is to present a uniform set of formats and methodologies which can be used as a basis for system safety analyses of fixed guideway transit systems. Despite the diverse nature of fixed guideway transit, which includes Automated Guideway Transit, Downtown People Movers, Light Rail Transit and Rail Rapid Transit, there is commonality among some of the system elements. The system safety analysis techniques presented in this document address these common elements and therefore may be applied to the various types of fixed guideway transit systems. Even though the safety analyses presented will not be applied identically to each system, the uniform set of formats and methodologies should result in more meaningful exchanges of safety information.

1.2 SCOPE

The Urban Mass Transportation Administration's (UMTA) system safety program states that UMTA:

- Recommend development of a system safety program by all properties
- Conduct periodic system safety reviews of each transit property
- Investigate unsafe conditions in transit property facilities, equipment and operations
- Require properties to report incidents/accidents.

System safety analysis techniques are tools for assessing and improving the safety of transit systems and as such are an integral part of the UMTA system safety program.

The system safety analysis techniques which are applicable to fixed guideway transit systems and are described in this document are:

- Preliminary hazard analysis (PHA)
- Subsystem hazard analysis (SSHA)
- Interface hazard analysis (IHA)
- Operating hazard analysis (OHA)
- Fault tree analysis (FTA)
- Fault hazard analysis (FHA).

As a group, these techniques are applicable to all stages of the development and operation of a fixed guideway transit system. The information and concepts contained in this document will enable the transit industry to determine which of the analysis techniques is best suited to a specific situation.

1.3 WHAT IS SYSTEM SAFETY ANALYSIS?

System safety may be defined as "the integration of skills and resources specifically organized to achieve accident prevention over the entire life cycle of a given system."*

Therefore, in a system safety program, hazards are identified during all stages of both the acquisition and operational phases of a transit system. The system safety program is designed to control or eliminate all forms of hazards by providing warnings and information concerning the control of those that cannot be eliminated, alerting the user as to their potential occurrence, and providing adequate written and oral instructions to resolve them.

System safety analysis, in its simplest terms, is a formalized method of identifying and eliminating or

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* R. A. Duregger, E. Leon, and J. R. Sample, System Safety Analysis Techniques as Applied to Shipboard Systems, 1972.

controlling system hazards. Specifically, a system safety analysis provides:

- Determination of hazards
- Timely awareness of hazards for those who must resolve them
- Traceability and control of hazards through all phases of a system's life cycle.

System safety analysis is a preventative feature of the system safety program. System safety analysis primarily identifies and describes hazards that might arise from flaws in the design and operation of a system or subsystem. Thus, system safety analysis is vital to the development of a system in which hazards have been eliminated or are controlled to an acceptable level.

1.4 HISTORY OF SYSTEM SAFETY ANALYSIS

Some preliminary work in system safety concepts was performed as early as 1947, and more was done during the 1953-1955 period; however, this work gained little immediate recognition outside the aircraft companies where the techniques were employed. Only when the Minuteman missile system began to be deployed was concern expressed that hazardous conditions could escape detection in the course of system engineering, integration and reliability activities, and that these conditions might lead to accidents of disastrous proportions.

At the request of the U.S. Air Force Ballistic Systems Division (BSD), The Boeing Company prepared a report describing general techniques that could be employed to provide a systematic approach to safety as a component of the design process--not as an after-the-fact discovery. At Boeing's direction, studies were implemented by the Bell Telephone Laboratories, using a fault tree analysis adapted from solid-state circuit logic diagram methods, to determine the probability of inadvertent launch from communication system error. This technique was expanded by Boeing and applied for similar purposes, first to the missile system and then to the total system complex.

The U.S. Air Force Ballistic Systems Division moved to expand the system safety activity and is credited with issuing the first system safety specification, BSD Exhibit 62-41, released on April 1, 1962, and entitled <u>System</u>

Safety Engineering: General Specification for the Development of Air Force Ballistic Missiles. This specification was applied to all BSD contracts.

At the direction of the U.S. Department of Defense (DOD), a single system safety specification, MIL-S-38130A, appeared in 1966, having mandatory application to all DOD activities. This specification was merely an interim adoption of the Air Force issue of September 1963, and the services agreed that it would be replaced as soon as practicable. A triservice committee was formed in March 1967, and in July 1969 released MIL-STD-882 for use by all services. A key feature of MIL-STD-882 is that it represents a transition from a specification (MIL-S-38130A) to a standard (MIL-STD-882). MIL-STD-882 provides an overall framework within which the system safety programs suited to individual project needs are to be developed and specified. The Standard specifically states that it is to be used in preparing safety requirements for inclusion in work statements, plans and other program documents. Each provision of the Standard must be considered regarding the extent of its applicability, any deviations or supplementary requirements.

It must be recognized that MIL-STD-882 is not applicable to all procurements. It is a specific responsibility of acquisition management to determine the degree of the Standard's applicability. Although its complete exclusion implies that completely adequate standards of safety can be achieved without its use, the Standard must under no circumstances be incorporated directly into work requirements or be used without definition of the standard of system safety to be achieved. The establishment of an enlightened perspective in determining the degree of use of the Standard is an essential prerequisite to a cost-effective and beneficial program.

2.0 BASIC SYSTEM SAFETY ANALYSIS METHODS

2.0 BASIC SYSTEM SAFETY ANALYSIS METHODS

Basic system safety analysis techniques are defined in this chapter. The discussion also lists the specific techniques applicable to transit, and graphically presents when each technique is applicable in the life cycle of a transit system.

2.1 BASIC SYSTEM SAFETY ANALYSIS TECHNIQUES

The system safety analysis techniques presented in this document are based upon inductive and deductive reasoning. Webster's Third International Dictionary defines these terms as follows:

- Inductive--an instance of reasoning from a part to a whole, from particulars to generals or from the individual to the universal

- Deductive--a method of reasoning by which concrete applications or consequences are deduced from general principles, to draw a conclusion necessarily from given premises.

Usually, both inductive and deductive reasoning are used when performing safety analyses. However, the analysis techniques contained in this document are categorized in terms of their predominant mode of reasoning. This enables the reader to distinguish between those analysis techniques that seek to identify hazards by determining the potential effects of an event and those that seek to identify hazards by determining the potential causes of an event.

Safety analysis techniques that investigate effects begin with a bottom or lower-level event or occurrence and proceed upward to determine what effect the lower-level event has on the total system. These analysis techniques use what may be called a "bottom-up" approach, based on inductive reasoning.

Safety analysis techniques that investigate causes begin with a selected top-level event or occurrence and proceed downward to determine all of the elements which contribute to the occurrence of the top-level event. These techniques use a "top-down" approach, based on deductive reasoning.

The system safety analysis techniques described in this document fall into one of two categories--effect-investigating ("bottom-up" approach) or cause-investigating ("top-down" approach).

2.1.1 The Top-Down Approach: An Example

Simple logic is used in performing the various system safety analyses. To demonstrate, Figure 2-1 presents a fault tree analysis (FTA) of an undesired event, a pedestrian being hit by a vehicle while crossing a street. The events presented in the fault tree are discussed below.

Every day people cross streets busy with vehicular traffic, yet seldom do they consciously consider all the events that might occur which could be injurious. Consider the events that could lead to being hit by a vehicle while crossing a street.

There are a number of possible scenarios related to being hit by a vehicle while crossing a street. For simplicity, consider only two obvious alternatives:

- Event 1--A vehicle goes through the intersection at the wrong time and the driver does not see the pedestrian.

  OR

- Event 2--The pedestrian enters the intersection at the wrong time and the driver of the vehicle cannot stop in time.

Let's explore the subevents of Event 1 as we continue our top-down analysis. Event 1 has two elements:

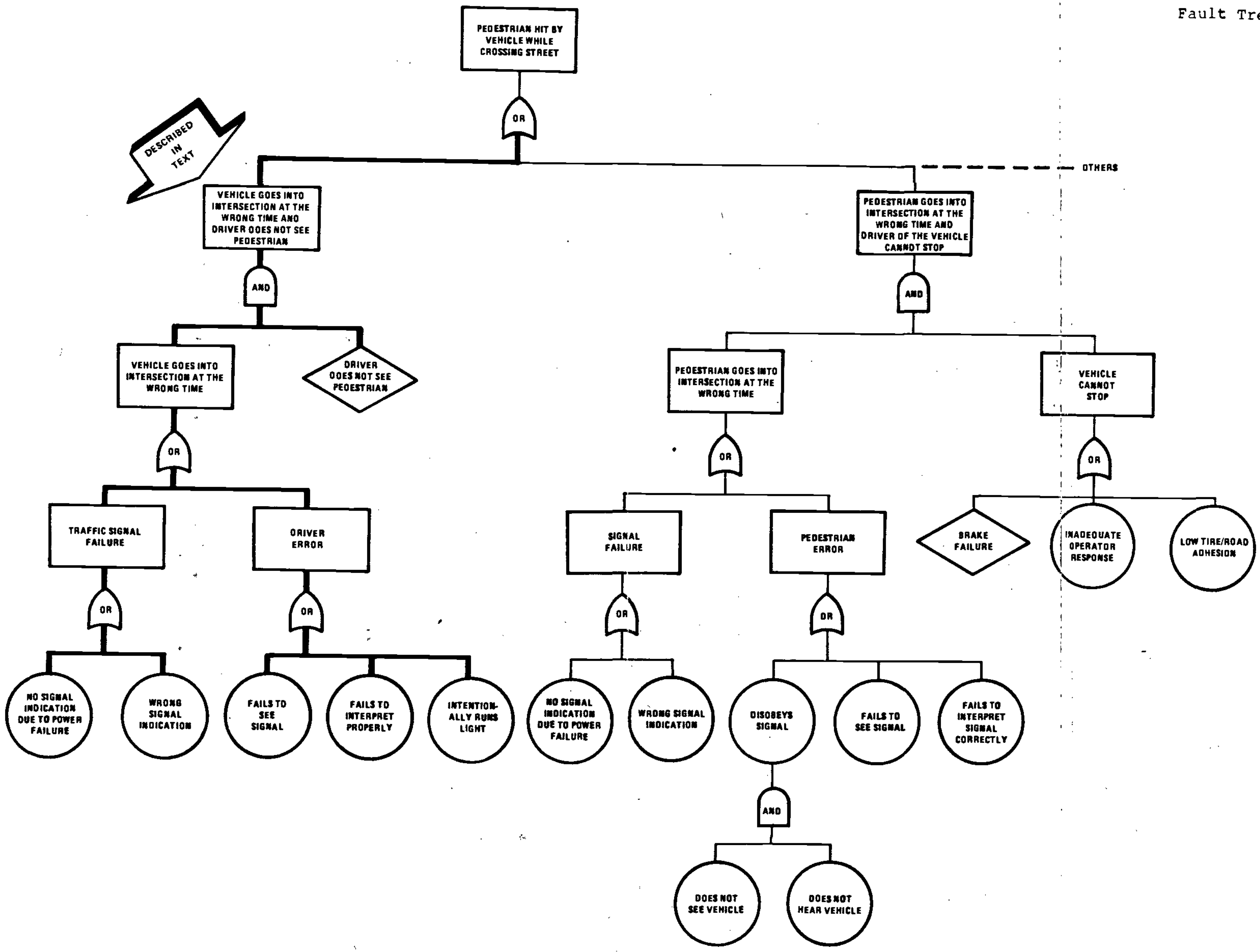
- The vehicle must go through the intersection at the wrong time.

  AND

- The driver does not see the pedestrian.

Next, we must ask ourselves what would cause the driver of a vehicle to go into an intersection when he

FIGURE 2-1
Fault Tree Analysis Example



wasn't supposed to? We might think of the following reasons:

- Traffic signal failure

  <u>OR</u>

- The driver made a mistake (driver error).

Let us explore the causes of the traffic signal failure first. The traffic signal failure could be caused by:

- A power failure, and thus no signal indication

  <u>OR</u>

- The signal gives the wrong indication to the vehicle driver, i.e., green when it should be red.

Now let us think of the possible mistakes the vehicle driver could make. The driver could:

- Fail to see the traffic signal

  <u>OR</u>

- Fail to interpret the traffic signal properly, i.e., think the light is green when it is really red

  <u>OR</u>

- Have no desire to stop, intentionally running the red light.

Now let us refer back to the second element of Event 1--"the driver does not see the pedestrian." Some of the reasons he may not see the pedestrian include:

- Poor motorist vision
- Eyes not on the road.

Each of the subevents we have identified could be broken down further. Generally, the process is continued only until we arrive at the level of detail that permits decisions on how to prevent the top event from occurring.

We have now completed to a reasonable level of detail a top-down analysis of Event 1--"a vehicle goes through the intersection at the wrong time and the driver does not see the pedestrian." We could, through the same process, explore Event 2.

The top-down analysis example just completed displays the approach used in a fault tree analysis. Figure 2-1 shows the events we just developed with fault tree symbols. The fault tree contains, in addition to Event 1 which we analyzed, the development of Event 2.

A detailed description of how to perform a fault tree analysis appears in Chapter 4.0 of this report.

2.1.2 The Bottom-up Approach: An Example

The previous example evaluated the events that could lead to the occurrence of an undesired event--being hit by a vehicle while crossing an intersection. In the following example, the problem is to determine the gross hazards that could exist in the design of a pedestrian walkway.

A preliminary hazard analysis (PHA) is the appropriate safety analysis technique. In addition to identifying hazards, the PHA will be helpful in developing guidelines and criteria for the walkway design; it can be used to designate management and technical responsibilities for safety tasks and as a checklist to ensure their accomplishment; and it can indicate the information that must be reviewed in codes, specifications, standards and other documents governing precautions and safeguards to be taken for each hazard.

Figure 2-2 presents a preliminary hazard analysis for two of the hazards that may exist in the design of a pedestrian walkway.

The bottom-up approach is used in several of the safety analysis techniques contained in this document; they are fully discussed in Chapters 3.0 and 4.0.

2.1.3 Qualitative Analysis Versus Quantitative Analysis

Safety analyses can be used qualitatively or quantitatively. A qualitative analysis is a review of all factors affecting the safety of a system. All possible conditions and events and their consequences are considered to determine whether they could cause or contribute to injury or damage. The objective is to achieve maximum safety by eliminating or controlling all significant hazards.

SYSTEM TITLE PEDESTRIAN WALKWAY	PRELIMINARY HAZARD ANALYSIS	PREPARED BY ______ PAGE ____ OF ____ REVISION ______ DATE ______				
HAZARD	CAUSE OF HAZARD	TRIGGERING EVENT	POTENTIAL ACCIDENT	HAZARD CATEGORY	POTENTIAL ACCIDENT PREVENTION MEASURES	RESOLUTION
LOW MOTORIST VISIBILITY	POOR ILLUMINATION BUILDINGS LOCATED DIRECTLY BY STREET CROSSING HILL PRIOR TO INTERSECTION	PEDESTRIAN IN INTERSECTION	PEDESTRIAN STRUCK	I	INCREASE ILLUMINATION OF INTERSECTION CONSTRUCT WALKWAY IN AN AREA WHERE PEDESTRIANS ARE VISIBLE/INSTALL TRAFFIC SIGNAL INSTALL WARNING SIGNS ON GRADE PRIOR TO CREST	ILLUMINATION LEVEL RAISED TO MEET HIGHWAY CODES WALKWAY CONSTRUCTED ON AERIAL STRUCTURE SIGNS AND FLASHING LIGHTS INSTALLED
HIGH VEHICLE SPEED	SPEED LIMIT TOO HIGH POSTED SPEED LIMIT IGNORED	PEDESTRIAN IN INTERSECTION	PEDESTRIAN STRUCK	I	REDUCE SPEED ON STREET PRIOR TO INTERSECTION	VEHICLE SPEED APPROACHING INTERSECTION POSTED AS 25 MPH

FIGURE 2-2
Preliminary Hazard Analysis Example

A quantitative analysis is a mathematical assessment of an actual or potential event, such as an accident. Quantitative evaluations can be used to establish absolute or relative frequencies of occurrence. A quantitative analysis must always be preceded by a qualitative analysis. Therefore, any mention of a quantitative analysis implies that a qualitative analysis will also be performed.

2.2 TYPES OF SYSTEM SAFETY ANALYSIS TECHNIQUES AND THEIR APPLICATION TO THE PHASES IN THE LIFE CYCLE OF A TRANSIT SYSTEM

There are six system safety analyses which are applicable to fixed guideway transit systems:

- Preliminary hazard analysis (PHA)
- Subsystem hazard analysis (SSHA)
- Interface hazard analysis (IHA)

- Operating hazard analysis (OHA)
- Fault tree analysis (FTA)
- Fault hazard analysis (FHA).

To fully comprehend the utility of these analyses, it is important to understand at what point they are applicable to the life cycle of a transit system.

As defined in this document, the life cycle of a transit system is divided into two phases, acquisition and operation. The acquisition phase is initiated once the decision is made either to build a new system or to extend or rehabilitate an existing system. It extends up to the time the system is put into revenue service, and has four stages:

- The planning stage begins with the decision to build a new system or extend or rehabilitate an existing system and ends at the onset of preliminary design.

- The design stage begins at the onset of preliminary design and ends when the design is finalized and ready to go into production.

- The procurement stage begins when the fabrication or construction of equipment and facilities starts, and ends with the final inspection and testing.

- The integration/test/checkout stage begins when the equipment is installed, extends throughout the period of system test and checkout, and ends when the system begins revenue operation.

The operational phase of a system's life cycle extends from the beginning of revenue service until the system is no longer in use.

Figure 2-3 shows when in the life of a transit system each safety analysis technique provides the most benefit.

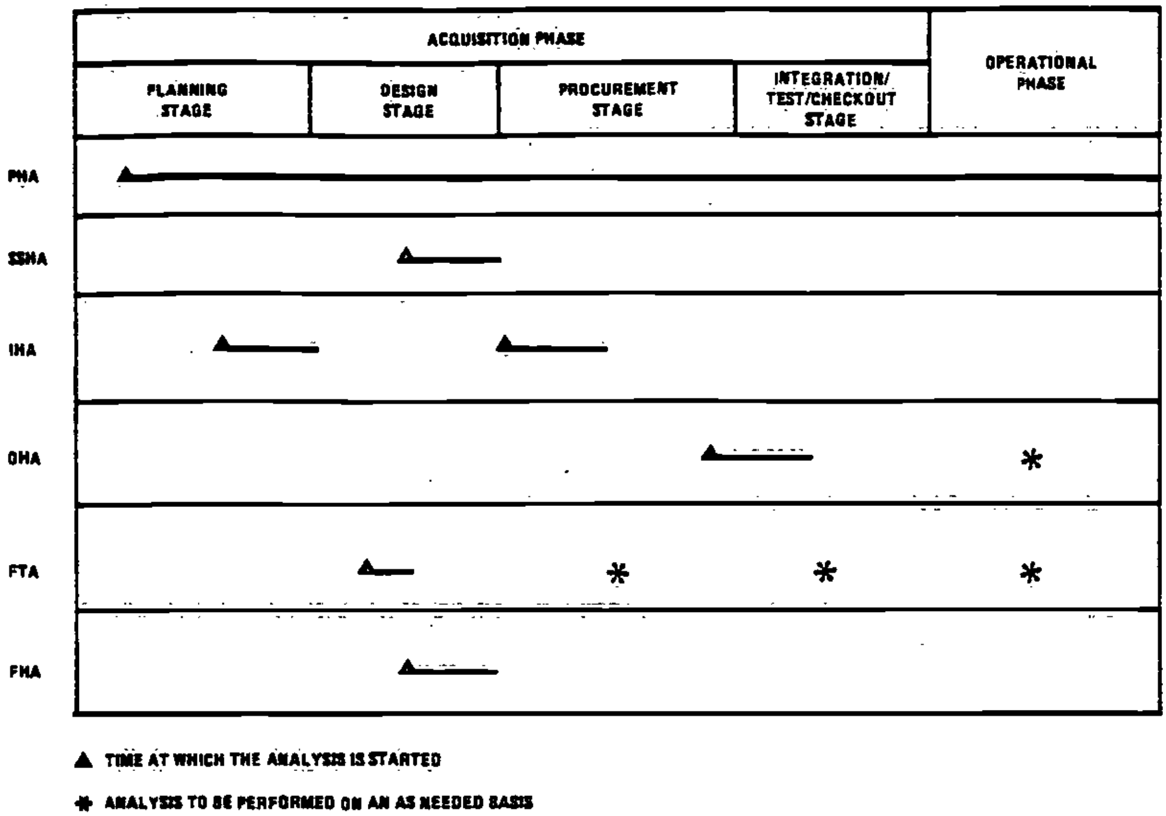


FIGURE 2-3
Schedule Showing Preferred Application of System Safety Analyses

3.0 APPLICATION OF SYSTEM SAFETY ANALYSIS TECHNIQUES TO FIXED GUIDEWAY TRANSIT SYSTEMS

3.0 APPLICATION OF SYSTEM SAFETY ANALYSIS TECHNIQUES TO FIXED GUIDEWAY TRANSIT SYSTEMS

The application of system safety analysis techniques to fixed guideway transit systems is examined in this chapter from two perspectives: (a) historical and (b) the special system safety analysis requirements of transit systems. An overview of the nature and purpose of the six relevant system safety analysis techniques is also provided.

3.1 HISTORY OF APPLICATIONS

The concept of safety in fixed guideway transit systems changed drastically during the 1970s. The heightened level of safety consciousness in the public sector and transit industry, the influence of aerospace design, and the increasing complexity of transit technology were the major reasons for the change. This shift in the concept of safety laid the groundwork for the application of system safety analysis to fixed guideway transit systems.

The following paragraphs outline the application of system safety analyses to various transit systems. The list of examples is not exhaustive, but simply indicates the variety of ways in which system safety analysis is being used in fixed guideway transit systems.

3.1.1 Morgantown Personal Rapid Transit (PRT)

The Morgantown (West Virginia) Safety Program Plan (1971) required that a project fault tree be constructed and that quantitative levels of safety be incorporated into the system design and operating plan.

The plan called for operating hazard analyses (OHA) to be conducted on test plans, procedures and related test equipment; on operational plans, procedures and related operational support equipment; and on maintenance plans, procedures and related maintenance equipment. The results of these analyses were to be used either in verifying the safety level of the plan, procedures or equipment, or in implementing changes to incorporate the safety provisions.

3.1.2 Bay Area Rapid Transit (BART)

In a 1973 report, Safety Methodology in Rail Rapid Transit System Development, the National Transportation Safety Board recommended that a failure mode and effects analysis (FMEA) be performed on BART. The report stated that the FMEA should include all components, assemblies, systems and operating procedures that control or influence passenger and train safety.

The 1978 BART System Safety Program Plan required system safety analyses to be conducted for selected existing safety-critical systems or related procedures, and for all proposed projects or modifications that have a potential safety impact. Safety analysis techniques to be used included fault tree analysis (FTA), failure mode and effects analysis, and stress and failure analysis. A stress and failure analysis is performed when a single failure of a structural member of a mechanical system may cause injury or system damage. The FMEA (similar to a fault hazard analysis in this application) identifies potential malfunctions and analyzes their potential effects, and is to be performed when a single failure of a component of a system (or subsystem) may cause injury or system damage.

3.1.3 Transit Expressway Revenue Line (TERL)

The 1974 System Safety Program Plan for the TERL Project (Pittsburgh) specified that the following analyses were to be performed:

- Preliminary Hazard Analysis (PHA)--to be performed as part of the initial task of developing system safety criteria, and to identify in broad terms the potential hazards associated with the TERL design and operational concepts. The analysis was described in the program plan as a comprehensive, qualitative study. The PHA was to provide the basis for subsequent system safety analyses which would involve more detailed and extensive evaluations of the TERL system.

- Subsystem Hazard Analysis (SSHA)--to determine the functional relationships of components and equipment making up each subsystem and to identify all components whose performance degradation or functional failure could result in hazardous conditions.

- Operating Hazard Analysis--to identify and evaluate the safety considerations associated with the environment, personnel, procedures and equipment involved in the operational phase of a given system/element.

- Fault Tree Analysis--to determine the probability of occurrence of each identified hazardous condition of a catastrophic or critical nature.

3.1.4 Metropolitan Atlanta Rapid Transit Authority (MARTA)

In the 1975 MARTA Program Plan, various types of system safety analyses were scheduled to be performed. They consisted of:

- Preliminary Hazard Analyses--qualitative studies of the MARTA system performed at a major subsystem level to analyze the system and operations for detection and definition of hazards

- Subsystem Hazard Analyses--expansion of the PHAs conducted during the definition and design stages for application in safety reviews, for inputs to specifications, and for generation of procedures to eliminate, reduce or control critical hazards

- Operating Hazard Analyses--determination of safety requirements for personnel, procedures and equipment used in installation, maintenance, support, testing, transportation, storage, operations, emergencies and training during all phases of the MARTA development

- Qualitative Analyses--nonmathematical reviews performed in the design stage, concerning all factors affecting the safety of the MARTA rapid transit system

- Quantitative Analyses--mathematical reviews of the catastrophic and critical hazards identified by the above-mentioned qualitative analyses.

The following analyses were requirements in the MARTA vehicle, train control and yard control specifications:

- Preliminary hazard analysis
- Subsystem hazard analysis.

3.1.5 Greater Cleveland Regional Transit Authority (GCRTA)

The 1979 GCRTA System Safety Program Plan recommended the use of both inductive (bottom-up approach) and deductive (top-down approach) processes to identify hazards. It also recommended a failure mode and effects analysis (similar to a fault hazard analysis) as one of several information tools that could be used in the identification and assessment of hazards; other tools were test reports, data on toxicological properties, flammability information, operating rules and regulations, and administrative procedures.

Finally, the System Safety Program Plan recommended that the experiences of other transit systems be used as input to the hazard identification process.

3.1.6 Baltimore Region Rapid Transit System (BRRTS)

According to the 1978 BRRTS System Safety Program Plan, the following analyses were scheduled to be performed:

- Preliminary Hazard Analysis--to identify hazardous conditions within the system.
- Fault Tree Analysis--to gain a more precise understanding of the causes of selected safety-critical events.
- System Hazard Analysis (SHA)/Subsystem Hazard Analysis--to identify hazards or risks associated with interfaces and to specify the means for controlling the identified conditions. (An SHA is similar to an interface hazard analysis.)
- Maintenance Hazard Analysis (MHA)--to identify hazards that may be encountered during maintenance or as a result of improper maintenance of the system. (An MHA is similar to an operating hazard analysis.)

The BRRTS train control specification called for four types of safety analyses:

- Preliminary hazard analysis
- Subsystem hazard analysis

- Operating hazard analysis
- Quantitative analysis--fault tree or logic network.

The BRRTS vehicle specification called for the following analyses to be performed:

- Preliminary hazard analysis
- Subsystem hazard analysis
- Operating hazard analysis
- Quantitative analysis--fault tree or logic network
- Sneak circuit analysis--to be performed on the door and brake interface
- Safety-critical items list.

In 1979 a BRRTS preliminary system hazard analysis was performed. It provided a systematic listing and assessment of hazardous conditions that could affect the BRRTS. (A preliminary system hazard analysis in this application is similar to a preliminary hazard analysis.)

3.1.7 Washington Metropolitan Area Transit Authority (WMATA)

In 1970, the National Transportation Safety Board published a report entitled, Study of Washington Metropolitan Area Transit Authority's Safety Procedures for the Proposed Metro System. The report included a copy of MIL-STD-882 as a reference and encouraged its use as a guideline for system safety.

In 1975 the General Engineering Consultant for the WMATA automatic train control system performed a hazard mode and effects analysis (HMEA). The analysis included over 1,000 component failure modes. (An HMEA is similar to a fault hazard analysis.)

A report published in 1980 by the WMATA Systems Safety Engineering Department presented the results of two fault tree analyses. The FTAs used data from the incident reporting and corrective action program and information obtained from interviews with operations and maintenance personnel and manufacturers' manuals. The fault trees were used to analyze delays in revenue service and a train collision while in revenue service.

3.1.8 Pittsburgh Light Rail Transit System

The 1980 draft version of the Pittsburgh Light Rail Transit System Safety Program Plan stated that the following analyses would be performed:

- Preliminary Hazard Analysis--to identify the hazards associated with the respective subsystems

- Fault Tree Analysis--to determine the most critical and probable sequence of events on selected systems that could result in a hazardous condition.

3.1.9 Los Angeles Downtown People Mover (LADPM)

The 1980 LADPM System Safety Program Plan stated that qualitative and quantitative safety analyses would be performed to maximize safety by eliminating, minimizing or controlling all hazards regardless of criticality or probability of occurrence. The qualitative analyses required include:

- Preliminary Hazard Analyses--to be performed at a major system element level and to deal with the relationships between the system and the operating environment. The procedures for operating the system and the manner in which it will be expected to operate will be considered for the startup period and for regular service.

- Subsystem Hazard Analyses--to expand the PHA during the definition and design stages. The analyses will be performed on a structured tier or level basis and will be carried out to the component level. They will address the safety of the system and how it is affected by environmental operating conditions, hardware, software, and human and equipment interfaces.

- Operating Hazard Analyses--to determine safety requirements for personnel, procedures and equipment used in installation, testing, maintenance, support, transportation, storage, operations, emergencies and training during all stages of the LADPM development.

The quantitative analyses are to include mathematical reviews of the retained critical and catastrophic hazards identified by the qualitative analyses.

The preceding examples show how system safety analyses have been applied to fixed guideway transit systems. Although the analysis techniques were developed by the military, they are now being widely applied in the fixed guideway transit industry.

3.2 SPECIAL SYSTEM SAFETY ANALYSIS REQUIREMENTS IN FIXED GUIDEWAY TRANSIT SYSTEMS

The complexity and sophistication of modern fixed guideway transit systems have necessitated the development and use of sophisticated safety analysis techniques. These techniques provide assurance that virtually all hazards that could cause injury or damage to a system have been identified and either eliminated or controlled. It is precisely this high level of safety assurance that modern transit systems require.

The fail-safe method of safety design, which ensures that any malfunction affecting safety will cause the system to revert to a state that is generally known to be safe, has proven impractical in modern transit systems. A 1974 study of automatic train control (ATC) by the Transportation Systems Center concluded that it is literally impossible to achieve fail-safe design in a large, complex control system that has many interacting elements and functions. Regardless of how carefully a system is designed and tested, there will always be certain combinations of component failures or operational conditions that cannot be wholly compensated for. Such events may have very low probabilities (1×10^{-6} or less), but they represent hazards which must be resolved.

Modern transit systems operate on very short headways. If a failure occurs, it is not simply a matter of stopping one train. The effect reverberates through the entire system (or a large part of it). Thus, the effects of a single failure can produce hazards of greater significance than the failure itself, hazards which persist long after the failure has been corrected.

The advantage of system safety analysis techniques, when applied to modern transit systems, is that they enable the safety analyst to identify those parts of the system which are critical to safety, and to trace the paths where failure must be prevented. In turn, this shows the designer of the system which parts of the system must be provided with redundant components, functionally equivalent mechanisms, self-checking circuits, inhibitory devices, etc.

3.3 SYSTEM SAFETY ANALYSES APPLICABLE TO TRANSIT

This section describes the nature and purposes of the six system safety analysis techniques relevant to transit systems.

3.3.1 Preliminary Hazard Analysis

System safety has an effect on the entire life cycle of a transit system, from preliminary engineering through operations. The preliminary hazard analysis is the first safety analysis performed in transit systems being developed or in existing systems where extensions or rehabilitations are planned. It is defined as a systematic listing and assessment of conditions which could potentially affect the safe operation of a system. The PHA uses the bottom-up approach described in Section 2.1 to identify hazards and relate them to the entire system.

The PHA, also known as a gross hazard analysis, is a comprehensive study of the system as a whole, in its operating environment. Although the PHA is the first safety analysis performed in a system safety program (hence, the term "preliminary"), it is updated throughout the program; therefore the information it provides should be thought of not as preliminary but rather as broad in nature and covering all elements of the system.

Determining potential hazards early in the planning stage by performing a PHA minimizes the need for costly design changes later in the acquisition phase. Since the scope of the PHA encompasses the total system, it serves as a basic hazard analysis framework from which other hazard analyses and safety evaluations can be derived.

The purposes of conducting a PHA are to:

- Develop scenarios of hazardous situations which could exist within the transit system by identifying hazards; developing the effects of the hazards and the potential injuries to people and damage to equipment; ranking the hazards according to severity; and proposing possible means by which the hazards can be eliminated or controlled

- Document the history of incorporating safety improvements during the system development by documenting decisions made to resolve safety issues; identifying feasible alternatives for preventing hazards; and providing a history explaining why certain procedures were needed and developed

- Provide the basic framework for incorporating lower-level analyses (i.e., subsystem hazard analysis, operating hazard analysis) into a larger, more comprehensive analysis covering the entire system

- Provide the basis for developing or revising a manual of rules and procedures.

3.3.2 Subsystem Hazard Analysis

A subsystem hazard analysis is used to determine subsystem hazards that could adversely affect the safe operation of the total system. It is similar to a preliminary hazard analysis except that it is confined to a specific subsystem and is more detailed. The preliminary hazard analysis defines general elements of the subsystem which require analysis, while the SSHA expands these elements to include the entire subsystem. Therefore, the SSHA is performed after the initial PHA has been completed. And, like the PHA, the SSHA uses the bottom-up approach to investigate the effects on the system of lower-level events.

The SSHA is performed after the subsystem has been fully defined and detailed design information is available. The level of insight provided by an SSHA depends on the extent to which the subsystem hardware configuration is defined. The SSHA identifies components and lower-level elements whose performance, degradation, functional failure or inadvertent functioning can cause a hazard.

The results of the SSHA are used to update the PHA and to increase its level of detail. The SSHA is usually performed only once and is updated only if the subsystem design changes.

An SSHA is conducted to:

- Identify specific subsystem design features that can potentially impact the safe operation of the system

- Identify areas where design changes are necessary to eliminate or control hazards

- Identify safety-related interfaces between various elements of a subsystem

- Determine a baseline for evaluating safety aspects of proposed design changes.

3.3.3 Interface Hazard Analysis

The interface hazard analysis is used to determine hazards associated with the integration and interface of subsystems. It is similar to both the preliminary hazard analysis and the subsystem hazard analysis, using the bottom-up approach to identify hazards present in the interfaces among the subsystems. The IHA is also called a system hazard analysis because it analyzes the interfaces of the entire system. However, "system hazard analysis" is somewhat misleading, as it implies that the entire system is analyzed when in fact the IHA covers subsystem interfaces only.

An IHA is performed after the initial PHA has identified hazards in the overall system. A preliminary IHA can then be performed by considering each of the subsystems as "black boxes" and analyzing the potential hazards that their integration could cause. The initial IHA can be performed concurrently with the subsystem hazard analysis so that the hazards can be eliminated or controlled during the design of the individual subsystems. However, the IHA should be revised after the SSHA is complete to ensure that hazards which are present in the actual integration of the subsystems are identified and resolved. The results of the IHA are used to update the PHA and to increase its level of detail. The IHA results are also used as input to the operating hazard analysis in those cases where the hazard resolution requires special procedures.

The purposes of conducting an IHA are to:

- Ensure that hazards associated with subsystem interfaces have been addressed

- Identify hazards that may not have been identified during the subsystem hazard analysis

- Identify hazards created by the integration of the subsystems into the total system

- Identify hazards created by one subsystem that could affect the safe operation of other subsystems

- Allow the identification of independent, dependent or simultaneous failures that could potentially affect the safe operation of the system.

3.3.4 Operating Hazard Analysis

The operating hazard analysis is a systematic review and assessment of the activities required in the test, operation or maintenance of equipment to determine those conditions which could lead to injury, death or equipment damage.

An OHA can be applied to the operation of a system, subsystem or item of equipment, as well as to the activities of testing and maintenance. However, because of the detailed level of the analysis, only one activity can be analyzed at a time. Although an OHA can be performed on either human or automatic activities, its primary purpose is to identify and evaluate hazards associated with the man/machine interface. It uses a bottom-up approach to achieve these ends.

An operating hazard analysis differs from the previous hazard analyses discussed in that its standardized format is supplemented with additional data. An OHA consists of:

- A detailed activity description
- An activity sequencing diagram
- An OHA columnar form
- Revised or newly developed procedures.

Because it is complex and performed at a very detailed level, the OHA is time-consuming and can be highly expensive if performed on an unlimited basis. Therefore, an operating hazard analysis should be considered only for areas known or suspected to have a significant impact on the safe operation of the system. These problem areas can be determined from previous analyses (PHA, SSHA, etc.), the experience of the analyst, or the history of prior use. An OHA can be extremely beneficial when applied to areas such as procedures necessary for passenger evacuation following a collision or derailment.

The results of the operating hazard analysis provide input to testing, operation and maintenance procedures.

The input is usually in the form of warning or caution devices, special emergency procedures, or revisions to existing or proposed safety procedures. The OHA should be performed before and during the integrated testing of a property under development and whenever a procedural problem is identified or changes are made to equipment in an existing property.

The benefits derived from conducting an OHA are:

- Identification of hazards to employees involved in the test, operation or maintenance of equipment
- Identification of hazards to the system and passengers as a result of testing, operation or maintenance procedures
- Assurance that the hazards associated with the test, operation and maintenance of equipment have been eliminated or controlled
- Allocation of training resources to areas that provide the most benefit
- Documentation of why certain procedures were developed or changed.

3.3.5 Fault Tree Analysis

A fault tree analysis is a systematic method for identifying factors that could cause an undesired event to occur. It is one of the principal techniques used to analyze system safety.

The FTA provides a systematic, descriptive approach to the identification, assessment and control of hazards. It can be used to identify potential problem areas, evaluate their impacts on the system, and numerically assess the level of safety inherent in the system design.

A fault tree analysis is used to analyze a specific system failure or an undesired event. By analyzing the conditions that cause the undesired event to occur, the FTA identifies the component failures or combinations of failures that cause the event to occur. These failures or subsequent undesired events are also analyzed to determine their causes. This top-down approach continues until the entire system is graphically represented (in a fault tree) through a combination of logic gates and events. At this point, depending upon the desired result of the analysis, probabilities can be assigned to the lower-level events. By using Boolean algebra, the probability of the main undesired event or system failure can be calculated.

Because of its versatility, a fault tree analysis can be used for a variety of reasons. Depending upon how detailed the analysis is, and whether quantitative results are desired, an FTA can be used to determine:

- Causes of system failure
- Probability of system failure
- The functional relationship of human errors and equipment failure
- The level of protection the system design provides against failures
- An integrated picture of the system operation
- Potential events which could affect multiple subsystems
- The impact that changes to the system design would have on the overall system failure.

3.3.6 Fault Hazard Analysis

A fault hazard analysis identifies hazards at the component level. It is a systematic process for examining failure modes, determining their subsequent effects on the subsystem and system, and identifying associated safety hazards. The FHA, because it analyzes the effects of component failure modes on the subsystem and system, can be used to supplement both the fault tree analysis and preliminary hazard analysis. The FHA is derived from the failure mode and effects analysis, which emphasizes reliability. However, the emphasis in the FHA is on safety. Both techniques use the bottom-up approach.

Because the FHA is performed at the component level instead of at the overall system level, the design of the subsystem being analyzed must be detailed. However, the FHA is most valuable when used before the design is finalized or committed to production. Otherwise, any changes to the design resulting from the analysis could have severe cost implications. For these reasons, there is only a brief time period during which an FHA is optimally cost-effective.

The FHA is the primary analysis technique used to ensure that the hazardous effects of component failures on system operation are identified. These component failures are examined for:

- Their effects on system operation
- The safety implications of their occurrence.

Thus, the FHA provides identification of component failures and their effect on both equipment and personnel.

The purposes of conducting an FHA are to:

- Isolate components and identify component failure modes that adversely affect system safety

- Identify the effects that component failure modes have on other components in the subsystem and on the subsystem itself

- Provide data for determining the effect of design changes to the subsystem

- Provide rationale for altering designs in order to eliminate or control hazards.

4.0 FORMATS AND METHODOLOGIES OF SYSTEM SAFETY ANALYSES APPLICABLE TO FIXED GUIDEWAY TRANSIT SYSTEMS

4.0 FORMATS AND METHODOLOGIES OF SYSTEM SAFETY ANALYSES APPLICABLE TO FIXED GUIDEWAY TRANSIT SYSTEMS

The formats and methodologies for the following analyses are contained in this chapter:

- Preliminary hazard analysis (PHA)
- Subsystem hazard analysis (SSHA)
- Interface hazard analysis (IHA)
- Operating hazard analysis (OHA)
- Fault tree analysis (FTA)
- Fault hazard analysis (FHA).

A recommended format with appropriate definitions and a methodology are described separately for each analysis. An example of how each type of analysis can be applied to a fixed guideway transit system is also presented.

Except for fault tree analysis, all of the analysis techniques described in this chapter use a columnar format. The formats for three of these analysis techniques (PHA, SSHA and IHA) are very similar. To permit easy comparison, Figure 4-1 presents a cross section of the headings of all five columnar formats.

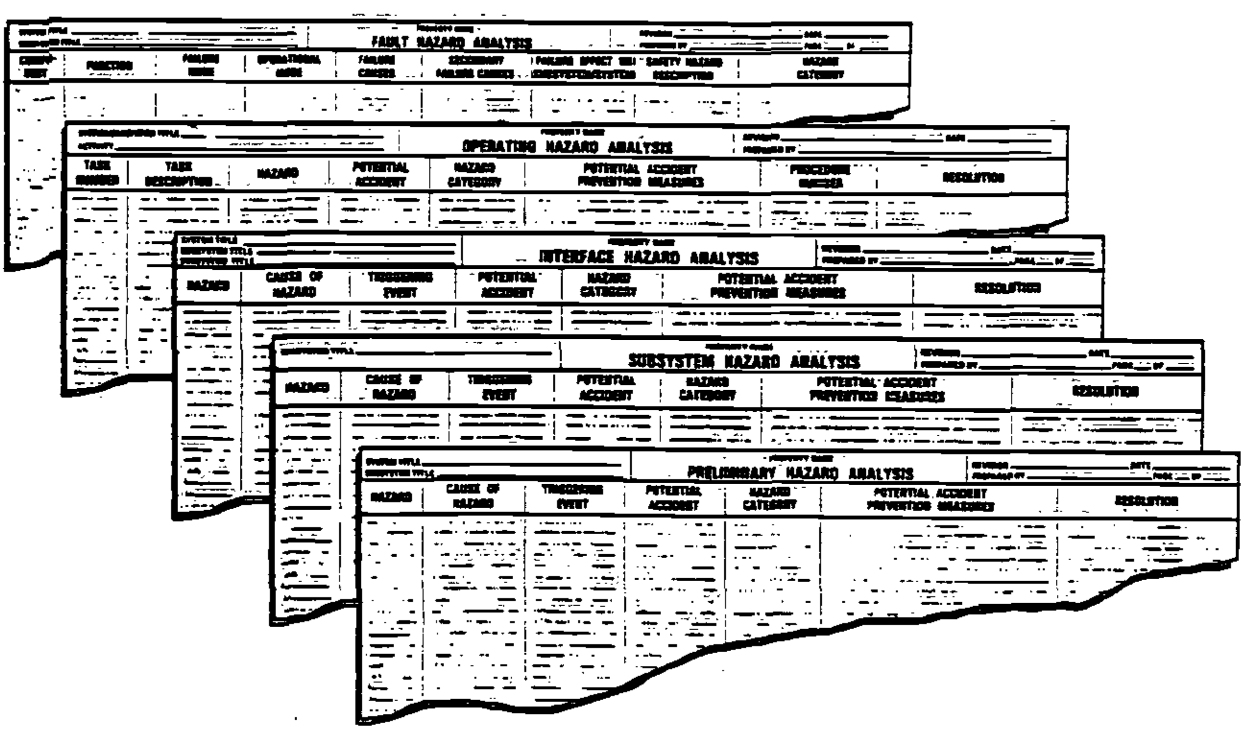


FIGURE 4-1
Cross Section of Analysis Formats

4.1 PRELIMINARY HAZARD ANALYSIS

The preliminary hazard analysis format and the methodology for performing the analysis are described below.

4.1.1 PHA Format

Figure 4-2 shows the format for and the definitions which pertain to a preliminary hazard analysis.

4.1.2 Methodology for Performing a PHA

A PHA consists of the following three activities:

- Hazard identification
- Hazard assessment
- Hazard resolution.

The process used to accomplish each of these three activities is discussed below.

4.1.2.1 Hazard Identification

The three most common methods of identifying hazards are:

- Use of a hazard checklist in conjunction with the review of design and operation schemes
- Examination of conceptual design and operational schemes using the analyst's experience to postulate hazards
- An examination of information and data from similar systems.

The hazard checklist is merely a listing of hazards that are generic in nature and could appear in a variety of systems. The hazard checklist is used to stimulate the safety analyst's thoughts on what hazards may exist in the system and their effects. Although several hazard checklists developed in other industries have been applied to transit, the development of a specialized checklist for a transit system would facilitate application of the PHA to fixed guideway transit systems.

The use of conceptual design and operational schemes to postulate a hazard is the second method used in hazard identification. The validity of using this method to

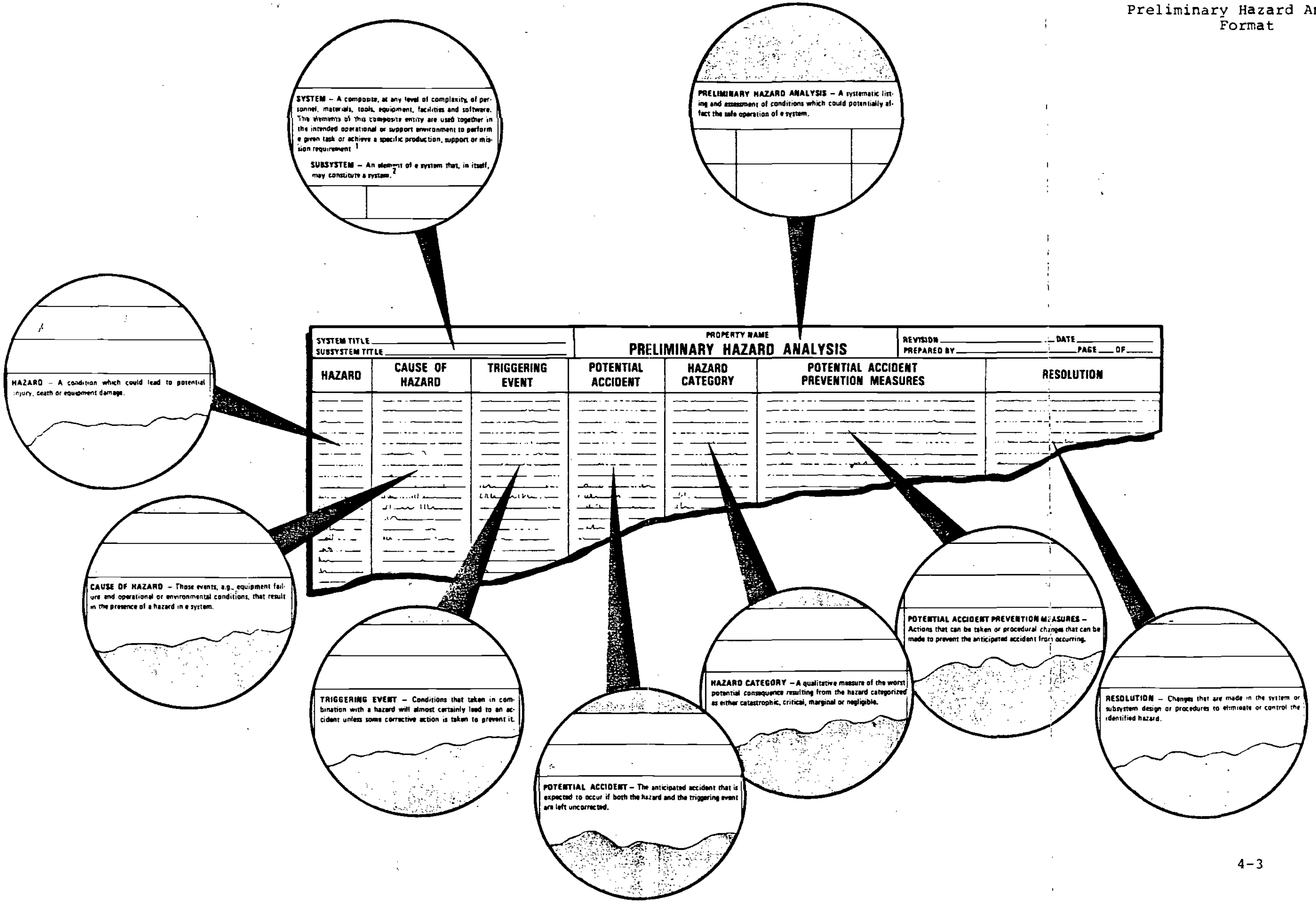


FIGURE 4-2
Preliminary Hazard Analysis
Format

identify hazards depends heavily upon the proficiency and experience of the analyst. To use this approach, the analyst reviews design data which describe the system to be analyzed and gathers information from both design and operational personnel. The analyst then uses imagination, intuition and logic to identify hazards which could exist in the system. Questions he tries to answer during the process typically take the form of "What would happen if...," or "How can specific equipment fail?" and the like.

The examination of data from similar systems is the third method used to identify hazards. This approach basically consists of researching accident/injury data from other transit systems. Sometimes the data reports list the causes of the accident or injury. If they do, the analyst can readily identify the hazards. If causes are not given, the analyst must use available information to help identify similar hazards that could exist in the system being analyzed.

In a typical PHA, the analyst uses all three methods listed above to identify possible hazards in the system.

4.1.2.2 Hazard Assessment

After a specific hazard has been identified, the next step is to assess its impact on the system. First, however, it is necessary to define the events which must be present in order for the hazard to precipitate an accident. Triggering events can occur normally in the operation of a system or they can be abnormal occurrences or "mistakes." The presence of the hazard and the occurrence of the triggering event lead to a potential accident.

For example, assume that the transit system being analyzed is a rail rapid system with automatic train operation (ATO). A hazard could be "train door opens at a location that does not have a platform." This hazard could be caused by a false "train berthed" signal being transmitted by ATO. When this hazard is coupled with a triggering event ("a passenger who does not recognize the situation exits the train through the open door") the situation becomes more serious. Unless some corrective action is taken, an accident in which passengers step or fall onto the guideway is likely to occur.

After a hazard is developed into a potential accident by defining a triggering event, the hazard scenario is judged by the analyst to be in one of the four following severity categories.

- Category I (Catastrophic): A hazard that may result in loss of life
- Category II (Critical): A hazard that may result in severe injury, severe occupational illness or major system damage
- Category III (Marginal): A hazard that may result in minor injury, minor occupational illness or minor system damage
- Category IV (Negligible): A hazard that will not result in injury, occupational illness or system damage.

4.1.2.3 Hazard Resolution

Hazard resolution is defined as the elimination or control of hazards. Although elimination of hazards is the ultimate goal, it is often impractical to achieve since the most significant method of eliminating a hazard is to design it out of the system. Therefore, control of a hazard is the most widely used form of hazard resolution.

To perform the hazard resolution, the safety analyst (having developed a hazard scenario) proposes alternative methods of preventing an accident from occurring. These methods will consist of suggestions for eliminating or controlling the hazard. The suggested alternatives can be either design or procedural changes, or both.

The four sequential steps for hazard resolution are:

- Design for minimum hazard. The major effort throughout the system development process must be to ensure inherent safety through the selection of appropriate design features.
- Safety devices. Known hazards that cannot be eliminated through design selection must be eliminated or controlled at an acceptable level through the use of appropriate safety devices.

- Warning devices. Where it is not possible to preclude the existence or occurrence of an identified hazard, devices must be employed for the timely detection of the condition and the generation of an adequate warning signal.

- Special procedures. Where it is not possible to reduce the magnitude of a hazard through design or the use of safety and warning devices, special procedures and/or precautionary instructions must be developed.

After the alternative solutions are listed, the actual resolution of the hazard is determined and documented in the PHA. Although the hazard resolution is not always one of the proposed alternatives, traceability of safety decisions is provided by documenting the chosen resolution in the PHA.

4.1.3 Example of a Preliminary Hazard Analysis

Figure 4-3 displays a partially completed PHA for a manually operated rail system with wayside aspects for train protection. A single hazard was explored and no attempt was made to delineate exhaustively all causes of the hazard.

SYSTEM XYZ LRT SYSTEM SUBSYSTEM TITLE WAYSIDE SIGNALING		PROPERTY NAME PRELIMINARY HAZARD ANALYSIS			REVISION ____ DATE ____ PREPARED BY ____ PAGE ____ OF ____	
HAZARD	CAUSE OF HAZARD	TRIGGERING EVENT	POTENTIAL ACCIDENT	HAZARD CATEGORY	POTENTIAL ACCIDENT PREVENTION MEASURES	RESOLUTION
SIGNAL DISPLAYED IMPROPERLY	TRACK CIRCUIT MALFUNCTION	TRAIL TRAIN MOVES INTO OCCUPIED CONTROL AREA	REAR-END COLLISION	I	MAKE CERTAIN FAIL-SAFE PHILOSOPHY IS PROPERLY APPLIED IN CONJUNCTION WITH FULL ANALYSIS OF EQUIPMENT RELIABILITY PROPERTIES	

FIGURE 4-3
Preliminary Hazard Analysis Example

4.2 SUBSYSTEM HAZARD ANALYSIS

The format and methodology for performing a subsystem hazard analysis are very similar to the PHA's format and methodology; the basic difference is in their scope. As described in Section 3.3.2, the SSHA is confined to a specific subsystem and is more detailed than a PHA.

4.2.1 SSHA Format and Methodology

The SSHA format is identical to the PHA format, with the exception of (1) the title and (2) changing "system title" to "subsystem title" in the top left section of the format.

The methodology for performing an SSHA is the same as the PHA methodology, which was described in Section 4.1.2.

4.2.2 Example of a Subsystem Hazard Analysis

The subsystem hazard analysis example displayed in Figure 4-4 examines a wayside signaling system. A single hazard was explored and no attempt made to determine exhaustively all of the causes of the hazard. The definitions of the SSHA format headings are the same as those presented in Figure 4-2.

SUBSYSTEM TITLE WAYSIDE SIGNALING		PROPERTY NAME SUBSYSTEM HAZARD ANALYSIS			REVISION ____ DATE ____ PREPARED BY ____ PAGE __ OF __	
HAZARD	CAUSE OF HAZARD	TRIGGERING EVENT	POTENTIAL ACCIDENT	HAZARD CATEGORY	POTENTIAL ACCIDENT PREVENTION MEASURES	RESOLUTION
WAYSIDE SIGNAL IMPROPERLY DISPLAYED	AMPLIFIER GAIN INCREASE RELAY FAILURE	TRAIL TRAIN MOVES INTO OCCUPIED CONTROL AREA	REAR-END COLLISION	I	RECEIVER COUPLING AND AMPLIFICATION MUST USE FAIL-SAFE DESIGN USE NON-WELDABLE CONTACTS; DESIGN FOR KNOWN MINIMUM PICK-UP VOLTAGE	

FIGURE 4-4
Subsystem Hazard Analysis Example

4.3 INTERFACE HAZARD ANALYSIS

The interface hazard analysis format and the methodology for performing the analysis are described below.

4.3.1 IHA Format

The format used in performing an IHA (shown in Figure 4-5) is similar to that used in performing a PHA. The format differences include:

- The title
- The addition below the "system title" of space for two subsystem titles, in the top left section of the format.

The definitions of the IHA format headings are the same as those presented in Figure 4-2.

4.3.2 Methodology for Performing an IHA

The following steps should be followed to perform an interface hazard analysis:

- Step 1--Identify each of the subsystems contained in the total system.
- Step 2--Construct a block diagram to indicate how the subsystems functionally interface in the overall system context. Label each block in the diagram with the name of the subsystem it represents.
- Step 3--List the name of the system being analyzed on the IHA format.
- Step 4--Using the block diagram developed in Step 2, list the names on the IHA format of two systems that interface.
- Step 5--Using the process described in Section 4.1.2 on PHA methodology, identify the hazards that are present in the functional connection of any subsystem to another subsystem. The output from one subsystem should be analyzed for its effect on the input to any other subsystem. In this analysis factors to be considered include zero output, degraded output, erratic output,

excessive output, mismatched connectors and improper clearances. Typical areas to be analyzed include electrical signals, transmission of torque, etc.

- Step 6--Continue completing the information required in the IHA format columns using the same procedures as those described in Section 4.1.2 for a PHA.

- Step 7--Repeat Steps 4 through 6 for each subsystem identified in the block diagram.

After the analysis is complete, the results are used as input to expand the PHA or to change subsystem designs, or they can be analyzed further by using the operating hazard analysis.

4.3.3 Example of an Interface Hazard Analysis

Figure 4-5 displays a partially completed interface hazard analysis of the interface between a vehicle and wayside signaling. A single hazard was explored and no attempt made to delineate exhaustively all causes of the hazard.

SYSTEM XYZ LRT SYSTEM SUBSYSTEM TITLE VEHICLE SUBSYSTEM TITLE WAYSIDE SIGNALING		PROPERTY NAME INTERFACE HAZARD ANALYSIS			REVISION ____ DATE ____ PREPARED BY ____ PAGE __ OF __	
HAZARD	CAUSE OF HAZARD	TRIGGERING EVENT	POTENTIAL ACCIDENT	HAZARD CATEGORY	POTENTIAL ACCIDENT PREVENTION MEASURES	RESOLUTION
TRAIN DOES NOT SHUNT TRACK CIRCUIT	EFFECTIVE SHUNT RESISTANCE TOO HIGH	TRAIL TRAIN MOVES INTO OCCUPIED CONTROL AREA	REAR-END COLLISION	I	DEVELOP PROCEDURES TO PERIODICALLY CLEAN RAILS WELD STAINLESS STEEL BEADS ON INFREQUENTLY USED RAIL SPECIFY LOW RESISTANCE FOR TRUCK	

FIGURE 4-5
Interface Hazard Analysis Example

4.4 OPERATING HAZARD ANALYSIS

The operating hazard analysis format and the methodology for performing the analysis are described below. An example of an OHA is also presented.

4.4.1 OHA Format

Figure 4-6 presents the format for an operating hazard analysis and includes definitions of the format headings.

4.4.2 Methodology for Performing an OHA

The procedure for performing an operating hazard analysis is described below:

- Step 1--Identify the activity to be analyzed. Source documentation that can be used to identify activities requiring an operating hazard analysis includes:

  - Preliminary hazard analysis
  - Subsystem hazard analysis
  - Interface hazard analysis
  - Operating procedures
  - Maintenance procedures
  - Test procedures.

  Because an operating hazard analysis is a fairly complex and time-consuming analytical technique, the activity to be analyzed should be carefully selected and defined.

- Step 2--Describe the activity to be analyzed in detail. This detailed description must include identification of the tasks or actions necessary to perform the activity. Additional information to be contained in the description includes:

  - Location of the equipment being tested, operated or maintained

  - System operating mode at the time the activity is to be performed

  - Subsystem operating mode at the time the activity is to be performed

  - Identification of any other subsystem affected by the activity.

The description must be sufficiently detailed to permit any unsafe aspects of the activity to be identified.

- Step 3--From the description of the activity, develop an activity sequencing diagram of all the tasks to be performed. The symbology for the sequencing diagram is shown in Figure 4-7.

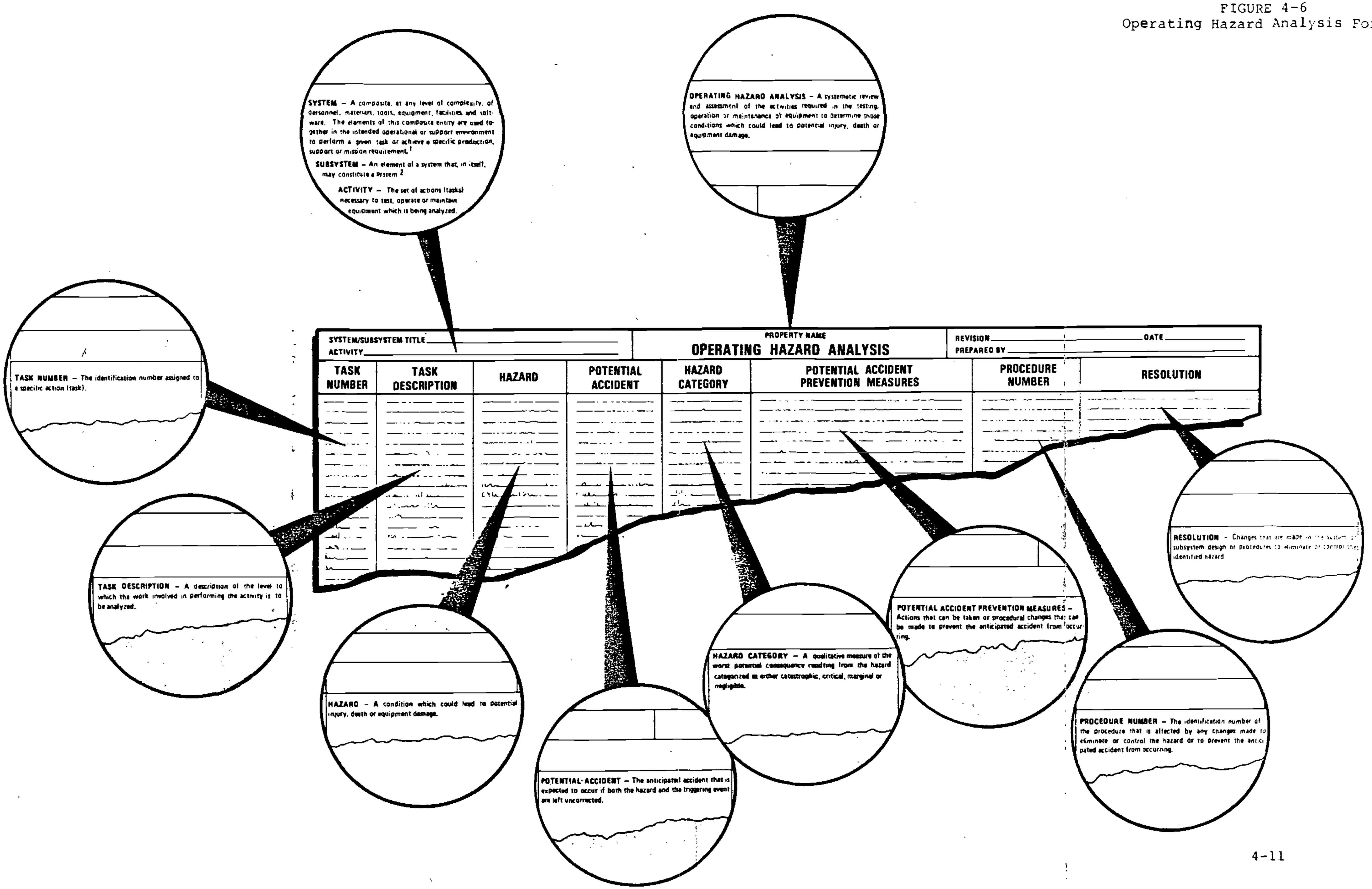
DESCRIPTION	SYMBOLOGY
TASKS WHICH MAY BE PERFORMED IN SEQUENCE, BUT NOT CONCURRENTLY	TASK 1 TASK 2 TASK 3
TASKS WHICH MAY BE PERFORMED CONCURRENTLY OR CONSECUTIVELY.	TASK 1 / TASK 2
TASKS WHICH MUST BE PERFORMED CONCURRENTLY.	TASK 1 ↕ TASK 2
TASKS WHICH MUST BE PERFORMED IN A MANDATORY SEQUENCE: (ALL TASKS PRIOR TO AN ARROW MUST BE ACCOMPLISHED BEFORE PROCEEDING TO NEXT TASK.)	TASK 1 → TASK 2 → TASK 3

FIGURE 4-7
Sequence Diagram Symbology

- Step 4--Complete the operating hazard analysis in the format shown in Figure 4-6, using information from both the activity description (Step 2) and the sequencing diagram (Step 3).

- Step 5--Revise the sequencing diagram (Step 3) to incorporate changes in the task sequencing or additions or deletions of tasks. The revisions to the sequencing diagram are based upon those items appearing in the accident prevention measure column of the OHA format. If it is determined from the operating hazard analysis that any task necessary to perform the activity

FIGURE 4-6
Operating Hazard Analysis Format



has hazards associated with it, then the hazards must be eliminated or controlled. The hazard resolution may not be limited to procedural changes, but may also involve design changes or installation of safety or warning devices. In any of these cases, the sequencing diagram will require updating to correctly describe the revised activity.

- Step 6--Revise the activity description (Step 2) to incorporate the results of the OHA. This will necessitate either revising the written procedure, if it was used as input to the activity description, or ensuring that the activity description and the sequencing diagram are used in the development of new procedures.

4.4.3 Example of an Operating Hazard Analysis

An operating hazard analysis of a vehicle tachometer recalibration is presented in this section. When the wheels on a vehicle are machined to restore the running surface or when they are replaced, the vehicle tachometer must be recalibrated to reflect the new diameter of the wheel. The vehicle speed indicator is related to the rotation speed of the wheel. Therefore, if the tachometer is incorrectly recalibrated, the vehicle can be moving at a higher speed than is indicated by the speed indicator. False indication of the vehicle speed can contribute to the derailment of the vehicle.

For simplicity, the OHA example is performed only on those tasks that are required for the actual tachometer recalibration. The hypothetical procedure number 001 lists these tasks as:

- Measure diameter of wheel
- Determine tachometer compensation from wheel wear table
- Open door to train control equipment (which is located in the vehicle equipment cabinet)
- Set wheel wear compensation switch to proper setting
- Close door to train control equipment

Figure 4-8 is a sequence diagram of the above tasks, and Figure 4-9 presents the operating hazard analysis.

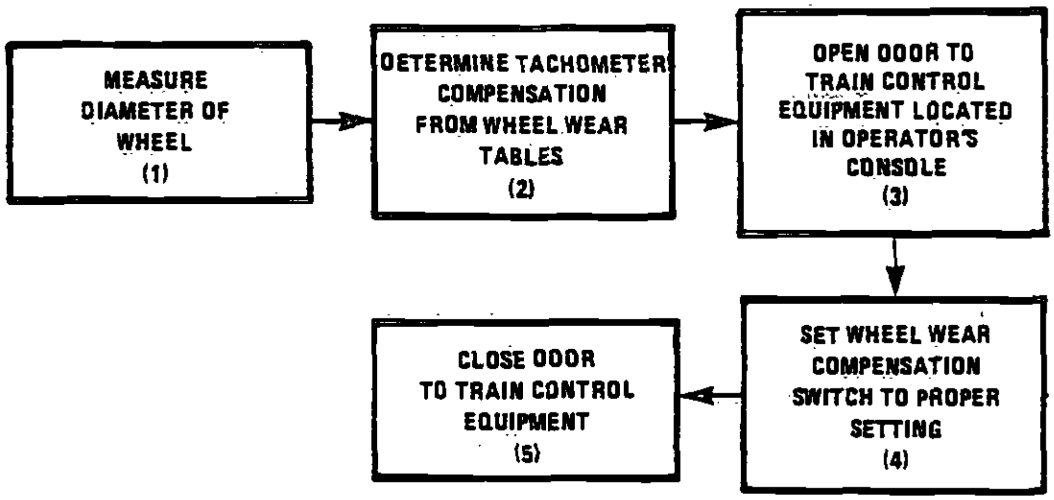


FIGURE 4-8
Sequence Diagram Example: Tachometer Recalibration After Installation of New Wheels

SYSTEM/SUBSYSTEM TITLE VEHICLE-TRAIN CONTROL ACTIVITY RECALIBRATION OF TACHOMETER AFTER INSTALLATION OF NEW WHEELS				PROPERTY NAME OPERATING HAZARD ANALYSIS		REVISION ____ DATE ____ PREPARED BY ____	
TASK NUMBER	TASK DESCRIPTION	HAZARD	POTENTIAL ACCIDENT	HAZARD CATEGORY	POTENTIAL ACCIDENT PREVENTION MEASURES	PROCEDURE NUMBER	RESOLUTION
(1)	MEASURE DIAMETER OF WHEEL	INCORRECT MEASUREMENT MEASURED WHEEL FROM WRONG AXLE	DERAILMENT	I	CHANGE PROCEDURE TO INCLUDE: —CHECK BY 2nd PERSON —INSTRUCTION ON WHICH WHEEL TO MEASURE	001	PROCEDURE 001 CHANGED
(2)	DETERMINE TACHOMETER COMPENSATION FROM WHEEL WEAR TABLE	TABLE READ INCORRECTLY	DERAILMENT	I	CHANGE PROCEDURE TO INCLUDE CHECK BY 2nd PERSON	001	PROCEDURE 001 CHANGED
(3)	OPEN DOOR TO TRAIN CONTROL EQUIPMENT	-	-	-	-	001	-
(4)	SET WHEEL WEAR COMPENSATION SWITCH TO PROPER SETTING	SET WRONG SWITCH SET SWITCH INCORRECTLY	DERAILMENT	I	CHANGE PROCEDURE TO INCLUDE CHECK BY 2nd PERSON	001	PROCEDURE 001 CHANGED
(5)	CLOSE DOOR TO TRAIN CONTROL EQUIPMENT	-	-	-	-	001	-

FIGURE 4-9
Operating Hazard Analysis Example

4.5 FAULT TREE ANALYSIS

A fault tree analysis is a systematic method for identifying factors that could cause an undesired event to occur. This section contains definitions of fault tree symbols, the methodology for an FTA, an example of fault tree construction and a discussion of fault tree quantification.

4.5.1 Fault Tree Symbols

Figure 4-10 presents definitions of the symbols used in the construction of a fault tree.

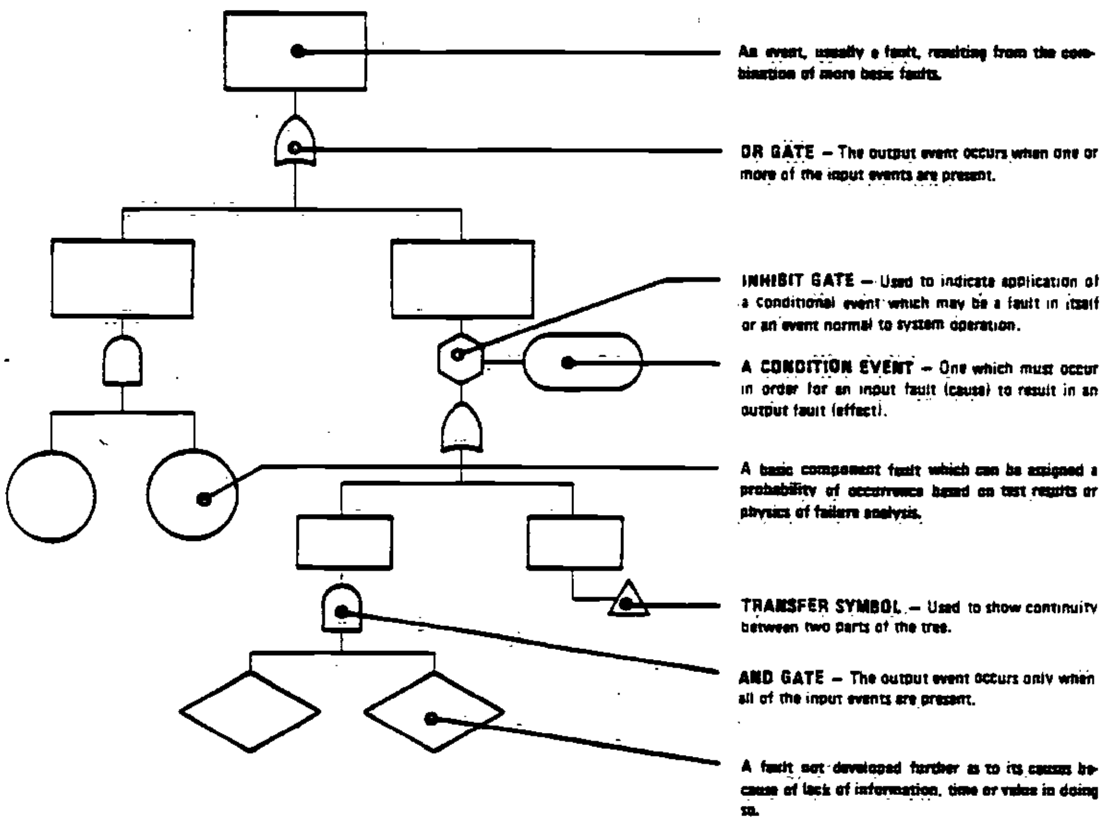


FIGURE 4-10
Fault Tree Symbols

4.5.2 Methodology for Performing an FTA

The goal of fault tree analysis is to model the conditions that can result in the undesired event. Therefore, careful consideration must be given to the selection of the undesired event. It must be specifically defined so that the fault tree is limited to only those areas that are to be considered. To construct the fault tree, the safety analyst must have a thorough understanding of the system. This understanding must include the various modes of system operation and the component failures that can occur.

Another decision the analyst must make prior to constructing the fault tree is whether the analysis is to be limited to primary failures or whether it will be extended to include secondary and command failures.

- Primary failures are component failures that occur when the component is operating within design conditions--for example, failure of a motor because of insulation breakdown.

- Secondary failures are component failures that occur when the component is subjected to abnormal stresses exceeding design conditions--for example, failure of a motor because of excessive external temperature or vibration, or because it is overloaded as a result of dragging brakeshoes.

- Command failures occur when a commponent state or event occurs at the wrong time because of the receipt of a command. Command failures may be caused by system faults or as a result of human error. For example, a command failure would be a circuit breaker opening due to a human error when it should be closed.

Including secondary and command failures in the fault tree analysis is a much more time-consuming and complex process than limiting the analysis to primary failures. However, in order to ensure that all events that contribute to the top undesired event have been identified, it is usually necessary to include all three failure types.

The procedure for constructing a fault tree is described below. For purposes of clarity, some steps of the process are referenced to the fault tree example shown in Figure 4-11. The condition analyzed is a rear-end collision of two trains. The system is equipped with wayside signaling. References to the fault tree example are contained in parentheses.

- Step 1--The undesired event to be analyzed is selected and its descriptor placed inside a rectangle at the top of the page.

- Step 2--The conditions, events and failures that could contribute to the occurrence of the undesired "top" event are determined by reviewing the system requirements, functions, design and environment.

- Step 3--The tree is constructed by diagramming events to show their relationship to each other and to the top event. The events that could directly cause the top event are placed on the first level ("trail train moves into occupied control area"; "trail train cannot stop in time to avoid a collision").

- Step 4--The procedure in Step 3 is repeated for each event on the fault tree. Combinations of events and failures that contribute to the occurrence of a higher-level event are added to the tree ("operator disobeys signal"; "wayside signal displayed improperly").

- Step 5--The process is continued until the desired level of detail is reached in the tree. A branch of the tree is usually developed to the point where additional development does not add significant insights to the particular analysis ("operator response inadequate") or to a component or subassembly level ("braking malfunction"). If the fault tree is to be quantified, the tree must extend to the level at which probabilities of occurrence can be assigned to each event. This level is represented by either a circle or a diamond, depending upon the nature of the event.

4.5.3 Fault Tree Quantification

Quantification of the fault tree may be desirable either to evaluate the probability of occurrence of a hazard which has been identified, or to evaluate the effect

effect of design improvements that have been incorporated into the system design. By using Boolean algebra, the probability expressions for the occurrence of the top undesired event can be derived. If the probability of occurrence of each input event is known, the probability of the top event can be calculated.

The process for quantifying the fault tree is described below.

- Step 1--Assign probabilities of occurrence to the events on the lowest levels of fault tree.

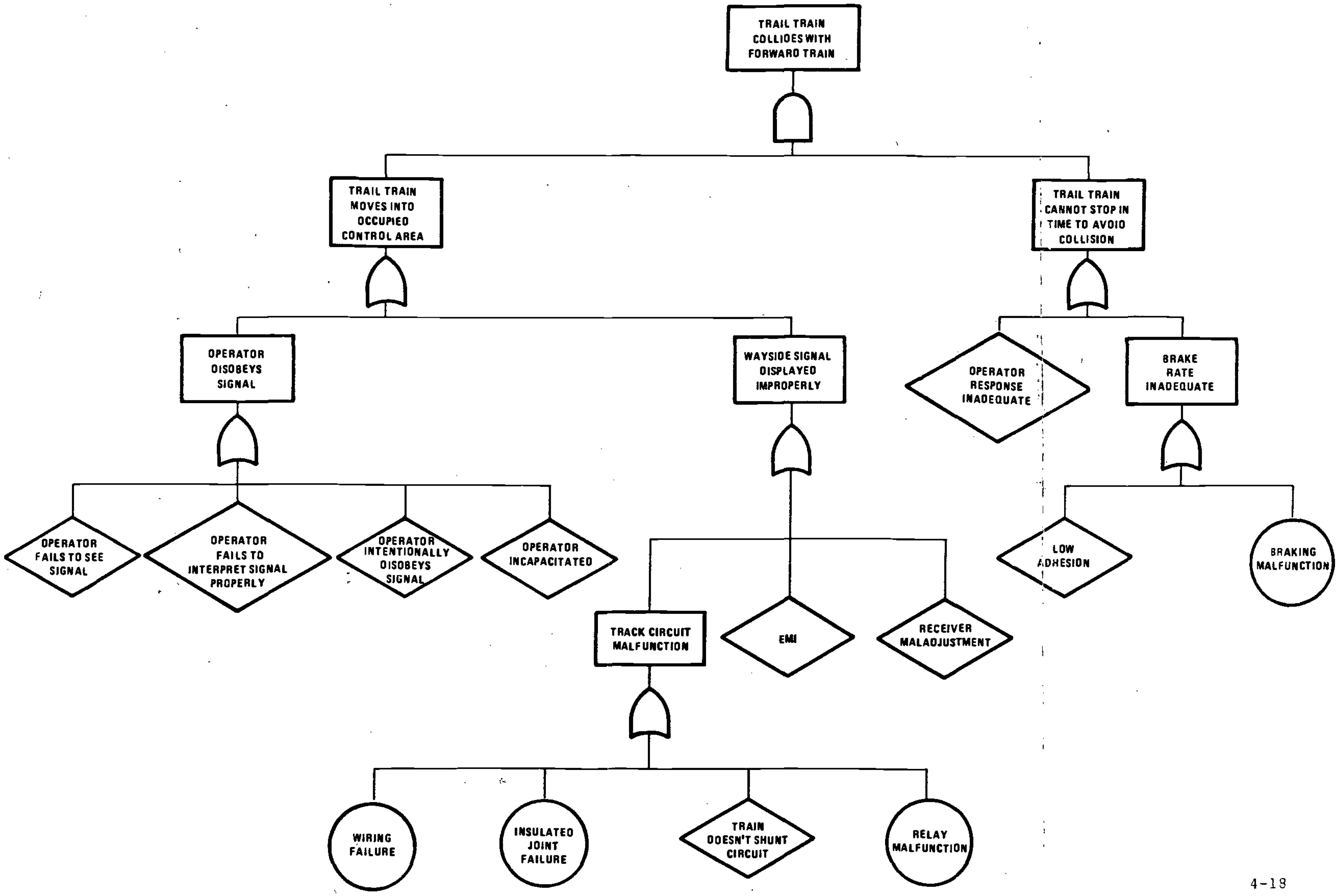
- Step 2--Use Boolean algebra to express relationships among the events shown in the fault tree. Where two (or more) events (X,Y) are linked by an OR gate to a higher-level event (Z), the Boolean expression is of the form $X + Y = Z$. Where two (or more) events are linked by an AND gate to a higher-level event, the Boolean expression form is $X \cdot Y = Z$; simplified, it becomes $XY = Z$.

- Step 3--Convert the Boolean expression to the corresponding algebraic expression. Assuming that X and Y are mutually exclusive events, the Boolean expression $X + Y = Z$ is converted to $P(X) + P(Y) = P(Z)$, where P(X), etc., represent the respective occurrence probabilities. For $XY = Z$, Z is impossible and $P(Z) = 0$, by definition. Where X and Y are independent events, the corresponding algebraic expression must avoid double counting of the probability of joint occurrence. Thus, the Boolean expression $X + Y = Z$ is converted to $P(X) + P(Y) - P(XY) = P(Z)$. The expression $XY = Z$ is simply converted to $P(X)P(Y) = P(Z)$.

- Step 4--Enter into the algebraic expression the probability of occurrence of the events on the lowest levels of the fault tree. Then, solve the equation to obtain the probability of occurrence of the event on the next higher level of the fault tree. Continue until the probability of occurrence of the top undesired event has been obtained.

To illustrate the fault tree quantification approach, Figure 4-12 presents an abridged version of the fault tree shown in Figure 4-11. (For the purposes of this example,

FIGURE 4-11
Fault Tree Analysis Example



the events in Figure 4-12 are considered to be mutually exclusive.) In the abridged fault tree, the Boolean expression for the lowest-level events is C + D = A. The corresponding algebraic expression is P(C) + P(D) = P(A). If Event C's probability of occurrence has been determined to be 0.01, and that of D also to be 0.01, then the probability of A [i.e., P(A)] is 0.01 + 0.01, which equals 0.02.

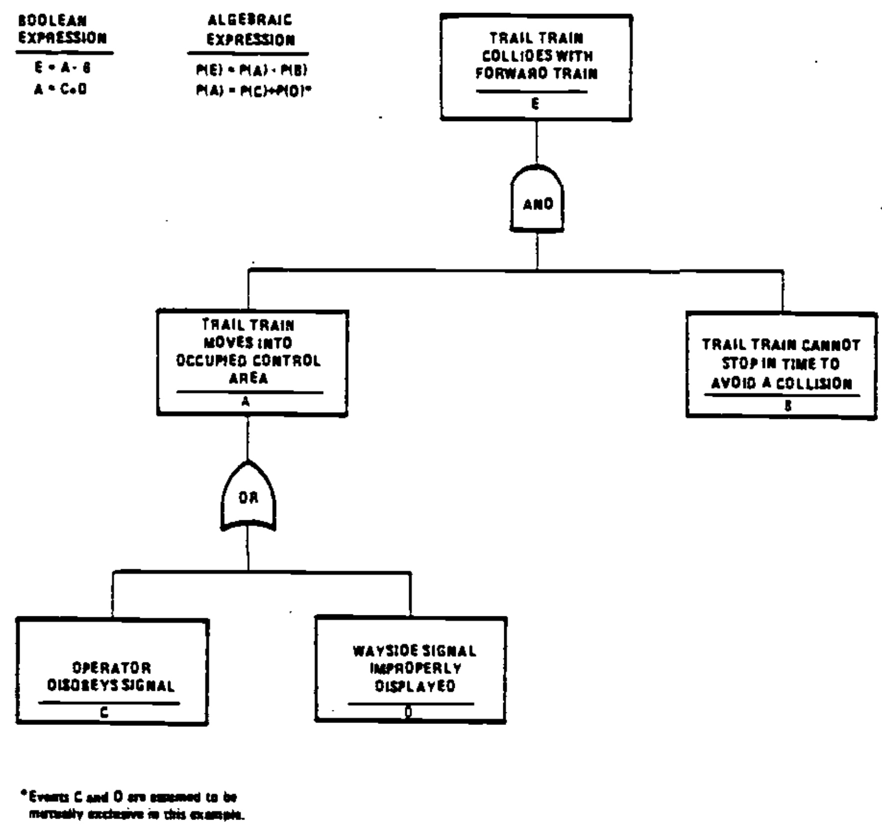


FIGURE 4-12
Fault Tree Quantification

The Boolean expression for the next higher level of events in Figure 4-12 is A · B = E, simplified to AB = E. The corresponding algebraic expression is P(A)P(B) = P(E). If the probability of B is known to be 0.1, and we have just determined the probability of A to be 0.02, then P(E) equals (0.02)(0.1), or 0.002. Thus, in this example, the probability that the top undesired event (E) will occur is 0.002.

When quantifying a fault tree, it is essential that the fault tree be developed to levels where data are available. For example, the fault tree presented in Figure 4-11 includes on its lowest level such events as "wiring failure" and "relay malfunction." These are events for which sufficient data are available to determine empirically their probability of occurrence; in fact, failure rate tables exist for many lower-level events.

4.6 FAULT HAZARD ANALYSIS

The fault hazard analysis format, the methodology for performing the analysis and an example of an FHA are contained in this section.

4.6.1 FHA Format

Figure 4-13 presents the format for a fault hazard analysis and includes definitions of the format headings.

4.6.2 Methodology for Performing an FHA

The subsystem to be analyzed must be well defined in order to perform an FHA. Once the subsystem is sufficiently defined and understood, the FHA may be performed according to the following procedure:

- Step 1--Prepare a complete list of all the components in the subsystem being analyzed.
- Step 2--Take the first component from the above list and enter it in the first column of the FHA format.
- Step 3--Determine the function that the component performs in the subsystem. If the component performs more than one function, list subsequent functions on the FHA format below the primary function.
- Step 4--Determine those failure modes of the component which have a reasonable chance of occurring. Make a separate entry for each unique manner in which the component can fail.
- Step 5--For each component failure mode, list the system operational mode that it affects. For example, if a component is only used during daily startup of the system, its failure would probably not affect normal operations.
- Step 6--List both the primary and secondary causes of the component failure.
- Step 7--List the effect that the component failure has on both the subsystem and the system.
- Step 8--Using the information from Step 7, determine if a hazard exists. This determination

is primarily based on whether or not the component failure affects the safe operation of either the subsystem or the system. If it is determined that a hazard exists, briefly describe it in the FHA format column labeled "Hazard Description."

- Step 9--Identify the category of the hazard and enter it in the FHA format.

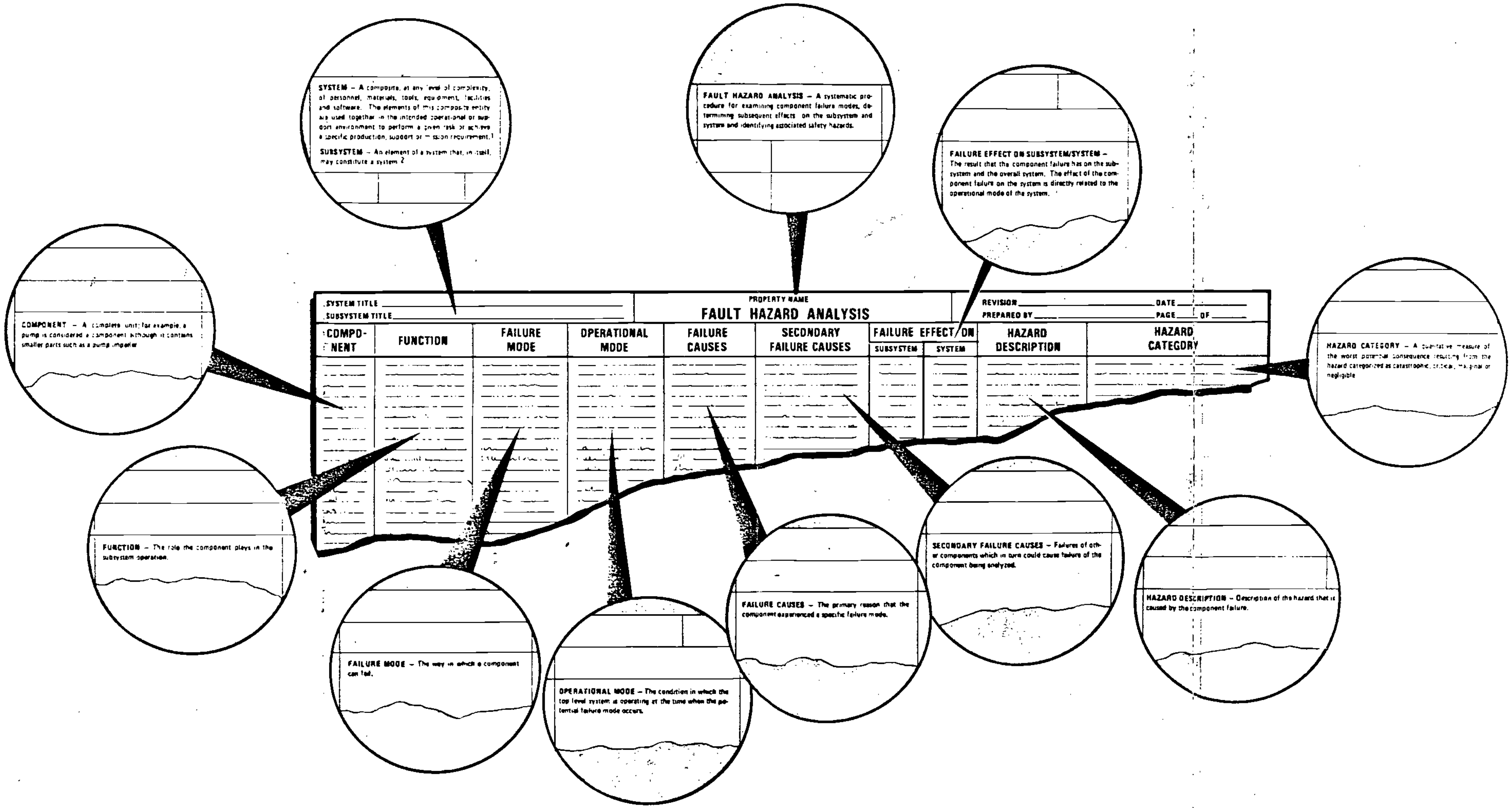
Steps 2 through 9 are repeated until every component on the list developed in Step 1 has been analyzed.

The FHA is not complete until a summary of the results has been prepared. If no hazards have been identified, this information should be documented. If hazards have been identified, they must be investigated to determine possible means for eliminating or controlling them. There are several ways to proceed at this point. A preliminary hazard analysis may be performed for each hazard identified by the FHA, in which case the hazard resolution will be documented in the PHA. An alternative is to prepare a report containing the necessary safety information. This report should suggest alternative methods for resolving the hazards and note the actual resolution chosen.

4.6.3 Example of a Fault Hazard Analysis

Figure 4-14 displays a partially completed fault hazard analysis of a signal relay from a wayside signaling subsystem. No attempt was made to explore exhaustively all failure causes or failure effects.

FIGURE 4-13
Fault Hazard Analysis Format



SYSTEM XYZ LRT SYSTEM SUBSYSTEM WAYSIDE SIGNALING				PROPERTY NAME FAULT HAZARD ANALYSIS		REVISION ____ DATE ____ PREPARED BY ____ PAGE ___ OF ___			
COMPONENT	FUNCTION	FAILURE MODE	OPERATIONAL MODE	FAILURE CAUSES	SECONDARY FAILURE CAUSES	FAILURE EFFECT ON		HAZARD DESCRIPTION	HAZARD CATEGORY
						SUBSYSTEM	SYSTEM		
SIGNAL RELAY	SWITCHES WAYSIDE SIGNAL INDICATION	CONTACTS ARE CLOSED WHEN THEY SHOULD BE OPEN	NORMAL OPERATION	CONTACTS WELDED CLOSED STUCK ARMATURE	SHORT CIRCUIT IN WIRING EMI	WAYSIDE SIGNAL DISPLAYED IMPROPERLY	INADEQUATE TRAIN SEPARATION	UNPROTECTED TRAIN	I

FIGURE 4-14
Fault Hazard Analysis Example

APPENDIX A

SOURCES

APPENDIX A

SOURCES

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APPENDIX B

GLOSSARY

APPENDIX B

GLOSSARY

acquisition phase - that phase of the life cycle of a system which extends from the time the decision is made either to build a new system or to extend or rehabilitate an existing system, to the time the system is put into revenue service.

bottom-up approach - typified by preliminary hazard analysis. This approach begins with a bottom or lower-level event or occurrence and proceeds upward to determine what effect the occurrence of the lower-level event has on the total system.

cause of hazard - those events, e.g., equipment failure and operational or environmental conditions, that result in the presence of a hazard in a system.

deductive - a method of reasoning by which concrete applications or consequences are deduced from general principles, to draw a conclusion necessarily from given premises.

design stage - the second stage of the acquisition phase of the development of a system. This stage begins at the onset of preliminary design and ends when the design is finalized and ready to go into production.

fail-safe - a characteristic of a system which ensures that any malfunction affecting safety will cause the system to revert to a state that is generally known to be safe.

fault hazard analysis (FHA) - a systematic process for examining failure modes, determining their subsequent effects on the subsystem and system, and identifying associated safety hazards.

fault tree analysis (FTA) - a systematic method for identifying factors that could cause an undesired event to occur.

hazard - a condition which could lead to potential injury, death or equipment damage.

hazard category - a qualitative measure of the worst potential consequence resulting from the hazard, categorized as either catastrophic, critical, marginal or negligible.

inductive - an instance of reasoning from a part to a whole, from particulars to generals or from the individual to the universal.

integration/test/checkout stage - the fourth (and last) stage of the acquisition phase of the life cycle of a system. This stage begins when the equipment is installed, extends throughout the period of system test and checkout, and ends when the system begins revenue operation.

interface hazard analysis (IHA) - determines hazards associated with the integration and interfaces of subsystems. Similar in approach to a preliminary hazard analysis.

operating hazard analysis (OHA) - a systematic review and assessment of the activities required in the test, operation or maintenance of equipment to determine those conditions which could lead to potential injury, death or equipment damage.

operational phase - that phase of the life cycle of a system which extends from the beginning of revenue service until the system is no longer in use.

planning stage - the first stage of the acquisition phase of the life cycle of a system. This stage begins with the decision to build a new system or extend or rehabilitate an existing system and ends at the onset of preliminary design.

potential accident - the anticipated accident that is expected to occur if the hazard and the triggering event are left uncorrected.

potential accident prevention measures - actions that can be taken or procedural changes that can be made to prevent the anticipated accident from occurring.

preliminary hazard analysis (PHA) - a systematic listing and assessment of conditions which could potentially affect the safe operation of a system.

procurement stage - the third stage of the acquisition phase of the life cycle of a system. This stage begins with the fabrication or construction of the equipment and facilities and ends with the final inspection and testing.

qualitative analysis - a review of all factors affecting the safety of a system.

quantitative analysis - a mathematical assessment of an actual or potential event, such as an accident.

resolution - changes that are made in the system or subsystem design or procedures to eliminate or control the identified hazard.

subsystem - an element of a system that in itself may constitute a system.[1]

subsystem hazard analysis (SSHA) - a systematic listing and assessment of conditions within a subsystem which could potentially affect the safe operation of a system.

system - a composite, at any level of complexity, of personnel, materials, tools, equipment, facilities and software. The elements of this composite entity are used together in the intended operational or support environment to perform a given task or achieve a specific production, support or mission requirement.[2]

system safety - "the integration of skills and resources specifically organized to achieve accident prevention over the entire life cycle of a given system."[3]

system safety program - a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily in service.

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top-down approach - typified by fault tree analysis. This approach to analysis begins with a selected top-level event or occurrence and proceeds downward in determining all of the elements which contribute to the occurrence of the top-level event.

triggering event - conditions that taken in combination with a hazard will almost certainly lead to an accident unless some corrective action is taken to prevent it.

APPENDIX C

LIST OF ABBREVIATIONS

APPENDIX C

LIST OF ABBREVIATIONS

ATC	automatic train control
ATO	automatic train operation
ATP	automatic train protection
BART	Bay Area Rapid Transit
BRRTS	Baltimore Region Rapid Transit System
DOD	Department of Defense
FHA	fault hazard analysis
FMEA	failure mode and effects analysis
FTA	fault tree analysis
GCRTA	Greater Cleveland Regional Transit Authority
HMEA	hazard mode and effects analysis
IHA	interface hazard analysis
LADPM	Los Angeles Downtown People Mover
MARTA	Metropolitan Atlanta Rapid Transit Authority
MHA	maintenance hazard analysis
OHA	operating hazard analysis
PHA	preliminary hazard analysis
PRT	Personal Rapid Transit
SHA	system hazard analysis
SSHA	subsystem hazard analysis
TERL	Transit Expressway Revenue Line
UMTA	Urban Mass Transportation Administration
WMATA	Washington Metropolitan Area Transit Authority

APPENDIX D

INDEX

APPENDIX D

INDEX

SYSTEM SAFETY IMPLEMENTATION PLAN

FOR THE

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT
METRO RAIL PROJECT

APRIL 1984

PREPARED BY:

METRO RAIL TRANSIT CONSULTANTS

SYSTEM SAFETY IMPLEMENTATION PLAN

CONTENTS

PREFACE

It is a policy, from the highest levels of SCRTD Management, that safety be a primary consideration throughout the evolution of the Metro Rail system, from preliminary engineering through revenue operations. To fulfill the obligation of this policy, all applicable codes and regulations, augmented by modern system safety engineering technology and industry standards, will be used to ensure that the system achieves a level of safety that equals or betters that of other rail transit systems. Safety requirements include hazards elimination or control and provisions for emergencies.

During the preliminary engineering and final design phases, safety can be achieved by eliminating, minimizing, or controlling hazards through analysis, review, and design selection. This will include provisions for emergencies such as an emergency communications network, on-site emergency equipment, and access by emergency forces. Metro Rail personnel will be trained in procedures for the handling of emergencies in cooperation with District Transit Police and local police and fire services.

SECTION 2

SYSTEM SAFETY IMPLEMENTATION PLAN

2.1 GENERAL

2.1.1 INTRODUCTION

This System Safety Implementation Plan complies with the requirements set forth by the Southern California Rapid Transit District's (SCRTD) System Safety Program Plan and provides the basis for Metro Rail Transit Consultants' (MRTC) activities in this area. This plan follows the guidelines established by MIL-STD 882A, "System Safety Program Requirements," the UMTA "Index for Systems Safety Plans," and SCRTD's System Safety Program Plan. This safety plan adheres to established system safety procedures, practices, and techniques.

2.1.2 PURPOSE

The purpose of the System Safety Implementation Plan is to set forth an organized, thorough, and logical plan which describes organizational responsibilities and methods of accomplishment. The plan also describes the integration of coincident design, construction/acquisition, pre-operational testing, start-up operations and training activities. The program ensures that safety, consistent with established and approved project-wide safety criteria, is designed into the elements of the Metro Rail Project in a timely, cost-effective manner.

2.1.3 SCOPE

This MRTC System Safety Implementation Plan encompasses the completion of Preliminary Engineering and the Continued Preliminary Engineering, Final Design, construction/acquisition, preoperational testing and start-up operations phases of the Metro Rail Project.

2.2 ORGANIZATION

2.2.1 ORGANIZATIONAL STRUCTURES

The organization of the SCRTD System Safety Plan is a composite of both SCRTD and MRTC. Without close coordination and clear interface between the two organizations, the System Safety Plan cannot succeed. A synopsis of the two organizations is presented in the organizational charts found in the Introduction to the MRTC Systems Assurance Manual.

2.2.2 RESPONSIBILITIES OF SCRTD

SCRTD will have review and approval authority over all safety tasks developed by MRTC. SCRTD and MRTC will exchange data and safety-related information in order to facilitate the development of various procedures, analyses, and assessments.

2.2.3 RESPONSIBILITIES OF MRTC

MRTC will develop a plan using design analyses, studies, and testing to identify system performance limitations, failure modes, safety margins, and critical operator tasks. Design, engineering, education, management policy, and supervisory control will be considered in the identification, elimination, or control of hazards. The system safety discipline will be integrated with other management and engineering disciplines to achieve an optimum system design. Procedures for the development and integration of this effort will be applied to the entire MRTC organization in order to provide a system safety program consistent with overall SCRTD transit system requirements.

2.3 METHODS

2.3.1 PROGRAM OBJECTIVES

The objective of the MRTC System Safety Plan is to provide a systematic approach that addresses the following:

- Safety, consistent with established system safety goals, shall be designed into the transit system in a timely, cost-effective manner.

- Hazards associated with the various systems and subsystems shall be identified, evaluated, and eliminated, or controlled to an acceptable level for the entire life-cycle of the transit system.

- Historical safety data generated by other rapid transit properties and governing bodies shall be considered and used, wherever appropriate.

- Minimum risk shall be involved in accepting and using new designs, materials, and procedures.

- Retrofit actions needed to improve safety shall be limited by the inclusion of safety features during the design and development of the various systems and subsystems.

- Modifications to any system shall not diminish the inherent safety of that system or any interfacing system or subsystem.

2.3.2 SYSTEM SAFETY GOALS

The goals established in the SCRTD System Safety Program Plan are to define design group activities and management controls, plans, and monitoring processes to ensure that:

- Safety considerations, compatible with the system requirements, are incorporated in the Metro Rail subsystems during the design phase to minimize the potential of accidents in the system operation phase.

- Hazards associated with each subsystem of the SCRTD Metro Rail are identified, then eliminated or minimized to obtain an acceptable level of safety.

- A safety philosophy is instilled within the Metro Rail system that emphasizes preventive measures over corrective measures to eliminate unsafe conditions.

- Historical safety data generated by the newer transit properties (which have characteristics similar to the SCRTD Metro Rail) are analyzed and used to support the SCRTD Metro Rail system safety program.

- Security, system assurance and fire/life safety considerations are coordinated with safety efforts.

Additionally, the MRTC System Safety Plan includes design considerations and operational procedures that provide for the following:

- o The review of pertinent standards, specifications, regulations, design handbooks, and other sources of design guidance for applicability to transit system design.

- o The elimination or control of identified hazards through design solution, material selection, or substitution. Potentially hazardous materials will be carefully analyzed and selected to provide optimum safety characteristics.

- o The separation of hazardous substances, components, and operations from other activities, areas, personnel, and incompatible materials.

- o Placement of equipment to reduce personnel exposure to hazards during operations and maintenance activities.

- o The minimization of hazards caused by adverse environmental conditions.

- o A design that will minimize human error in the operation and maintenance of the transit system.
- o Consideration of alternate approaches to limit hazards that cannot be eliminated, including interlocks, redundancy, fail-safe design, system protection, and fire protection devices.

- o The protection of power sources, controls, and critical components by redundant subsystems or physical separation and shielding.

- o Suitable warning of hazardous conditions in operations, maintenance, and repair instructions.

- o Distinctive markings (graphics and colors) on hazardous components, equipment, and facilities as a protective measure.

- o Limiting the effects of a mishap on personnel, the public, or equipment.

- o The review of designs and design criteria for both inadequate and overly restrictive requirements regarding safety.

2.3.3 HIERARCHY OF HAZARD RESOLUTION

The listed requirements will be addressed in procedures and policies to be developed for the System Safety Plan. The following hierarchy of hazard resolution is used to prepare policies and procedures:

A. Design for Minimum Hazard - Provisions will be made in all initial design selections for the elimination of hazards. If the hazard cannot be eliminated, then it will be controlled to an acceptable level through alternate design selections.

B. Safety Devices - Hazards that cannot be eliminated or controlled through design selection will be controlled to an acceptable level by safety design features. Provisions will be made for periodic functional checks of safety devices.

C. Warning Devices - When neither design nor safety devices can effectively eliminate or control an identified hazard, warning devices will be used to alert operating personnel. Warning signals will be designed to reduce the probability of mistaken reaction.

D. Procedures and Training - When design selection and safety and warning devices are inadequate, procedures and training will be used to control hazards. Precautionary notes will be standardized and certain safety-critical tasks may require certification of personnel.

2.3.4 HAZARDS ANALYSES

Procedures will be developed for the various types of hazards analyses. These will provide for the systematic examination of all system elements, sub-sysems, assemblies, personnel/public interface and the interrelationship of system components. The analysis will involve logistics, training, maintenance, modification, and operational environment.

As a minimum, these hazards analyses will include:

- Preliminary Hazards Analysis (PHA)
- Subsystem Hazards Analysis (SSHA)
- System Hazards Analysis (SHA)
- Operating and Support Hazards Analysis (O&S)

These formal analyses will be forwarded to appropriate MRTC management with recommended corrective actions noted. Where problems arise that cannot be resolved by MRTC due to constraints or conditions imposed by SCRTD, the matter will be transmitted to SCRTD for redirection or guidance.

2.3.5 SYSTEM SAFETY DATA

Safety data will be used to prevent design and construction deficiencies, particularly those of a controllable nature. Safety data are accumulated by the system safety engineer(s) from prior transit programs, earlier work on similar systems, and other historical sources. The data will be used to evaluate the safety of the system or to verify compliance with system safety requirements. At a minimum, these data will consist of mishap reports, mishap probabilities, failure rates, test results, system safety analyses, hazard mode and effects analyses, fault tree analyses, and human factors data. Liaison with other data sources (federal, state, and local authorities) will help to identify hazards and evaluate safety design deficiencies. Deliverable data will be transmitted to SCRTD via established procedures and policies. All nondeliverable data will be indexed, filed, and maintained in the MRTC Library for use and review by MRTC staff, SCRTD officials, and regulatory agencies requesting use of the information.

2.3.6 SAFETY TESTING AND DEMONSTRATIONS

Tests and demonstrations will be prescribed to validate selected safety features of the various systems. Tests or demonstrations will be performed on safety-critical equipment and procedures to determine the hazard severity or to establish the margin of safety of the design. Induced or simulated failures will be used to demonstrate the failure mode and acceptability of safety-critical equipment. Where costs for safety testing are prohibitive, safety characteristics or procedures will be verified by engineering analyses, analogy, mockups or other means approved by SCRTD. Procedures for safety testing and demonstrations will be developed by MRTC and forwarded to SCRTD for review and approval.

2.3.7 TRAINING

Approved safety procedures will be developed and included in instruction, orientation, and training plans for SCRTD, public safety and other personnel. This effort is not expected to receive in-depth attention until the latter parts of the project. However, low-level efforts will be ongoing through the life of the project to gather vital information and provide interim training as needed.

2.3.8 AUDIT PROGRAM

Techniques and procedures will be implemented that will enable the objectives and requirements of the SCRTD System Safety Program to be accomplished as planned. Procedures will also be developed to provide for adequate on-the-job safety surveillance during system installation, construction, checkout, maintenance, and modification activities. The activities of the system safety engineer(s) will be audited by MRTC Quality Assurance personnel to verify adherence to the program. Copies of those audits will be distributed to MRTC and SCRTD management as deemed appropriate.

2.4 SAFETY CERTIFICATION

A final critical event in the development of a rail rapid transit system is the safety certification of that system. One of the main objectives of this System Safety Implementation Plan is the safety certification of the Metro Rail Project.

The increased safety assurance of a rail rapid transit system is best demonstrated when system safety is one of the integral parts of the safety certification process. Information and data from the SCRTD System Safety Program will help provide the verification required for safety certification. Two basic areas will be included:

A. Safety statements and analyses reports
B. System and subsystem specification compliance

2.5 SUMMARY

The System Safety Plan will provide for an orderly accomplishment of safety tasks required to attain the established and approved Metro Rail Project system safety goals.

This plan addresses the purpose of the System Safety Plan, outlines organizational responsibilities, and defines plan objectives and requirements. This plan also describes methods of hazard analysis and outlines the acquisition and use of system safety data. Finally, it lays the groundwork for activities to accomplish safety certification and sets the tone for safety testing and demonstrations, training, and audits.

Policies and procedures will be developed by MRTC to provide for the design and operation of a safe rapid transit system, as defined by the Metro Rail Project and the SCRTD System Safety Program Plan.

III.

TASKS TO BE PERFORMED

SAFETY ENGINEERING AND

SAFETY CERTIFICATION

Task P99F096

Task P99F088

Subtask #1 - Participate in Design Reviews

Review drawings, specifications and contract documents for compliance with design criteria, codes, plans and procedures. Prepare design review comment sheets, assist designers with problem resolutions and attend design reviews and change control boards as necessary.

Subtask #2 - Provide Design Support to Other General Consultant Engineers

Assist other elements of MRTC with making proper provisions for the inclusion of system safety and fire/life safety within their area of concern. Draft sample text for specifications, plans and contract documents. Analyze designs and prepare designs for inclusion of system safety and fire/life safety requirements.

Subtask #3 - Review Contractor Analyses and Reports

Review analyses and reports prepared by elements outside MRTC for proper inclusion of system safety and fire/life safety requirements. Prepare comment sheets, reports or studies on reviews to MRTC/SCRTD as necessary.

Subtask #4 - Participate on Fire/Life Safety Committee

As part of the SCRTD Fire/Life Safety Committee, attend formal and informal meeting of that group including visits to other transit properties and attendance at seminars and conferences. Prepare meeting agendas, minutes of meetings and reports/studies as necessary.

Subtask #5 - Develop System Safety and Fire/Life Safety Characteristics and Trade-offs

Assist Designers, MRTC/SCRTD Management and Fire/Life Safety Committee in assessing system safety and fire/life safety characteristics for trade-offs in the design of the Metro Rail Project. Prepare studies, reports and analyses as necessary.

Subtask #6 - Update and Revise the Fault Tree Hazard Analysis (FTHA)

Revise, update and revise the Fault Tree Hazard Analysis to reflect design evolution and changes in the Critical/ Catastrophic Items List (C/CIL). This Subtask is part of Safety Certification.

Subtask #7 - Update and Revise the System/Subsystem Hazard (S/SSHA) Analysis

Revise, update and revise the System/Subsystem Hazard Analysis to reflect design evolution and changes in the Critical/Catastrophic Items List (C/CIL). This Subtask is part of Safety Certification.

Subtask #8 - Update and Revise the Interface Hazard Analysis (IHA)

Review, update and revise the Interface Hazard Analysis to reflect design evolution and changes in the Critical/ Catastrophic Items List (C/CIL). This Subtask is part of Safety Certification.

Subtask #9 - Assist in Preparation of Single-Point Failure Summaries

Using the system, subsystem, interface hazards analyses and the fault tree analyses previously tasked; assist other MRTC elements in a summary and identification which will be compiled of all major single-point failures which must be eliminated or controlled in the design/operation of the transit system. Review and prepare studies if appropriate on the impact of these single-point failures on system safety. The deliverable for this effort will be a compilation of all major single-point failures recognized within the transit system.

Subtask #10 - Update and Revise Design Criteria

Review, update and revise the SCRTD Design Criteria for System Safety and Fire/Life Safety to verify that proper provisions are included in the criteria. The deliverable for this effort will be a revised and updated SCRTD Design Criteria. This Subtask is part of Safety Certification.

Subtask #11 - Update and Revise the Design Criteria Checklists

Review, update and revise the Design Criteria Checklists to reflect changes to the System Safety and Fire/Life Safety Design Criteria. This Subtask is part of Safety Certification.

Subtask #12 - Prepare the Construction Facilities Fire/Life Safety Inspection Program Plan

Prepare a program plan for Construction Facilities Fire/Life Safety Inspection. Utilizing MRTC subconsultants, assure proper inclusion of System Safety and Fire/life Safety requirements. Expedite, coordinate delivery to schedule.

Subtask #13 - Prepare the Fire Hazard/Toxic Materials List

Prepare a listing of Fire Hazard/Toxic Materials. Utilizing MRTC subconsultants, assure proper inclusion of System Safety and Fire/Life Safety requirements. Expedite, coordinate delivery to schedule.

Subtask #14 - Assist in Development of the Critical/Catastrophic List (C/CIL)

Assist in development of the Critical/Catastrophic Items List by furnishing SCRTD with identified category I and II hazards (as defined by MIL-STD-882A) throughout the design evolution. This Subtask is part of Safety Certification.

Subtask #15 - Prepare Safety and Fire/Life Safety Work Plans and Schedule

Plan, allocate, chart resources and work load for coming fiscal year. Prepare documentation detailing tasks and deliverables.

Subtask #16 - Update and Review MRTC Implementation Plan

Review, update and revise the MRTC Implementation plan to reflect design criteria changes and design evolution.

Subtask #17 - Assist in Refinement of the System Safety Program Plan

Participate in the review, update and revision of the SCRTD's System Safety Program Plan in order to maintain consistency with the developing definition of systems and subsystems.

FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION PROCEDURE FOR THE METRO RAIL PROJECT

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1.1 OBJECTIVE

The objective of this Failure Reporting, Analysis, and Corrective Action (FRACA) procedure is to provide a method for systematically reporting, analyzing, and initiating corrective action on all failures and problems that arise during testing, evaluation, and system operations on Metro Rail.

1.2 SCOPE

The FRACA Reporting Form shall be used by all contractors/suppliers, SCRTD employees, and SCRTD consultants to record all failures and problems occurring during Metro Rail testing, preoperational and operational phases of subassemblies, assemblies, subsystems, and systems; commencing with the first application of power. It also includes deficiencies in documentation pertaining to test, evaluation, and operations.

1.3 PROCEDURE

The format for failure reporting, analysis, and corrective action suitable to accomplish the failure recurrence control functions is shown in Figure 1-1. Instructions for making entries on the form follow Figure 1-1.

1.3.1 FAILURE REPORTING FORM

The following instructions for the failure reporting form (Figure 1-1) shall be followed carefully to ensure that information is available to properly evaluate the incident.

A. Instruction for Completing Failure Report Form

Begin by entering the number of the incident as assigned by SCRTD Systems Assurance.

Next, enter the applicable system code as listed in Appendix B.

Then enter the applicable subsystem code as identified in Appendix C.

RTD

METRO RAIL
FAILURE REPORT

FAILURE REPORT NUMBER ____________ SYSTEM [|] SUBSYSTEM [|]

1. LOCATION	2. REPORTED BY:		
	AUTH.	DATE	TIME
3. DESCRIPTION OF REPORTED TROUBLE:			
4. REPORT REC'D BY		DATE	
5. FIELD TEAM ASSIGNED		DATE	
FIELD TEAM DISPATCHED		DATE	
6a. FIELD TEAM ARRIVED ON SITE:	AUTH.	DATE	
b. FAULT ISOLATION COMPLETE	AUTH.	DATE	
c. REPAIRS STARTED		DATE	
d. REPAIRS COMPLETED	AUTH.	DATE	
e. MANUAL SATISFACTORY YES ( ) NO ( ) EXPLAIN	6f. SAFETY:		
7. DESCRIPTION OF TROUBLE FOUND AND REPAIRS ACCOMPLISHED.			
	AUTHENTICATION		
8. FAILED LRU:	DEFECT CODE	REPAIR CODE	

QUAN	MANUFACT MODEL NO	DESCRIPTION	SERIAL NO	SYS	NO-SYS

8A TIME REQUIRED TO GET SPARES TO SITE:

9. REPLACEMENT LRU ☐ PART AVAILABLE ON REQUEST ☐ PART TO BE ORDERED

10. SERVICE RESTORED: TECH	AUTH.	DATE/TIME
11a. FAILURE CLASSIFICATION ☐ INDEPENDENT (CHARGEABLE) ☐ NON-CHARGEABLE		
11b. FAILURE ☐ SYSTEM ☐ NON-SYSTEM	11c. CHARGEABLE TIME/MIN.	
11d. COMMENTS		
12. CONTRACTOR		DATE
13. SCRTD REPRESENTATIVE		DATE

FIGURE 1-1 FAILURE REPORTING FORM

Continue to make entries on the Failure Reporting Form by location number on the form as follows:

1.	Location:	Enter the specific location, as appropriate to the location codes in Appendix A.
2.	Reported By:	Enter the name or I.D. Number of the individual that reported the incident, together with the date and time. It should be noted that the date and time must be authenticated by an SCRTD representative.
3.	Description of Reported Trouble:	Describe the anomaly as thoroughly as possible. Use attachments where necessary.
4.	Report Received By:	Upon receipt of the Failure Report, Systems Assurance will complete this entry.
5.	Field Team Assigned/ Dispatched:	Enter time and date of assignment of responsible technician(s) and actual time and date technician(s) were dispatched.
6a.	Field Team Arrived On Site:	Enter time and date of technician(s) arrival at problem location.
6b.	Fault Isolation Completed:	Enter time and date fault was isolation
6c. & 6d.	Repairs Started/ Repairs Completed:	Enter time and date maintenance action started, and time and date maintenance action completed.
6e.	Manual Satisfactory:	If the maintenance manual satisfactorily defines the method and procedures for repair, enter "YES". If the manual does not sufficiently describe method and procedures for repairing the fault, enter "NO" and describe the deficiency and/or error.

6f. Safety:	Indicate potential impact on safety, if applicable; if no impact on safety exists, enter "N/A". Safety Impact Numbering is as follows: (1) Castastrophic - system loss, and/or serious injury or death. (2) Critical - major system damage, and/or severe injury. (3) Marginal - minor system damage, and/or minor injury. (4) Negligible - no system damage and/or injury. A failure that causes another system to fail unsafely will be automatically classified as a (1).
7. Description of Trouble Found and Repairs Accomplished:	This section shall be fully and carefully completed with all information that can be identified. Fully describe the fault and the repair actions in detail (use the back of the form if necessary). This data will be validated by the SCRTD representative.
8. Failed LRUs:	Enter the failed lowest replaceable units (LRUs); fully identify, including the serial number of each item. This data will be authenticated by the SCRTD representative. Enter the defect and repair codes which best describe that failed part. (See Appendix E and Appendix F for a list of proper defect and repair codes, respectively.)
8a. Time Required to Get Spares to Site:	Enter travel time to acquire spare part(s). This time is to be isolated from other factors.

9.	Replacement LRUs:	Enter the LRUs used to replace failed items. The same information that is recorded for the failed components, including the serial number of the replacement components, shall be recorded. The information will be used to validate the spare parts lists for adequacy and to update the configuration list with the serial numbers of the in-place equipment.
10.	Service Restored:	Enter the date and time the service was restored; if the incident was found to be of a nonfailure type, it should be so indicated. Include the name of the technician that restored the service and the authentication of fault clearing, date, and time by the SCRTD representative. An explanation of a discrepancy between service restoration time and repairs completed time is required.
11.	Failure Classification:	Entries in this section shall be made by the Contractor and SCRTD representative(s).
12. & 13.	Approval:	The Contractor's representative and the SCRTD's representative shall sign the failure report, signifying that all parties agree the information is valid.

B. Routing and Handling of Failure Reports

Upon occurrence of a failure, the individual discovering it shall report the occurrence to Central Control.

The Failure Report will be completed by the originator (individual discovering the anomaly) and sent to Central Control after the incident maintenance work has been completed and authenticated. The Failure Report Number Log (Figure 1-2) will record the system, date, time, and name information. Failure Reports will be held for regularly scheduled meetings of the evaluation team.

FAILURE NUMBER	DATE/TIME SYS	DATE/TIME INIT	FIELD ACTION COMPLETED DATE/TIME	INITIALS	FAILURE NUMBER	DATE/TIME SYS	DATE/TIME INIT	FIELD ACTION COMPLETED DATE/TIME	INITIALS

FIGURE 1-2 FAILURE REPORT NUMBER LOG

When Item 11 of the Failure Report is completed by the evaluation team, the report shall then be distributed to the various signatories. Upon completion of signatures, the report shall be expeditiously routed to the analysis group, and a copy sent to the System Assurance Organization (for initiating the analysis efforts).

C. Failure Review Board

A Failure Review Board will be established consisting of representative(s) of the SCRTD, an MRTC System Assurance representative, and representative(s) of the Equipment Contractor. The Failure Review Board will review all test records to verify failure classifications and assign responsibility and chargeability. The Board's decision on all failure reports will be final. The component responsible for the failure will be determined along with action to prevent recurrence.

D. Daily Review of Failure Reports

A periodic review of all closed Failure Reports will be conducted to determine:

1. That the incident was or was not a valid failure. The Failure Report will be appropriately annotated.

2. The system or nonsystem affecting aspects of the incident.

3. That times entered in all date/time blocks were authenticated by an SCRTD representative.

4. If the original report description was comprehensive and sufficiently complete to allow logical fault isolation.

5. That the description or repair action was sufficiently completed to allow valid analysis.

6. That all entries and data were examined to determine if all or any part of the data should be voided.

E. Procedures for the Release of Data Analysis

The Failure Reports that are not found to be complete or valid during the review will be so annotated and documented thereon and forwarded to the Failure Review Board for verification/classification.

The Failure Reports that are found to be valid in all respects will be forwarded to the Failure Review Board for final sign-off prior to being sent to the analysis group. Once the Failure Report has been signed off by the Failure Review Board, it is no longer subject to question; it will be used in the analysis as is and will not be changed or modified in any way.

F. Classification of Failure Actions

Chargeable failures are those failures which meet all of the following criteria:

1. A failure occurring in a subsystem during inspection or test period(s) when an examination or demonstration is in progress.

2. A failure verified by subsequent retesting or investigation of the failed item. (The only deviation to this will be safety critical failures which are chargeable without exception.)

3. An independent (primary) failure which meets one or more of the following conditions:

   a. Inability of the equipment to function satisfactorily or performance outside of specification parameters.

   b. Failure symptoms which are detected under operation, and recur in subsequent retesting, and diagnosis of the cause or basic part failure has been determined.

1.4 FRACA FLOW ACTIVITIES

See Figure 1-3 for flow chart of failure analysis activities during inspection/tests.

1.5 ANALYSIS PROCEDURES

The information on the Failure Report will be transferred to a form that is arranged for the assemblance of data and appropriate calculations. The form (Figure 1-4, Test Failure Visibility Detail) will be kept on each LRU that is reported in a Failure Report. This categorizing of the information will facilitate performing the necessary calculations and trend analysis. This trend analysis will provide an alert when several failures have occurred with any one LRU. In addition, all trends and results will be examined daily by the Failure Review Board. All data will be examined to determine where actions should be taken to adjust the data gathering or to examine a subsystem, equipment, or LRU technically. Any of these actions may be directed by the Review Board.

1.6 CORRECTIVE ACTION PROCEDURES

The SCRTD selected contractor shall establish, document, and maintain procedures to ensure that conditions adverse to Reliability and Quality, shall be promptly identified and corrected. Such conditions may include failures, malfunctions, deficiencies, deviations, and defects in material and equipment. In the case of such adverse conditions, the measures shall, once the cause and condition are determined, ensure that corrective action shall be taken to preclude repetition of such conditions. This corrective data and related information shall be documented and made readily available to the SCRTD. Corrective action shall be extended to all vendors and subcontractors at all tiers and shall include as a minimum:

A. The analysis of data and examination of nonconforming equipment to determine extent and causes.

B. The introduction of required improvement and corrections, initial and follow-up review of the adequacy of such measures, and monitoring of the effectiveness of corrective action taken.

C. The analysis of failure trends or work performance to prevent the recurrence of failures and/or nonconformances.

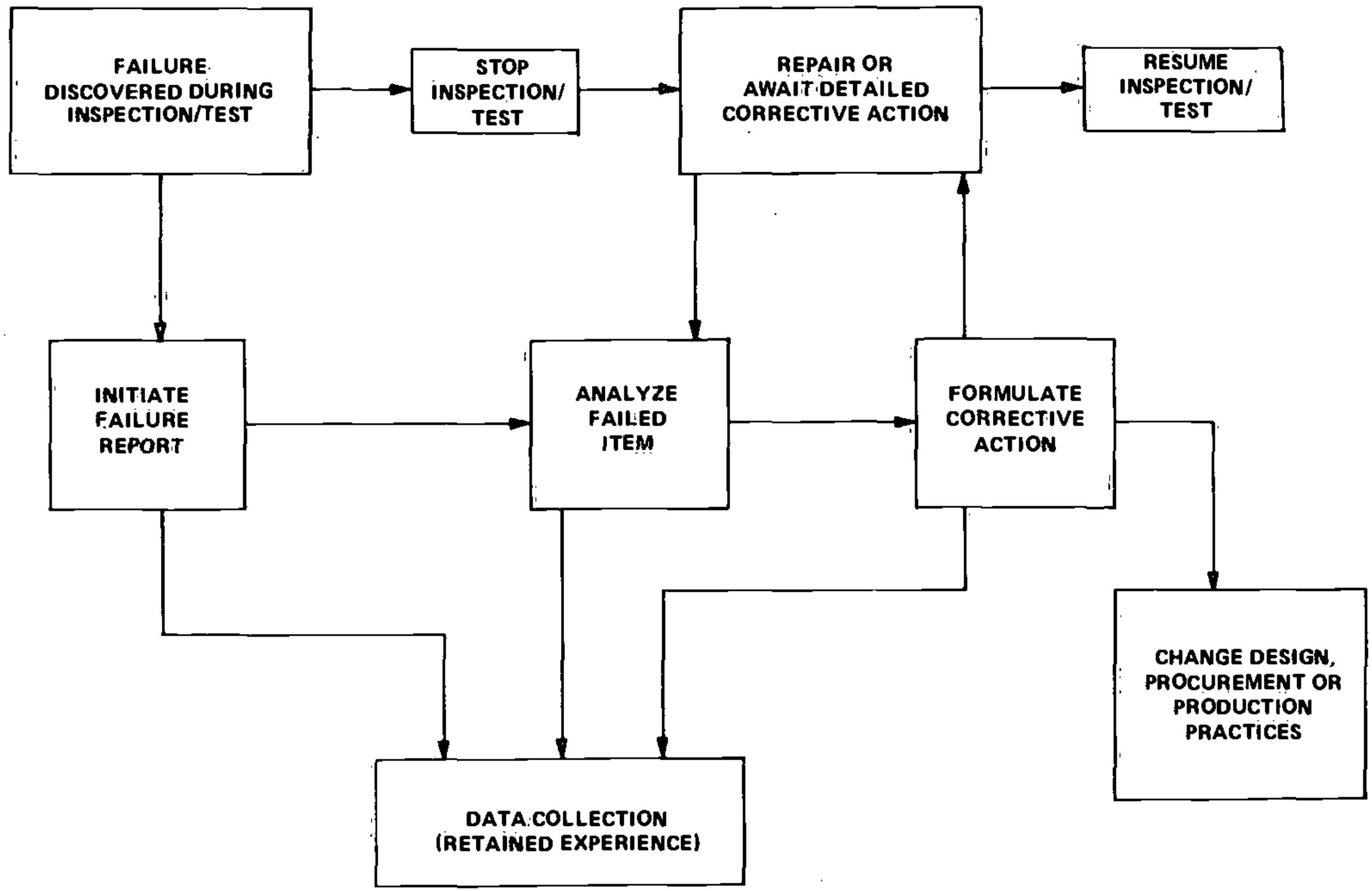

FIGURE 1-3 – <u>FLOW CHART OF FAILURE ANALYSIS ACTIVITIES DURING INSPECTION/ TESTS</u>

PART NUMBER	QUANTITY	TEST DURATION	TOTAL TEST HOURS	NO. OF FAILURES

FIGURE 1-4 TEST FAILURE VISIBILITY DETAIL

APPENDIXES

APPENDIX A

LOCATION CODES

LOCATION CODES

First (far left) space indicates the "line"; use the numeral "1" to designate the phase one line.

Second space (from left) indicates the track. Use the numeral "1" for the INBOUND track. Use the numeral "2" to designate the OUTBOUND track. For reference, inbound and outbound are in respect to Union Station. Use "0" if not applicable.

The remaining five spaces are used to indicate the location within 200 feet. Enter the information obtained from the nearest track marker. This may be simplified if the location is an area previously defined as a station, shop, yard, etc., by use of the following codes in place of the footage marker number:

00001	Union Station
00002	Civic Center
00003	5th/Hill
00004	7th/Flower
00005	Wilshire/Alvarado
00006	Wilshire/Vermont
00007	Wilshire/Normadie
00008	Wilshire/Western
00009	Wilshire/Crenshaw
00010	Wilshire/La Brea
00011	Wilshire/Fairfax
00012	Fairfax/Beverly
00013	Fairfax/Santa Monica
00014	La Brea/Sunset
00015	Hollywood/Cahuenga
00016	Hollywood Bowl
00017	Universal City
00018	North Hollywood
00019	Central Control Facility
00020	Yard
00021	Repair Shop
00050	Other (specify)

APPENDIX B

SYSTEM CODES

SYSTEM CODES

01 Track/Right-of-Way
02 Automatic Train Control (ATC)
03 Structures/Grounds
04 Vehicles (other than passenger vehicles)
05 Escalators/Elevators
06 Traction Power (Substation)
07 Fare Collection
08 Maintenance Equipment/Facilities
09 Station Facilities
10 Fire Suppression/Intrusion
11 Communications
12 Administration Facilities
13 Auxiliary Power
14 Passenger Vehicle

APPENDIX C

SUBSYSTEM CODES

SUBSYSTEM CODES

TRACK/RIGHT-OF-WAY (01)

01	Running rail
02	Security
03	Turnout
04	Crossover
05	Auto Train Stop
06	Bed/ballast
07	Tie, concrete
08	Tie, wood
09	Hardware (ie; fasteners, anchors, etc.)
10	Guard rail
11	Contact rail
12	Coverboard
13	Bumping post
14	Signals
15	Switches
99	Inspection

ATC (02)

01	TCR control and indication
02	Vital circuit/nonvital circuit
03	Train dispatching control
04	High-frequency track circuit/ATP
05	Power track circuit
06	Wayside signal/pushbutton box/sign
07	Switch/derail
08	Track switch heater
09	Power distribution
10	Wayside junction box/case
11	Vehicle ATP
12	Automatic Train Supervision (ATS)
13	Switch Machine
99	Inspection

STRUCTURES/GROUNDS (03)

01 Heating, ventilation, A/C (HVAC)
02 Plumbing
03 Electrical
04 Lighting
05 Escalators/elevators
06 Security/fencing
07 Air systems (pneumatic)
08 Glazing/structural
09 General housekeeping
10 Graffiti
99 Inspection

VEHICLES (04)

01 Automobile
02 Forklift
03 Rerail truck
04 Hi-rail truck
05 Pickup
06 Track geometry vehicle
07 MOW vehicle
99 Inspection

ESCALATORS/ELEVATORS (05)

01 Escalator panels
02 Elevator cab
03 Elevator enclosure
04 Elevator mechanism
99 Inspection

TRACTION POWER (06)

01 Uninterruptible power supply (UPS)
02 Contact rail
03 Feeder/cable
04 Breaker
05 Rectifier

TRACTION POWER (06) (con't.)

06 Transformer
07 Fuse
08 Battery/battery charger
09 Indicators/warning devices
99 Inspection

FARE COLLECTION (07)

01 Ticket vendor
02 Bill changer
03 Fare gate
04 Revenue cart
05 Magnetic encoder
06 Add fare machine

MAINTENANCE EQUIPMENT/FACILITIES (08)

01 Pipe/tubing bender
02 Welding machine
03 Air brake system test bench
04 Magnetic particle inspection unit
05 Power hacksaw
06 Milling machine
07 Engine lathe
08 Radial drill
09 Contour bandsaw
10 Steam cleaner
11 Sandblast unit
12 Oven
13 Undercutter
14 Overhead crane, 20 ton (HR)
15 Overhead Crane, 7.5 ton (pit)
16 Balancing machine
17 Portable lift
18 Stationary lift (vehicle)
19 Vapor degreaser
20 Wheel press
21 Boring machine
22 Wheel trueing machine
23 Ultrasonic cleaner
24 DC power supply

MAINTENANCE EQUIPMENT/FACILITIES (08) (con't.)

25 Truck overhaul lift
26 Speedswing
27 Tamper
28 Liner
29 Rail drill
30 Rail saw
31 Coach screwing machine
32 Portable generating equipment
33 Concrete mixer
34 Pneumatic tools
90 Miscellaneous equipment
99 Inspection

STATION FACILITES (09)

01 ______________________
02 ______________________
03 ______________________
99 Inspection

FIRE SUPPRESSION/INTRUSION (10)

01 Wet standpipe deluge system
02 Wet standpipe system
03 HALON system
04 Warning/alarm system, water flow
05 Warning/alarm system, seismic detection
06 Warning/alarm system, smoke detection
07 Intrusion annunciation system
08 Warning/alarm system, gas detection
99 Inspection

COMMUNICATIONS (11)

01 Radio
02 CCTV
03 PA system
04 Supervisory control and data acquisition (SCADA)

COMMUNICATIONS (11) (con't.)

05 DC power
06 Telephone
07 Cable transmission
08 Intercom
99 Inspection

ADMINISTRATION FACILITIES (12)

01 Furniture and fixtures
02 Copying device
03 Calculator
04 Typewriter
90 Other
99 Inspection

ELECTRICAL DISTRIBUTION (PLANT) (13)

01 Switchboard
02 Transformer
03 Panel
04 Wiring

APPENDIX D

TYPE OF MAINTENANCE CODES

TYPE OF MAINTENANCE CODES

CATEGORY	CODE	DEFINITION
Preventive	I	Scheduled inspection (PM)
Preventive	S	Directed by service bulletin
Preventive	T	A special inspection or test
Preventive	M	Casual preventive maintenance
Preventive	D	Reported by non-SCRTD personnel service
Corrective	F	Discovered during the performance of other corrective repairs
Corrective	C	Discovered during a PM and unable to be completed by PM crew
Corrective	H	Reported by SCRTD personnel
Fabrication	A	Of special equipment

APPENDIX E

DEFECT CODES

DEFECT CODES

CATEGORY	CODE	DEFINITION
Climatic Conditions	C10	Condensation
	C20	Corrosion
	C22	Frozen
	C23	Pitted
	C24	Rusted
	C25	Flooded
Physical Damage	D10	Accident or collision
	D12	Derail damage
	D13	Dropped
	D21	Cut
	D23	Seismic damage
	D25	Fire/smoke damage
	D26	Damaged by foreign object
	D28	Leaking
	D29	Obstructed/blocked
	D2A	Punctured
	D2B	Torn/ripped
	D31	Broken (glass)
	D33	Other (specify)
Electrical	E10	Bad connection
	E13	Defective wiring
	E21	Burned contact
	E29	Dirty/oxidized contacts
	E2A	Flashed/arcing
	E2B	Insulation breakdown
	E2C	Interlock malfunction
	E2D	Loss of third rail power
	E2J	Overload damage
	E2L	Tripped circuit breaker
	E2M	"Trainline" problem
	E32	Miswired; connected incorrectly
	E40	Motor defective (nonspecific)
	E41	Damaged armature
	E42	Damaged commutator
	E46	Out-of-round
	E48	Motor overload (MOL)

CATEGORY	CODE	DEFINITION
Electrical (con't.)	E49	Worn damaged brush(es)
	E50	Open circuit (no continuity)
	E51	Blown fuse
	E52	Broken lead/connection
	E53	Burned-out bulb/lamp
	E61	Distorted output
	E62	Excessive hum/static
	E63	Abnormally high input level
	E64	Abnormally high output level
	E67	Incorrect current
	E68	Incorrect frequency
	E69	Incorrect signal
	E6A	Incorrect time delay
	E6B	Incorrect voltage
	E6D	Abnormally low input level
	E6E	Abnormally low output level
	E6H	No high tone
	E6J	No input
	E6K	No low tone
	E6L	No output
	E6M	Overspeed
	E71	Change of value
	E72	Grounded
	E73	Shorted
	E74	Welded contacts
	E75	Other (specify)
Mechanical	M13	Broken/sheared
	M14	Cracked, stress
	M15	Cracks, thermal
	M16	Ruptured
	M20	Contaminated
	M21	Buildup of scale
	M22	Dirty
	M23	Sticky/gummy
	M31	Defective part
	M36	Packing/gasket defective
	M37	Delaminated
	M38	Deteriorated
	M3A	Rough/scored
	M3B	Separated
	M3C	Stripped

CATEGORY	CODE	DEFINITION
Mechanical (con't.)	M41	Bent, buckled, dented, twisted
	M43	Deformed, distorted (track surface)
	M44	Out of balance/tolerance
	M45	Stretched
	M51	Chipped/peeling
	M52	Incorrect torque
	M53	Missing hardware
	M54	Unseated
	M55	Weak
	M5B	Worn (still within limits)
	M5C	Worn beyond limits
	M60	Jammed/stuck
	M66	Seized
	M67	Sticking
	M68	Tight
	M71	Blistered
	M72	Burned
	M73	Carbonized
	M74	Crystalized
	M75	Hot/overheated
No Defect	N11	Cannot duplicate failure reported
	N12	No defect found in testing/inspection
	N13	No defect; operator error
	N14	Self-clear during test/inspection
	N23	Requires track test to demonstrate
Pneumatic/Hydraulic	P10	Contaminated
	P11	Air in system
	P12	Oil contaminated
	P21	Defective air bellows/bag
	P22	Defective piping
	P23	Dry
	P33	Fitting off/loose/open
	P34	Worn beyond limits
	P35	Overserviced
	P40	Low/insufficient fluid
	P51	Restricted function
	P52	Airflow obstructed

CATEGORY	CODE	DEFINITION
System Operation	S11	Chattering
	S12	Erratic operation
	S13	Intermittent operation
	S14	Motion, lateral (side-to-side)
	S15	Motion, vertical (up-and-down)
	S16	Noisy
	S20	Fails to operate
	S21	Will not close
	S22	Dark car
	S23	Dead car
	S29	ATP failure
	S2A	ATO failure
	S2B	Cab signal failure
	S2C	Internal failure
	S2E	No dynamic braking
	S2F	No-go indication
	S2H	No pressure
	S2J	No public address
	S2K	Will not open
	S2N	Will not recharge
	S2R	Station bypassed
	S2S	Long station-stop
	S2T	Short station-stop
	S2U	Will not transmit
	S2V	Will not turn off
	S2W	Will not turn on
	S2X	Unable to move
	S32	Faulty audio
	S41	Brakes in "emergency"
	S42	Cold car (no heat)
	S43	Error; console display readout
	S44	Abnormally high pressure
	S45	Abnormally high temperature
	S47	Low compression
	S48	Low pressure
	S49	Abnormally low temperature
	S4A	Poor braking
	S4C	Slow acceleration
	S4D	Slow brake release
	S50	Manual bypass switch used
	S51	ATP cut-out seal broken

CATEGORY	CODE	DEFINITION
Wheels (rail)	W10	Flange
	W11	Chipped flange
	W12	Cut flange
	W13	High flange
	W14	Low flange
	W15	Sharp flange
	W16	Thin flange
	W17	No flange
	W23	Flat spot; 1.5-2.4 inch
	W24	Flat spot; 2.5-3.5 inch
	W25	Flat spot; 3.5-4.5 inch
	W26	Flat spot; 4.5-6.5 inch
	W27	Flat spot; less than 1.5 inch
	W32	Limit, wheel
	W33	Mismatched wheels
	W41	Tread out of contour
	W42	Defective wheel tread
	W43	Profile bad
Miscellaneous	Z10	Administrative
	Z11	Cannibalized (by direction)
	Z12	Condemned (by direction)
	Z13	Failed safety test
	Z16	Temporary truck removal
	Z25	Failed diagnostic test
	Z31	Closed
	Z34	Open
	Z35	Overcharged
	Z37	Unable to adjust
	Z42	Improperly adjusted
	Z43	Improper spacing/clearance
	Z44	Incorrectly assembled
	Z45	Mismatched pair
	Z47	Wrong part
	Z56	Derail

APPENDIX F

REPAIR CODES

REPAIR CODES

CATEGORY	CODE	DEFINITION
Adjustments	B02	Aligned
Repair/Correction	R02	Discharge/recharge
	R04	Freed binding part(s)
	R07	Reassembled correctly
	R11	Repaired
	R15	Rewired
	R18	Serviced (add fluids, lubricant, etc.)
Surface Treatment	S02	Cleaned
	S06	Machined
	S07	Painted/coated
	S01	Burnished/polished
	S03	Dressed/filed
	S04	Ground/turned
	S08	Patched
Fabricate, Modify, or Rebuild	E01	Fabricate
	E02	Modified
	E05	Rebuilt
Inspection/Testing	J01	Diagnostic tests
	J02	Inspected; found okay
	J05	Tested
	J06	Track test
	J07	Trouble shoot
	J10	Inspected; repairs required
Removal/Replacement	N02	Removed
	N03	Removed and replaced (with like part)
	N04	Removed to repair
	N05	Replaced
	N09	Replaced minor hardware

CATEGORY	CODE	DEFINITION
Administrative	C30	Travel to/from assignment
Remove Obstrution	P01	Cleared jam
	P06	Cleared blockage (of track)
Miscellaneous	M06	Rerail

Power, Signals, and Communications:
Problems and Solutions
In Maintenance of Communication Equipment

SCHEDULED MAINTENANCE PLANNING TECHNIQUE FOR RAIL RAPID TRANSIT COMMUNICATION SYSTEMS

By W. E. Price · Assurance Engineer

apta
American Public Transit Association

1984 RAPID TRANSIT CONFERENCE · BALTIMORE, MARYLAND
JUNE 14, 1984 · 7:45-9:45 a.m.

DMJM
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INTRODUCTION

Increased equipment complexity, cost, and quantities have resulted in increased demands on Rail Rapid Transit maintenance resources. The significance of communication systems to rapid transit dependability necessitates a maintenance program that provides the highest level of availability in the most economical manner. Efficient maintenance management contributes to the availability of equipment and services by improving the effectiveness and economy of planned maintenance operations. Such planned or scheduled maintenance will generally provide the following:

- o Increased system dependability through minimization of unscheduled maintenance activities due to equipment failures
- o Prolonged life of the equipment through minimization of extreme part degradation/deterioration.
- o Reduced maintenance costs through requiring less top assembly repair parts and skilled maintenance personnel

The objective of scheduled maintenance is to prevent deterioration of the inherent design capability by performing scheduled actions that are planned to increase the service life of communication equipment and prevent accelerated equipment failure. This form of maintenance is generally regarded as the care and servicing of operational equipment by providing for systematic inspection, detection and correction of incipient failures either before they occur or before they develop into major defects which could impact revenue service.

The planning of an effective, scheduled maintenance program consists of the identification, scheduling, and determination of tasks and requirements for the scheduled maintenance actions. The optimum schedule is one which would not <u>increase</u> maintenance costs without <u>increasing</u> equipment protection. In addition, in determining the appropriateness of scheduled maintenance applicable to a given item or piece of equipment, two factors must be given prime consideration. These factors are that (1) scheduled maintenance tasks are performed on non-critical elements only when performance of the task reduces the life cycle cost (LCC) of the end item or (2) when such tasks are performed on critical elements to prevent a decrease in reliability and/or deterioration of safety requirements to unacceptable levels. These factors can be best applied utilizing Reliability Centered Maintenance (RCM) principles on the individual subsystems and their components to arrive at the most efficient scheduled maintenance plan [1]. The steps involved in this planning development effort are the cornerstone to this paper.

METHOD

The utilization methodology of RCM is based upon injection of both qualitative and quantitative data into a detail logic sequencing process. The steps involved in this effort of iteration are the following:

a. Prepare a generation breakdown:

   A generation breakdown is a top-down classification analysis of the system into incremental hardware levels. It entails breaking the system into subsystems, each subsystem into assemblies, the assemblies into subassemblies, and continuing down to the lowest hardware level. This is generally performed by maintenance allocation diagramming [2].

b. Identify all repairable/replaceable items in the system which are critical in terms of revenue service operation and/or operating safety. The criticality or consequence severity of an item can be determined from safety hazard analyses and/or failure mode, effects and criticality analyses (FMECA).

c. Determine the possible causes of failure to each repairable/replaceable item. This can be achieved by analyzing the FMECA or the design and tolerance specifications of the item to predict what may cause a failure.

d. Segregate each item which requires a maintenance action into three (3) categories which determine the scheduled line-maintenance burden. These categories consist of (1) hardtime, (2) on-condition, and (3) condition monitoring [3].

e. Determine the frequency of failure (in terms of MTBF or failure rate) for each item analyzed from the generation breakdown.

f. Determine, for each replaceable/repairable item, all of the possible preventive maintenance tasks that can be performed. In addition, estimate the costs for each task to be performed and the impact costs incurred if scheduled maintenance is not performed.

Once the data necessary for RCM logic is captured, utilizing the steps previously mentioned, the sequencing process can be applied. This process can be reapplied as available data moves from a predicted state to measured values with a higher degree of certainty and as possible design changes are made. Once all items have been subjected to the logic sequencing process, an overall system study is conducted to arrive at the overall scheduled maintenance plan. The steps involved in this planning effort are the following:

a. Determine the feasibility of consolidating hard time replacements or inspections for occurrence at the same interval. A minimization of the summations of the individual costs is then sought.

b. Schedule required maintenance actions and develop into a scheduled maintenance program.

c. Develop a data collection system for accurate assessment of the scheduled maintenance program. The data sufficient for assessing the effectiveness and economy of a scheduled maintenance program are (1) failure history of end item, (2) equipment age, (3) scheduled and unscheduled maintenance history, and (4) cost.

The result of these activities will merge individual component requirements into a system scheduled maintenance plan by optimizing the frequency of scheduled maintenance requirements and the sequence of performance of individual scheduled tasks.

LOGIC MODEL

The RCM logic is applied to each replaceable/repairable item in the system. The maintenance task requirements are identified against the repairable items; however, individual failure modes must be addressed during the application of the RCM logic. Thus for a given item, different scheduled tasks could be arrived at due to the different failure modes and their inherent design characteristics. As an example, a given component/item might undergo condition monitoring by a communication system operator during normal central operations to detect the majority of predicted failure modes for the item under analysis, while still retaining an on-condition or hard time requirement due to a failure mode that doesn't have failure detection capability.

Figure 1 displays the RCM logic to be used to determine if a component should have a scheduled maintenance requirement. Each decision block is numbered and detailed instructions for each block are provided below.

The following is a detailed set of instructions for application in the logic in figure 1:

Block 1. These questions are asked for each failure mode identified for the component under analysis. The answer to these questions is based on the failure effects and criticality documented as part of the FMECA. A "yes" answer indicates that a failure mode exists which results in either a safety hazard or a transit trip abort due to a critical loss of capability.

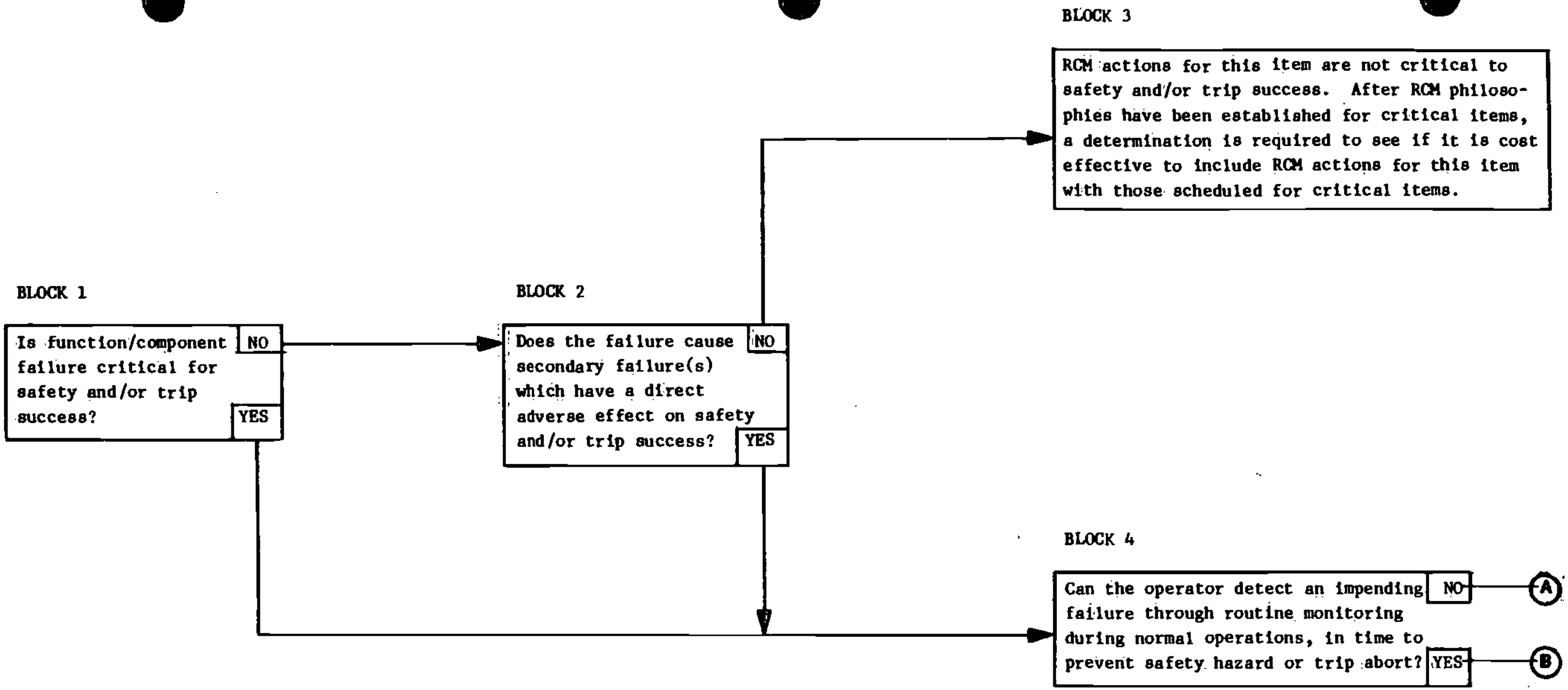

FIGURE 1 - RCM LOGIC

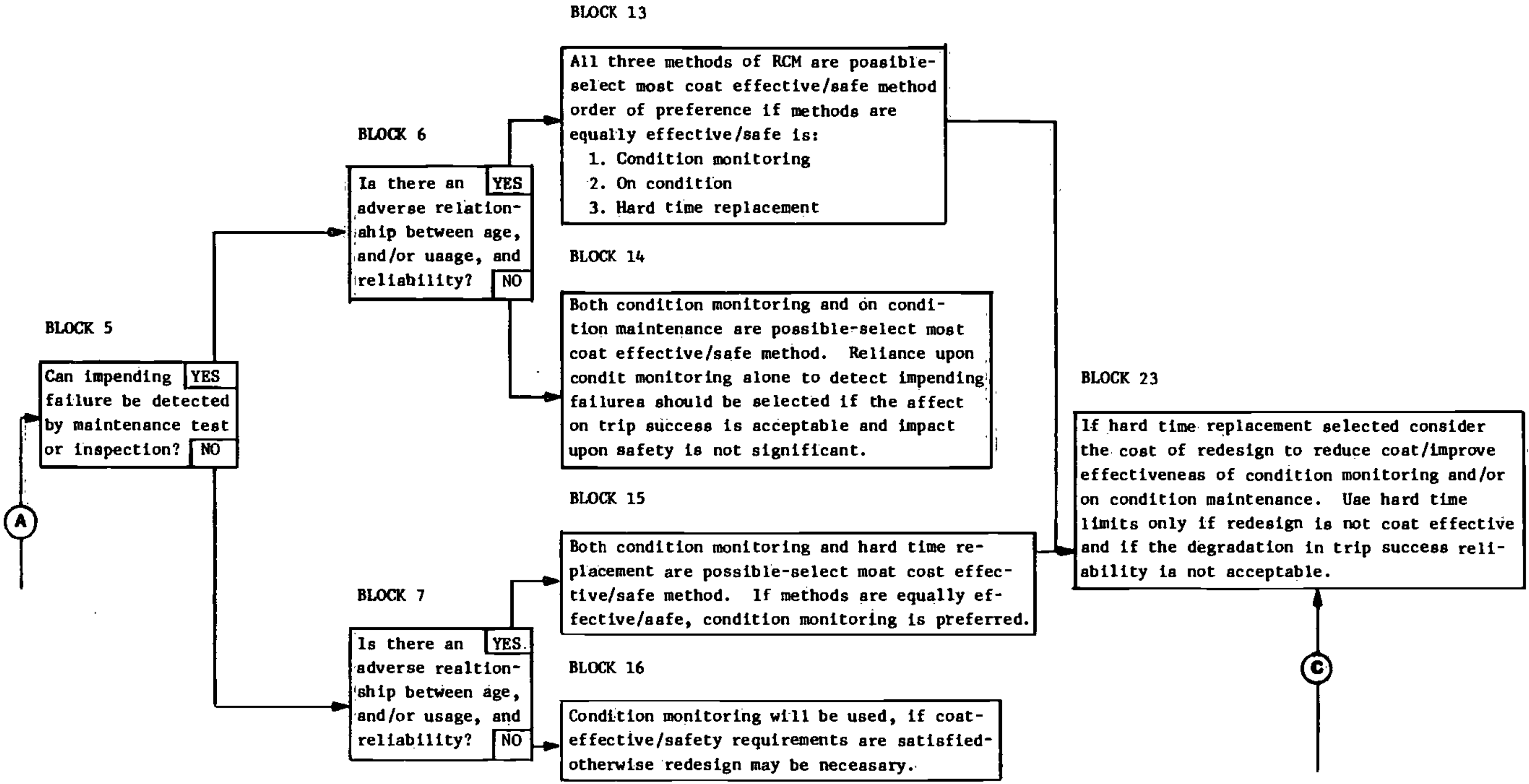

FIGURE 1 - RCM LOGIC (Cont'd)

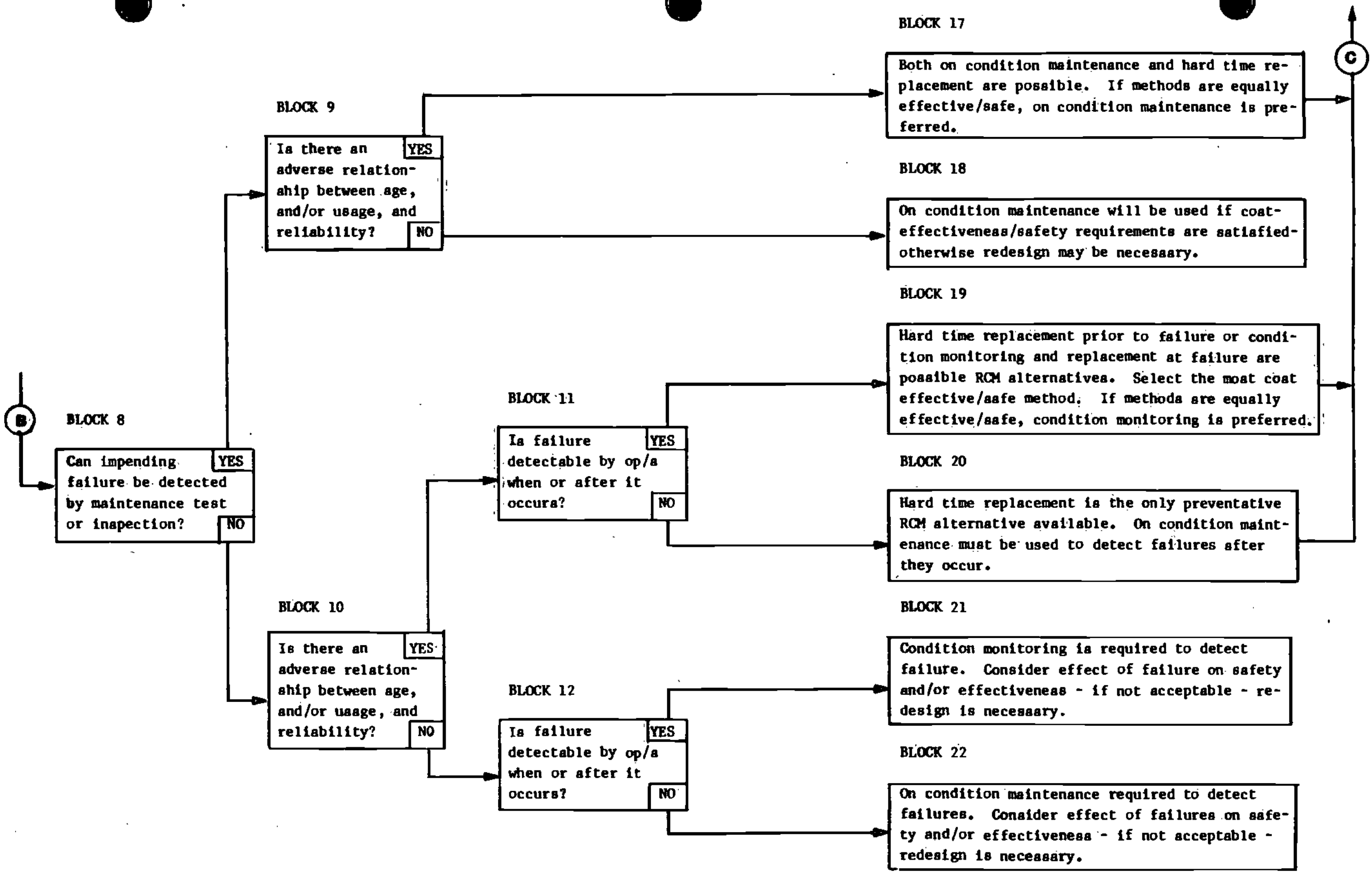

FIGURE 1 - RCM LOGIC (Cont'd)

Components and modes for which a "yes" answer is obtained are referred to as critical. These critical items are analyzed further to determine if a scheduled task will help prevent deterioration of reliability or safety levels, thus minimizing the risk of a system abort or safety hazard. A "no" answer indicates the component is noncritical in terms of trip success and/or safety and scheduled maintenance would only be justified on an economic basis or if it causes secondary failures which are critical.

Block 2. The instructions for this block are the same as for block 1 except that these questions refer to secondary failures caused by the primary failure modes considered in block 1. "Yes" answers identify critical components which have secondary failures which result in either a safety hazard or a trip abort. These critical components are analyzed further to determine what scheduled maintenance actions can be performed that will prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels. A "no" answer to each question in Block 1-2 indicates that the component is noncritical and can be operated to failure without incurring a safety hazard or a trip abort. For these components, Block 3 is addressed to determine if a scheduled maintenance task is justifiable from an economic standpoint.

Block 3.

(a) Block 3 is addressed to identify scheduled tasks which can be performed and which will decrease the cost of ownership of the end item. To address this block, it must first be determined whether a scheduled task can be done. This can be determined by applying the questions in blocks 4 through 12, keeping in mind that the questions are being addressed for noncritical components.

(b) In determining if a scheduled maintenance task is economically justified, the difference in ownership cost for the end item must be calculated between a maintenance plan that has a scheduled task(s) for the component under analysis and a plan which calls for only condition monitoring of the component. It is not intended that a complete life cycle cost be calculated for each alternative, but rather those cost factors which would be different between the alternatives should be determined. Consideration must also be given to any manpower, downtime, and/or availability constraints on the end item if an additional scheduled task is included in the maintenance plan for a noncritical component. If a substantial cost savings can be realized through some scheduled maintenance action which impacts one or more system constraints, then a trade-off analysis would be performed. It is not envisioned that a scheduled maintenance action for noncritical components would be economically justifiable in many cases.

(c) This block should not be addressed until the RCM logic has been applied to the critical components of the system/equipment under analysis because the results of the critical component analysis could affect the cost of feasible scheduled tasks on noncritical components. For example, a noncritical inspection may not be economically justifiable by itself, as it requires access time and cost, but if the access time and cost is determined to be required for a critical component inspection, then the noncritical inspection may be justifiable. For this reason, the economic aspects of noncritical tasks should only be addressed after the scheduled maintenance requirements for critical components are determined. If the analysis shows that scheduled maintenance (on-condition, hard time, or both) on the noncritical component under analysis does reduce the cost of ownership of the system/equipment, then this task(s) would be included in the overall maintenance plan. If a scheduled task is not feasible or is not economically justified for the noncritical component under analysis, then the component would be operated to failure and only unscheduled maintenance would be performed on it.

Block 4. The question in block 4 is intended to identify those critical failure modes which can be detected through routine operator monitoring with sufficient leadtime to prevent a trip abort and/or safety hazard. If there is a high probability that the failure mode under analysis can be detected with sufficient leadtime before it will actually occur to prevent a trip abort or incurrence of a safety hazard, then the question is answered "yes". This is the case for failure modes which have a sufficient time difference between onset of initial degradation and actual failure and a means of detecting the onset. The detection means can be in the form of instrumentation (gauges, warning lights, etc.) or operational characteristics (sound, etc.). The question is answered "no" if the operator cannot detect an impending failure, or if the time difference between onset and actual failure is not long enough to prevent a trip abort or safety hazard.

Block 5.

(a) The question in this block is addressed to identify the potential efficiency of a scheduled maintenance task on the component under analysis. The question must be considered in two parts. First, the impending failure must be physically detectable either by visual inspection or through use of test or measurement equipment. To be detectable, measurable physical properties of the component must change with the onset of degradation to allow identification of impending failure through comparison with normal properties.

(b) The second consideration is the probability that the scheduled inspection or test will coincide with the time between failure onset and occurrence so that the impending failure will be caught. As an example, a component which fails within seconds after the onset of any measurable degradation would not be a good candidate for a scheduled task. The probability that any reasonable inspection interval would result in the inspection occurring within the time between onset and failure is very small in this case; consequently, the payoff would be extremely small. On the other hand, if the time between measurable failure onset and actual failure occurrence is measured in days or months, then an inspection interval can be established which would result in a high probability of detecting the failure under analysis before it occurs. In answering this consideration, the failure distributions from the Reliability program, data from a historical review, and applicable test results must be analyzed.

(c) If the impending failure is physically measurable and a reasonable task interval can be established which results in an acceptable probability of detection, then the question in block 5 is answered "yes". If one or both of these considerations is not met, then block 5 is answered "no".

Block 6.

(a) The question in this block is addressed to identify wearout-type components and to determine the feasibility of scheduling a hardtime type replacement of the component. This question is answered "yes" if the probability of component failure increases as calendar time or usage indicators (operating hours, miles, rounds, cycles) increase.

For these items, a scheduled removal can be identified at a point in time or after a specified amount of usage when the probability of failure increases to an unacceptable level. Removal and replacement with a new item will decrease the probability of failure back to its original level. This question is answered "no" if the probability of failure is independent of both calendar time and usage. This is the case for components which exhibit an exponential failure rate.

(b) In answering the question in this block as "yes", it should be noted that a means of measuring the interval between scheduled replacements must be provided for the component. If the usage on the component cannot be economically maintained, then the question in this block is answered "no" because a hardtime replacement would not be feasible.

Block 7. The same instructions that were provided for block 6 apply to block 7.

Block 8. The same instructions that were provided for block 5 apply to block 8.

Block 9. The same instructions that were provided for block 7 apply to block 9.

Block 10. The same instructions that were provided for block 7 apply to block 10.

Block 11. The question in block 11 is addressed to identify hidden functions were incurrence of the failure mode may go undetected until the function is required. If the operator cannot detect that a failure has occurred, then on-condition type tests or inspections may be required to insure that a failure has not occurred and that there is a high probability that the hidden function will be available when required.

Block 12. The same instructions that were provided for block 11 apply to block 12.

Block 13.

(a) This block identifies critical components that exhibit wearout characteristics and impending failures can be detected by both routine operator monitoring and maintenance test or inspection. For components in this class, condition monitoring is always performed and on-condition and/or hard time tasks is only included if condition monitoring does not maintain the required trip success and/or safety levels. If this is the case, then on-condition and/or hard time maintenance would be considered if their inclusion in the maintenance plan would satisfy the trip success safety requirements.

(b) For the components that fall into this category after application of the RCM logic, routine operator monitoring during normal operations would provide an acceptable level of reliability and safety at the least cost.

Block 14. This block identifies critical components where impending failures can be detected by the operator through routine monitoring and by maintenance test or inspection. For components in this class, the condition monitoring by the operator is selected and the on-condition task is not required as long as both offer the same probability of detection. If the analysis shows that the on-condition test or inspection provides a more reliable detection probability, then it should be considered for inclusion in the maintenance plan along with the condition monitoring requirement.

Block 15. This block identifies critical components that exhibit wearout characteristics and the operator can detect impending failures through routine monitoring. For components in this class, condition monitoring is done by the operator and an analysis would have to be performed to justify a hardtime task against the component. A hardtime task would not be justifiable for components that can be condition-monitored unless a hardtime replacement limit can be established with a high degree of confidence and supported with real and applicable data, and the analysis shows that hardtime replacement would sustain in higher level of reliability and/or safety.

Block 16. This block identifies critical components where impending failures can be detected by the operator through routine monitoring, but on-condition and hardtime maintenance tasks would not provide any benefit. For these components, condition monitoring would be the only maintenance requirement other than the unscheduled repair or replacement tasks after an impending failure is detected. If the condition monitoring does not sustain the required safety levels and trip effectiveness, then feasible redesigns must be addressed to satisfy the requirements.

Block 17.

(a) This block identifies critical components that exhibit wearout characteristics and impending failures can be detected through maintenance test or inspections. For components that fall into this category, the inherent reliability and safety levels can be preserved by either a hardtime replacement or an on-condition test or inspection. Hardtime replacement and on-condition test may both be feasible to maintain acceptable reliability/safety levels. Each of the three alternatives must be analyzed in terms of cost and the reliability and safety levels that can be maintained under each alternative.

(b) For those cases where the frequency of the on-condition type task is high, a hardtime replacement may be more cost effective if the hardtime limit can be established with a high degree of confidence and it provides the necessary reliability and safety protection levels. In other cases where the component is costly and/or there is not enough data to establish a hardtime replacement limit with any degree of confidence, then the on-condition type task may be more cost effective. In each case, the benefits and risks of each alternative maintenance policy should be analyzed to select the most effective. If both on-condition and hardtime are considered feasible then the benefits and risks should justify the selection of the alternative. This alternative would be chosen if neither the hardtime limit nor the on-condition limits can be established with a high degree of confidence and cost/safety effectiveness can be improved by the use of both. If both are equally effective/safe, then the on-condition task is preferred over the hardtime task.

Block 18.

(a) This block identifies critical components where the only feasible means of sustaining the inherent reliability and safety levels is through an on-condition type maintenance test or inspection. For these components the frequency of the scheduled inspection or test must be established along with the critical values/characteristics of the component which separate a good component from one which has experienced an onset of failure. These critical characteristics should be clearly stated and easily measurable wherever possible to prevent uncertainty on the part of inspector or tester after performing the required task. If the reliability and safety levels without an on-condition task are acceptable, then no on-condition maintenance is required.

(b) Component redesign should be considered when the on-condition task does not maintain the required safety levels or trip effectiveness.

Block 19.

(a) This block identifies critical components that exhibit wearout characteristics, but impending failures cannot be detected either through routine operator monitoring or by maintenance tests or inspections. Actual failures are detectable by the operator either at the time of occurrence or after occurrence so that unscheduled repair or replacement can be accomplished in the event of failure. For these components, the only feasible scheduled task that will prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels would be a scheduled removal at specified intervals of time or usage. If the reliability and safety levels are adequate without the hardtime task, then it should not be included in the maintenance plan.

(b) Prior to making a final determination for components in this category, an analysis is made concerning the feasibility of redesign to provide a means of maintenance testing or inspection for impending failures. The ability to test for specified wear or degradation limits might reduce the number of component replacements and consequently provide a life cycle cost savings when analyzed with the cost of redesign to provide the detection capability. This alternative is especially considered for high value components where hardtime replacements are the only means of sustaining the required reliability and safety levels.

Block 20.

(a) This block identifies critical components that exhibit wearout characteristics, but impending failures cannot be detected either through routine operator monitoring or by maintenance tests or inspections. In addition, actual failures go undetected by the operator due to the hidden-function nature of the component. For components that fall into this class, an on-condition type maintenance test or inspection must be included in the maintenance plan to detect failures that have occurred and insure that there is a high probability of the hidden function being available when required.

(b) In addition to the on-condition task to detect failures that have occurred, a scheduled hardtime replacement is established based on the wearout characteristics of the component to prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels. Establishment of the hardtime task is dependent upon an analysis to determine the feasibility and cost effectiveness of redesigning the component under analysis as described under block 19. If reliability and safety levels are adequate without the tasks, then they should not be included in the maintenance plan.

Block 21.

(a) This block identifies components which have critical failure modes with no means of detecting impending failures or reducing the probability of a trip abort or safety hazard. Actual failures are detectable by the operator either at the time of occurrence or after occurrence so that unscheduled repair or replacement can be accomplished in the event of failure. For components in this category there are two alternatives. One alternative is to redesign or make redundant the component and/or interfacing components to eliminate the critical failure modes or to provide a means of detecting the impending failure. In the second case, no scheduled maintenance is performed and the risks of incurring a trip abort or safety hazard would have to be acceptable.

(b) To determine which alternative is taken, the feasibility and costs of the redesign must be determined along with the potential benefits from the redesign. In some cases, the required redesign may involve the addition of a test point or measurement device, while in other cases the cost of redesign may be prohibitive or the redesign may not be technically feasible. The intent of the RCM logic in this case is to highlight the problem so that the possible solutions may be addressed.

Block 22.

(a) The block identifies components which have critical failure modes with no means of detecting impending failures, no wearout characteristics, and no means for the operator to detect failures that have occurred. For components that fall into this category, an on-condition type task is included in the maintenance plan to detect failures that have occurred and to insure that there is a high probability of the hidden function being available when required.

(b) There are two alternative courses of action that can be taken because of the nondetectability of impending failures. The first is to redesign or make redundant the component and/or interfacing components to eliminate the critical failure modes or provide a means of detecting impending failures. The second alternative is to accept the inherent probability of failure and risk of incurring a trip abort and/or safety hazard.

(c) To determine which alternative should be taken, the feasibility and costs of a redesign or addition must be determined along with the potential benefits from each one. In some cases the required redesign may involve the addition of a test point or measurement device, while in other cases the cost of redesign may be prohibitive or a redesign may not be technically feasible.

Block 23. This block is included in the RCM logic to highlight those areas where redesign should be actively pursued as an alternative to hardtime replacements. Hardtime replacements should be included only if required system and safety levels cannot be achieved through condition monitoring and/or on-condition maintenance and a redesign to achieve the required levels is not feasible or is not cost effective.

SUMMARY

The RCM technique is decision logic that can be applied to transit communication systems for developing scheduled maintenance programs. Primarily hardware-oriented, it is adaptable to operating software appliques in rail rapid transit. Once the system under analysis is defined and understood, RCM can be employed very raidly. Characteristics of the RCM technique that have been found useful include:

1. Identifies items in the system which are critical in terms of revenue service and/or operating safety

2. Highlights maintenance problem areas for design review consideration

3. Provides supporting justification for scheduled maintenance task requirements

4. In field of all available alternatives, selected maintenance activities are conspicuous.

The author is currently investigating other systems in rail rapid transit where RCM could be applied.

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CAR EQUIPMENT:

CAR MAINTENANCE PHILOSOPHIES AND PRACTICES

RELIABILITY CENTERED MAINTENANCE (RCM) TECHNIQUES FOR RAIL RAPID TRANSIT APPLICATIONS

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1984 RAPID TRANSIT CONFERENCE
Baltimore, Maryland
JUNE 14, 1984 · 10:00 A.M.-12:00 NOON

DMJM

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ABSTRACT

This paper presents a methodology for deriving a detailed maintenance plan for rail rapid transit systems utilizing an organizational maintenance hierarchy. This methodology centers around analysis procedures based on reliability-centered maintenance (RCM) concepts.

The basic concept of RCM is to develop determination of maintenance requirements in the form of scheduled and unscheduled maintenance tasks. RCM provides the basis for the scheduled maintenance workload for the system and impacts the ability to sustain the inherent dependability of the system and maintain sufficient safety margins for operations and maintenance personnel in rail rapid transit environments.

An eventual result becomes a scheduled maintenance program that will minimize the number of service critical failures and optimize the ratio of scheduled maintenance to total maintenance conducted. Subsequently, the impact of service failures are minimized as will the cost of the total organizational maintenance effort.

I. INTRODUCTION

This paper provides analysis techniques for deriving the detailed maintenance plan for rail rapid transit systems/equipment during final design and construction/acquisition phases of a project. The maintenance plan for a transit system/equipment is a description of the requirements and tasks to accomplish achieving, restoring, or maintaining the operational capability of the system/equipment. This plan evolves from iterations of maintenance engineering analyses, which upon completion, identifies the detailed maintenance concept, maintenance tasks, organizational level maintenance descriptions, support and test equipment requirements, and facility requirements. This paper however, will concentrate solely on that part of maintenance planning which requires determination of maintenance requirements in the form of scheduled and unscheduled maintenance tasks.

The procedures presented herein represent an evolution from the procedures developed in 1968 by representatives of various commercial airlines which chartered the Maintenance Steering Group (MSG). This group developed decision logic for providing scheduled maintenance programs for the Boeing-747 aircraft. Subsequently, these procedures were refined and the peculiarities of the Boeing-747 were deleted to create a more universal document entitled "Airline Manufacturer's Maintenance Program Planning Document-MSG-2".

Eventually, the value of the MSG-2 concept to the Department of Defense was acknowledged by the Secretary of Defense in his annual Defense Department report for fiscal year 1976, citing success of the U.S. Navy application of the MSG-2 concept to new aircraft entering service in fiscal year 1977, to in-service aircraft by the end of fiscal year 1979, and to all other military-oriented equipment by the end of fiscal year 1979. The Department of Army (DA) implementation of the MSG-2 concept was eventually called reliability centered maintenance (RCM).

In the following section, the process by which specific input data is required to initiate development of RCM is discussed.

In the latter part of the second section, a detailed method of integrating reliability and logistics considerations into maintenance tasking is shown, using fault absorption methodology as a model characteristic.

The third section discusses the logic sequencing process which is applied to each repairable item in the system. Subsequently, the scheduled maintenance burden is identified based on the criteria and categorization of the maintenance requirements. Once all components are subjected to the logic sequencing process, a system analysis can be conducted to arrive at the overall maintenance plan.

Section Four covers the system analysis which merges individual component requirements into a system maintenance plan by optimizing the frequency of scheduled maintenance requirements and the sequence of performance of individual scheduled tasks.

II. PARAMETERIZATION OF RCM

In this section, the parameters which govern the evolution of the maintenance plan and data required to accomplish the decision logic are discussed and analyzed. Maintenance requirements for RCM logic categorization fall into the following:

1. Hardtime

2. On-condition

3. Condition Monitoring

On-condition maintenance is scheduled inspections or verification tests (BIT) designed to measure deterioration or onset degradation of a component. Depending on the level of deterioration, corrective maintenance may be performed or the component might remain in service.

Hardtime maintenance is scheduled removal tasks at predetermined fixed intervals of age or usage. With mechanical-type equipment (e.g. motors, gears, etc.), this form of maintenance is often considered.

Condition monitoring maintenance is unscheduled or remedial tasks. Condition monitored components are those which are allowed to fail or are components where impending failure can be detected by a master station or central control operator thorough routine monitoring during normal operation of revenue service.

The rationale behind the maintenance categorization is to determine the scheduled maintenance burden at the maintainer level, impact the operations and logistics support cost incurred by the transit system, and impact the operational readiness characteristics of the system. The end result is to reduce the scheduled maintenance burden and related costs incurred by the system while maintaining the necessary readiness rate.

1. <u>Hardtime Limits</u>

   Hardtime limits are established for components where condition monitoring and/or on-condition maintenance is not feasible from a safety and/or cost effectiveness standpoint (e.g., does not provide adequate assurance of detection prior to failure).

   Hardtime limits are established as a prerequisite for assuring safety or cost effectiveness. The general techniques to be followed in establishing hardtime replacement intervals are as follows:

a. The quantitative safety hardtime limit is usually established by first establishing the cumulative failure distribution for the component, and then establishing a replacement interval which results in an extremely low probability of failure prior to replacement.

b. The hardtime limit for the component falls within the anticipated service life of the system. If the limit exceeds the service life, preventive replacement is not required.

c. Where the failure does not cause a safety hazard but rather causes system failure, the readiness hardtime interval is established in a trade-off process involving the cost of replacing components, the cost of a failure, and the readiness requirement of the equipment/system.

The process of establishing the replacement interval (Tr) is accomplished through minimization of the following cost equation:

$$C(Tr) = (Cpr + Cf(F(Tr)))/Tr$$

where

C(Tr) = Expected cost per unit time.

Cpr = Cost of a preventive replacement.

Cf = Cost of a failure (includes cost of part replaced and system downtime). If CF = Cpr then cost is not a determining factor. The value of Tr should be established based on mission requirements.

F(Tr) = Expected number of failures in interval Tr.

Tr = Replacement interval.

Depending upon the equation defining the failure distribution, this equation can be solved by differentiation or by iteration (substituting different values for Tr and calculating the resultant expected cost).

After the minimum-cost replacement interval has been established, the effects on system downtime should be reviewed to assure an acceptable readiness rate is achieved.

In the establishment of hardtime limits, one must note the desirability of consolidating several hardtime replacements to occur at the same interval. A minimization of the summations of the individual costs is then sought. The minimization formula previously presented can be used in summation to establish this group hardtime replacement interval. However, if the intervals are relatively close to each other, a mean interval may be selected and used if the effects on the cost and readiness of individual items are not materially affected.

2. <u>On-Condition Limits</u>

On-condition maintenance is established for those items where condition monitoring is not feasible from a safety, system, and/or cost-effective standpoint.

On-condition maintenance intervals are established for two purposes: (1) to locate imminent failures and (2) to detect the occurrence of a failure. In either of these cases, the consequence of a failure may be a safety hazard and/or operation abort.

The objective of on-condition maintenance is the ability to schedule the inspections such that there is a very low probability that a failure will occur between inspections. This probability of failure is composed of the probability that failure onset will occur, and the onset will go to failure all within the inspection interval. If the average time to onset is much larger than the average time from onset to failure, consideration should be given to establishing a usage-dependent inspection program, i.e., wait to start inspections until the item has obtained a certain amount of usage. Of course, such usage-dependent intervals would only be feasible where usage information is maintained by the field on the item under consideration.

Where the failure does not cause a safety hazard, but rather causes a system failure, the inspection interval is established in a trade-off process involving the cost of conducting inspections, the cost of a failure, and the readiness requirement of the equipment/system.

The process of establishing the inspection interval (Ti) is accomplished through minimization of the following cost equation:

$$C(Ti) = [CTi + Cf\ (F(Ti))]/Ti$$

where

C(Ti) = Expected cost per unit time.

CTi = Cost of an inspection

Cf = Cost of an undetected failure (i.e., cost of the end item operating in a degraded mode)

F(Ti) = Expected number of failures in interval Ti.

Depending upon the equation defining the failure distribution, this equation can be solved by differentiation or by iteration (substituting different values for Ti and calculating the resultant expected cost).

In establishing inspection intervals, one must consider the desirability of arranging several inspections to occur at the same interval. A minimization of the summation of the individual cost is then sought. The minimization formula previously presented can be used in summation to establish this group inspection interval. However, if inspection intervals are relatively close to each other, a mean interval may be selected if cost/readiness of individual items are not materially affected.

3. Condition Monitoring

Condition monitoring is the process where the operator detects either experienced or impending failure through routine monitoring of operation and use. The experienced failures are those that are detected by the operator when or after they occur. The impending failures are those detectable either directly, by the operator through the human senses (heat, noise, etc.), or indirectly, through the incorporation of design features such as built-in test equipment (BITE) and sensors/annunciators before they occur.

Condition monitoring (CM) is generally the most desirable of the three types of maintenance requirements, as it will result in the least number of maintenance actions. However, the constraints of system readiness, and/or safety may force the inclusion of an on-condition (OC) or hardtime (HT) task in combination with condition monitoring if they provide for sustaining higher levels of reliability and/or safety.

The cost of condition monitoring must be determined for impending and experienced failures so that a comparison to on-condition and hardtime can be made. Normally there should be low cost associated with a condition monitoring system. The operator is already assigned to a system and through performance of normal duties, impending and experienced failure can be detected. Whenever condition monitoring is a cost alternative, it should be the most effective.

The cost equation for CM is:

$$C(T_D) = (P_{DA} C_{DA} + P_{ND} C_{ND} + P_{DB} C_{DB}) N_f + C_{WD}$$

Where $C(T_D)$ = Expected cost of detected and nondetected failure in interval T.

C_{DA} = The cost of a failure detected after it occurs (i.e., cost of test equipment, degradation of the system).

C_{ND} = The cost of a failure not detected during interval T.

C_{DB} = The cost of a failure detected before it occurs (i.e., cost of redesign of end item).

P_{DA} = The probability of a failure being detected after it occurs.

P_{ND} = The probability of a failure not being detected during T.

P_{DB} = The probability of a failure being detected before it occurs during T.

N_f = The total number of expected failures during the interval T.

C_{WD} = The additional total life cycle cost per end item incurred by incorporating the warning device divided by the number of expected intervals during the life cycle.

The probability that a failure can be detected by condition monitoring, either impending or experienced, will be determined from the FMECA or historical data. This probability is comprised of factors such as the probability of the warning device, if included, detecting a failure and emitting a signal, and the probability of the operator perceiving the signal.

The readiness would be calculated for either case of condition monitoring: without a warning device, and with a warning device. These values and the cost estimates would be traded off with those obtained from on-condition, hardtimes, or a combination of any of the three, to determine the optimum maintenance requirement.

4. Data Gathering for RCM

The RCM process as described in Section I is applied once a component's failure modes, effects, criticality, and safety characteristics have been identified. Individual failure modes are addressed during the application of the RCM logic. Thus for a given component, different scheduled maintenance tasks can be arrived at due to the different failure modes and their characteristics. As an example, a given component might undergo condition monitoring by operations during normal operating periods to detect the majority of predicted failure modes for the component, while still having an on-condition or hardtime requirement due to a failure mode that is not detectable.

For purpose of example, a digital remote terminal unit (RTU) which is a functioning part of supervisory control and data acquisition systems in rail rapid transit applications is utilized. A picture of a typical RTU is shown in Figure 1. The standard RTU is a microprocessor-based unit of modular design, which affords maximum flexibility in providing input/output (I/O) data to various systems at different far end locations.

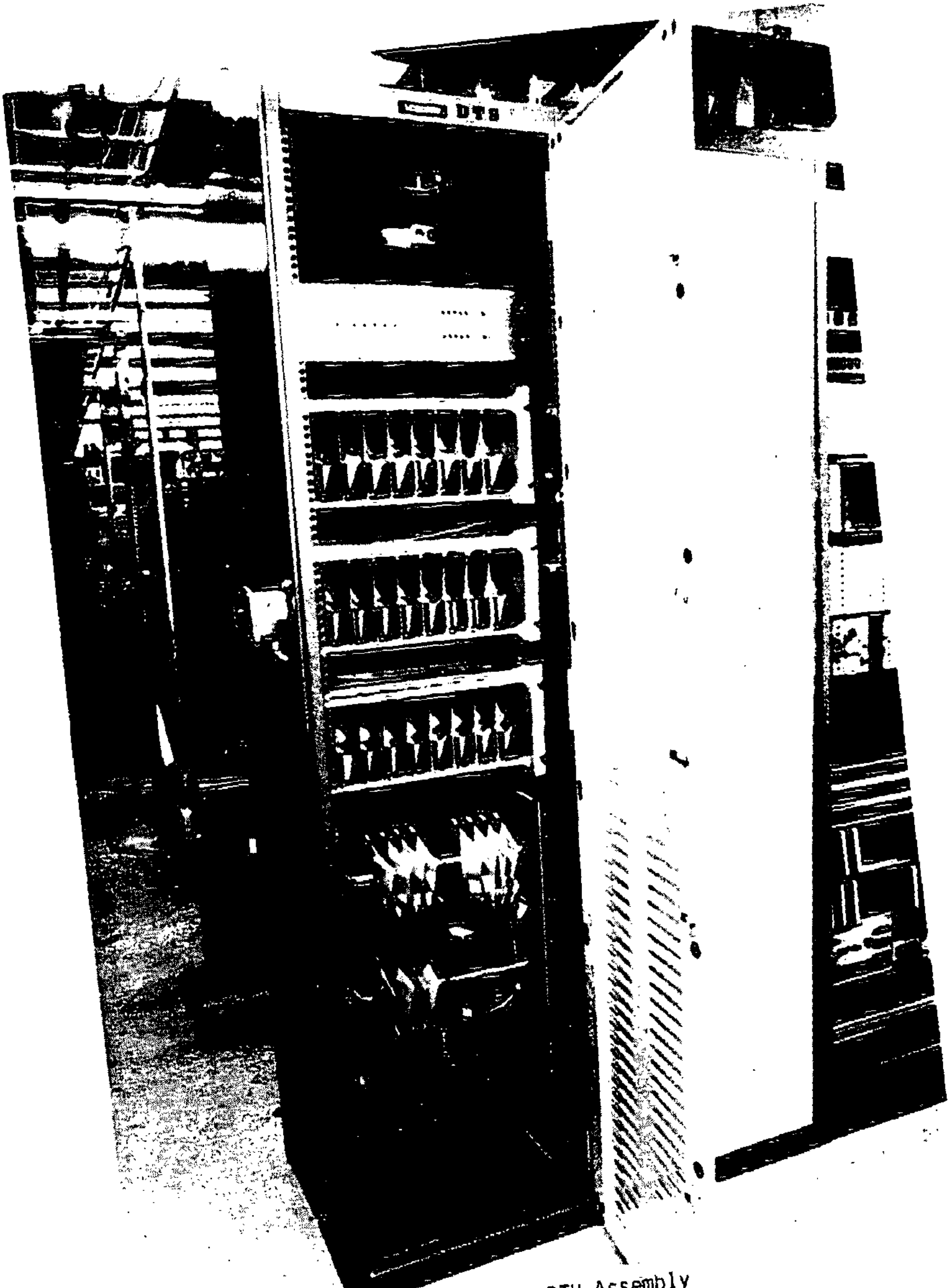

FIGURE 1 - RTU Assembly

Generally, each terminal unit monitors, in parallel form, dry contact closures from traction power, train control, and communication equipment and converts the closures into a coded binary serial data stream. This stream, with framing, status, and error detection bits added, is sent to a Central Data Processing Network for error detection decoding and data processing. Each RTU also receives data from the Central Data Processing Network, after an error detection and decoding process of the data is converted to appropriate parallel contact closures.

Typically an RTU is composed of relay interfacing hardware, digital control equipment, micro-computer, and a communication device, such as a modem. For the purpose of simplicity and reduction of repeatability, this paper will only concern itself with the input side of the RTU.

A standard concept with the RTU in this application is that the transit system cannot function properly if there exists a significant period of time when monitoring or control from operations is lost due to RTU failure. Subsequently, a component failure mode which disables the function of the RTU is considered critical to revenue service.

As examples of a typical failure modes, effects, and criticality analysis (FMECA) of the RTU, see Figures 2 through 4. Figure 5 depicts a safety hazard analysis of the RTU being studied in this paper.

In the following sections, this data's utilization to RCM will be discussed and elaborated further. Reference will be made to the analysis data which is contained in this section.

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS (FMECA)

FUNCTION PERFORMED: Provides remote terminal processing capability within the SCADA Subsystem.

SUBFUNCTION/FUNCTION: Relay Input Card/RTU
SUBSYSTEM: SCADA
SYSTEM: Communications

GENERAL DESCRIPTION				FAILURE CAUSE/EFFECT						DESIGN/CONTROL MECHANISMS		
					FAILURE EFFECT ON							
FMECA NO.	ITEM/ FUNCTIONAL IDENTIFICATION	LRU FUNCTION	FAILURE MODE	PROBABLE CAUSE OF FAILURE	ITEM/ COMPONENT	NEXT HIGHER LEVEL	TOP LEVEL SYSTEM	REVENUE SERVICE	C. R.	FAILURE PREDICTABILITY	FAILURE DETECTION METHOD	BASIC MAINTENANCE ACTIONS
01	Relay Input Card	Controls external relays for switching purpose of large current and voltages	Loss of function	No Field 28V Power	Loss of subfunction	Loss of RTU Assembly function	Temporary loss of Remote RTU	Possible delay/or loss of operational Availability	II	None	Cannot close any interposer relays once selected, even though close or trip LEDs do illuminate	1. Check 28V power supply (it does not effect logic power LED) 2. Check for short circuit across and open circuit to field 24 and FLDRTN lines.
02	Relay Input Card	Controls external relays for switching purpose of large current and voltages	Loss of function	Sample (comparison) relay has open circuit to the coil	Loss of subfunction	Loss of RTU Assembly function	Temporary loss of Remote RTU	Possible delay/ or loss of operational Availability	II	None	Cannot close any interposer relays once selected, even though close or trip LEDS do illuminate	Check with scope to see SAMRTN ramp to .7V with respect to system common when operate relay closes

Figure 2
Relay Input Card FMECA

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS (FMECA)

FUNCTION PERFORMED: Provides remote terminal processing capability within the SCADA Subsystem

SUBFUNCTION/FUNCTION: Digital Input Card
SUBSYSTEM: SCADA
SYSTEM: Communications

GENERAL DESCRIPTION				FAILURE CAUSE/EFFECT						DESIGN/CONTROL MECHANISMS		
					FAILURE EFFECT ON							
FMECA NO.	ITEM/ FUNCTIONAL IDENTIFICATION	LRU FUNCTION	FAILURE MODE	PROBABLE CAUSE OF FAILURE	ITEM/ COMPONENT	NEXT HIGHER LEVEL	TOP LEVEL SYSTEM	REVENUE SERVICE	C. R.	FAILURE PREDICTABILITY	FAILURE DETECTION METHOD	BASIC MAINTENANCE ACTIONS
01	Digital Input Card	Converts analog to digital signals	Loss of function	Input voltage out of range due to bad transducer or SCA line resistor	Partial loss of PC Board	Temporary loss of remote RTU	Delay/or loss of remote RTU	Possible delay/or loss of operational Availability	II	None	One or more points of a single board convert to wrong value	Check channel input voltage with high impedence voltmeter.
02	Digital Input Card	Converts analog to digital signals	Loss of function	Board calibration out of limits	Partial loss of PC Board	Temporary loss of remote RTU	Delay/or loss of availability	Possible delay/or loss of operational availability	II	None	One or more points of a single board convert to wrong value	Recalibrate with PTZERO and PTGAIN POTs.

Figure 3
Digital Input Card FMECA

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS (FMECA)

FUNCTION PERFORMED: Provides remote terminal processing capability within the SCADA Subsystem

SUBFUNCTION/FUNCTION: CPU Board/RTU
SUBSYSTEM: SCADA
SYSTEM: Communications

GENERAL DESCRIPTION				FAILURE CAUSE/EFFECT						DESIGN/CONTROL MECHANISMS		
					FAILURE EFFECT ON							
FMECA NO.	ITEM/ FUNCTIONAL IDENTIFICATION	LRU FUNCTION	FAILURE MODE	PROBABLE CAUSE OF FAILURE	ITEM/ COMPONENT	NEXT HIGHER LEVEL	TOP LEVEL SYSTEM	REVENUE SERVICE	C. R.	FAILURE PREDICTABILITY	FAILURE DETECTION METHOD	BASIC MAINTENANCE ACTIONS
01	CPU Board	Provides data acquisition storage, and control of RTU	Loss of function tinn	Auto-restart option is causing 234, Pin 2 of the CPU board to go to Logic 0 because TIMINT is not being reset in time	Loss of subfunction	Loss of RTU Assembly function	Temporary loss of Remote RTU	Possible delay/or loss of operational Availability	II	None	Unit seems to do nothing but repeatedly go through an initialization sequence, or unit reinitializes frequently, losing accumulator, change of state and other pertinent data.	1. Replace CPU board 2. Replace PROM firmware program or verify.
02	CPU Board	Provides data acquisition storage, and control of RTU	Loss of function	Power on reset absent unit did not necessarily complete all nf initialization.	Loss of subfunction	Loss of RTU Assembly function	Temporary loss of Remote RTU	Possible delay/or loss of operational Availability	II	None	Unit does seem to initialize once; howevery, it seems to do nothing else.	1. Check for POR at the CPU Board, motherboard connector Pin C. Replace power supply if missing.

Figure 4
CPU (Processor) Board FMECA

SUBSYSTEM HAZARD ANALYSIS (SSHA)

SUBSYSTEM: SCADA　　　　PREPARED BY________　　　　DATE________

SYSTEM: Communications

GENERAL DESCRIPTION			HAZARD CAUSE/EFFECT			CORRECTIVE ACTION
(1) FUNCTION DESCRIPTION & No.	(2) SYSTEM MODE	(3) HAZARD DESCRIPTION	(4) POTENTIAL CAUSE	(5) EFFECT ON SUBSYSTEM/ INTERFACING SUBSYSTEM	(6) HAZ CAT	(7) REDESIGN/CONTROL REMARKS
RTU	Maintenance	Destruction of PC Board/Erroneous data	Insertion of incorrect PC Boards	Damage to PCB or rack connector. Erroneous data could cause erroneous operation of system. Application of high potential or bad data on pin contacts through error by other interfacing subsystems.	III D	O&M Manuals supplied will include proper methodology for PC board insertion.
CPU Board	Operating	Erroneous operation of RTU assembly	Component (CPU Board) failure	Minor degradation to operation of subsystem and/or interfacing subsystem.	III C	Monitor RTU status configuration IAW Operations and Installation Manual.
Power Supply	Operating	Erroneous operation of RTU assembly	Change in AC supply or load	Possible degradation due to burn out of logic circuits (ICs) and other components due to overvoltage. Erratic operation due to undervoltage.	III B	Power supplies are line and load regulated to less than 1% and have overcurrent protection in case of short circuits.

Figure 5
RTU Safety Analysis

5. Fault Absorption Model

The Fault Absorption Model [1] is a modular representation of a system suitable for modeling the absorption of independent single failures in line-replaceable hardware elements. In addition, it models the application of unrestricted repair of soft failures to those hardware elements that fail gracefully.

A module that is critical is not fault-tolerant (i.e., those elements for which each failure is relevant).

Alternatively, a module that is soft is fault-tolerant (i.e., those elements for which relevant failure is always preceded by one or more sequential nonrelevant failures).

The concatenation of these modules, chosen to represent the various hardware elements composing the system, is the Fault Absorption Model for that system.

The baseline for the development of a system's Fault Absorption Model is the traditional System Reliability Model. Added to this baseline is the information concerning rates of occurrence of each hardware failure and the maintenance resources required by the system to enable it to react to these failures.

Along with this information, its supporting computational steps are provided in a form that is direct, simple, and structured.

With these extensions to the baseline reliability model, the resulting Fault Absorption Model becomes a tool that is capable of integrating the system design, logistic design, and RCM modeling specialties within engineering.

To reduce the previous descriptions to more concrete terms, an example will be offered for a critical circuit, representing a group of processor logic circuits and for a soft circuit, representing a set of redundant modems.

Example 1 - Critical Circuit

In a critical circuit, each logic circuit board to be presented fails independently of the other logic boards and any logic board failure disables the RTU in a system-relevant way. Logic boards are replaceable singly and spare logic boards are provisioned as operational spares.

Commencing with the Relay Input Card, the assumption is made that sixteen logic boards compose the set, and that their aggregate failure rate is 83 failures per 1 million hours (with reciprocal MTBF of 12022 hours). This data is shown in Figure 6a.

Since some maintenance action must take place for each of these failures, this failure rate is carried down to the "maintenance line". This line serves to connect and total all maintenance actions at the system level. Figure 6a. shows the addition of this maintenance rate information to the critical circuit.

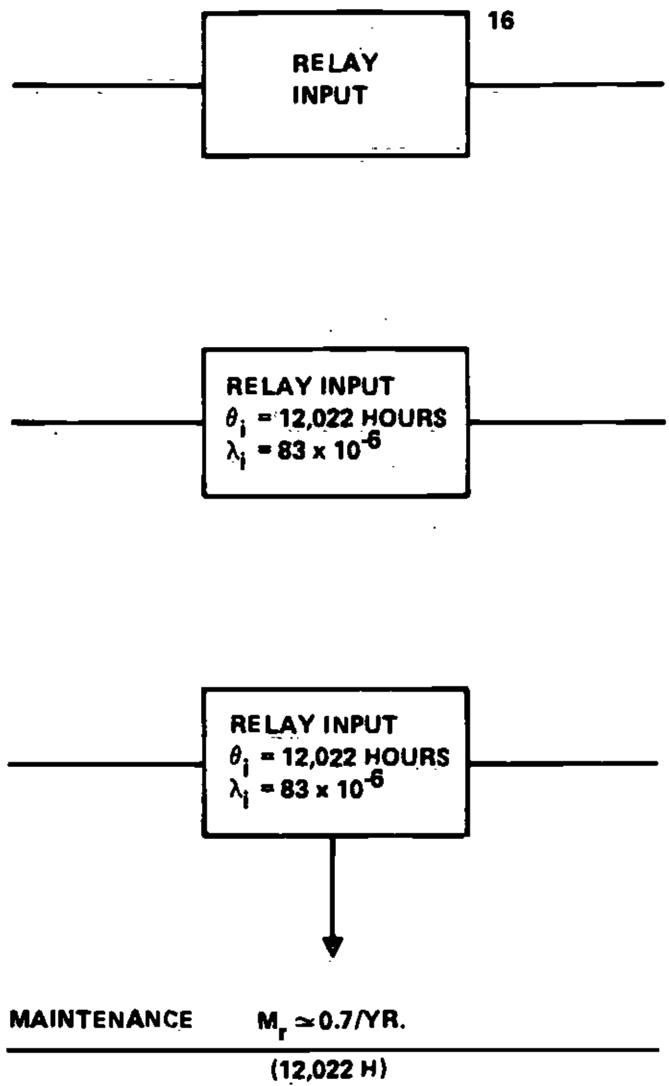

FIGURE 6a. CRITICAL CIRCUIT – RELAY INPUT

This particular failure must then be related to the types of maintenance action appropriate to the system. For this example, three basic types of maintenance are meaningful:

> Type 1 - Fully automatic. Indication is provided to operations that the action has been successfully completed. The time during which operations are disrupted is negligible.
>
> Type 2 - Semiautomatic. Indication is provided to operations that specific action is required of them, and the facilities to accomplish the action are available. Disruption time is short, but operationally noticeable.
>
> Type 3 - Predominantly manual. Facilities are provided to support operations but since these failures are relatively serious, the depth and/or duration of disruption to the system is serious.

The addition of this maintenance information is shown in Figure 6b.

All failures in non-fault-tolerant equipment, of which this logic is an example, are relevant failures. Therefore, a "relevance line" is introduced, similar to the maintenance line. This relevance line serves to connect and total all relevant events at the system level. Its incorporation is shown in Figure 6c.

The system requirements for this example recognize several degrees of system impact caused by relevant failures. The relevance line enumerates the total of relevant events for this critical station, but the degree of system impact for this failure type must also be identified.

To accomplish this identification, the following four hypothetical degrees of impact are defined to be significant to the system requirements. They are characterized in terms of their impact on throughput, functional scope, and disruption of system operations:

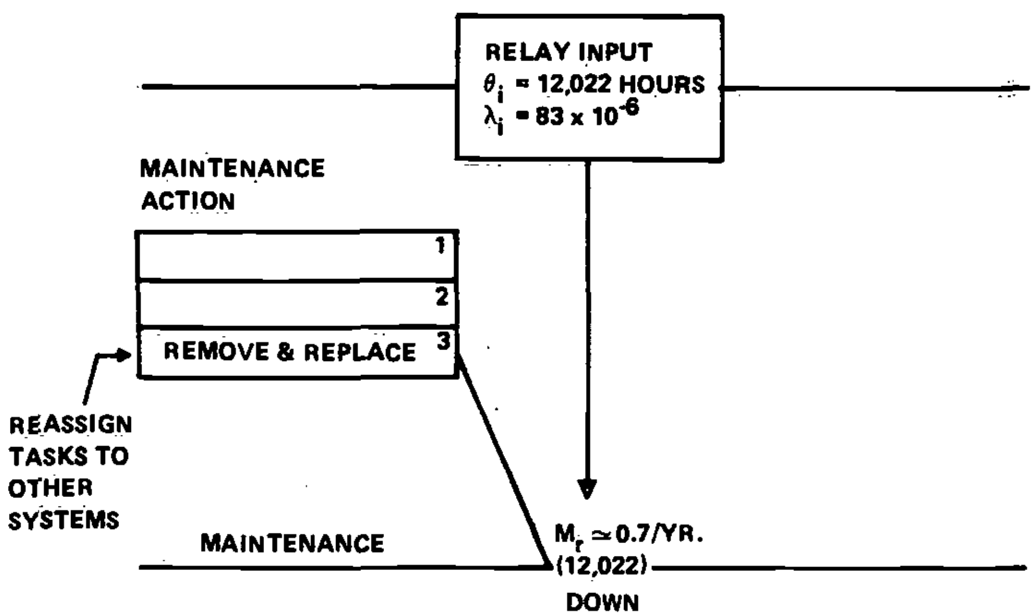

FIGURE 6b. CRITICAL CIRCUIT – RELAY INPUT

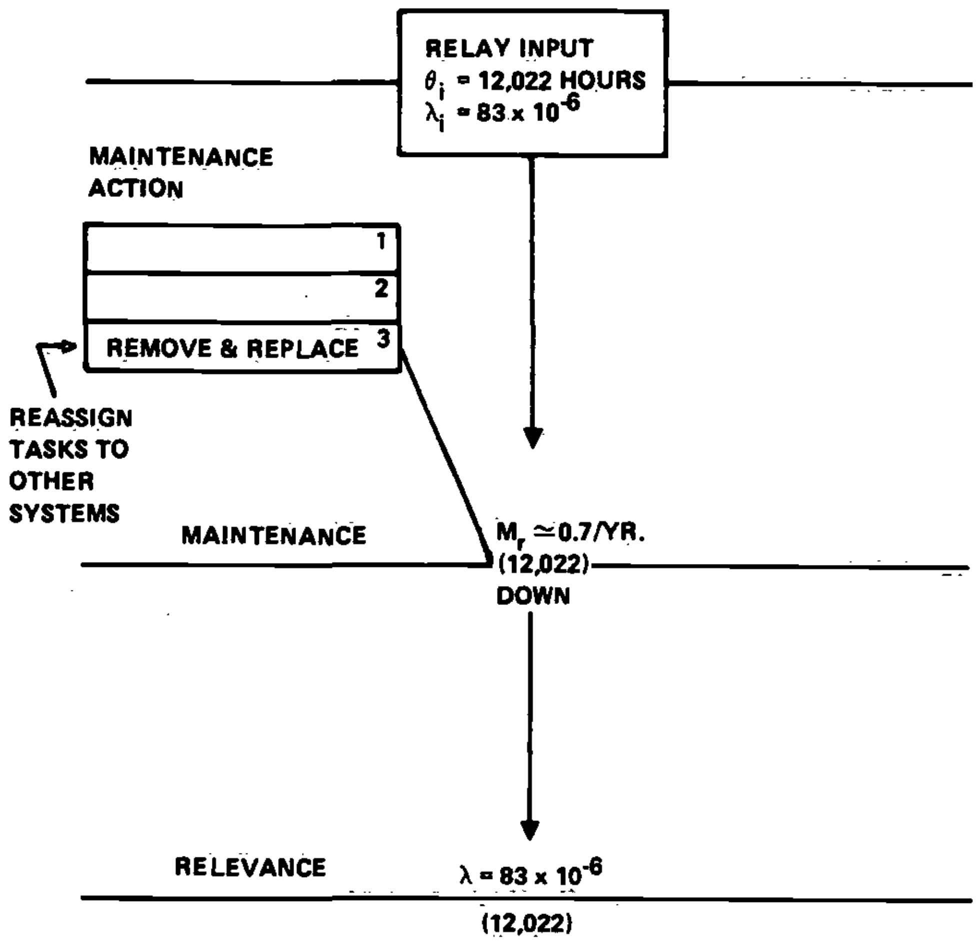

FIGURE 6c. CRITICAL CIRCUIT – RELAY INPUT

Degree 100. This impact is minimal, leaving the remaining system fully operational and with throughput greater than that required for full load operation. This impact is essentially an erosion of the design safety margin.

Degree A. This impact does not diminish system functions. The system throughput does not fall below 70 percent of that required for full load operation. The disruption to system operations is very short.

Degree B. This impact reduces system functionality and/or reduces its throughput below the 70 percent level of Degree A. Recovery does not exceed 1 hour, and the throughput after recovery is at least to the 70 percent level.

Degree C. This impact is identical to Degree B except that operational disruption during recovery exceeds 1 hour.

Since these impacts are defined as significant to specific system requirements, the failure shown as relevant in Figure 6c must be associated uniquely with one of the requirements. This information is incorporated as shown in Figure 6d.

Figure 6d also incorporates impact lines similar to the maintenance and relevance lines to assist later in the system-level summing of the rates associated with each level. These sums describe the capability of the system against which the requirement will be compared and compliance estimated. Figure 6d is defined as the critical circuit for the sample group of relay input boards. Figures 7a through 8d depicts similar details for the digital input and processor logic boards.

Example 2 - Soft Circuit:

The actively redundant modems chosen to illustrate the soft circuit are fault tolerant in the sense described previously and the soft circuit used to model these boards.

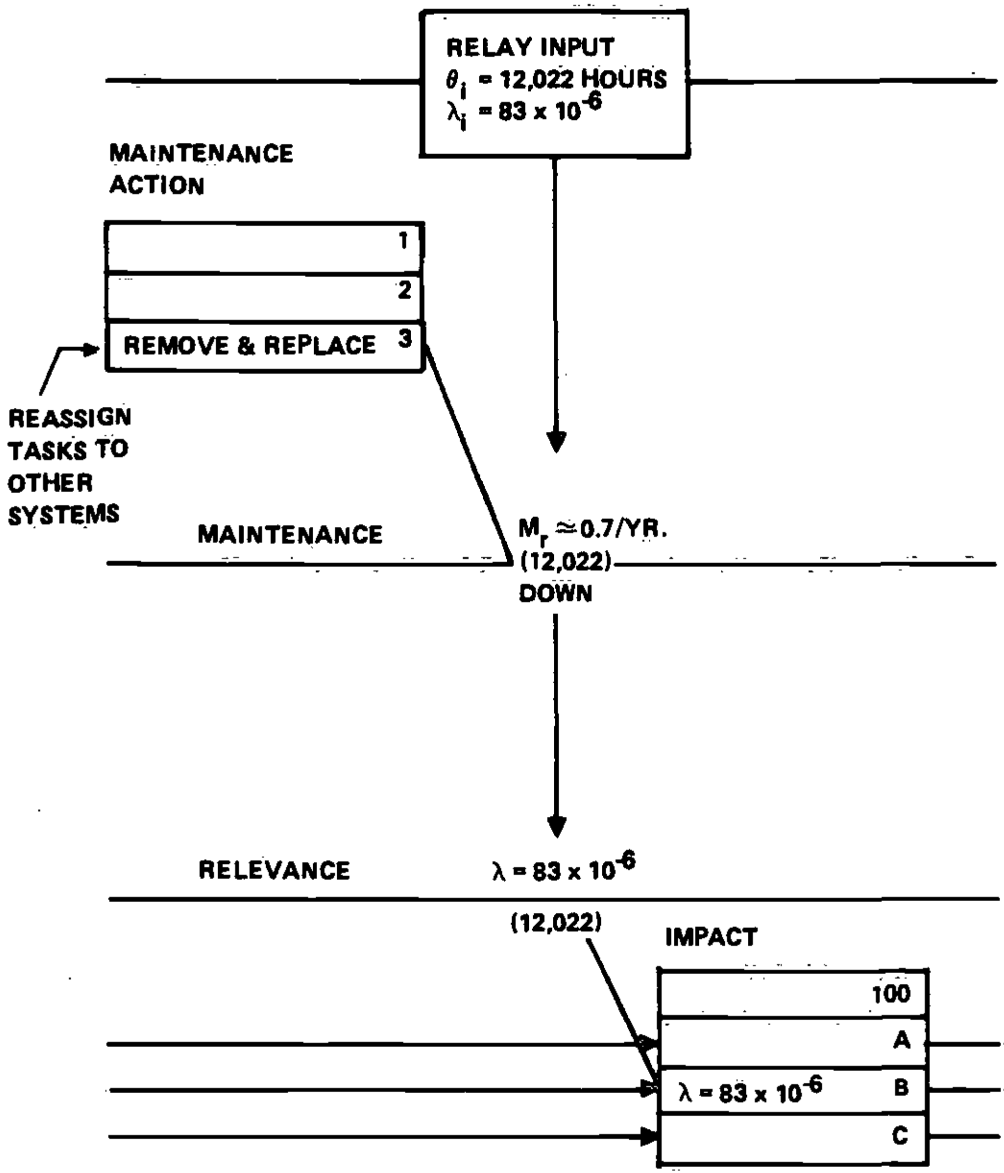

FIGURE 6d. CRITICAL CIRCUIT – RELAY INPUT

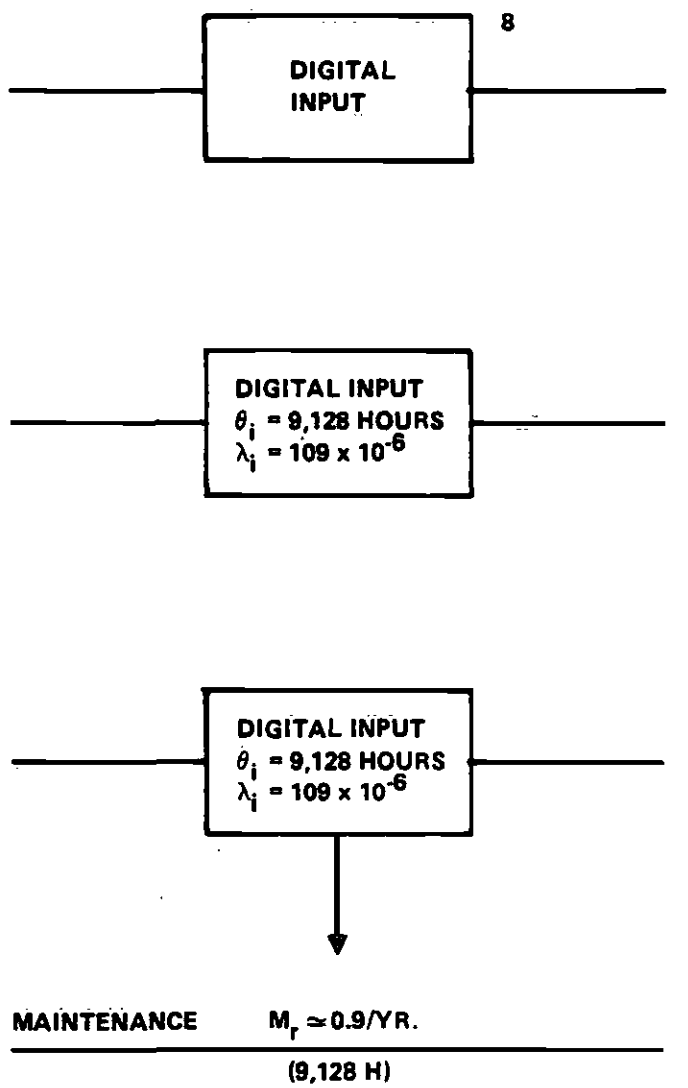

FIGURE 7a. CRITICAL CIRCUIT – DIGITAL INPUT

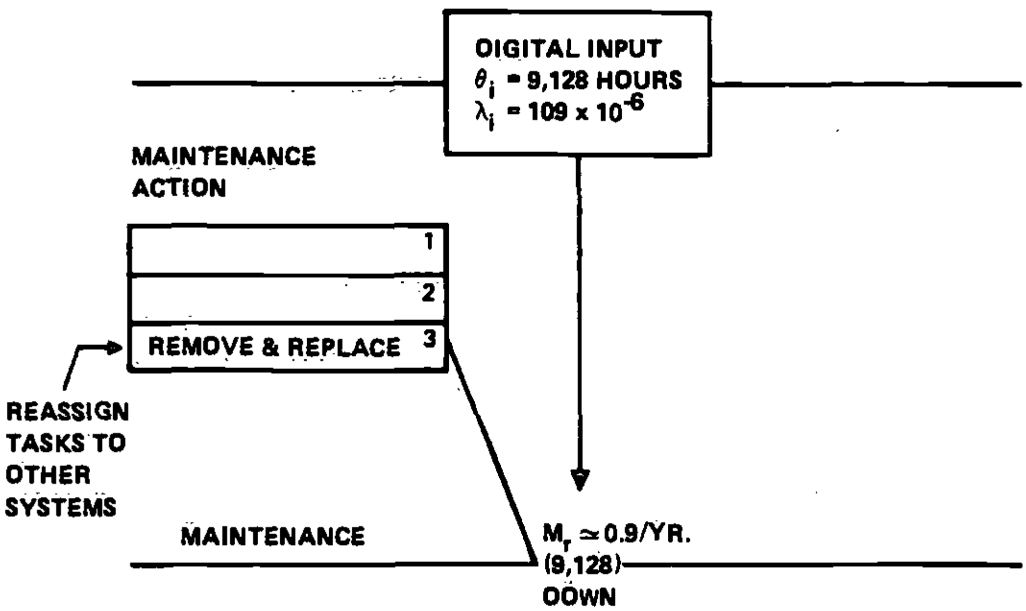

FIGURE 7b. CRITICAL CIRCUIT – DIGITAL INPUT

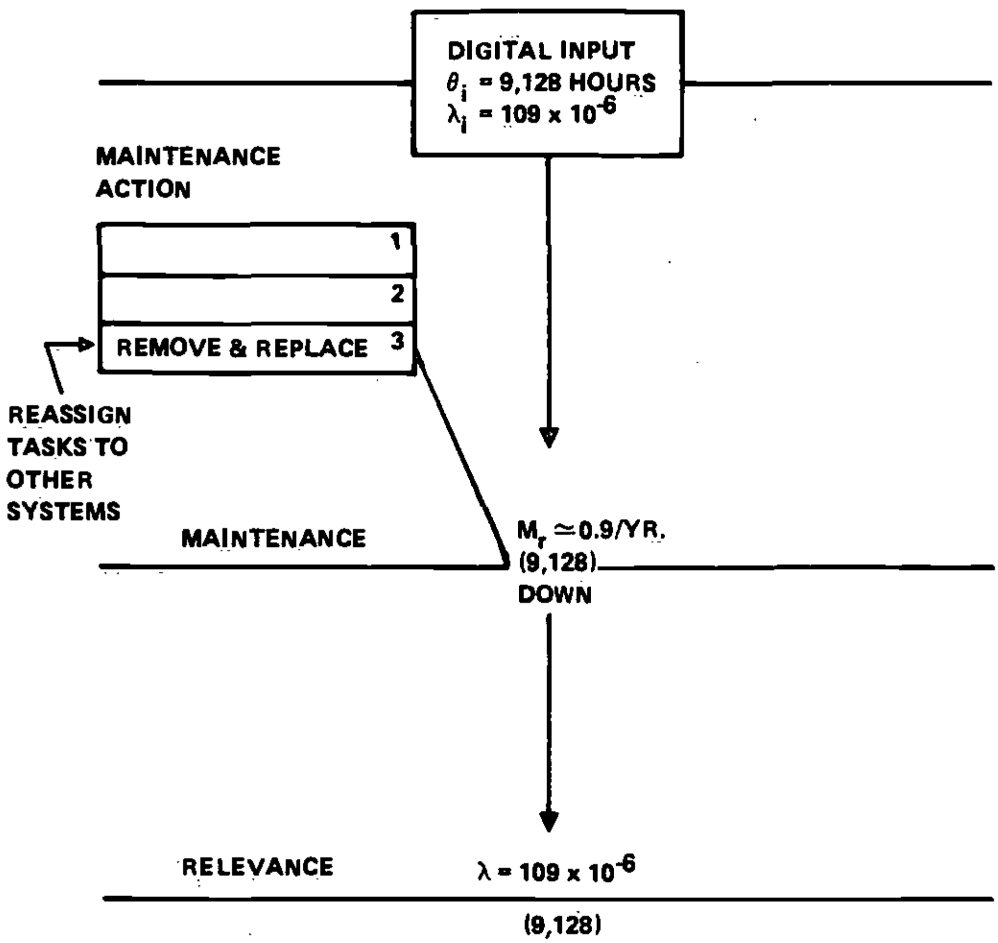

FIGURE 7c. CRITICAL CIRCUIT – DIGITAL INPUT

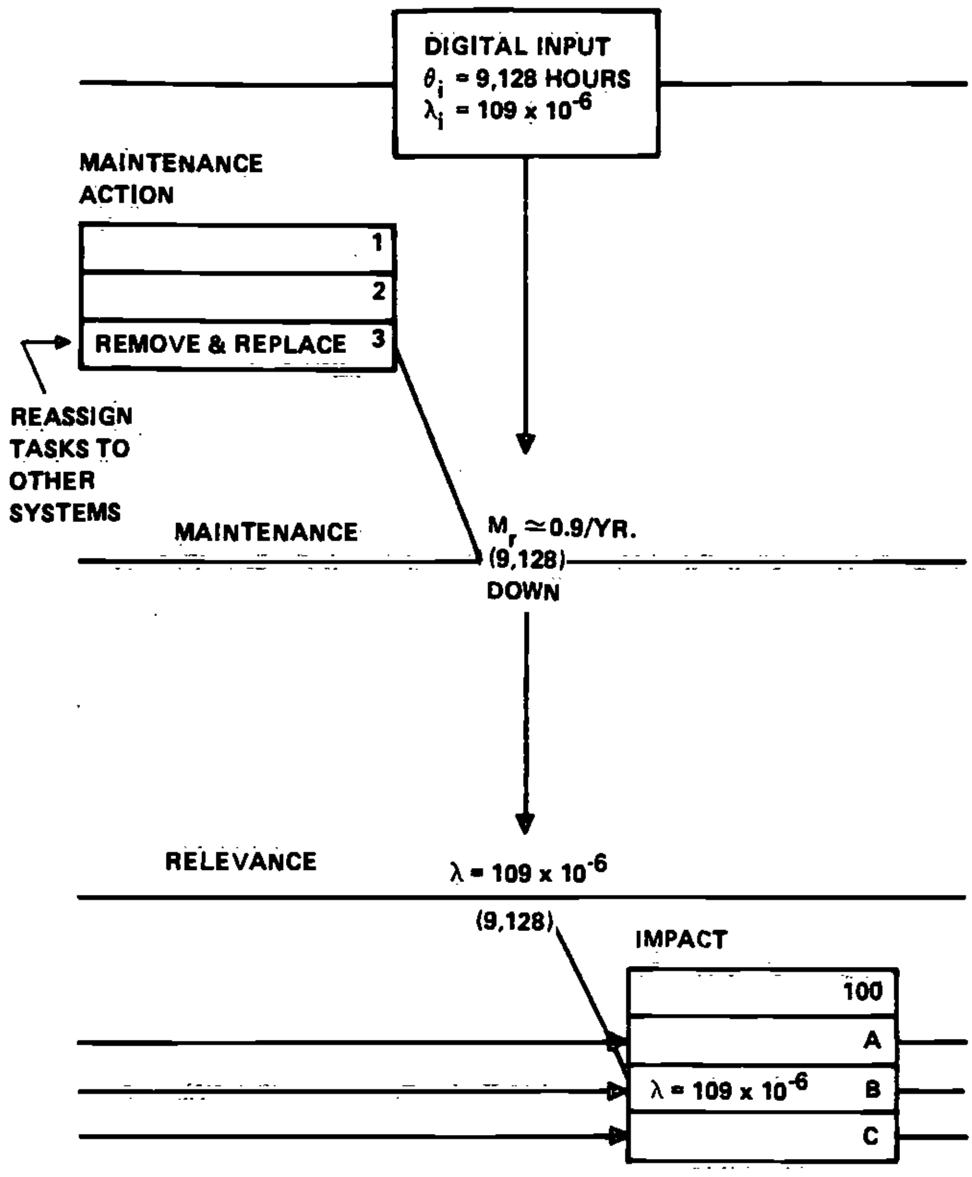

FIGURE 7d. CRITICAL CIRCUIT – DIGITAL INPUT

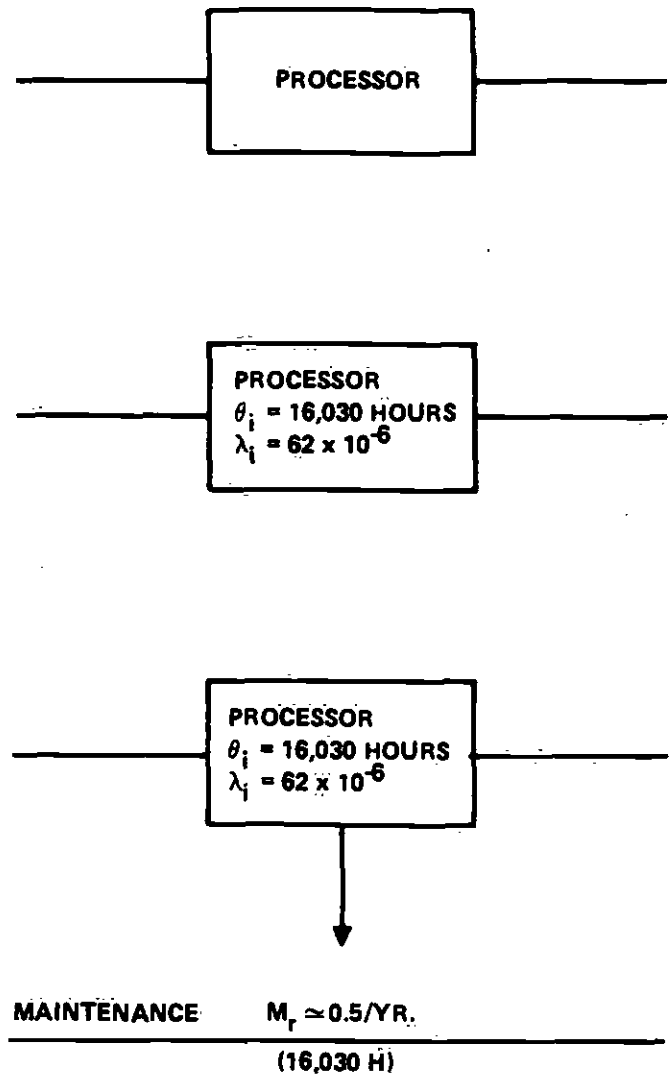

FIGURE 8a. CRITICAL CIRCUIT – PROCESSOR

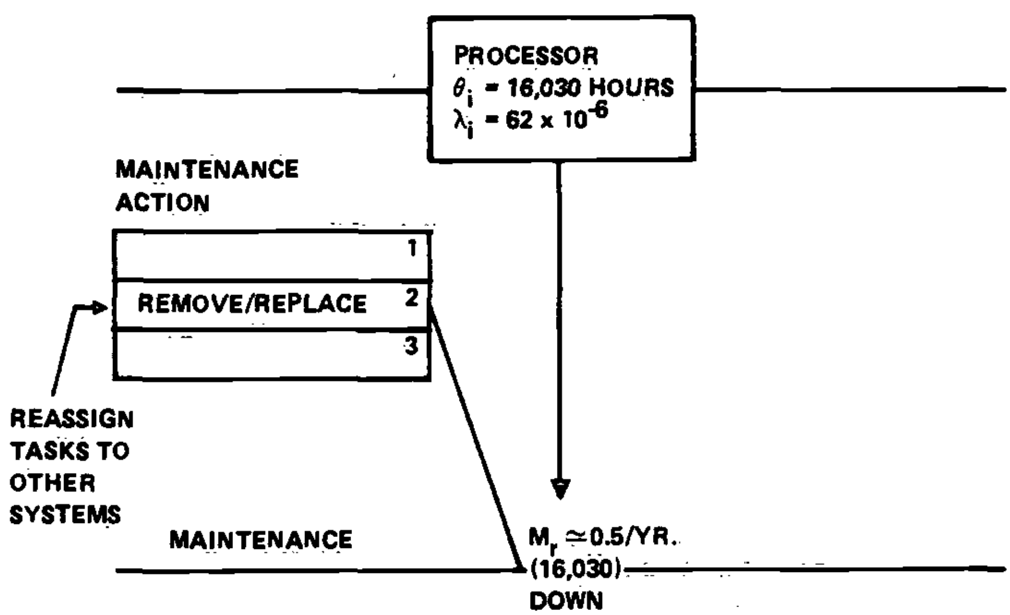

FIGURE 8b. CRITICAL CIRCUIT – PROCESSOR

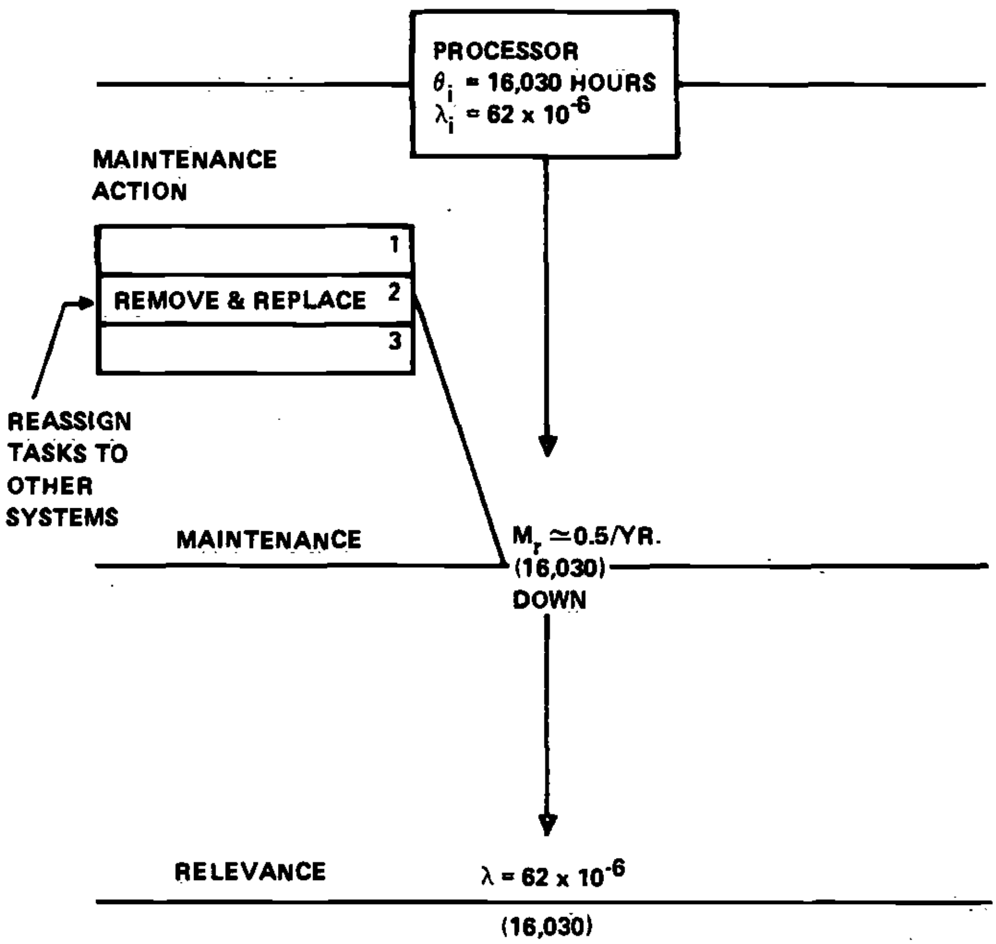

FIGURE 8c. CRITICAL CIRCUIT – PROCESSOR

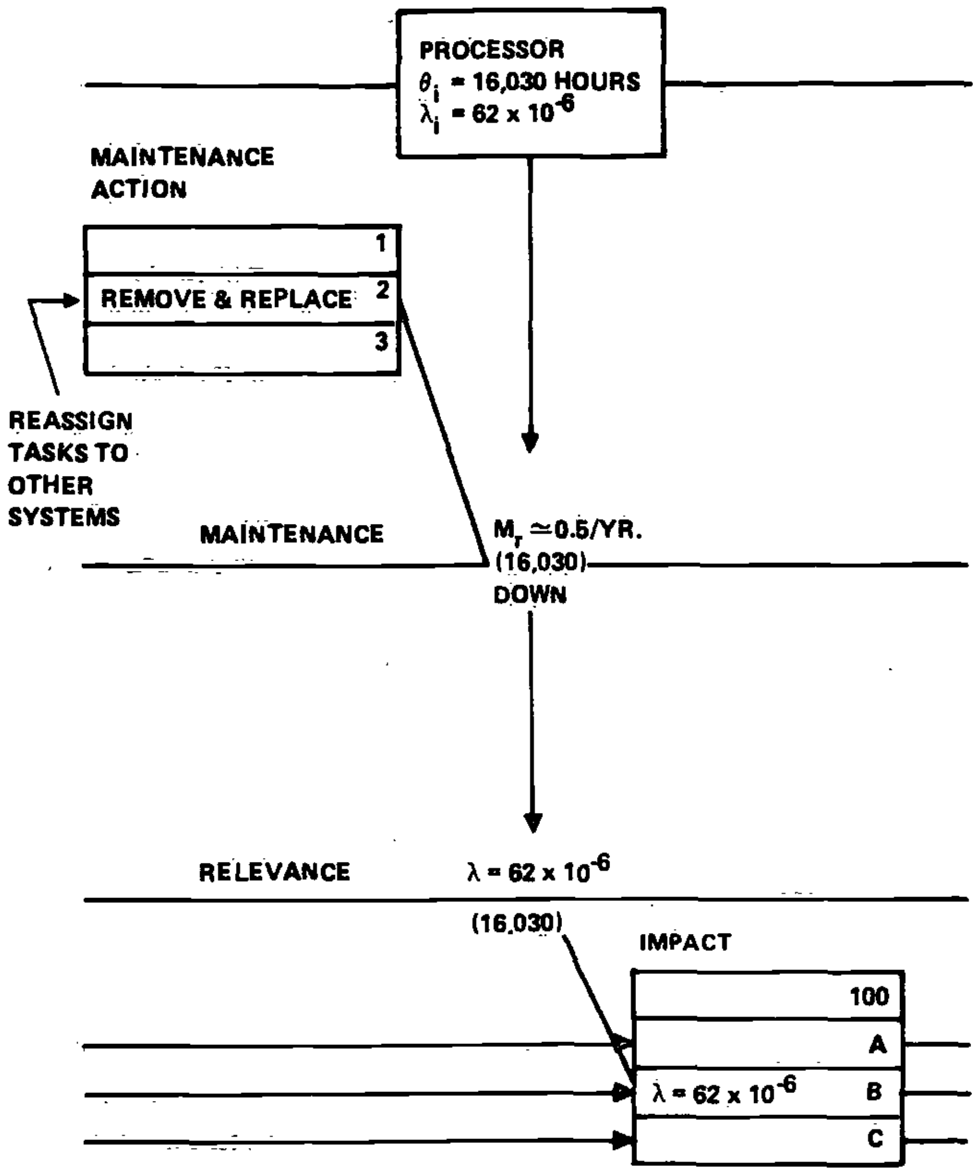

FIGURE 8d. CRITICAL CIRCUIT – PROCESSOR

The first step in developing the fail soft circuit reflects the independent failure of each modem board. In this example, two such modems boards are assumed, and relevant system impact will take place when none of these boards survives.

The representation for such a set of modem boards is shown in Figure 9a. The failure rate for each modem board is assumed to be 15 failures per 1 million hours (with reciprocal MTBF of 65,892 hours). This data is added to the soft circuit representation as shown in Figure 9a.

The maintenance rate data, with its maintenance line, is added to the soft circuit as discussed previously for the critical circuit and is shown in Figure 9b. The data shown reflects the fact that the initial failure rate for the group of two cards is double the individual board failure rate, reflecting an MTBF of one-half the individual board value.

Since this type of failure does not cause relevant system impact, and since the system design permits fully automatic reaction to this failure, the type of maintenance action to be indicated will be a mere "logging" of the event by operations. This information is added as shown in Figure 9b.

Since this failure event is nonrelevant at the system level (it merely erodes the design safety margin), it will be absorbed. No repair is initiated, the remaining modem board continues operation, and the modem failure rate is adjusted. This information is added as shown in Figure 9c.

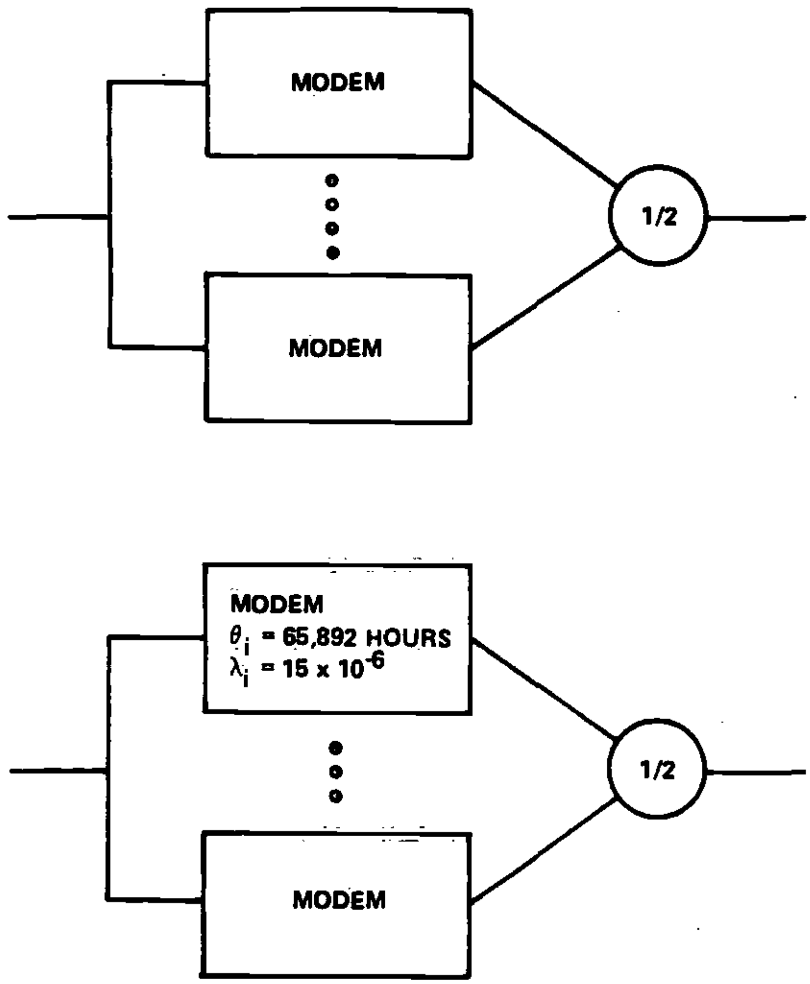

FIGURE 9a. SOFT CIRCUIT – MODEM

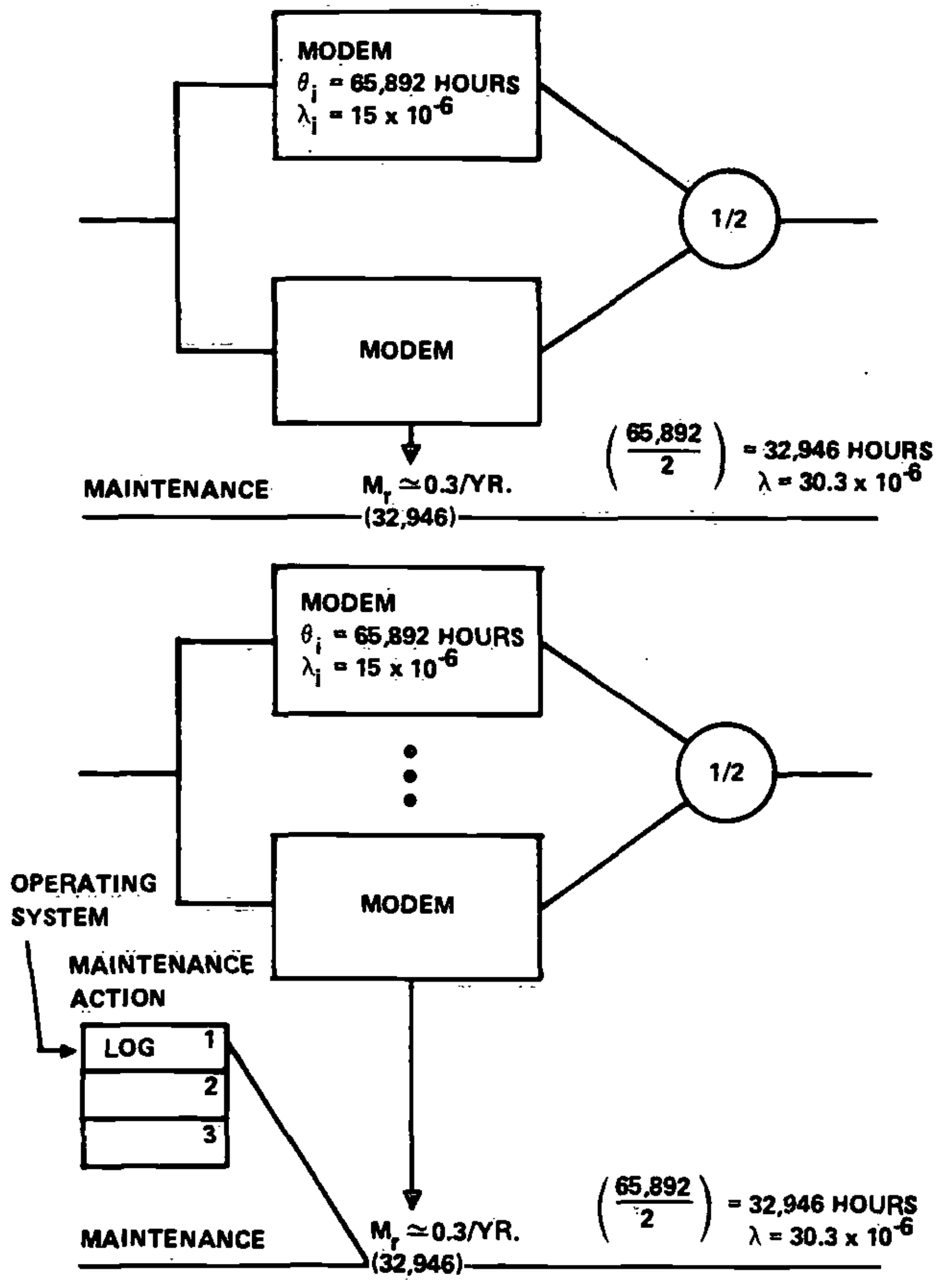

FIGURE 9b. SOFT CIRCUIT – MODEM

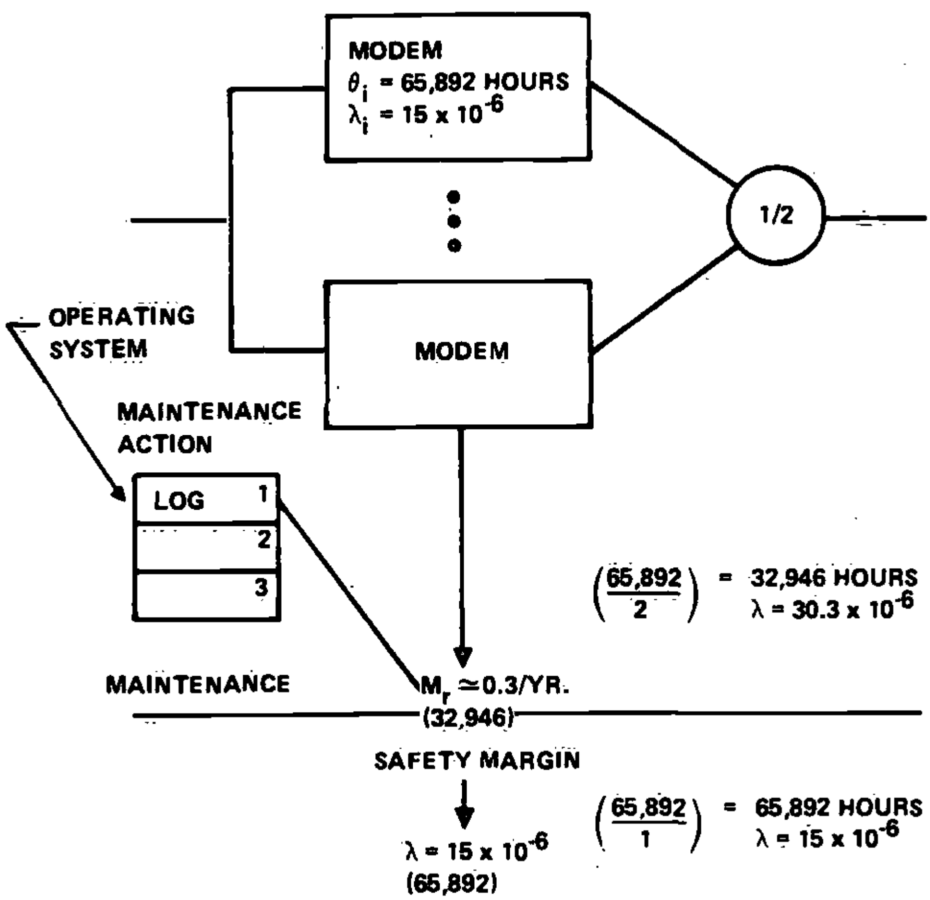

FIGURE 9c. SOFT CIRCUIT – MODEM

The failure of the single remaining modem board (the second failure) is the failure that impacts the system relevantly.

This mean-time-between-relevant-failures is the sum of the mean times associated with the previous succession of nonrelevant failures, and the average failure rate over this mean-time-between-relevant-failures is the reciprocal of that mean time.

This information is added to the soft circuit as shown in Figure 9d. Since no repair has as yet been applied, this rate and time information will reflect relevance with failure absorption. The appropriate maintenance action will be a remove and replace delay task in which the tasks previously assigned to the associated operationally regraded RTU (of which this modem is a part) are reassigned to another system (e.g. with respect to communications, it could be the radio system).

The impact of this series of failure events, along with the associated manual maintenance task, is a Degree B impact. This is shown in Figure 9e. Since nonrelevant failures are absorbed rather than repaired, this Degree B impact is labeled "Absorption Impact".

Next, to support the future option of applying maintenance to the nonrelevant failures depicted in the soft circuit, it is necessary to compute the mean time (and its average rate) for the relevant failure that would result. The form of this computation is chosen to reflect the repair scenario conventionally referred to as "unrestricted repair". The implications of this type of repair are relatively simple:

1. Repair actions are begun immediately upon detection of the failure.

2. Each nonrelevant failure has its own fully equipped repair team assigned to it.

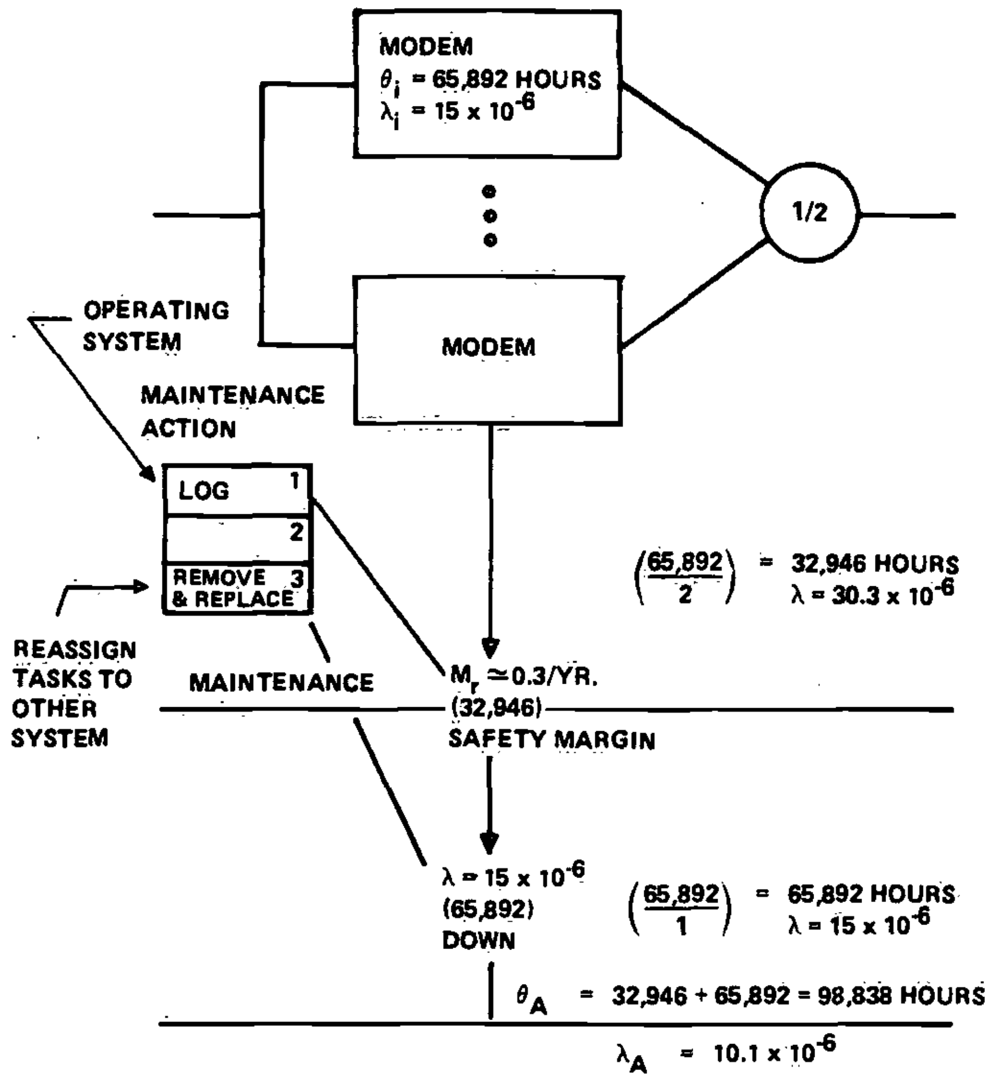

FIGURE 9d. SOFT CIRCUIT – MODEM

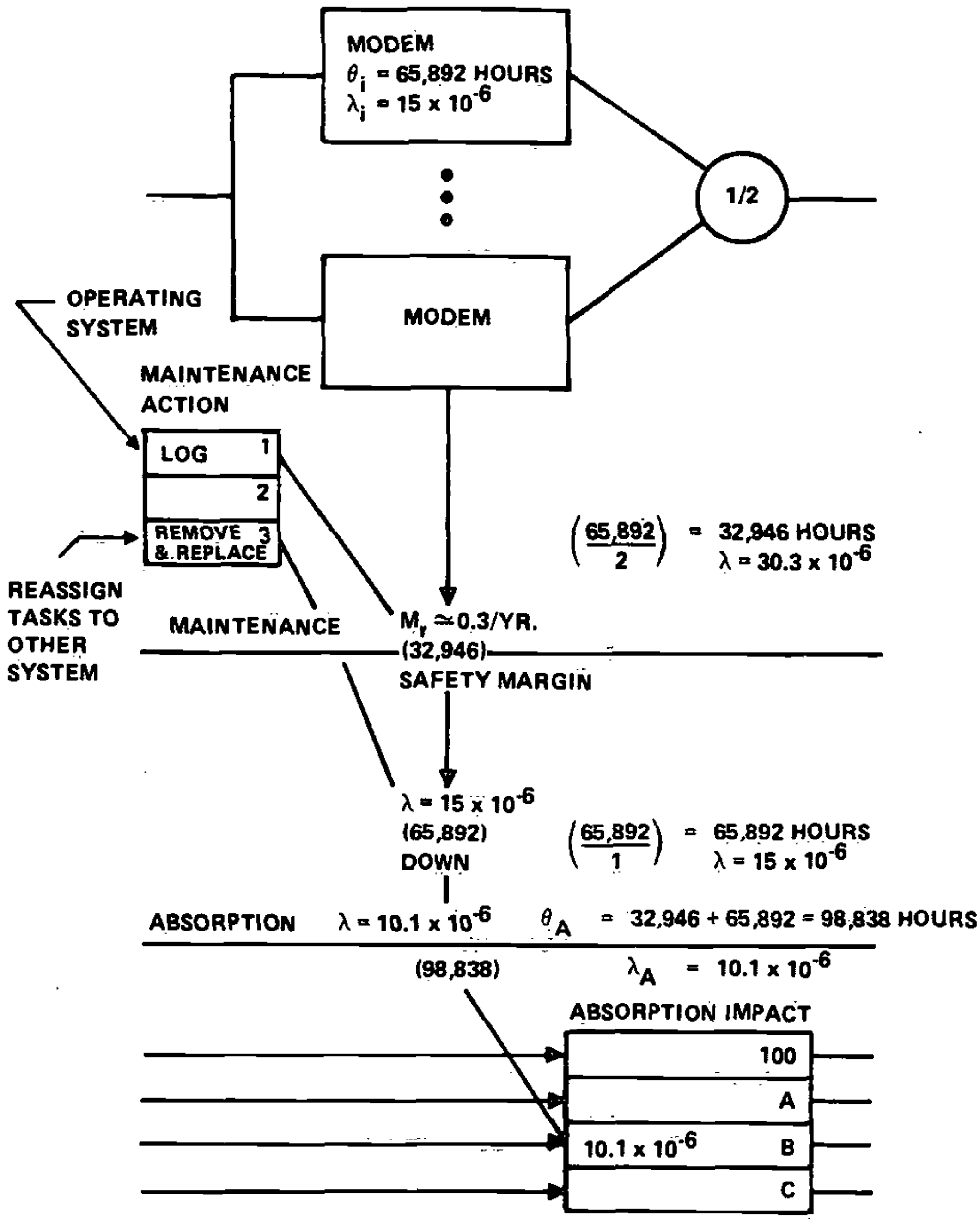

FIGURE 9e. SOFT CIRCUIT – MODEM

3. In the case of multiple nonrelevant failures, the successful repair of any one of them is sufficient to forestall the occurrence of the future relevant failure (2).

4. The system continues to operate while nonrelevant failures are repaired.

With this scenario, the mean-time-between relevant-failures with unrestricted repair is as follows:

$$\theta_R = \left[\left(\frac{\theta_i}{N}\right)\left(\frac{\theta_i}{N-1} * \frac{RT_1}{MTTR}\right)\left(\frac{\theta_i}{N-2} * \frac{RT_2}{MTTR}\right) \bullet\bullet\bullet \left(\frac{\theta_i}{M} * \frac{RT_{(N-M)}}{MTTR}\right)\right]$$

where:

θ_R = Mean-time-between-relevant-failures with unrestricted maintenance

θ_i = MTBF at the board level

N = Total number of boards modeled

RT_x = The number of repair teams concurrently working on x failures

MTTR = The MTTR for one repair team working on one failure $\left(MTTR << \frac{\theta_i}{N}\right)$

M = Number of boards (out of N boards) required to be operational to avoid relevant system-level impact.

Applying this expression to the soft circuit example yields:

$$\theta_R = \left(\frac{\theta_i}{N}\right)\left(\frac{\theta_i}{N-1} \cdot \frac{RT_i}{MTTR}\right)$$

$$= \left(\frac{65892}{2}\right)\left(\frac{65892}{1} \cdot \frac{1}{1.16}\right)$$

$$= (32946)(56803)$$

$= 1.871446407 \times 10^9 h$

The average failure rate over this scenario is:

$_R = 1/\theta_R$

$= (1.871446407 \times 10^9)^{-1}$

$= 5.343461 \times 10^{-10}$ per hour

This information is shown in Figure 9f.

The completed critical circuits and soft circuit (Figure 9f) are shown concatenated in Figure 10.

After all critical circuits and soft circuits are assembled to form the complete Fault Absorption Model, the maintenance action and relevance rates are totaled as shown in Figure 11. For numeric illustration, the data shown in Figure 11 is the summation of those events depicted for the RTU of Figure 10.

In this case, the maintenance rates associated with the logic and modem module, respectively, combine to the absorption relevant rates combine to produce 264.1 X 10^{-6} events per hour, all producing Degree B impact. For unrestricted repair, the maintenance rate produces 5.3×10^{-10} events per hour.

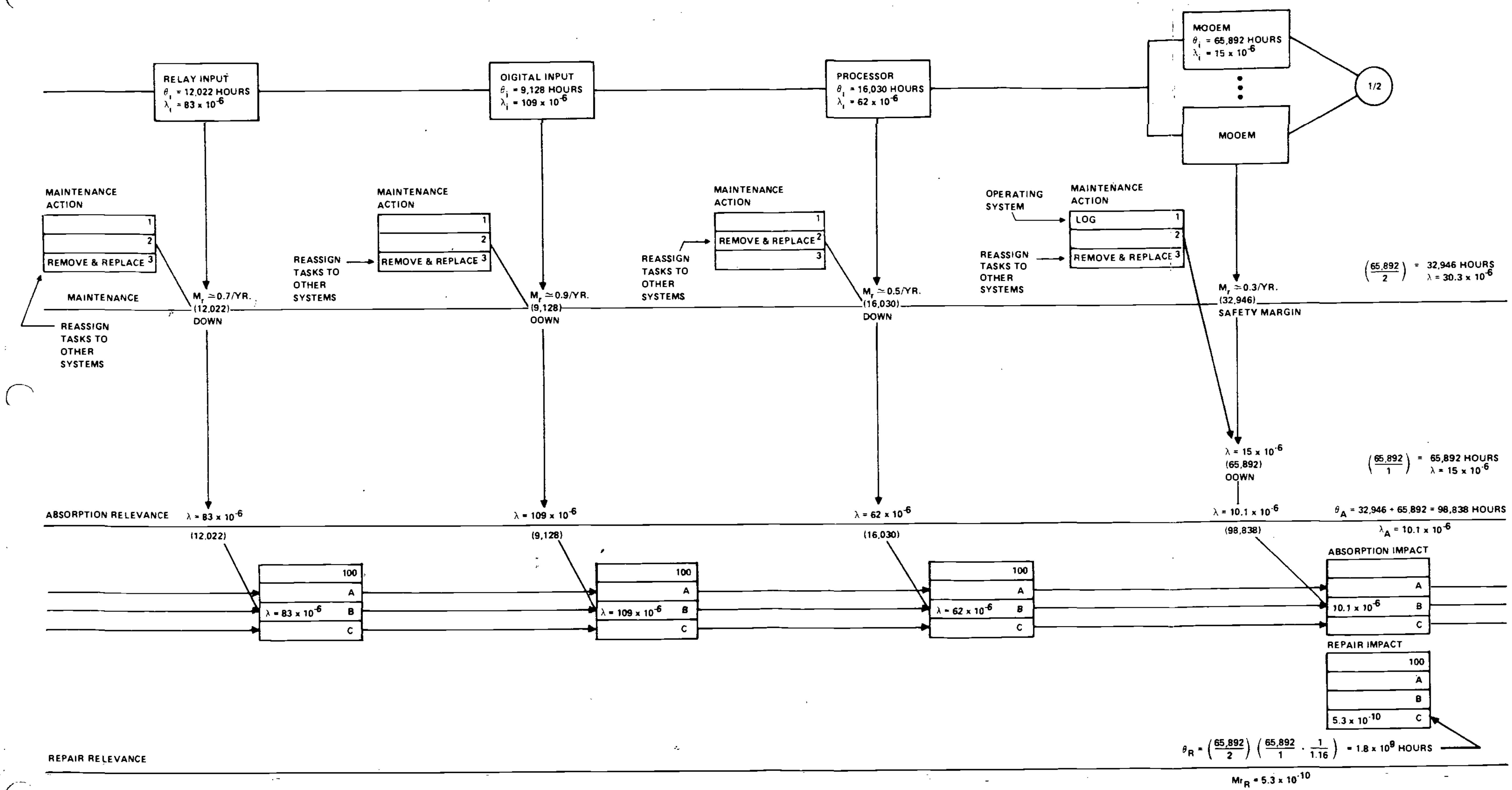

FIGURE 10.
CRITICAL CIRCUIT/SOFT CIRCUIT RTU FAM

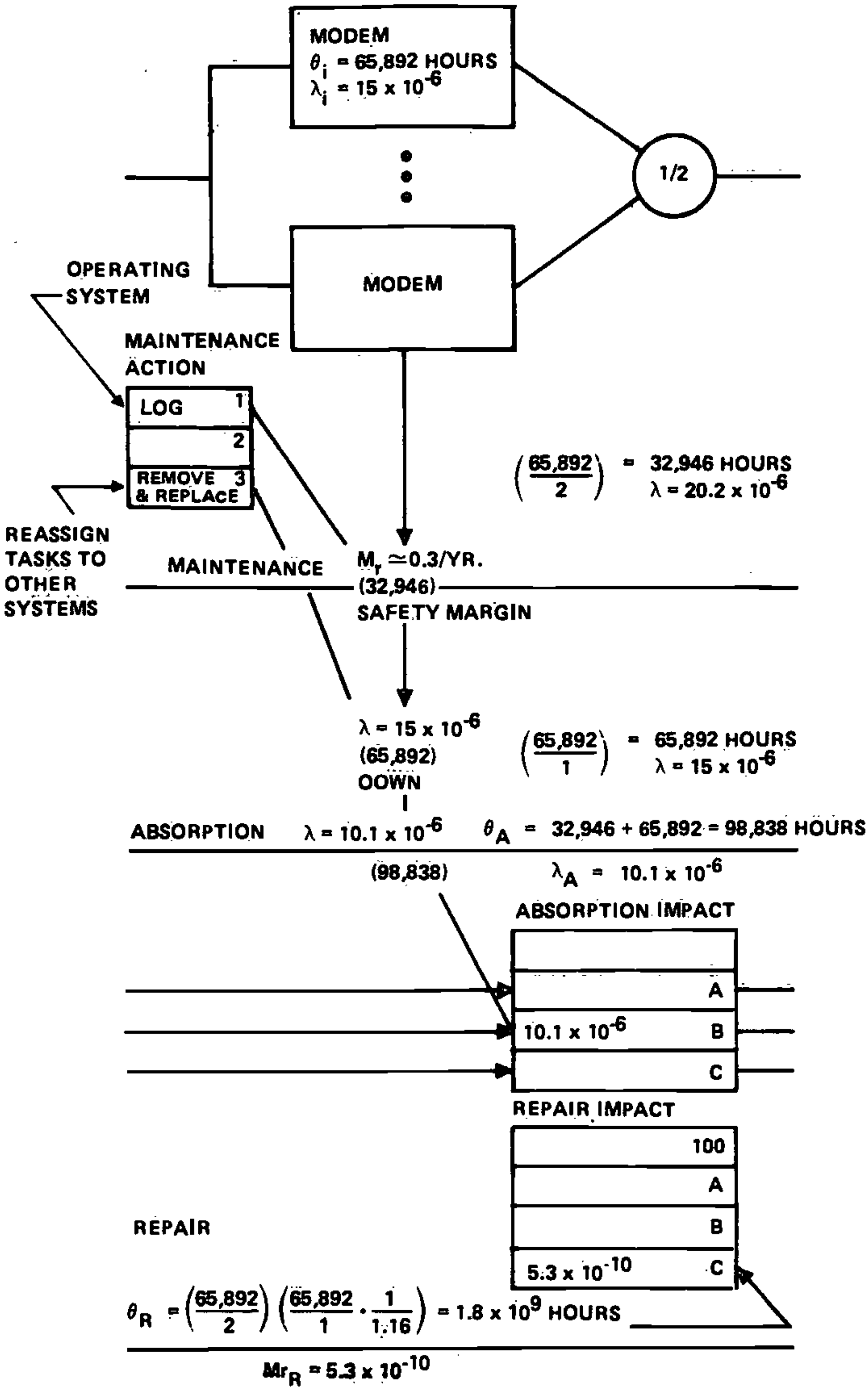

FIGURE 9f. SOFT CIRCUIT – MODEM

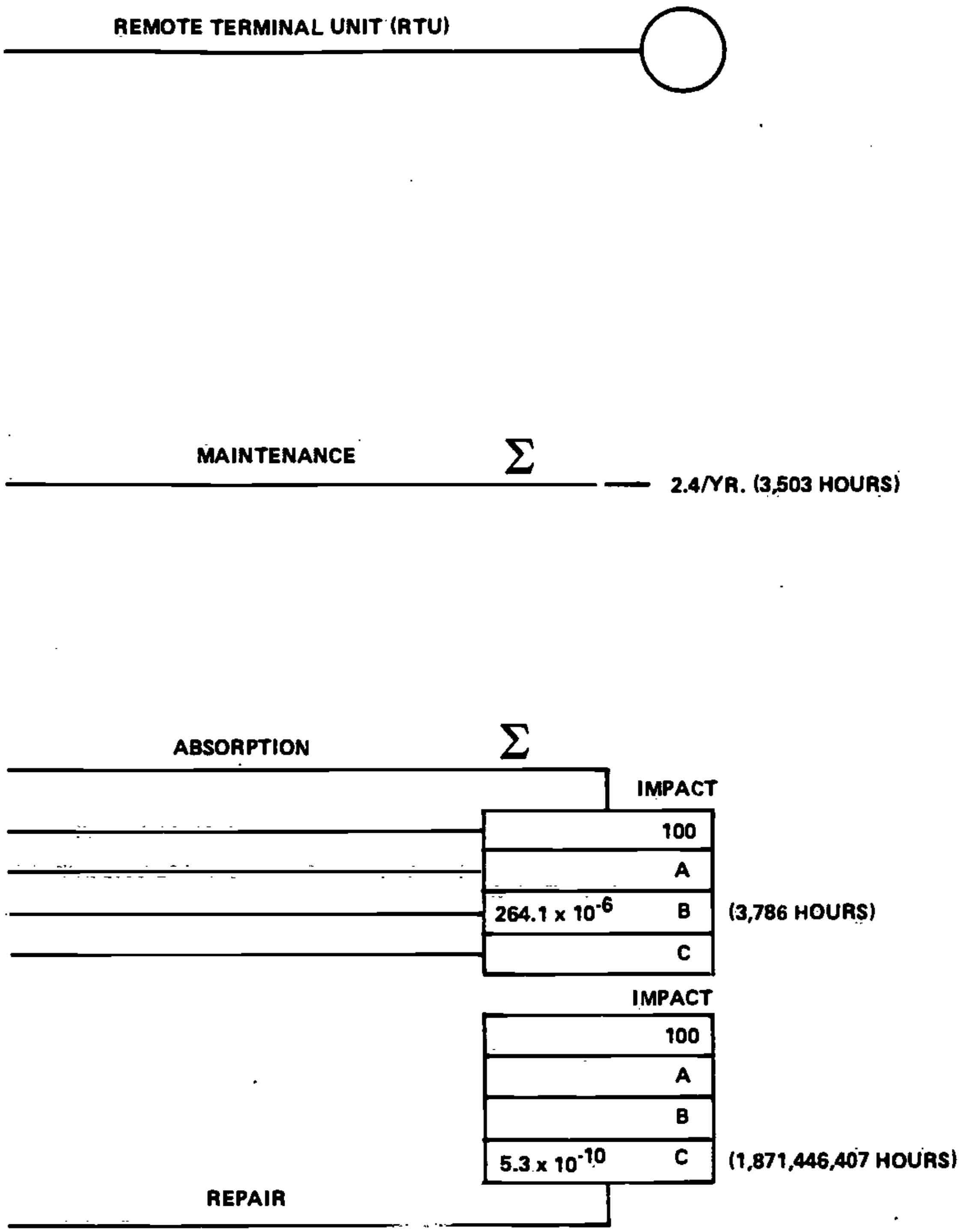

FIGURE 11. RTU FAM SUMMATION

Subsequently, these summations can be applied to the parameter of expected number of failures with system impact consequence as described in parts 1, 2, and 3 of this section.

For RCM purposes, the extent of necessary repair can be immediately assessed and an indication as to the initial validity of RCM concept that would result from repair of any or all fault-tolerant equipment.

III. LOGIC SEQUENCING

The RCM logic presented in this document is designed to accomplish the following:

1. Using data from the system safety and reliability analyses, identifying components in the system which are critical in terms of system requirements and/or operating safety.

2. Provide a logical analysis process to determine the feasibility and desirability of scheduled maintenance task requirements.

3. Provide the supporting justification for scheduled maintenance task requirements.

The logic process is based upon the following criteria:

1. Scheduled maintenance tasks should be performed on noncritical components only when performance of the scheduled task will reduce the life cycle cost of the system.

2. Scheduled maintenance tasks should be performed on critical components only when such tasks will prevent a decrease in reliability and/or deterioration of safety to unacceptable levels, or when the tasks will reduce the life cycle cost of the system.

See Figure 12 for RCM logic network diagram.

1. <u>Detailed Instructions for RCM Logic Application (Blocks 1-12 Figure 12)</u>

   Figure 12 displays the RCM logic to be used to determine if a component should have a scheduled maintenance requirement. Each decision block is numbered and detailed instructions for each block are provided below. The results of the logic process are recorded on a data sheet in accordance with the instructions in part 2 of this section.

   The following is a detailed set of instructions for application in the logic in figure 12:

   <u>Block 1</u>. These questions are asked for each failure mode identified for the component under analysis. The answer to these questions is based on the failure effects and criticality documented as part of the FMECA. A "yes" answer indicates that a failure mode exists

which results in either a safety hazard or a transit trip abort due to a critical loss of capability.

Components and modes for which a "yes" answer is obtained are referred to as critical. These critical items are analyzed further to determine if a scheduled task will help prevent deterioration of reliability or safety levels, thus minimizing the risk of a system abort or safety hazard. A "no" answer indicates the component is noncritical in terms of trip success and/or safety and scheduled maintenance would only be justified on an economic basis or if it causes secondary failures which are critical.

Block 2. The instructions for this block are the same as for block 1 except that these questions refer to secondary failures caused by the primary failure modes considered in block 1. "Yes" answers identify critical components which have secondary failures which result in either a safety hazard or a trip abort. These critical components are analyzed further to determine what scheduled maintenance actions can be performed that will prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels. A "no" answer to each question in Block 1-2 indicates that the component is noncritical and can be operated to failure without incurring a safety hazard or a trip abort. For these components, Block 3 is addressed to determine if a scheduled maintenance task is justifiable from an economic standpoint.

Block 3.

(a) Block 3 is addressed to identify scheduled tasks which can be performed and which will decrease the cost of ownership of the end item. To address this block, it must first be determined whether a scheduled task can be done. This can be determined by applying the questions in blocks 4 through 12, keeping in mind that the questions are being addressed for noncritical components.

(b) In determining if a scheduled maintenance task is economically justified, the difference in ownership cost for the end item must be calculated between a maintenance plan that has a scheduled task(s) for the component under analysis and a plan which calls for only condition monitoring of the component. It is not intended that a complete life cycle cost be calculated for each alternative, but rather those cost factors which would be different between the alternatives should be determined.

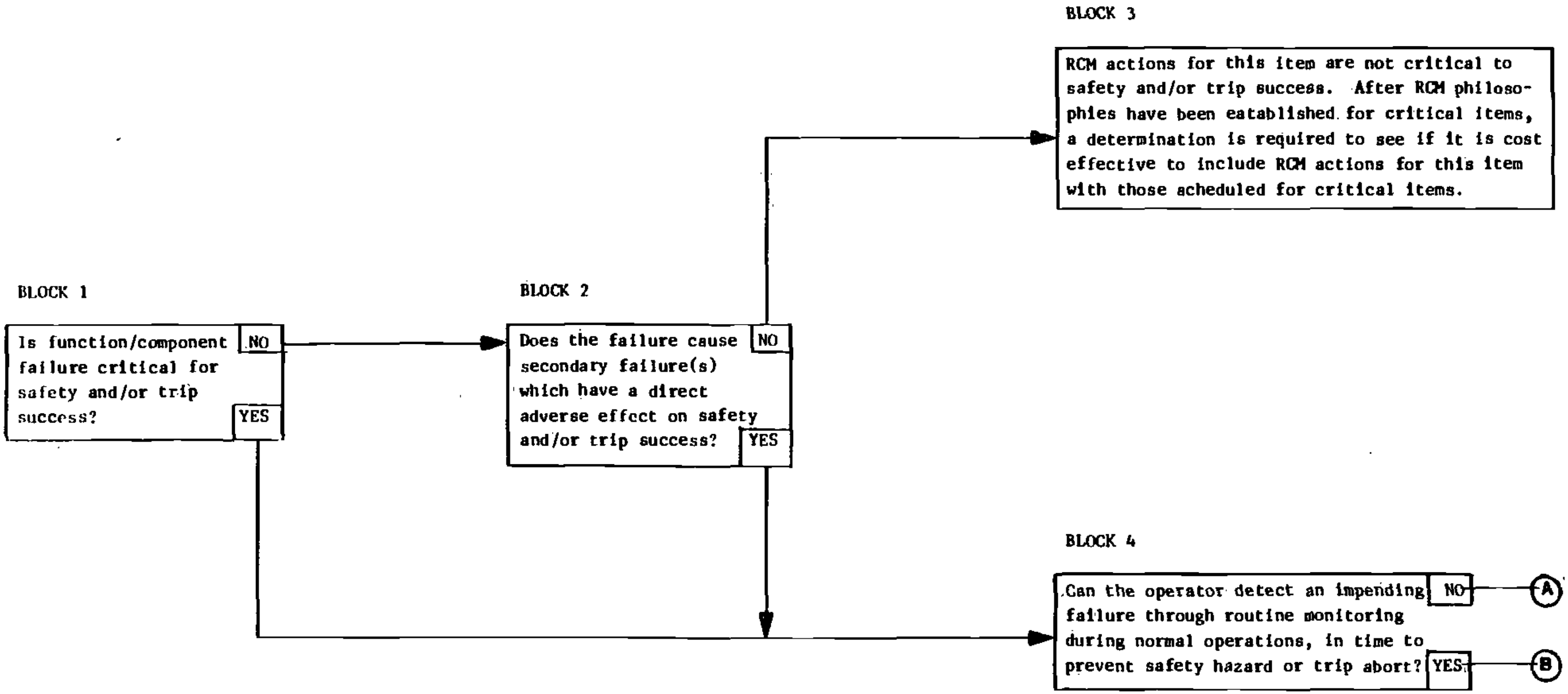

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Figure 12
RCM Logic

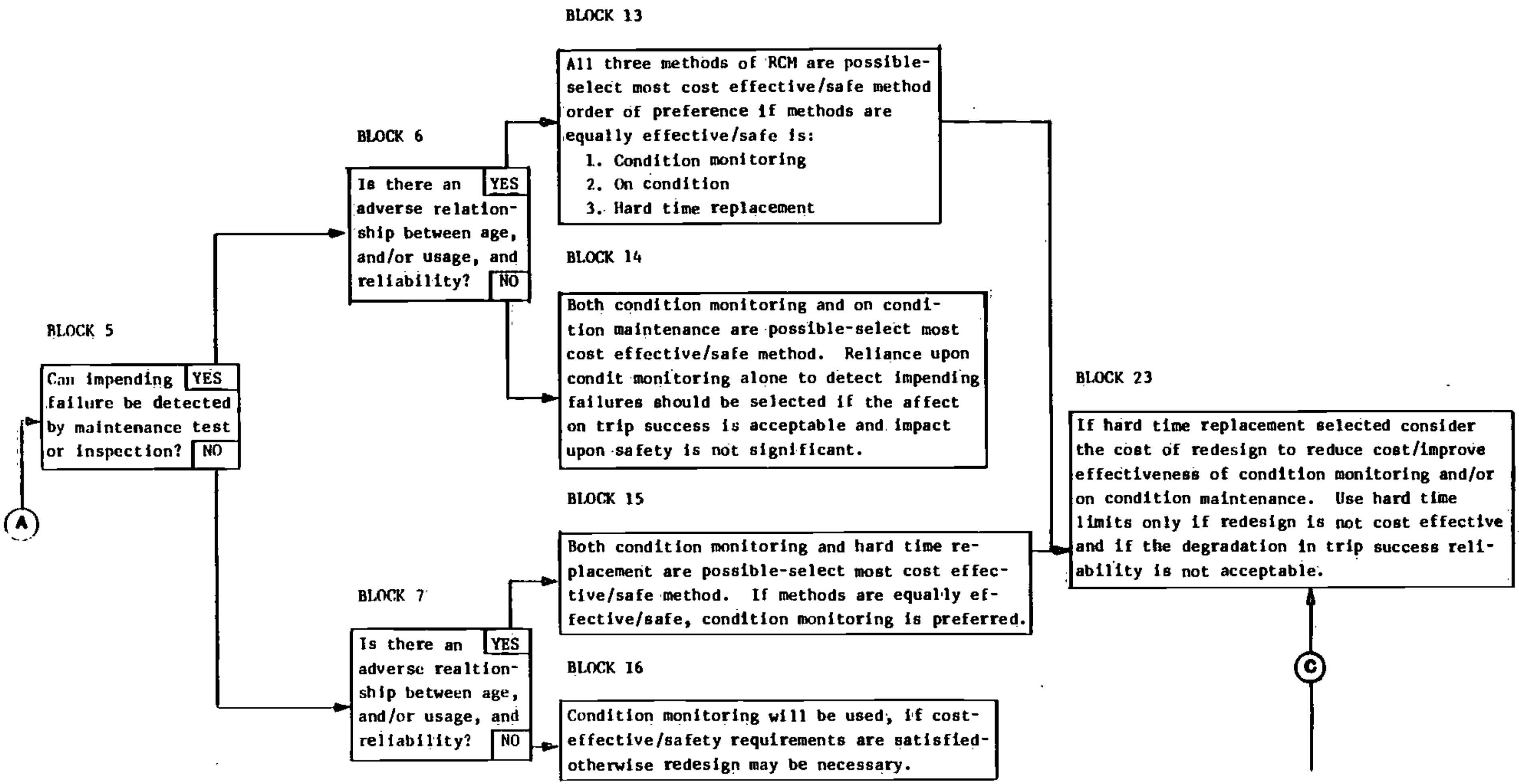

Figure 12
RCM Logic (Cont'd)

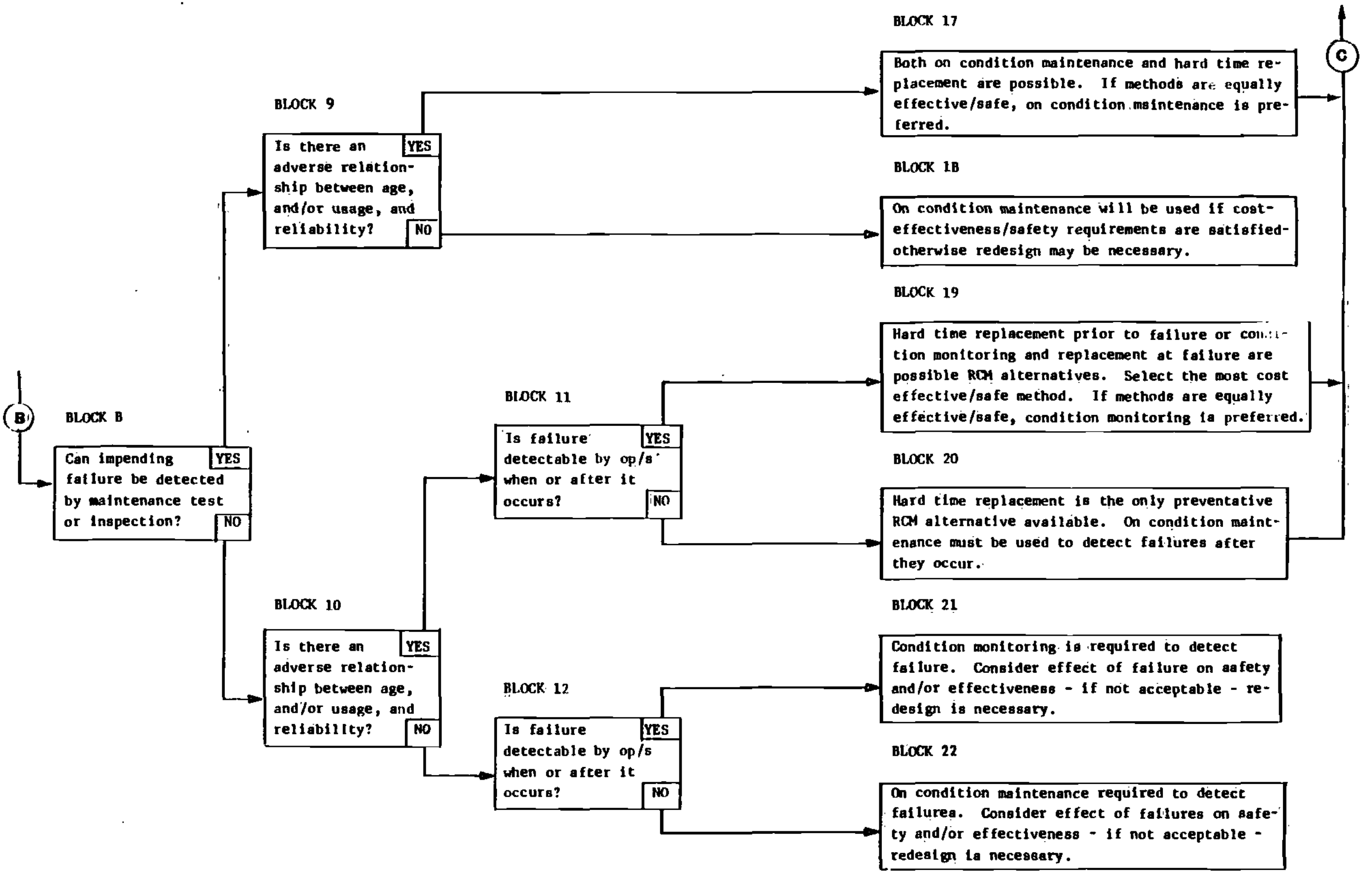

Figure 12
RCM Logic (Cont'd)

Consideration must also be given to any manpower, downtime, and/or availability constraints on the end item if an additional scheduled task is included in the maintenance plan for a noncritical component. If a substantial cost savings can be realized through some scheduled maintenance action which impacts one or more system constraints, then a trade-off analysis would be performed. It is not envisioned that a scheduled maintenance action for noncritical components would be economically justifiable in many cases.

(c) This block should not be addressed until the RCM logic has been applied to the critical components of the system/equipment under analysis because the results of the critical component analysis could affect the cost of feasible scheduled tasks on noncritical components. For example, a noncritical inspection may not be economically justifiable by itself, as it requires access time and cost, but if the access time and cost is determined to be required for a critical component inspection, then the noncritical inspection may be justifiable. For this reason, the economic aspects of noncritical tasks should only be addressed after the scheduled maintenance requirements for critical components are determined. If the analysis shows that scheduled maintenance (on-condition, hard time, or both) on the noncritical component under analysis does reduce the cost of ownership of the system/equipment, then this task(s) would be included in the overall maintenance plan. If a scheduled task is not feasible or is not economically justified for the noncritical component under analysis, then the component would be operated to failure and only unscheduled maintenance would be performed on it.

Block 4. The question in block 4 is intended to identify those critical failure modes which can be detected through routine operator monitoring with sufficient leadtime to prevent a trip abort and/or safety hazard. If there is a high probability that the failure mode under analysis can be detected with sufficient leadtime before it will actually occur to prevent a trip abort or incurrence of a safety hazard, then the question is answered "yes". This is the case for failure modes which have a sufficient time difference between onset of initial degradation and actual failure and a means of detecting the onset. The detection means can be in the form of instrumentation (gauges, warning lights, etc.) or operational characteristics (sound, etc.). The question is answered "no" if the operator cannot detect an impending failure, or if the time difference between onset and actual failure is not long enough to prevent a trip abort or safety hazard.

Block 5.

(a) The question in this block is addressed to identify the potential efficiency of a scheduled maintenance task on the component under analysis. The question must be considered in two parts. First, the impending failure must be physically detectable either by visual inspection or through use of test or measurement equipment. To be detectable, measurable physical properties of the component must change with the onset of degradation to allow identification of impending failure through comparison with normal properties.

(b) The second consideration is the probability that the scheduled inspection or test will coincide with the time between failure onset and occurrence so that the impending failure will be caught. As an example, a component which fails within seconds after the onset of any measurable degradation would not be a good candidate for a scheduled task. The probability that any reasonable inspection interval would result in the inspection occurring within the time between onset and failure is very small in this case; consequently, the payoff would be extremely small. On the other hand, if the time between measurable failure onset and actual failure occurrence is measured in days or months, then an inspection interval can be established which would result in a high probability of detecting the failure under analysis before it occurs. In answering this consideration, the failure distributions from the Reliability program, data from a historical review, and applicable test results must be analyzed.

(c) If the impending failure is physically measurable and a reasonable task interval can be established which results in an acceptable probability of detection, then the question in block 5 is answered "yes". If one or both of these considerations is not met, then block 5 is answered "no".

Block 6.

(a) The question in this block is addressed to identify wearout-type components and to determine the feasibility of scheduling a hardtime type replacement of the component. This question is answered "yes" if the probability of component failure increases as calendar time or usage indicators (operating hours, miles, rounds, cycles) increase. For these items, a scheduled removal can be identified at a point in time or after a specified amount of usage when the probability of failure increases to an unacceptable level. Removal and replacement with a new item will decrease the probability of failure back to its original level. This question is answered "no" if the probability of failure is independent of both calendar time and usage. This is the case for components which exhibit an exponential failure rate.

(b) In answering the question in this block as "yes", it should be noted that a means of measuring the interval between scheduled replacements must be provided for the component. If the usage on the component cannot be economically maintained, then the question in this block is answered "no" because a hardtime replacement would not be feasible.

Block 7. The same instructions that were provided for block 6 apply to block 7.

Block 8. The same instructions that were provided for block 5 apply to block 8.

Block 9. The same instructions that were provided for block 7 apply to block 9.

Block 10. The same instructions that were provided for block 7 apply to block 10.

Block 11. The question in block 11 is addressed to identify hidden functions were incurrence of the failure mode may go undetected until the function is required. If the operator cannot detect that a failure has occurred, then on-condition type tests or inspections may be required to insure that a failure has not occurred and that there is a high probability that the hidden function will be available when required.

Block 12. The same instructions that were provided for block 11 apply to block 12.

Block 13.

(a) This block identifies critical components that exhibit wearout characteristics and impending failures can be detected by both routine operator monitoring and maintenance test or inspection. For components in this class, condition monitoring is always performed and on-condition and/or hard time tasks is only included if condition monitoring does not maintain the required trip success and/or safety levels. If this is the case, then on-condition and/or hard time maintenance would be considered if their inclusion in the maintenance plan would satisfy the trip success safety requirements.

(b) For the components that fall into this category after application of the RCM logic, routine operator monitoring during normal operations would provide an acceptable level of reliability and safety at the least cost.

Block 14. This block identifies critical components where impending failures can be detected by the operator through routine monitoring and by maintenance test or inspection. For components in this class, the condition monitoring by the operator is selected and the on-condition task is not required as long as both offer the same probability of detection. If the analysis shows that the on-condition test or inspection provides a more reliable detection probability, then it should be considered for inclusion in the maintenance plan along with the condition monitoring requirement.

Block 15. This block identifies critical components that exhibit wearout characteristics and the operator can detect impending failures through routine monitoring. For components in this class, condition monitoring is done by the operator and an analysis would have to be performed to justify a hardtime task against the component. A hardtime task would not be justifiable for components that can be condition-monitored unless a hardtime replacement limit can be established with a high degree of confidence and supported with real and applicable data, and the analysis shows that hardtime replacement would sustain in higher level of reliability and/or safety.

Block 16. This block identifies critical components where impending failures can be detected by the operator through routine monitoring, but on-condition and hardtime maintenance tasks would not provide any benefit. For these components, condition monitoring would be the only maintenance requirement other than the unscheduled repair or replacement tasks after an impending failure is detected. If the condition monitoring does not sustain the required safety levels and trip effectiveness, then feasible redesigns must be addressed to satisfy the requirements.

Block 17.

(a) This block identifies critical components that exhibit wearout characteristics and impending failures can be detected through maintenance test or inspections. For components that fall into this category, the inherent reliability and safety levels can be preserved by either a hardtime replacement or an on-condition test or inspection. Hardtime replacement and on-condition test may both be feasible to maintain acceptable reliability/ safety levels. Each of the three alternatives must be analyzed in terms of cost and the reliability and safety levels that can be maintained under each alternative.

(b) For those cases where the frequency of the on-condition type task is high, a hardtime replacement may be more cost effective if the hardtime limit can be established with a high degree of confidence and it provides the necessary reliability and safety protection levels. In other cases where the component is costly and/or there is not enough data to establish a hardtime replacement limit with any degree of confidence, then the on-condition type task may be more cost effective. In each case, the benefits and risks of each alternative maintenance policy should be analyzed to select the most effective. If both on-condition and hardtime are considered feasible then the benefits and risks should justify the selection of the alternative. This alternative would be chosen if neither the hardtime limit nor the on-condition limits can be established with a high degree of confidence and cost/safety effectiveness can be improved by the use of both. If both are equally effective/safe, then the on-condition task is preferred over the hardtime task.

Block 18.

(a) This block identifies critical components where the only feasible means of sustaining the inherent reliability and safety levels is through an on-condition type maintenance test or inspection. For these components the frequency of the scheduled inspection or test must be established along with the critical values/characteristics of the component which separate a good component from one which has experienced an onset of failure. These critical characteristics should be clearly stated and easily measurable wherever possible to prevent uncertainty on the part of inspector or tester after performing the required task. If the reliability and safety levels without an on-condition task are acceptable, then no on-condition maintenance is required.

(b) Component redesign should be considered when the on-condition task does not maintain the required safety levels or trip effectiveness.

Block 19.

(a) This block identifies critical components that exhibit wearout characteristics, but impending failures cannot be detected either through routine operator monitoring or by maintenance tests or inspections. Actual failures are detectable by the operator either at the time of occurrence or after occurrence so that unscheduled repair or replacement can be accomplished in the event of failure. For these components, the only feasible scheduled task that will prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels would be a scheduled removal at specified intervals of time or usage. If the reliability and safety levels are adequate without the hardtime task, then it should not be included in the maintenance plan.

(b) Prior to making a final determination for components in this category, an analysis is made concerning the feasibility of redesign to provide a means of maintenance testing or inspection for impending failures. The ability to test for specified wear or degradation limits might reduce the number of component replacements and consequently provide a life cycle cost savings when analyzed with the cost of redesign to provide the detection capability. This alternative is especially considered for high value components where hardtime replacements are the only means of sustaining the required reliability and safety levels.

Block 20.

(a) This block identifies critical components that exhibit wearout characteristics, but impending failures cannot be detected either through routine operator monitoring or by maintenance tests or inspections. In addition, actual failures go undetected by the operator due to the hidden-function nature of the component. For components that fall into this class, an on-condition type maintenance test or inspection must be included in the maintenance plan to detect failures that have occurred and insure that there is a high probability of the hidden function being available when required.

(b) In addition to the on-condition task to detect failures that have occurred, a scheduled hardtime replacement is established based on the wearout characteristics of the component to prevent or decrease the probability of reliability and/or safety deterioration to unacceptable levels. Establishment of the hardtime task is dependent upon an analysis to determine the feasibility and cost effectiveness of redesigning the component under analysis as described under block 19. If reliability and safety levels are adequate without the tasks, then they should not be included in the maintenance plan.

Block 21.

(a) This block identifies components which have critical failure modes with no means of detecting impending failures or reducing the probability of a trip abort or safety hazard. Actual failures are detectable by the operator either at the time of occurrence or after occurrence so that unscheduled repair or replacement can be accomplished in the event of failure. For components in this category there are two alternatives. One alternative is to redesign or make redundant the component and/or interfacing components to eliminate the critical failure modes or to provide a means of detecting the impending failure. In the second case, no scheduled maintenance is performed and the risks of incurring a trip abort or safety hazard would have to be acceptable.

(b) To determine which alternative is taken, the feasibility and costs of the redesign must be determined along with the potential benefits from the redesign. In some cases, the required redesign may involve the addition of a test point or measurement device, while in other cases the cost of redesign may be prohibitive or the redesign may not be technically feasible. The intent of the RCM logic in this case is to highlight the problem so that the possible solutions may be addressed.

Block 22.

(a) The block identifies components which have critical failure modes with no means of detecting impending failures, no wearout characteristics, and no means for the operator to detect failures that have occurred. For components that fall into this category, an on-condition type task is included in the maintenance plan to detect failures that have occurred and to insure that there is a high probability of the hidden function being available when required.

(b) There are two alternative courses of action that can be taken because of the nondetectability of impending failures. The first is to redesign or make redundant the component and/or interfacing components to eliminate the critical failure modes or provide a means of detecting impending failures. The second alternative is to accept the inherent probability of failure and risk of incurring a trip abort and/or safety hazard.

(c) To determine which alternative should be taken, the feasibility and costs of a redesign or addition must be determined along with the potential benefits from each one. In some cases the required redesign may involve the addition of a test point or measurement device, while in other cases the cost of redesign may be prohibitive or a redesign may not be technically feasible.

Block 23. This block is included in the RCM logic to highlight those areas where redesign should be actively pursued as an alternative to hardtime replacements. Hardtime replacements should be included only if required mission and safety levels cannot be achieved through condition monitoring and/or on-condition maintenance and a redesign to achieve the required levels is not feasible or is not cost effective.

In section IV, utilizing the RTU as described in the previous sections, RCM will be applied for the model examples.

IV. RCM DETERMINATES

This section contains illustrative examples of RCM application to the RTU equipment described in Section II and documentation in accordance with the logic sequencing process as described in Section III. The results presented in these examples do not necessarily reflect the most cost effective maintenance plan for all items of the same class or commodity. The examples are only intended to reflect the process of RCM logic application and documentation.

Example 1: Relay Input Card

The component under analysis is a relay input card that is used to interface the Digital Input Card to field equipment such as train control equipment, traction power equipment, fire and intrusion alarm equipment, and status displays.

Using the Failure Modes, Effects and Criticality Analysis (FMECA) data available (see Figure 2 in Section II), the RCM logic is applied with the following results:

Block 1. Is component failure critical for safety and/or trip success? This question would be answered "yes" because the failure modes identified do independently produce a revenue trip abort. (See Figure 13 for logic sequencing of the Relay Input Card).

Block 2. This block is not addressed because of the "yes" answer to block 1.

Block 3. This block is not addressed due to the "yes" in block 1.

Block 4. Can the operator detect an impending failure through routine monitoring during normal operations, in time to prevent safety hazard or trip abort? This question is answered "no" for both failure modes because the failure detection method is based on remote testing or inspection and has no capability of remote monitoring from a central control facility.

Blocks 5-7. These blocks are not addressed because block 4 was answered "no" for both failure modes.

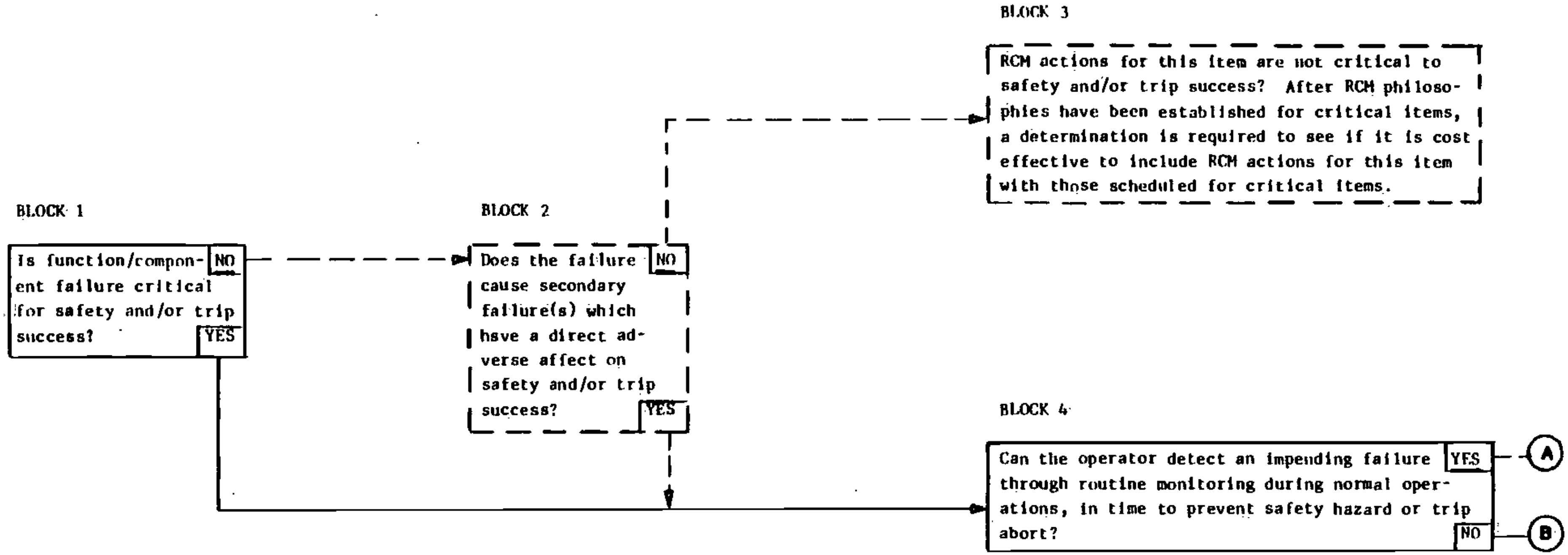

Figure 13
RCM Logic for Relay Input Card

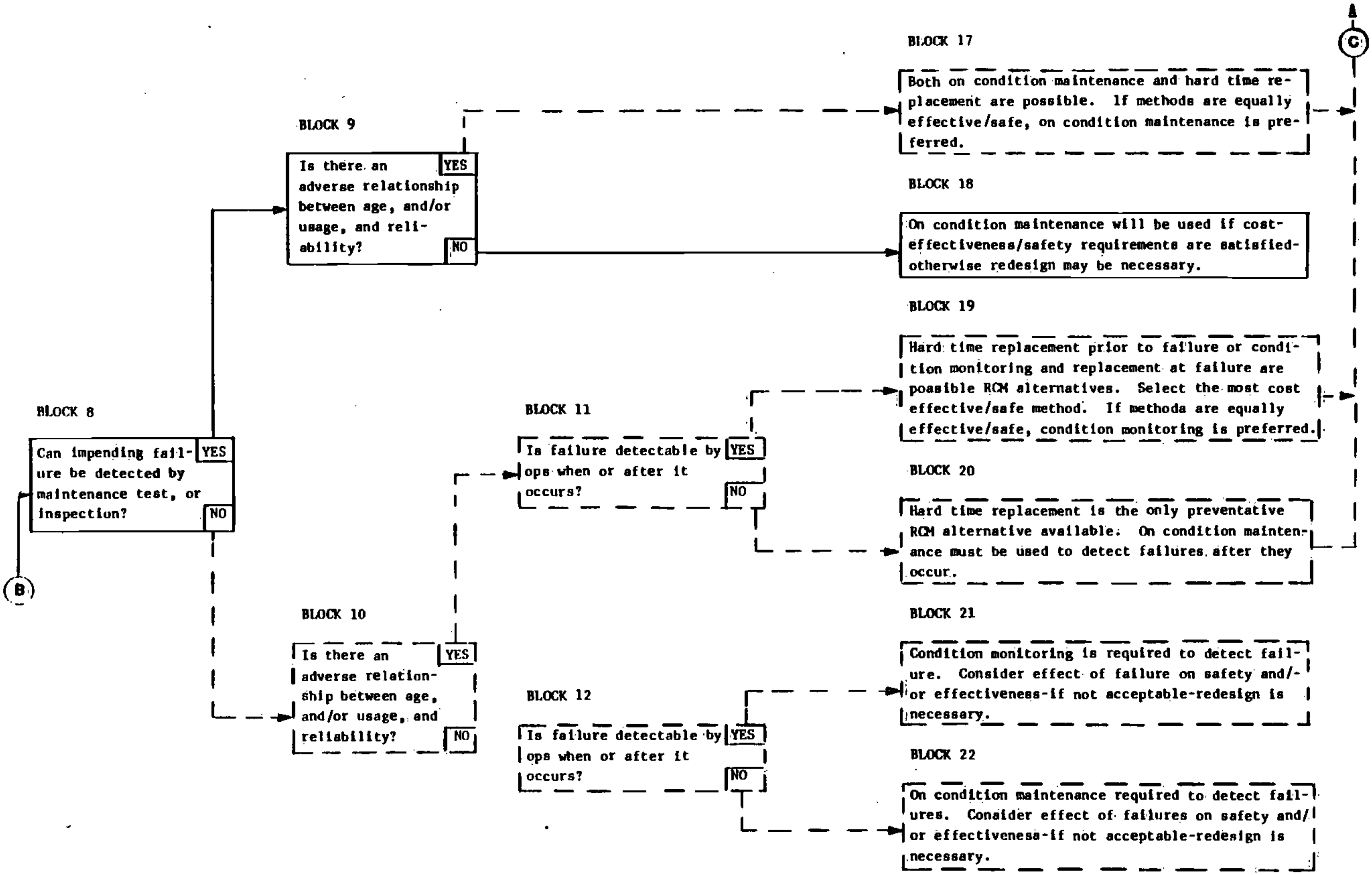

Figure 13.
RCM Logic for Relay Input Card (Cont'd)

Block 8. Can impending failure be detected by maintenance test or inspection? This question is answered "yes" because of the rationale given for block 4.

Block 9. Is there an adverse relationship between age, and/or usage, and reliability? Unknown. No real and applicable data is available to determine if the predicted failure modes are age dependent or whether they are caused by excessive stress applied during operation. Because there is no data to support this question, it should be answered "no" for each failure mode.

Blocks 10-12. These blocks are not addressed because block 8 was answered "yes" for both failure modes.

Blocks 13-16. These blocks are not addressed because block 4 was answered "no" for both failure modes.

Block 17. This block is not addressed because of the "no" answer for block 9.

Application of the RCM logic to the failure modes identified for the relay input card has led to block 18. The instructions for block 18 are contained in Figure 13. Using the cost equation of on-condition maintenance from Section II, the minimum cost inspection interval can be determined. It is derived as follows [4]:

If CTi = \$30.00; Cf = \$29,000. and F(Ti) = 0.79(FAM)

Ti = 9600 hours or every 400 days.

This time represents the interval during which an inspection of the sixteen (16) relay input cards will detect impending failures.

Example 2: Digital Input Card

This component interfaces digital points to the DGM data bus and provides level detection, contact wetting (for the relay input card), input protection, and signal conditioning.

Using the Failure Modes, Effects and Criticality Analysis (FMECA) data available (See Figure 3 in Section II), the RCM logic is applied with results similar to the relay input card. See Figure 14 for logic sequencing of the Digital Input Card. Using the cost equation of on-condition maintenance from Section II, the minimum cost inspection is determined.

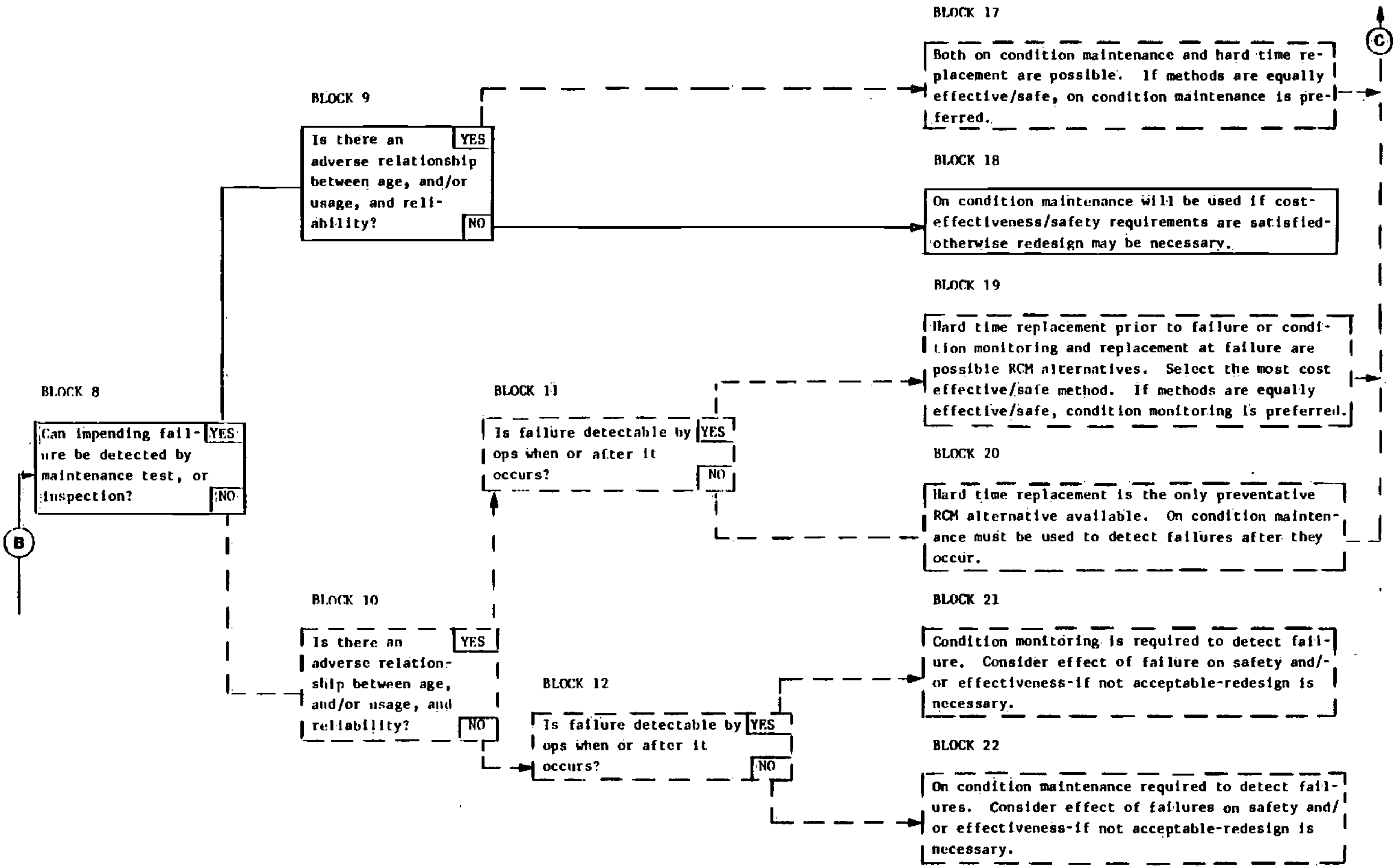

Figure 14.
RCM Logic for Digital Input Card (Cont'd)

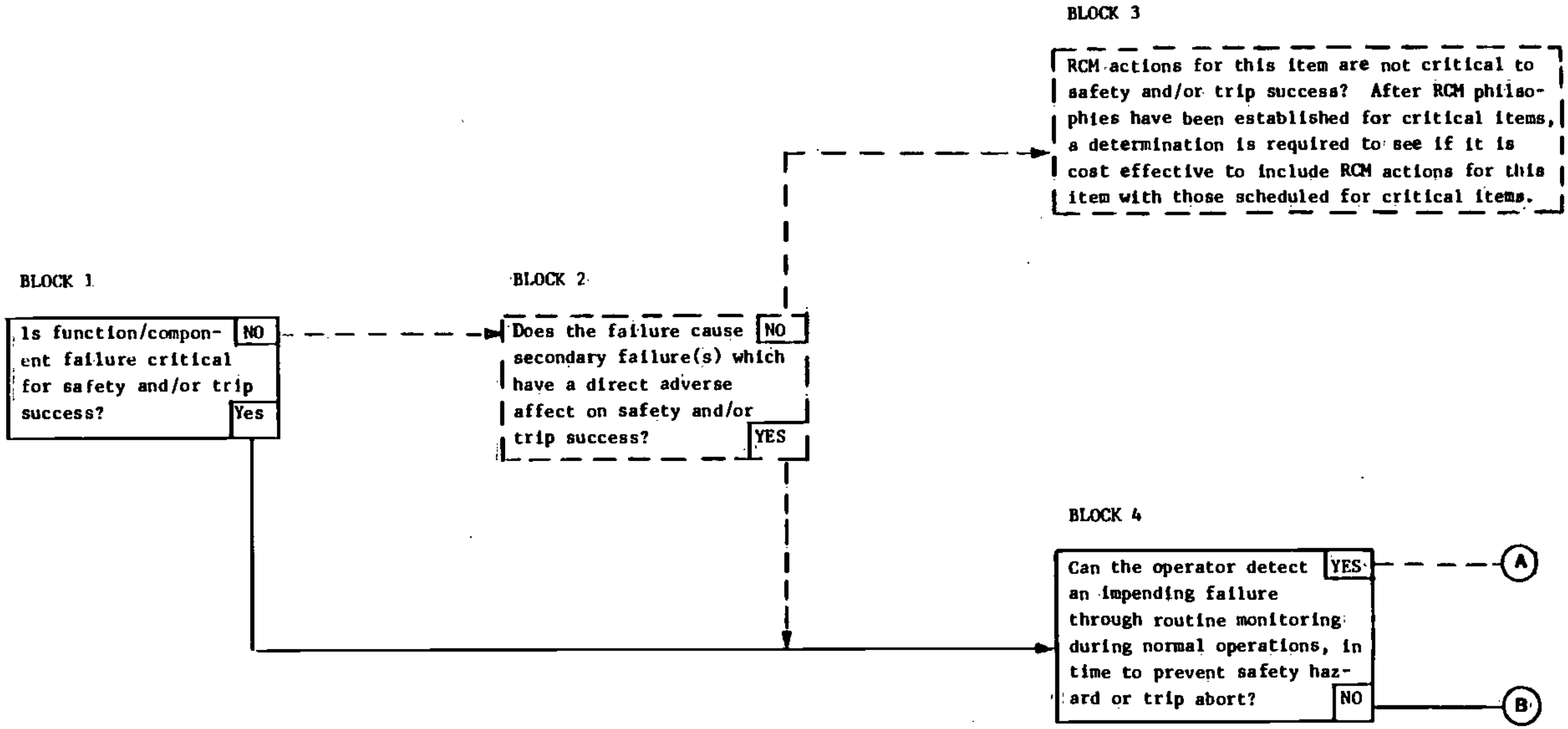

Figure 14.
RCM Logic for Digital Input Card

If F(Ti) = 0.81(FAM)

Ti = 7440 hours or every 310 days

This time represents the interval during which an inspection of the eight (8) digital input cards will detect impending failures.

Example 3: Processor Card

The CPU or Processor Card is typically the heart of the RTU. It provides the functional control for all other components of the unit. It contains a micro-computer, memories, communications interface, and logic for the data bus control. The data bus is used to interface the I/O cards to the microcomputer using the FMECA data available (See Figure 3 in Section II), the RCM logic is applied with the following results:

Failure Modes (Block 1)

The failure modes of the Processor are critical because the effects represent a complete loss of function to the RTU. Subsequently, a revenue service trip can be aborted. Impending failures can be detected by the Central Control operator (block 4) by a visual annunication of RTU failure (which is controlled by the processor internal to the RTU), and by maintenance test and inspection (block 5) through visual checks of the "CPU RUN" L.E.D. and through testing of the initialization sequence. In addition, there is no supportive evidence that the failure modes exhibit an increasing failure rate with age or usage (block 6).

The RCM analysis shows that both condition monitoring and on-condition maintenance are feasible. In this case however, the condition monitoring mode satisfies both trip success and safety requirements. Consequently, an on-condition maintenance task is not justifiable for either failure mode. See Figure 15 for logic sequencing of the Processor Board.

Example 4: Modem Subassembly

The modem unit contains two (2) modems which provide data communications interfacing between the far end RTU and near end Data Processing equipment. The primary modem is normally selected for receipt of serial data from the near end equipment. The secondary modem is used in the event of a failure to the primary modem. Automatic switchover is provided for these units.

Using the Fault Absorption Model data for the modem units from Section II (See Figures 9a through 9F), the RCM logic is

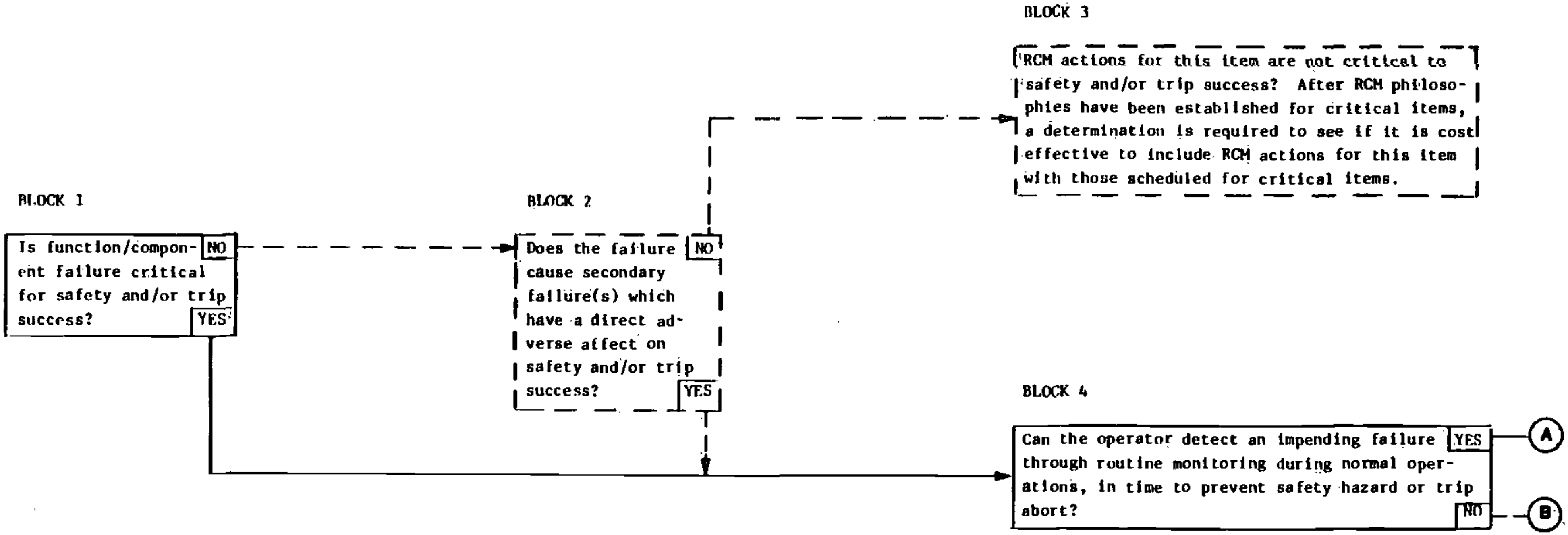

Figure 15.
RCM Logic for Processor Board

applied with results shown in Figure 16. Subsequently, no scheduled maintenance tasks are required for these units.

Since the modem subassembly has failure annunciation capability which allows single modem failures at the far end to be displayed at a Central Control facility, it wouldn't be cost effective to conduct any RCM actions. If this annunication capability was not provided, the failure event of a modem would still remain noncritical and would simply be absorbed. Consequently, any RCM actions would be unfeasible, because of the very low unrestricted repair rate (See Figure 9F).

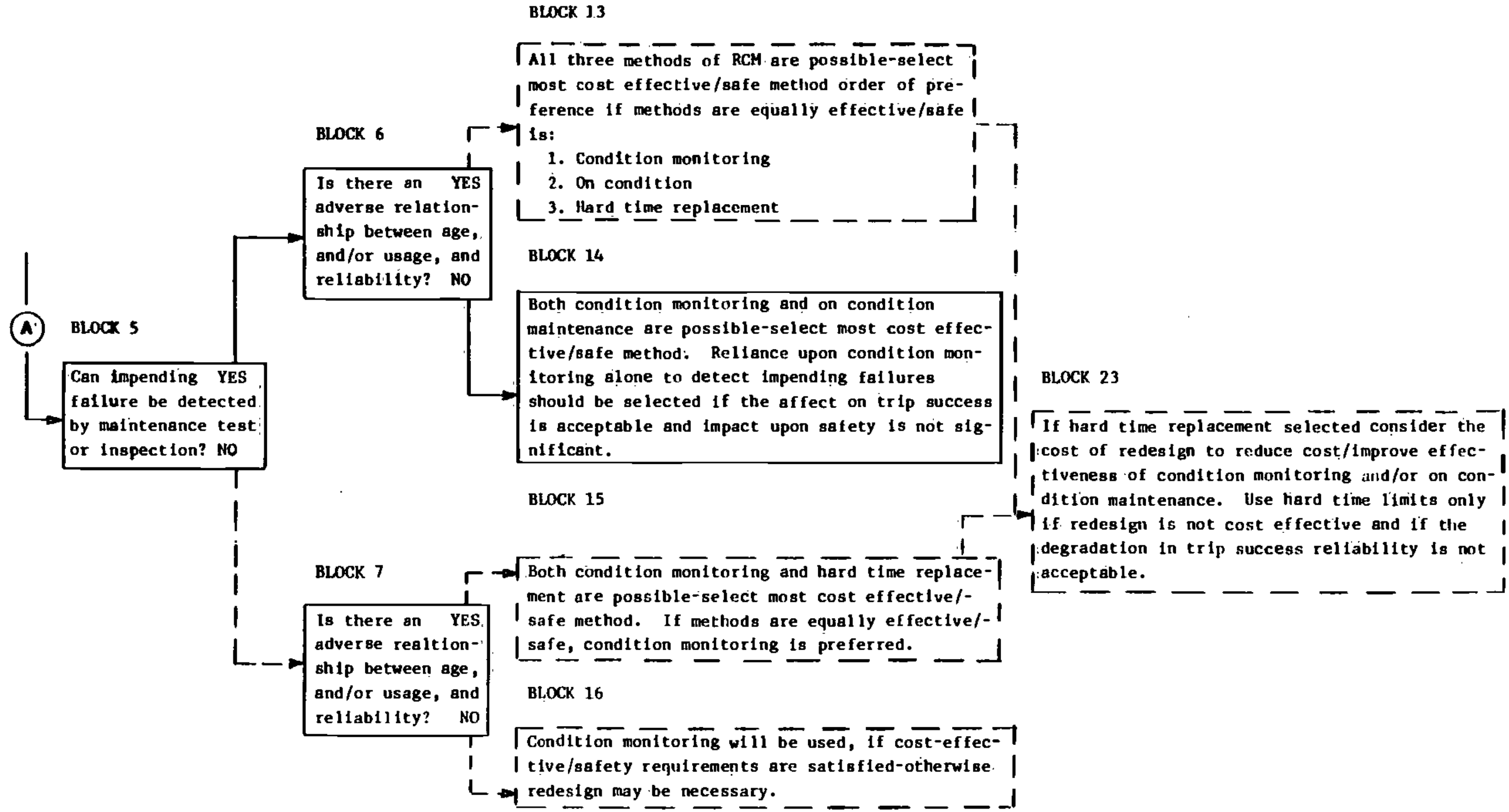

Figure 15.
RCM Logic for Processor Board (Cont'd)

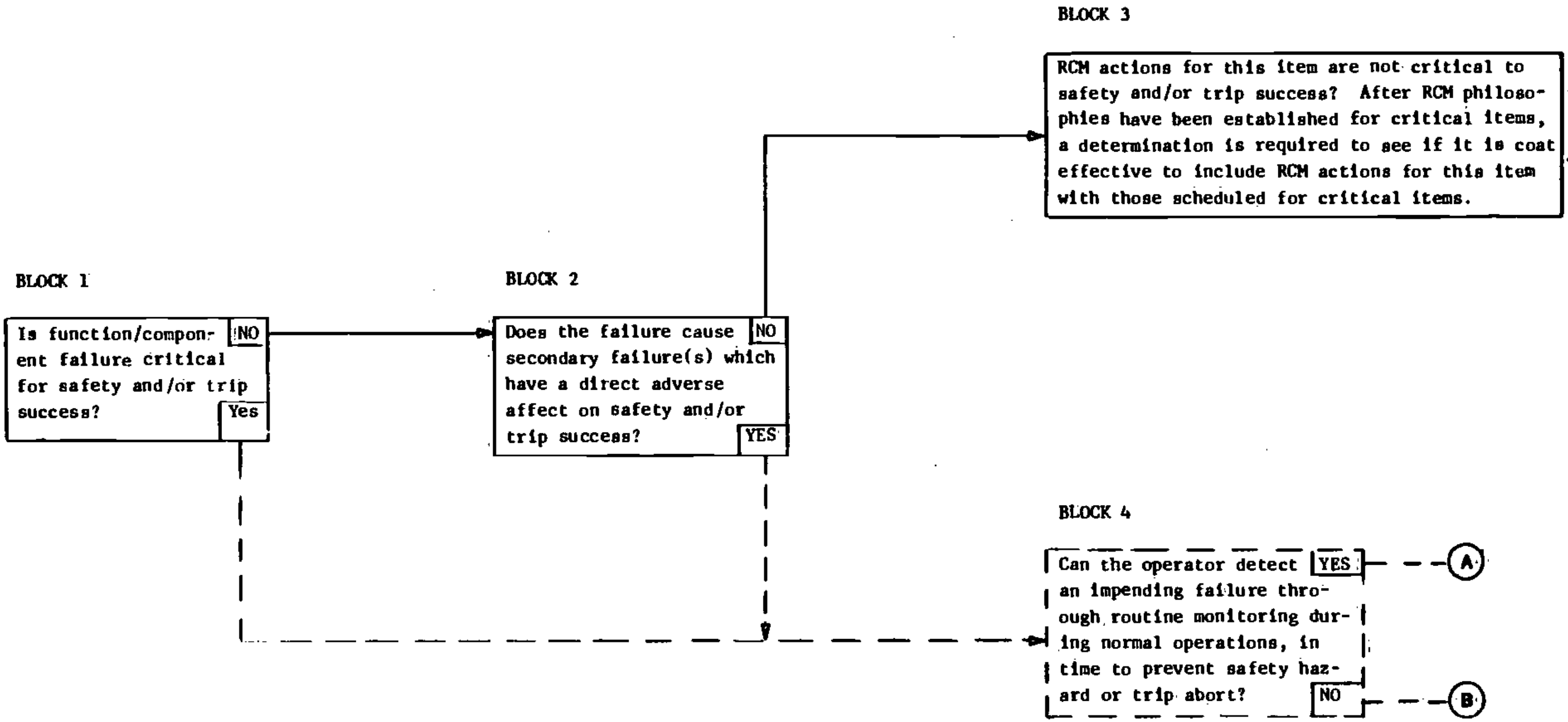

Figure 16.
RCM Logic for Redundant Modem Unit

V. CONCLUSION

To conclude, the concepts and methodologies shown in the previous sections can be utilized to determine scheduled maintenance tasks and optimize the level of maintenance required for rail rapid transit systems. A myriad of formulas are developed to minimize failures of service critical components and optimize proportionately the number of scheduled maintenance tasks to the total maintenance actions performed. Therefore, the effect of failures to revenue service activity tasks can be either absorbed or minimized in the level of impact, as can the related costs of the total maintenance application.

These methodologies can be implemented from final design to the fully operational project phase of a transit system.

Elements of this paper were used to develop the maintenance plans for the communications system of the Niagara Frontier (Buffalo) Light Rail Transit System.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the excellent work performed by Ms. Ann Marie Leone, a former working associate whose assistance in the development of RCM for this application--analyzing the designs and creating a model approach--provided the substantiation in format required for this paper. I would also like to acknowledge the helpful suggestions and assistance by Ms. Patricia Curran and her staff for the excellent production of this paper. Finally, all those individuals at DMJM for their assistance and diligence to undertaking the task of developing this document for the APTA Rapid Transit Conference.

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1 W. Clark, "Fault Absorption Model," Computer Sciences Corporation, Defense Systems Division, 1978.

2 W.E. Price, "Communications Systems Reliability Techniques," APTA 1983 Rapid Transit Conference, Pittsburgh, Pennsylvania.

3 MIL-STD-1388-1, Logistics Support Analysis, 15 October 1973.

4 A.M. Leone, "Analytical Approach of Reliability Centered Maintenance Methodologies," APTA 1984 Rapid Transit Conference, Baltimore, Maryland.

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: FIRE/LIFE SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.2.1	Combustible Content Total combustible content of each transit vehicle shall not exceed a heating value of 60,000,000 BTU of which no more than 33,000,000 BTU (55%) of the total combustible value shall be permitted above the floor assembly. Each combustible material shall be specifically identified by supplier's name and type, shape and use in the vehicle, and total weight and heating value. Heating values from this list shall be totalled for vehicle interior surface materials (including ducting, etc.), for other interior materials, for exterior materials not underfloor, and for all underfloor materials.			
2.4.2.2	Flammability of Vehicle Materials			
2.4.2.2.1	Upholstery and other fabric materials shall be tested by FAA Regulations 25.853 vertical test, Appendix F (b), with the following modifications: A. Average flame time after removal of the flame source may not exceed 10 seconds.			

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

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DISCIPLINE: FIRE/LIFE SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	B. Burn length shall not exceed 6 inches. C. Flaming dripping shall not be allowed. D. Fabrics that must be washed or dry cleaned must meet the requirements of parts A, B, and C above, after leaching, according to Federal Test Method 191b, Method 5830, or after dry cleaning according to AATCC-86-1968. Fabrics that cannot be machine washed or dry cleaned must be so labeled and must pass the leaching test as well as parts A, B, and C, after being cleaned as recommended by the manufacturer.			
2.4.2.2.2	Seat cushions shall be capable of passing the ASTM E162-78 Radiant Panel Test with a flame-propagation index (I_s) not exceeding 10. Additional provisions are: A. There shall be no flaming running or dripping of the material during the test. B. Wire mesh screening shall be used (in accordance with Section 5.9.2 of ASTM E162-78).			

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DISCIPLINE: FIRE/LIFE SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	C. A 6-inch pilot flame shall be used with the burner tip situated 1¼ inches beyond the frame to prevent its being extinguished.			
	D. Aluminum foil shall be used to wrap around the back and sides of the specimen.			
2.4.2.2.3	The composite of seat cushions and seat upholstery coverings shall be capable of passing the procedures required in 2.4.2.2.2 with an I_s not exceeding 35.			
2.4.2.2.4	Thermal and acoustical insulation, tested in its end-use configuration, and seat frames and seat shrouds shall be capable of passing the ASTM E162-78 Radiant Panel Test with an I_s not exceeding 25, with the additional provisions of 2.4.2.2.2.			
2.4.2.2.5	Wall and ceiling panels, windscreens, partitions, and ducting (including all materials in air-handling enclosures) shall be capable of passing the ASTM E162-78 Radiant Panel Test with an I_s not exceeding 35, with the added provision that there shall be no flaming running or dripping.			
2.4.2.2.6	Transparencies such as glazing, light diffusers, and windscreens shall be capable of passing ASTM E162-78 Radiant			

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REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Panel Test with an I_s not exceeding 100. Testing shall be on the car interior side and when these transparencies are located at the end of vehicles, the exterior side shall be tested as well.			
2.4.2.2.7	The floor-covering material placed over the structural floor shall be capable of passing the "Flooring Radiant Panel Test" (NFPA 253) with a minimum critical radiant flux of 0.50 watts/cm. Flooring material shall be tested together with any underlay that may be used. The flooring shall pass this test after being cleaned; the number of such cleanings shall be specified.			
2.4.2.2.8	Elastomers, used as door nosing and seals, and window gasketing shall be capable of passing ASTM C542-78.			
2.4.2.3	<u>Smoke Emission of Vehicle Interior Materials</u> All material listed in 2.4.2.2 shall be tested for smoke emission in accordance with ASTM E662-79, "Smoke Generated by Solid Materials". The optical density (D_s) in both flaming and nonflaming modes, determined in accordance with the test, shall not exceed 200 in 4 minutes.			

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DISCIPLINE: FIRE/LIFE SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.2.4	Fire Characteristics of Exterior Vehicle Materials			
2.4.2.4.1	The vehicle design shall arrange apparatus external to the passenger compartment, wherever practical, so as to isolate potential ignition sources from combustible material and to control fire and smoke propagation. Where it is necessary to install apparatus in passenger vehicles, suitable shields or enclosures shall be provided to isolate the apparatus from the passenger compartment.			
2.4.2.4.2	Battery cases shall be spaced well away from combustible materials at the vehicle trucks, and away from under-vehicle sources of high temperatures such as resistor banks and compressors.			
2.4.2.4.3	Exterior surfaces of vehicle end caps shall be capable of passing ASTM E162-78 Radiant Panel Test with an I_s not exceeding 35.			
2.4.2.4.4	Vehicle end caps and floor shall be designed to preclude propagation of underfloor fire to vehicle interior.			
2.4.2.4.5	Vehicle end caps shall be completely separated from the vehicle interior by vehicle exterior panels, or the void			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	space fully filled with thermal insulation meeting the requirements of 2.4.2.2.8 and 2.4.2.3.			
	The interior surface of the end caps shall meet the liner material requirements of 2.4.2.2.4 and 2.4.2.3.			
2.4.2.5	Toxicity			
	Those materials and products generally recognized to have high toxic products of combustion shall not be used.			
2.4.2.6	Underfloor Fire Separations			
2.4.2.6.1	The vehicle floor assembly shall be capable of passing ASTM E-119 fire endurance test for its classification.			
	The test time period selected shall be equal to that time necessary for safe evacuation of a maximum load of passengers from the vehicle in the worst case situation, or one hour, whichever is greater.			
2.4.2.6.2	The test specimen shall be a full-width vehicle section, including a portion of the vehicle walls which extend below the upper surface to the vehicle floor.			
	Specimen shall have an exposed area of 180 square feet. This area may be reduced to meet a length limitation im-			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	posed by the size of the test furnace, but the length should not be less than 15 feet. No fewer than two typical penetrations shall be included in the test specimen, which should be spaced from each other at a distance no greater than will exist in the actual construction.			
2.4.2.6.3	Specimen shall be placed within the combustion chamber with a clearance not less than 8 inches from the furnace wall.			
2.4.2.6.4	The test specimen shall be loaded to represent a crush passenger load.			
2.4.2.6.5	Conditions of acceptance for this test shall be those required for unrestrained assembly.			
2.4.3	ELECTRICAL REQUIREMENTS			
2.4.3.1	All motors, motor control, current collectors, and auxiliaries shall be a type and construction suitable for use on fixed trainway transit vehicles.			
2.4.3.2	Gap and Creepage			
2.4.3.2.1	Electrical circuits and associated cabling shall be designed with gap and creepage distance between voltage			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	potentials and carbody ground, in accordance with the environmental conditions to which the circuits and cabling will be subjected.			
2.4.3.2.2	The air gap distances between voltage potentials (up to 2000 volts) and ground in enclosed, clean, dry environments shall be consistent with the following formula: Gap (inches) = 0.125 + (0.0005 x nominal voltage) In selecting air gap distances, special consideration shall be given to the presence of contaminants encroaching upon the normal free air environment.			
2.4.3.2.3	Creepage distance for voltage potentials to ground shall comply with the requirements specified in the following documents: UL 508 - For voltages up to and including 300 V ac or dc NFPA 130 - For voltages above 300 V ac or dc. In other than ordinary enclosed environments, creepage distances shall be modified according to the anticipated severity of the environment.			

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REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.4

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.3.3	Propulsion Motors			
2.4.3.3.1	Motors shall be rated and tested per American Standard for Rotating Electric Machinery for Rail and Road Vehicles, IEEE 11.			
2.4.3.3.2	Motor leads shall have an insulation suitable for the operating environment and shall be supported and protected so as to offer the least possible chance of mechanical damage. Motor leads where entering the frame shall be securely clamped and shall fit snugly so as to prevent moisture from entering the motor case. Drip loops shall be formed in motor leads so as to minimize water running along the lead onto the motor case. Motor leads shall be sized according to IEEE S-135 or using 150% rms current whichever is greater. The rms current shall be based upon continuous round-trip operation of an AW2 consist between and including Union Station and North Hollywood Station, operating at PL-1, stopping at stations, and observing speed restrictions and the service braking rates. Primary voltage shall be 700 V dc in propulsion and 750 V dc in electric braking. Intermediate			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	station dwell time shall be 20 seconds, and terminal station turnback time shall be 120 seconds.			
2.4.3.4	Motor Control			
2.4.3.4.1	Motor control shall be rated and tested per American Standard for Electrical Control Apparatus for Land Transportation Vehicles, IEEE 16.			
2.4.3.4.2	Control equipment enclosures shall be arranged and installed to provide protection against moisture and mechanical damage.			
2.4.3.4.3	Metal enclosures that surround arcing devices shall be lined with insulating material approved by the authority having jurisdiction, with the exception that lining will not be required when the arc chutes extend through the enclosure and vent the arc to the outside air. Adequate shields or separations shall be provided to prevent arcing to adjacent apparatus and wiring.			
2.4.3.5	Power Resistors			
2.4.3.5.1	Self-ventilated resistors shall be mounted with air space between resistor elements and combustible materials.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Heat-resistant barriers shall extend horizontally beyond resistor supports to ensure protection from overheated resistors where necessary.			
	Forced ventilated resistors shall be mounted in ducts, enclosures, or compartments of noncombustible material and shall be mounted with air space between the resistor enclosure and combustible materials.			
	Provisions shall be made to filter the air where the operating environment is severe.			
2.4.3.5.2	Resistors and heating circuits shall incorporate protective devices for the following failures:			
	A. Failure of ventilation air flow			
	B. Failure of temperature controls			
	C. Short circuit in supply wiring			
2.4.3.5.3	Resistor elements shall be electrically insulated from the resistor frames, and frames shall be insulated from supports.			
	When forced ventilation is provided, the resistor leads shall be securely separated and cleated for protection in the			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	event of loss of air circulation of the ventilation system.			
	Leads shall be routed or protected from resistor heat.			
2.4.3.5.4	The current value used in determining the minimum size of resistor leads shall include an appropriate safety factor based on the load current seen by the lead under the most severe normal duty cycle.			
2.4.3.6	<u>Current Collection</u>			
2.4.3.6.1	Clearance or shielding shall be provided between any part of the current collector assembly that is at line voltage and any other portion that is at ground potential.			
	The shielding material shall be noncombustible.			
2.4.3.6.2	The minimum size of current collector leads shall be determined by adding the sum of the maximum expected auxiliary loads to the propulsion motor loads. For a propulsion system equipped with regenerative capability, the regenerative load must be included with the motor load.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.3.7	<u>Wiring</u>			
2.4.3.7.1	Single conductor wiring and conductors forming part of a multi-conductor cable between control group enclosures shall be suitably sized per NEC.			
2.4.3.7.2	Conductor sizes shall be selected by determining rms currents in the conductors and by considering maximum allowable voltage drops. Conductors shall be no smaller than the minimum sizes in 2.4.3.7.1. Conductors shall be derated for grouping and for ambient temperature greater than the manufacturer's design value, in accordance with criteria specified by NEC.			
2.4.3.7.3	Electrical insulation for wiring and power cable shall be capable of passing the following tests: A. Wires for lighting auxiliary circuits and for control, signal, and other low-voltage (less than 100 V ac and 150 V dc) functions shall meet the requirements of IPCEA S-19-81 (with Amendment FR-1) paragraph 6.19.6. or of UL 44 for thermosetting insulation and UL 83 for thermoplastic insulation.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	B. Power cable shall meet the requirements of IEEE Standard 383-1974, Section 2.5, with the additional requirement that circuit integrity continue for 5 minutes after the start of the test. C. All other electrical insulation shall meet suitable tests for the proposed use.			
2.4.3.7.4	Conductors of all sizes shall be provided with mechanical and environmental protection and shall be installed in any one or combination of the following ways: A. In flexible metallic conduit or raceways B. In nonmetallic raceway ducts or flexible tubing suitable for vehicle wiring C. In cable boxes D. As nonmetallic sheathed cable suitable for wiring Sufficient firestops shall be provided in raceways, at floor penetrations, at entrances to or exits from major components, and at changes of direction to control the spread of fire.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Wires connected to different sources of energy shall not be cabled together or run in the same conduit, raceway, tubing, junction box, or cable unless all such wires are insulated for the highest rated voltage in such locations.			
	Wires connected to electronic control apparatus shall not touch wires connected to a higher voltage source of energy than control voltage.			
	Conduits, electrical metallic tubing, non-metallic ducts or tubing and all wires with their outer casings shall be extended into devices and cases where practical.			
	They shall be rigidly secured in place by means of cleats, straps, or bushings to prevent vibration or movement and to give environmental protection.			
	Connections and terminations shall be made in a manner to assure their tightness and integrity.			
	Conductors and enclosures of any kind shall be protected from the environment and from mechanical damage.			
2.4.3.8	<u>Overload Protection</u>			
2.4.3.8.1	A main automatic circuit line breaker or line switch and overload relay for the			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	protection of the power circuits shall be provided.			
	Circuit breaker arc chutes, if utilized, shall be vented directly to the outside air.			
2.4.3.8.2	Cartridge-type fuses, if used in addition to the automatic circuit breaker, shall be installed in approved boxes or cabinets.			
	Railway-type ribbon fuses, if used, shall be installed in boxes especially designed for this purpose and shall be equipped with arc blowout aid.			
	Third rail shoe fuses mounted on the shoe beams shall be mounted so as to direct the arc away from grounded parts.			
2.4.3.8.3	Circuits used for purposes other than propelling the vehicle shall be connected to the main cable at a point between the current collector and the protective device for the traction motors.			
	Each circuit or group of circuits shall be provided with at least one circuit breaker, a fused switch, or fuse located as near as practicable to the point of connection of the auxiliary circuit, except that such protection may be omitted in circuits controlling safety devices.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.3.9	Battery Installation The design of battery installation and circuitry shall include the following: A. Minimal use of organic materials, particularly those having hygroscopic properties. B. Fire-retardant treatment for organic materials used. C. Battery chargers designed for protection against overcharging. D. Use of smoke and heat detectors, if appropriate. E. Use of an emergency battery cutoff switch, if appropriate. F. Isolation of battery compartment from car interior using noncombustible materials as defined in ASTM E136 if appropriate.			
2.4.3.10	Testing and Maintenance			
2.4.3.10.1	Qualification testing shall be performed by the equipment manufacturer in accordance with tests specified by the SCRTD.			
2.4.3.10.2	Periodic maintenance shall be performed in accordance with maintenance manuals			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	furnished by the equipment manufacturer. Frequency of maintenance shall be based upon operating experience.			
2.4.4	VENTILATION AND HEATING EQUIPMENT			
2.4.4.1	Control of Ventilation Equipment			
	Vehicles shall have provision for control of all ventilation equipment throughout the train from the controlling cab, in the event of a fire.			
2.4.4.2	Heater Protection			
2.4.4.2.1	Heater forced air distribution ducts and plenums shall incorporate over-temperature sensors, fusible links, or means of detecting insufficient air flow.			
2.4.4.2.2	Heater elements shall incorporate protective devices for the following failures: A. Failure of the ventilation air flow B. Failure of the temperature controls C. Short circuits in supply wiring			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.5	EMERGENCY EGRESS AND ACCESS MEANS			
2.4.5.1	Emergency Exits			
2.4.5.1.1	All vehicle side doors and end doors shall have capability for use as emergency exits. Side doors and end doors shall be designed to be operable by patrons under emergency conditions, including loss of electrical power to these doors.			
2.4.5.1.2	At least one vehicle side door on each side and both end doors shall be designed to be openable from the outside by rescue personnel during power loss.			
2.4.5.1.3	A means of exiting from the vehicle to the trackway from side doors and ends of the train shall be provided.			
2.4.5.2	During design, consideration shall be given to equipping the end doors between all vehicles with protective enclosures that will provide interim protection against smoke in trainway tunnels and aid patrons in making intervehicle transfers through a moving train during emergency conditions.			
2.4.5.3	Emergency lighting shall be provided throughout the vehicle and arranged at			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	each doorway to provide illumination to the door vestibule and threshold area.			
	Emergency lighting shall provide an illumination level of one footcandle measured at the floor.			
2.4.5.4	Power to emergency lighting and other designated emergency electrical equipment shall be available for a period of one hour in the event of loss of external power.			
	The onboard power supply for designated services shall be supplied from battery units on each vehicle or each dependent pair.			
2.4.6	FIRE PROTECTION			
2.4.6.1	Fire Extinguishers			
	Each vehicle shall be provided with at least two UL approved portable fire extinguishers of the 10-pound class, rated at 4A-30B:C.			
	Extinguishers shall be located for use by patrons, except that positions which become operators' areas in the front end of vehicle may be used as extinguisher locations.			

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REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.4.7	COMMUNICATIONS			
2.4.7.1	Public Address System			
	Each vehicle shall be equipped with public address system speakers by which train operators can communicate emergency information to passengers.			
	Provisions shall be made so that Central Control can address passengers directly.			
	Audibility shall be a minimum of 10 dB overy any background noise.			
2.4.7.2	Radio			
	Direct radio voice communication shall be provided between the train operator and Central Control.			
2.4.7.3	Devices shall be provided in each car by which passengers may alert and communicate with the train operator in emergencies.			
2.4.7.4	The communication systems described in 2.4.7.1, 2.4.7.2 and 2.4.7.3 shall be powered by the onboard emergency power supply referenced in 2.4.5.4.			
2.4.8	A means of manually uncoupling vehicles within a train, both from within and from the exterior, shall be provided.			

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DISCIPLINE: SYSTEM SAFETY

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

CONTRACT No.: A620

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.6	TRAIN CONTROL The Automatic Train Control (ATC) system shall ensure, to the maximum extent possible, life safety for all conditions of train operation.			
3.6.1	<u>Automatic Train Protection (ATP)</u> The ATP subsystem shall provide fail-safe control and implementation of safety-critical functions. The ATP subsystem shall be continuous. The ATP subsystem shall not be compromised by operation or failure of other systems and subsystems. Failures which affect operation within the ATP subsystem shall be detectable, but shall not compromise safety.			
3.6.1.A	<u>Train Detection</u> Track circuits shall be designed, configured and applied to ensure detection of stopped and moving passenger trains and maintenance vehicles. Continuous detection of broken rail shall be required to the maximum extent possible.			

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DISCIPLINE: SYSTEM SAFETY

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

CONTRACT No.: A620

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.6.1.B	Train Separation			
3.6.1.B.1	Block design and safe braking distances shall be based on worst case conditions for track, grade, vehicle, loading, and braking performance.			
3.6.1.B.2	The design shall ensure that trains on the same track maintain a safe following distance to prevent collisions.			
3.6.1.C	Speed Limit Enforcement			
3.6.1.C.1	The ATP design shall ensure that trains normally remain at or below safe speeds determined by block design. Trains shall be given an automatic brake command if the speed limit is exceeded.			
3.6.1.C.2	Speed limit information shall be transmitted by wayside equipment to equipment on the trains. The vehicle speed limit transmission decoding logic shall respond only to transmitted signals whose characteristics match those of a valid speed limit transmission signal. Both transmitted and actual speeds shall be displayed in the cab.			

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DISCIPLINE: SYSTEM SAFETY

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

CONTRACT No.: A620

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Absence of a valid speed limit transmission shall be interpreted by the vehicle ATC equipment as a zero mi/hr speed limit.			
3.6.1.C.3	Automatic actuation of vehicle propulsion and braking shall be implemented to prevent undesired movement and excess speed.			
3.6.1.C.4	No operation of and failure within the RCC and the SCADA equipment shall compromise the safety assured by the ATP subsystem.			
3.6.1.C.5	ATP speed enforcement for a fixed restricted speed shall be provided for a submode of manual operation, implemented when no speed limit transmissions are received by the train.			
3.6.1.D	<u>Route Security</u>			
3.6.1.D.1	Train movements through interlockings shall be protected by ATP.			
3.6.1.D.2	Trains on crossing/merging of branching routes shall not be permitted to make conflicting moves.			
3.6.1.D.3	The ATP subsystem shall prevent a train that is operating in automatic mode from entering an interlocking whose status is not vitally determined to be safe.			

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DISCIPLINE: SYSTEM SAFETY

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

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REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.6.1.D.4	The ATP subsystem shall give fail-safe wayside indications of the interlocking status to the train operator.			
3.6.1.D.5	The ATP subsystem shall prevent opposing moves between interlockings for trains operating in automatic mode.			
	The ATP subsystem shall provide a "STOP" wayside indication to trains operating in manual mode prior to entering.			
3.6.1.E	<u>ATP Cut Out Detection</u>			
	Cut out of the ATP on any passenger vehicle or train shall require an enabling signal from RCC before ATP bypass can be activated.			
	ATP may also be cutout by a sealed switch in the cab.			
	When ATP is bypassed, an alarm in the RCC shall be annunciated.			
3.6.1.F	<u>Vehicle Door Operation</u>			
	The design shall inhibit manual operation of vehicle side doors by either passengers or employees when the vehicle is in motion.			
	The design shall prevent the train from starting until all side doors are closed and latched.			

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DISCIPLINE: SYSTEM SAFETY

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

CONTRACT No.: A620

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.6.1.G	<u>Station Platform</u> The ATP subsystem shall prevent a train in the automatic operating mode from proceeding beyond a station platform if propulsion power is not continuously available for the train to berth at the next downstream station platform.			
3.6.2	<u>Automatic Train Operation</u> (ATO) The ATO subsystem shall perform berthing verification at all station platforms, regardless of travel direction. Berthing verification shall ensure that the train is wholly within a station platform area and that all doors will open to a platform.			
3.6.3	<u>Automatic Train Supervision</u> (ATS) The ATS subsystem shall not directly affect train safety. The ATS shall meet operational objectives without compromising safety. The ATS subsystem shall include equipment at the RCC for recording alarms and failures/malfunctions, including their time, location and nature, to facilitate proper response to emergency situations.			

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REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.6, TRAIN CONTROL, 07/86 Revision 2

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.6.4	Other Design Features			
3.6.4.A	Signal aspects, indications and terminology shall be consistent throughout the ATC system.			
3.6.4.B	The ATC system at wayside shall have an emergency backup power supply system to support train control in the event of power loss.			
3.6.4.C	Manual mimic boards and controls shall be located in the local train control rooms.			
3.6.4.D	When manual operations of a vehicle without ATP is permitted, adequate operational procedures shall be developed to assure safe operation.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.2	STATION FACILITIES			
2.2.1.3	The design of stations and their appurtenances shall conform to California Administrative Code (CAC) Title 24, CAC Title 19, CAC Title 8, California Public Utilities Commission (CPUC) General Orders except as specifically set forth in this chapter, and Uniform Building Code (UBC), 1979, as applied by Title 24, CAC.			
2.2.2.1	Building construction for underground stations shall be not less than UBC Type I construction.			
2.2.2.2	Where stations have floor levels at or above ground level, that portion which is above ground shall be not less than UBC Type II-FR construction.			
2.2.2.3	Stations having more than two levels below grade or more than 80 feet to the lowest level from grade will require protected level separation or other protection features to provide safe egress regardless of exit time calculations.			
2.2.2.4.1	Station public occupancy shall be separated from station ancillary occupancy by minimum 2-hour fire rated construction.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Exception: A maximum of 2 station agents, supervisors, or information booths may be located within station public occupancy areas when constructed of approved noncombustible materials and limited in floor area to 100 square feet each. Automatic fire protection systems installed in the area in which the booth is located shall extend into the booth.			
2.2.2.4.2	Station public occupancy shall be separated from power substations and transformer vault areas in station ancillary occupancies by 3-hour fire-rated construction.			
2.2.2.4.3	Station public and ancillary occupancies shall be separated from nontransit occupancies by 3-hour fire-rated construction.			
2.2.2.5.1	Electrical equipment areas which contain transformers and traction power equipment shall be separated from all other occupancies by 3-hour fire-rated construction.			
2.2.2.5.2	Vaults of not less than 3-hour fire-rated construction shall be constructed for oil-insulated electric transformers and shall meet the NEC requirements for vault construction, including door and sill requirements.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.2.2.5.3	Electrical equipment rooms, electric rooms, battery rooms, train control and communication rooms, and trash rooms shall be separated from other occupancies by 2-hour fire-rated construction.			
2.2.2.6.1	Openings in 3-hour fire-rated separations shall be protected by labeled 3-hour fire-rated (Class A) assemblies.			
2.2.2.6.2	Openings in 2-hour fire rated separations shall be protected by labeled 1½-hour fire-rated (Class B) assemblies.			
2.2.2.6.3	Openings in 1-hour fire rated separations shall be protected by 1-hour fire-rated (Class B) assemblies.			
2.2.2.6.4	Fire-rated assemblies protecting openings in fire-rated separations shall be automatic or self-closing. Automatic closing assemblies protecting openings into station public occupancies shall be activated by approved detection devices, responding to products of combustion other than heat. Alternatively, automatic closing assemblies may be released by heat-actuated devices alone where a separate smoke barrier is provided. Installation shall be in accordance with UBC Section 4306.			
2.2.2.7	Section 2.3.2.3 requirements for protection of underground guideways shall be applied to underground stations.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.3.2.3.1	Vent or fan shafts utilized for ventilation of subway tunnels shall not terminate at grade on any vehicle roadway or parking lot.			
2.3.2.3.2	Vent and fan shafts may terminate in the median strips of divided highways or on sidewalks designed to accept such shafts, or in open space areas, provided that their location at the level of the median strips, or sidewalk, or open space, is protected by a concrete curb. This curb shall be of sufficient elevation to exclude drainage into the shaft, but in no case shall the height be less than 6 inches.			
2.3.2.3.3	Installation of underground hazardous substance storage tanks and related piping shall not be permitted directly over any transit system subsurface structure or within 25' measured horizontally from the outside wall of such a subsurface structure (See 2.3.2.3.5).			
2.3.2.3.4	Installation of underground hazardous substance storage tanks and related piping, located in the area between 25 feet and 100 feet (measured horizontally from the outside wall) of any transit system subsurface structure, and within that same area such tanks and related piping which are within 2' below the lowest point of excavation limit, shall meet the following requirements:			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	A. Tanks shall be of double wall construction.			
	B. Tanks shall be equipped with an approved automatic leak detection and monitoring system.			
	C. Tanks shall be provided with an approved corrosion detection system.			
	D. Installation, maintenance and inspection shall conform to the requirements specified by the authority having jurisdiction.			
2.3.2.3.5	Existing underground hazardous substance storage tanks located in or under buildings which are located directly above or within 25 feet (measured horizontally from the outside wall) of the subsurface transit structure, shall be removed.			
	Where it is not possible to remove tanks, such tanks shall be abandoned in accordance with provisions of the authority having jurisdiction.			
2.3.2.3.6	Facilities dispensing hazardous substances from underground tanks where such tanks are located in the area within 100' (measured horizontally from the outside wall) of the subsurface structure shall be required to comply with the following:			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	A. The surface around pump islands shall be graded or drained in a manner to divert possible spills from subway vent gratings, entrances, or exits.			
	B. Appropriate continuous drains across driveways, ramps, and/or curbs of at least 6 inches in height shall separate facilities from adjacent subway property.			
	C. No connection (such as venting or drainage) of any storage tanks and related piping of hazardous substances to a fixed subsurface transit structure shall be permitted.			
	D. Points of dispensing for hazardous substances shall not be located less than 50 feet from the nearest subway system opening.			
2.3.2.3.7	Other fill or dispensing points for hazardous substances shall be subject to restrictions as prescribed in 2.3.2.3.6.			
2.2.2.8.1	All structural assemblies and building appurtenances shall conform to Type I structures per UBC Chapters 5, 17, and 18.			
2.2.2.8.2	Combustible adhesives and sealants used shall not compromise requirements of section 2.2.2.9.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.2.2.8.3	Elevators and escalators shall be constructed of noncombustible materials and conform to CAC Titles 24 and 8.			
2.2.2.9.1	Interior finishes shall be Class I (per UBC Chapter 42) for all exit access routes and exits. Platforms and mezzanines in transit stations shall be considered exit access routes for the purpose of determining interior finish requirements.			
2.2.2.9.2	Interior finishes in all other areas shall be UBC Chapter 42, Class I or II.			
2.2.3.1.1	Provisions shall be made for emergency ventilation for protection of patrons and employees from fire and products of combustion.			
2.2.3.1.3	Ventilation shaft terminals at grade shall be located as follows: A. Openings for blast relief shafts, and underplatform and smoke exhaust shafts at grade shall be separated by a minimum horizontal distance of 40 feet from the closest station entrance, surface emergency stair doorways, unprotected outside air intake or other openings, or from each other. o Where this distance is not practical, the horizontal distance may be reduced to 15 feet if the closest blast relief or underplatform and			

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	smoke exhaust shaft terminal is raised a minimum of 8 feet above the station entrance, emergency stair doorway and unprotected outside air intake or other opening, or the underplatform and smoke exhaust shaft terminal is raised a minimum of 8 feet above the blast relief shaft terminal.			
	B. The minimum distance between the edges of adjacent openings for outside air intake shafts protected by smoke dampers and blast relief shafts or underplatform and smoke exhaust shafts shall be as follows: $d = 0.25 \times (l_1 + L_2)$ Where: d = minimum distance in feet between the edges of the adjacent openings. L_1 and L_2 = lengths in feet of the adjacent parallel sides of the openings.			
2.2.3.2.1	Ventilation systems shall be designed so that in a fire emergency the air temperature in exit pathways does not exceed 120°F.			
2.2.3.2.2	Emergency ventilation systems shall produce airflow rates so as to provide a stream of noncontaminated air to patrons in egress path.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.2.3.3.1	Ventilation fans used for emergency service, their motors and all related components exposed to the ventilation airflow shall be designed to operate in an ambient atmosphere of 300°F for a period of at least 1 hour.			
2.2.3.3.2	Local fan motor starters and related operating control devices shall be isolated from the ventilation airflow by a separation having a fire-resistance rating of at least 2 hours.			
2.2.3.3.3	Fans used for emergency ventilation shall be single or dual-speed, reversible, or capable of changing direction of airflow by use of dampers.			
2.2.3.3.4	Fans required for emergency operation shall be capable of satisfying emergency air-velocity criteria in either supply or exhaust modes.			
2.2.3.3.5	Thermal overload protective devices shall not be provided on motor controls of fans used for emergency ventilation. Circuits shall be designed to maintain current to the emergency fan motors without operation of protective devices (unless excess current is sensed simultaneously with a no-airflow signal).			
2.2.3.3.6	Two independent electrical supplies shall be provided for each of the emergency fans. Automatic transfer			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	shall be provided in the event the normal supply source fails.			
2.2.3.4.1	Operation and fail-safe verification of proper operation of emergency fans shall be effected by Central Control with supply-off-exhaust indication provided for each fan as well as from a local control isolated as in 2.2.3.3.2.			
2.2.3.4.2	Controls shall be provided at the EMP for operating the ventilation system in all modes. This location and the local control shall override control from CC.			
2.2.3.4.3	Emergency ventilation shall be designed to operate in full coordination with the trainway ventilation system.			
2.2.3.4.4	Emergency ventilation systems shall be controlled in all operating modes; locally, from the EMP, and from CC.			
2.2.3.5.1	Ancillary area ventilation systems shall be arranged so that air is not exhausted into station public occupancy areas. Controls for shutdown of ancillary area ventilation systems shall be provided at the EMP.			
2.2.3.5.2	Battery storage or similar ancillary rooms in which hydrogen gas or other hazardous gases may be released shall require mechanical ventilation and be ventilated in accordance with NFPA 91 and as follows:			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	A. Exhaust ducts from battery rooms shall not connect with duct systems used for other purposes.			
	B. Exhaust system operation shall be proven by means of an air-flow switch, from which a no-air-flow signal produces an alarm at a continuously attended location and will cause battery charging serving the affected area to be deenergized.			
2.2.4.1	Electrical equipment and wiring materials and installations within stations shall comply with NEC and, other than for traction power, shall satisfy the following requirements:			
2.2.4.1.1	Materials manufactured for use as conduits, raceways, ducts, boxes, cabinets, equipment closures and their surface finish materials shall be capable of withstanding 932°F for 1 hour and shall not support combustion. Other materials when embedded in concrete are acceptable.			
2.2.4.1.2	All conductors shall be insulated. Copper ground wires may be bare. All thicknesses of insulation and jackets shall conform to NEC.			
2.2.4.1.3	Insulation shall conform to Article 310 of NEC and be moisture- and heat-resistant, and carry temperature ratings			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	corresponding to application not lower than 194°F.			
2.2.4.1.4	Wire and cable used in operating vital train signal circuits and power circuits to emergency fans, lights, etc., shall pass the flame-propagating criteria of IEEE 383 and have a minimum short circuit time of 5 minutes in the flame test of IEEE 383. Such tests shall be performed with the wire and/or cables protected as they will be when installed.			
2.2.4.1.5	o All conductors shall be enclosed in conduits, enclosed raceways, boxes and cabinets, except in traction power substations, electrical equipment rooms, train control rooms, or communications rooms. o Conductors in conduits or raceways may be embedded in concrete or run in concrete electrical duct banks. o Conductors shall not be installed exposed or surface-mounted in air plenums which may carry air at the elevated temperature accompanying the fire-emergency conditions.			
2.2.4.1.6	Overcurrent elements which (a) are designed to protect conductors serving emergency equipment motors, emergency lighting, and communications equipment, and (b) which are located in spaces			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	other than main distribution system equipment rooms, shall operate on magnetic principles and not depend upon thermal properties for operation.			
2.2.4.1.7	Wiring for fans essential for emergency ventilation service shall meet the requirements of 2.2.4.1.4.			
2.2.4.1.8	Conductors for emergency lighting, communications, etc. shall be protected from physical damage by transit vehicles or other normal transit system operations, and from fires in the transit system by suitable embedment or encasement, or by routing such conductors through areas of low fire potential (light hazard).			
2.2.4.1.9	Switches, electrical outlets, and lighting fixtures in areas where batteries are installed/charged shall be explosion proof per NEC.			
2.2.5.2	<u>Occupancy and Occupant Load</u>			
2.2.5.2.1	The occupant load for a station shall be determined based on an emergency condition requiring evacuation of that station load to a point of safety.			
2.2.5.2.2	A. Access to the platform and/or the station must be operationally constrained to a platform net area ocupancy equivalent to 4 square feet per person. For anticipated platform entraining			

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	loads that would result in area occupancies of less than 4 square feet per person, the calculated platform load will be limited to the net platform area divided by 4 square feet per person. The minimum total exit width in feet shall be equal to this platform load divided by 50 patrons per foot of exit width.			
	B. Notwithstanding other provisions in 2.2.5.2, exiting shall be provided, as a minimum, to accommodate the equivalent of 7 square feet per person.			
	C. Special design consideration shall be given to stations directly servicing areas where events occur that result in abnormal patron loads.			
2.2.5.2.3	If there are side platform stations, each platform shall be considered separately. At center platform stations, arrival of trains from both directions, plus their entraining loads, shall be considered.			
2.2.5.2.4	At mezzanines or multi-level stations, simultaneous platform loads shall be considered for all exit paths passing through that area.			
2.2.5.3.1	Exit capacities shall be calculated on the basis of 22-inch wide exit lanes. Width shall be measured in the clear at			

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	the narrowest point except that individual handrails may project 3½ inches into the required width. Fractional lanes shall not be counted in measuring exit capacities except that 12 inches added to one or more lanes shall be counted as ½ a lane.			
2.2.5.3.2	There shall be sufficient exit lanes to evacuate the station occupant load as defined in 2.2.5.2.1 from the station platforms in 4 minutes or less (see Figure 2-1 "Emergency Exit Capacity Calculation" of criteria).			
2.2.5.3.3	The station shall also be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less.			
2.2.5.3.5	The capacity in persons per minute (ppm), travel speeds in feed per minute (fpm), and requirements for exit lanes shall be as follows: A. Platforms, corridors, and ramps of 4 percent slope or less: Exit corridors and ramps shall be a minimum clear width of 5 feet 8 inches. In computing the number of exit lanes available, 1 foot 6 inches shall be deducted at each platform edge and 1 foot at each sidewall. Per exit lane: Capacity - 50 ppm Travel speed - 200 fpm			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	B. Stairs, stopped escalators, and ramps of over 4 percent slope: Exit stairs shall be a minimum clear width of 3 feet 8 inches. Exit ramps shall be a minimum clear width of 6 feet. Stopped escalators may be considered as emergency exits of two-lane capacity provided they are of nominal 4 feet width; of 1½ lane capacity provided they are of nominal 2 feet 8 inches width; and one-lane capacity if less than 2 feet 8 inches width. Per exit lane "up" direction: Capacity - 35 ppm Travel Speed - 50 fpm* Per exit lane "down" direction: Capacity - 40 ppm Travel Speed - 60 fpm* (*Indicates vertical component of travel speed) C. Doors and gates: Exit doors and gates shall be a minimum of 3 feet wide. Per exit lane: Capacity - 50 ppm D. Fare collection gates qualifying for use in exit paths shall be electrically deactivated to assume an acceptable exit mode in the event of a power failure or through a manual or remote control activation.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	1. Bi-parting gates when deactivated shall provide a clear unobstructed aisle, a minimum of 20 inches in width, mounted between consoles that do not exceed 3 feet 3 inches in height. Per gate: Capacity - 50 ppm 2. Turnstiles a minimum of 20 inches in width having a bar positioned to have maximum height of 3 feet which, when deactivated, will free wheel in the exit direction. Consoles shall not exceed 3 feet 3 inches in height. Per gate: Capacity - 25 ppm 3. Gates fitted with approved panic hardware and opening in the direction of exit travel, with minimum nominal width of 3 feet. Per gate: Capacity - 50 ppm per exit lane Fare gates not qualifying for use in exit paths shall be prominently marked "Not an Exit."			
2.2.5.3.6	From each platform there shall be a minimum of 2 exits not less than 100 feet apart. Platform exits shall be stairs, escalators stopped or moving in the			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	direction of egress to mezzanine level, emergency stairs, doorways, corridors, or walkways to a point of safety. Routes from platform ends into the underground trainway are not considered as exits for calculating exiting requirements.			
2.2.5.3.7	There shall be a minimum of 2 exits from each mezzanine not less than 40 feet apart.			
2.2.5.3.8	No point on the station platform(s) or mezzanine(s) shall be more than 300 feet from an exit.			
2.2.5.3.9	All exit measurements shall be to a point of access to the exit.			
2.2.5.3.10	Exits other than fare collection gates shall provide for at least 50 percent of the exit capacity in any fare barrier.			
2.2.5.3.12	Means of ingress shall be provided from each trainway to the platform, as follows: A. Two 2 feet 10 inch wide stairways, or other arrangement having equivalent capacity, shall be provided at each end of platform, arranged to provide full capacity exiting from either trackway.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	B. Gates at the top of each stairway shall swing in direction of access to platform and provide clear opening width of not less than 3 feet.			
	C. Gates, stairs, and landings shall conform to NFPA 101 and applicable building codes.			
2.2.5.3.13	Vertical circulation elements shall be comprised of stairs or stair/escalator combinations. Escalators shall not account for more than half the units of exit at any one level in the public area.			
2.2.5.4	Means of egress shall be arranged in accordance with applicable codes and regulations, except that for the purpose of the criteria, exits from station ancillary occupancy areas into station public occupancy areas shall be considered as discharging into a protected passageway leading directly to a point of safety.			
2.2.5.5.1	Station structures shall be provided with an emergency lighting system in accordance with UBC except as noted in 2.2.			
2.2.5.5.2	Emergency lighting system is installed and maintained per NFPA Article 700, "Emergency Systems" to provide an illuminance level of 1 footcandle.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
2.2.5.5.3	Exits shall be marked with readily visible signs complying with the requirements of UBC. Where emergency lighting is required, exit signs shall be illuminated from the emergency lighting source.			
2.2.5.5.4	Exit lights and essential signs shall be included in the emergency lighting system and be powered by an uninterruptable power supply. Emergency fixtures, exit lights, and signs shall be separately wired from the emergency distribution panels.			
2.2.5.5.5	Emergency lighting for stairs and escalators shall be designed to emphasize illumination on the top and bottom steps or landings. A minimum of one footcandle of emergency lighting shall be provided throughout the entire run of each stair and escalator (per UBC, Section 3312(a)).			
2.2.6.1.1	Fire alarm control system shall be installed in each station facility, conforming to NFPA 72A and 72D and CAC Title 19: A. Fire alarm devices shall be protected by a proprietary system Style D and Style 2 per NFPA 72D, Tables 3-9.1 & 3-10.1.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	B. The station facility fire alarm system shall be electrically supervised and operated on low voltage with battery standby power.			
	C. The public address system shall be utilized for sounding required building-audible fire alarm signals from the fire alarm control panel by means of a tone generator preceeding verbal announcements to direct patron evacuation. Audibility level shall be a minimum of 10 dB over any background noise.			
	D. All detector and extinguishing system fire alarm, smoke detection, valve switches, and water flow indicator signals throughout the system shall, when activated, be transmitted simultaneously within the local station and to a central supervising station per NFPA 72D.			
	E. The fire alarm control system shall provide means to trip special extinguishing systems and to control ventilation systems in accordance with applicable codes.			
2.2.6.1.2	The EMP shall include an annunciator panel which indicates by audible and visual alarm the activation and location of any fire signal generated at the station facility. It shall also indicate fire system supervisory signals and			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	a fire alarm control panel trouble signal.			
	A minimum of one EMP shall be located in the public area on the mezzanine adjacent to the fare array in the patron assist area in the pathway of the entrance to which the fire department will respond.			
2.2.6.1.3	Automatic fire detection devices shall be installed throughout all station ancillary areas where automatic sprinkler protection is not required, including return air and after the filters in air conditioning and ventilation systems serving more than one area.			
2.2.6.1.4	Manual fire alarm capability shall be provided by an emergency phone system.			
	A. Emergency phones shall be located adjacent to each fire hose cabinet throughout the station.			
	B. The emergency phones shall be a dedicated system that alarms at CC. The emergency phone system shall annunciate at CC and indicate station of origin.			
2.2.6.1.5	A supervised public address system shall be provided to facilitate patron evacuation in the event of an emergency.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2 CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	A. The public address system shall be operable from the EMP and from CC			
	B. The public address system shall conform to NFPA 72A and 72D. Supervision of the public address address system shall be through the station fire alarm control panel.			
2.2.6.1.6	Seismic alarm devices and controls shall be provided to detect a seismic event such that it will permit safe stopping of trains entering any zone of the system where a seismic event has occurred. Detection of a seismic event shall be annunciated in CC.			
2.2.6.1.7	Gas detection devices shall be provided to detect the presence of methane or other gases entering into the system. Presence of such gases shall be annunciated in CC.			
2.2.6.2.1	Automatic sprinkler protection in accordance with NFPA 13, UBC Chapter 38, and LA Plumbing Code shall be provided in all station ancillary areas, except as provided in 2.2.6.2.2. Any other exception shall be approved by the F/LS Committee.			
2.2.6.2.2	Train control and communication rooms shall be protected with an automatic Halon 1301 extinguishing system meeting NFPA 12A and LAFD Requirement 33, activated manually and through the			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2 CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	fire alarm control panel by a cross-zoned detection system.			
2.2.6.3	Standpipe and Hose Systems			
2.2.6.3.1	Class III standpipe system coverage shall be provided throughout the station per NFPA 14 and UBC Chapter 38. Fire hose outlets shall be located so that any point may be reached including in and around transit vehicles which may be stopped at the station, with 100 feet of hose and 30 feet of water stream.			
2.2.6.3.2	Manual and remote actuation of under-vehicle water spray extinguishing systems shall be provided at stations, supplied from platform standpipe systems. Separately controlled systems, shall be provided on each track for lengths along the platform corresponding to each vehicle pair, considering variations in stopping position. Provisions for removing third rail power shall be provided so that power is automatically removed from that section of track, prior to actuating the under-vehicle extinguishing system.			
2.2.6.4	Fire Extinguishers			
2.2.6.4.1	Portable fire extinguishers complying with NFPA 10, CAC Title 19, and LA Fire Code shall be placed at each fire hose location and at other locations as			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: FIRE/LIFE SAFETY - STATIONS

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS - VOL. 1, SECTION 2.2

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	required by hazard type and space utilization. Multipurpose dry chemical extinguishers having a capacity of 10 pounds and rated 4A-30B:C shall be used, supplemented by 10 pound, 10B:C CO_2 extinguishers in rooms used for electrical equipment; except that 10 pound 2A-20B:C Halon 1211 extinguishers shall be provided in train control and communication rooms.			
2.2.6.4.2	Maximum travel distance to nearest extinguisher shall not exceed 150 feet in public areas.			
2.2.6.5	<u>Emergency Access to Stations</u>			
2.2.6.5.1	Access to station entrances and emergency egress locations shall be from public streets, or an access road of 20 foot minimum paved width, with widened 28-foot turnouts wherever emergency vehicles may stop.			
2.2.6.5.2	An access road to a station shall be continous from a public street to a public street, or a 66-foot outside radius turnaround shall be provided.			
2.2.6.5.3	Fire Department inlet connections for automatic sprinkler and standpipe systems shall be located within 25 feet of vehicular access. Hydrant spacing and locations shall be determined by the FLSC.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SECURITY - FARE COLLECTION

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
4.6.1.A	Fare collection equipment shall be under CCTV surveillance and monitored from the Rail Control Center.			
4.6.1.B	Fare collection equipment shall be vandal resistant and equipped with tamper and intrusion detection alarms.			
4.6.1.C	Fare gates/turnstiles and array barriers shall cause minimum interference with patron movement, meet Fire/Fife Safety requirements, and discourage attempted fare evasion.			
4.6.2.A	Access to the central fare sorting/counting area shall be tightly controlled and secured from other accessible parts of the facility in which it is housed.			
4.6.2.B	Revenue pick-up and transportation shall be by the most protected, rapid, and efficient means possible.			
4.6.2.C	To the extent possible, all processing and handling of cash, tickets, or items having cash value shall be automated.			
4.6.2.D	The revenue collection and processing system shall be as compatible as possible with the existing SCRTD equipment and procedures.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3	STATION AND SITE			
3.3.1	Station and Site Layout			
3.3.1.A	Site access points shall be located to preclude traffic congestion. Traffic patterns for vehicles and pedestrians shall be clearly marked.			
3.3.1.B	Vehicle patterns that cross or result in counter-flow shall be minimized.			
3.3.1.C	Patron drop-off zones and taxi stands shall be located to minimize patron exposure to traffic. Patrons shall be able to move directly to the station entrance without crossing traffic lanes.			
3.3.1.D	If public parking is provided, spaces shall be set aside for the handicapped at the closest point to the station entrance to minimize their exposure to traffic.			
3.3.1.E	Bus loading and unloading zones shall be located so that patrons do not have to cross traffic lanes.			
3.3.1.F	Clearly defined and well-marked crosswalks and sidewalks shall be provided with slip-resistant surfaces.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.2	Station Architectural Features			
3.3.2.A	Signing			
3.3.2.A.1	Clear, legible, and well-illuminated signing and graphics shall be provided in stations. The signing and graphics shall be located in a manner which enhances the safety and convenience of patrons.			
3.3.2.A.2	Right-hand traffic shall be maintained where possible through signing.			
3.3.2.B	Architectural Psychology Any design features or vistas which may distract patrons at the head or foot of stairs and escalators shall be avoided.			
3.3.2.C	Platform			
3.3.2.C.1	A platform safety strip shall be provided as follows:			
3.3.2.C.1.a	The width of the safety strip shall be 18 inches, which includes the tactile strip and edge material.			
3.3.2.C.1.b	The platform edge material shall be slip-resistant and different in color and texture to distinguish it from the main platform area.			

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ____________ DATE: ____________

REVIEWER: ____________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ____________

REVIEW LEVEL: ____________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.2.C.1.c	A narrow tactile strip two inches or less in width shall contrast with the platform edge and the main platform area. It shall be designed to improve the probability of the safety strip being sensed by the blind.			
3.3.2.C.2	The underplatform design shall incorporate an area where one can crouch and not be struck by the collector shoe or other parts of the train. The contact rail shall be located on the opposite side of the tracks from the underplatform refuge.			
3.3.2.C.3	The platform design shall be coordinated with the track layout and the vehicle static and dynamic outline to provide an acceptable interface between the platform and vehicle. This interface is to minimize horizontal and vertical gaps at the vehicle door threshold. The dimensions shall be a nominal three inches for horizontal gap between platform and vehicle static outline; and a nominal 0.75 inches for the vertical gap downward from the vehicle doorsill to the platform finished floor. Alignment of the vehicle platform interface shall reduce the potential for catching and trapping the wheels of a wheelchair.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.2.C.4	Sufficient clear space shall be provided around overhead and side projections and corners to reduce the potential for bumping and walking into these protuberances.			
3.3.2.D	Station Walking Surfaces			
	All walking surfaces within the station shall have slip-resistant surfaces.			
3.3.2.E	Walkway Screening			
	When passarelles or pedestrian walkways are provided over the trackway, the walkways shall be screened.			
3.3.2.F	Top of Parapet			
	The top of the parapet shall be sloped away from the vertical circulation elements and visual openings to prevent objects from being placed upon them.			
3.3.2.G	Railings/Guardrails			
3.3.2.G.1	Railings and guardrails shall comply with the requirements of NFPA-101 and the applicable local codes.			
3.3.2.G.2	Glazed railings shall not be installed.			
3.3.3	<u>Elevators/Escalators</u>			
3.3.3.A	Elevators			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.3.A.1	Elevators shall meet the safety requirements in the elevator/escalator codes, ANSI A17.1, the handicapped requirements in ANSI A117.1, and Title 24 of the California Administrative Code.			
3.3.3.A.2	Two-way communication from within the elevator cab shall be provided between the patron and Rail Control Center (RCC).			
3.3.3.A.3	Elevators shall be sized to accommodate a horizontally positioned stretcher of the type carried in emergency vehicles.			
3.3.3.A.4	Remote elevator indicators and controls shall be provided at RCC for emergency operation.			
3.3.3.B	Escalators			
3.3.3.B.1	Escalators shall meet the safety requirements in the elevator/escalator code, ANSI A17.1.			
3.3.3.B.2	Signing and graphics shall be provided to enable patrons to determine the direction of escalator motion prior to their arrival at, and well clear of, the landing plate.			
3.3.3.B.3	Status indicators shall be provided.			

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.3.B.4	Adequate queuing space shall be provided at both the top and bottom of escalators.			
3.3.3.B.6	An emergency stop capability shall be provided at the top and bottom of escalators and shall meet the requirements of Cal/OSHA.			
3.3.3.B.7	The clearance between the combplate and the steps and the balustrade and the steps shall be such that no shoes, clothing, or other similar articles may be trapped between these elements.			
3.3.3.B.8	Sufficient clearance shall be provided between the structure and escalator moving handrails to prevent hands or clothing from being trapped.			
3.3.3.B.9	Safety devices shall include brakes that assure that the escalator will not move when power is removed and patrons are using the stopped escalator as a stairway.			
3.3.4	Stairs			
3.3.4.A	There shall be a minimum of one stair connecting all levels in the public area that meets Fire/Life Safety requirements.			
3.3.4.B	The tread-riser relationship shall meet the requirements of NFPA-101.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

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DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.4.C	The stairs shall be of a slip-resistant material with an eased nosing that is distinct and meets the requirements of ANSI A117.1, and Title 24 of the California Administrative Code.			
3.3.4.D	When gutters/runnels are provided, they shall be protected by the handrails.			
3.3.4.E	Handrails shall be continuous and meet the requirements of ANSI A117.1, and Title 24 of the California Administrative Code.			
3.3.5	<u>Fare Collection</u>			
3.3.5.A	Remote operation from the RCC shall be provided to permit control of inbound patrons passing through the fare collection array.			
3.3.5.B	In the event of a power loss, the fare collection array shall permit free exiting.			
3.3.5.C	Remote controls shall be provided to permit free exiting.			
3.3.5.D	Provisions shall be incorporated to permit access by the handicapped using wheelchairs.			
3.3.5.E	Sufficient exit gates shall be provided to allow rapid and complete discharge of station occupant loads.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ____________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - STATION AND SITE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.3, STATION AND SITE, 07/86 Revision 2

CONTRACT No.: ____________

REVIEW LEVEL: ____________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.3.6	Vehicle Approach System			
	A visual and audible method shall be provided to alert patrons of the impending arrival of a train.			
3.3.7	Other Design Features for Station and Site			
3.3.7.A	Patron flow patterns shall maintain a right-hand circulation where possible and shall be as simple as practicable.			
3.3.7.B	Maps shall be provided and located in the Emergency Management Panel (EMP) which show locations of shutoff controls for water, gas, electricity and fuel lines.			
3.3.7.C	Guards and restraining rails, and similar items, shall be installed in specific areas where trains pose a clear danger to patrons, personnel or equipment.			
3.3.7.D	Adequate lighting of stairs and escalators shall be provided.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SECURITY - STATION AND SITE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4

CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
4.3.1.A	Station and site landscape plantings and design features shall be coordinated with traffic movements and lines of sight so as not to interfere or obstruct with electronic or visual surveillance or result in potential hiding places for vandals/intruders.			
4.3.1.B	Station sites and parking lots shall be illuminated during hours of darkness and reduced visibility, in accordance with IES standards and APTA security guidelines.			
4.3.1.C.1	Parking lots shall be fenced and open-spaced to provide a high degree of visibility by an attendant when present.			
4.3.1.C.2	Controlled access shall be provided whenever possible.			
4.3.1.D	Traffic patterns and site layouts shall be structured to permit rapid and easy access to all portions of the site and station by security personnel, whether on foot or by vehicle.			
4.3.2.A.1	All levels of the station, including the platform and mezzanine, shall be as open as possible.			
4.3.2.A.2	Columns and other obstructions to visual and electronic surveillance shall be minimized.			

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SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

GROUP: ____________ DATE: ____________

REVIEWER: ____________

DISCIPLINE: SECURITY - STATION AND SITE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4

CONTRACT No.: ____________

REVIEW LEVEL: ____________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
4.3.2.B.1	Illumination of station elements shall be guided by applicable IES standards and APTA design guidelines.			
4.3.2.B.2	Emergency power and lighting requirements shall be developed as part of the overall security and safety requirements (See Table I-4-1 of Criteria).			
4.3.2.C	Construction and finish materials shall be graffiti- and vandal-resistant, easily cleaned, and meet the appropriate Fire/Life Safety requirements for flammability, smoke emission, and toxicity.			
4.3.2.D	CCTV cameras shall be used to cover selected sectors of the station and platform, and shall be monitored at Central Control.			
4.3.2.E	Station entrances shall be well lighted and designed to have high visibility by patrons and the public.			
4.3.2.F	No concessions other than newspaper vending machines and a public telephone will be considered for installation in transit stations.			
4.3.3.A	A single occupancy unisex restroom shall be provided. Restrooms shall be easily visible within the station mezzanine.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: SECURITY - STATION AND SITE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4

CONTRACT No.: ______

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
4.3.3.B	Conduit for electronic access control of restrooms shall be provided.			
4.3.4.A	Station entrances shall be secured and alarmed during nonrevenue hours.			
4.3.4.B	Non-public areas shall be secured to preclude unauthorized entry.			
4.3.4.B.2	Where public access is required through ancillary spaces for emergency purposes, access into that area shall be annunciated.			
4.3.4.B.3	Any unauthorized areas along an emergency egress route through ancillary space shall be secured against inadvertent entry.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______________________ DATE: ______________

REVIEWER: ______________________

DISCIPLINE: SYSTEM SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.5, PASSENGER VEHICLE, 07/86 Revision 2

CONTRACT No.: A650

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5	PASSENGER VEHICLE			
3.5.1	Doors			
3.5.1.A	Door Interlocks			
3.5.1.A.1	Summary logic shall prevent side doors from opening until the train is properly berthed and stopped at the platform, with friction braking applied and prevent the train from starting until all side doors are closed and locked.			
3.5.1.A.2	The train operator door controls shall be on the same side as the doors being operated.			
3.5.1.A.3	Door edges shall be designed with appropriate stiffness to prevent fingers from being inserted between fully closed leaves, yet to permit the withdrawal of trapped clothing or articles.			
3.5.1.A.4	A circuit shall be provided to remove door closing force when an obstruction is met.			
3.5.1.A.5	The design shall prevent doors on the side opposite the platform from being opened unintentionally.			
3.5.1.A.6	A positive door control device shall be provided to prevent side doors from unintentionally sliding open.			

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

CERTIFIABLE ELEMENT:

GROUP: ______ DATE: ______

REVIEWER: ______

DISCIPLINE: SYSTEM SAFETY - PASSENGER VEHICLE

REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.5, PASSENGER VEHICLE, 07/86 Revision 2

CONTRACT No.: A650

REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.1.B	Door Warning Signal			
	Patrons shall be alerted when doors are ready to close.			
	An audible warning shall sound inside the vehicle before the doors begin to close.			
	A combination of audible and visual warnings to alert hearing-impaired patrons shall be utilized if practical.			
3.5.1.C	Manual Releases			
3.5.1.C.1	Interior manual door controls shall be provided for use by the patrons.			
3.5.1.C.2	Exterior manual door controls shall be provided on the center set of vehicle doors for use by emergency teams with the correct tools/equipment.			
3.5.1.C.3	Interior emergency releases shall be provided for all side doors and be adequately labeled.			
3.5.1.C.4	Exterior side door status lights shall be provided to indicate door is open or unlocked.			
3.5.1.C.5	Intercar doors capable of being locked shall have the capability of being unlocked and opened from the outside.			

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REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.1.D	Door Width Side door openings shall be wide enough to permit use by patrons in wheelchairs.			
3.5.1.E	End Doors			
3.5.1.E.1	Signs shall be placed on end doors to discourage patrons from moving between vehicles except in an emergency.			
3.5.1.E.2	End doors shall be wide enough to permit emergency egress of a handicapped person with assistance from others.			
3.5.1.E.3	End doors on the control cab end of the vehicle shall have suitable and safe exterior step and handholds for egress to ground level.			
3.5.2	<u>Inter-Car Closure</u> Restraining devices shall be provided between adjoining cars of the train to help prevent patrons passing between cars from falling. The space between cars shall be kept to a minimum.			
3.5.3	<u>Lighting</u>			
3.5.3.A	Interior lighting levels shall be consistent with "APTA Transit Security Guidelines Manual" of 30 or more footcandles on the reading plane.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.3.B.	Emergency lighting shall be provided and powered by a backup system. The minimum level and duration of the lighting shall be one footcandle for one hour.			
3.5.4	<u>Communications</u>			
3.5.4.A	Each vehicle shall be provided with a patron intercom (IC) system to permit communication between a patron and the train operator. The IC shall be suitably protected from vandalism.			
3.5.4.B	Communications capability between RCC and the train operator and from RCC to on-board patrons shall be provided.			
3.5.4.C	All vehicles shall be numbered uniquely to provide for positive identification.			
3.5.4.D	Operating instructions and vehicle number shall be applied to the sidewall immediately below each remote IC station on each vehicle.			
3.5.4.E	Emergency communication capabilities for the vehicle shall be provided with a backup power system.			
3.5.4.F	The vehicle intercom operating controls, positions, and locations shall be readily			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	accessible to, and operable by, elderly and handicapped patrons.			
3.5.5	Windows			
3.5.5.A	The cab windows and F-end door windows shall be Group I glass; be certified to comply with the requirements of ANSI Z26.1, Table 1, Item 1; and pass the following test requirements:			
3.5.5.A.1	Glass shall pass ANSI Z26.1 Test 8, Impact, using shot bag dropped from a height of 15 feet.			
3.5.5.A.2	Glass shall pass ANSI Z26.1 Test 26, Penetration Resistance, modified to include entire windshield assembly, simulating the impact of a one-pound ball at 80 mi/hr and the impact of a five-pound ball at 50 mi/hr.			
3.5.5.B	Side windows and R-end windows shall be Group II glass; be certified to comply with the requirements of ANSI Z26.1, Table 1, Item 3; and shall have:			
	Maximum luminous light transmittance of 37 to 55 percent,			
	Maximum solar heat transmittance of 27 percent,			
	Minimum average sound transmission loss of 30 dBA in octave band with 1,000 Hz center frequency.			

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REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.5, PASSENGER VEHICLE, 07/86 Revision 2

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REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.5.C	R-end door and cab windows shall be Group III and be certified to comply with the requirements of ANSI Z26.1, Table 1, Item 1.			
3.5.6	Interior Design Features			
	Seating and standing arrangement shall enable patrons to move easily and safely within a moving or stopped vehicle.			
	Provisions shall be made for priority seating for the elderly and physically disabled, and for locating a wheelchair.			
3.5.6.B	Sharp edges and protrusions shall be avoided.			
3.5.7	Cab Control/Indications			
3.5.7.A	The following conditions and system failures shall be detected and displayed:			
3.5.7.A.1	Overspeed (annunciated as well)			
3.5.7.A.2	Propulsion failures			
3.5.7.A.3	Door(s) open			
3.5.7.A.4	Activation of cut outs and bypasses			
3.5.7.A.5	Electric and friction braking failures			
3.5.7.A.6	Train berthed.			

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REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.7.B	Cut outs and bypasses shall be provided for dynamic functions that, upon failure or malfunction, interrupt normal train operations.			
3.5.7.C	An external light shall indicate when the vehicle is operated with ATP cut out.			
3.5.8	Power/Propulsion			
	Normal or abnormal/emergency conditions or operations shall not result in unsafe conditions.			
3.5.8.A	The manual controller shall have a "deadman" or equivalent capability in the manual mode.			
3.5.8.B	The mode selection switch and the manual controller shall be interlocked to assure that the manual controller's capability is locked out from the mode selection switch in the "Automatic" or "Off" position.			
3.5.8.C	A current collector/contact rail isolation device, suitable for on-board vehicle storage, shall be provided.			
3.5.9	Braking			
3.5.9.A	Emergency brake control shall be failsafe to the extent that no single failure or series of common mode or common cause failures can result in less than			

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REVIEW REFERENCE: SCRTD Metro Rail System Design Criteria & Standards, Vol. I, Section 3.5, PASSENGER VEHICLE, 07/86 Revision 2

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REVIEW LEVEL: ______

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	75 percent of emergency braking effort per dependent pair being available.			
3.5.9.B	When the safety-critical emergency stop circuit is activated, the P-signal and BRK signal circuits and the traction power line breaker shall be opened.			
	The emergency stop circuit shall ensure an irretrievable stop after an emergency application is initiated and ensure that the train is brought to zero speed before it can proceed in any mode of operation.			
3.5.9.C	There shall be redundant methods of automatically/manually applying emergency braking.			
3.5.9.D	Trip stops shall be used to provide safe stopping.			
3.5.10	<u>Auxiliary/Electrical</u>			
	Failures or malfunctions shall not result in unsafe operations or conditions.			
3.5.10.A	Approved protection shall be provided against short circuits and overloads.			
3.5.10.C	High voltage power shall be physically separated from communications circuitry and low voltage control circuitry.			

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REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.11	Other Design Features			
3.5.11.A	Anticlimbers shall be located at each end of the vehicle.			
3.5.11.B	Patron emergency instructions shall be placed in each vehicle.			
3.5.11.C	Emergency equipment to aid in evacuating the vehicle shall be located within the vehicle.			
3.5.11.D	Fire extinguishers shall be provided.			
3.5.11.E	Exterior lighting shall include vehicle headlights and taillights.			
3.5.11.F	The capability for remote uncoupling from within the vehicle shall be provided.			
3.5.11.G	A safe method of externally uncoupling vehicles shall be provided.			
3.5.11.H	Locations of fire extinguishers, patron intercoms, and door releases shall be clearly marked.			
3.5.11.I	Vehicle electrical, electromechanical, hydraulic and mechanical system designs shall use approved redundancy, fail-safe, or fail-operational principles.			
3.5.11.J	Restraining devices shall be provided to secure the truck to the carbody.			

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REVIEW LEVEL:

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
3.5.11.K	Provisions shall be made to electrically and pneumatically isolate a vehicle that has an operational malfunction, such as stuck brakes or inoperable traction devices, from the remainder of the vehicles within the consist.			

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METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

GROUP: ____________________ DATE: __________

REVIEWER: ____________________

DISCIPLINE: SECURITY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4

CONTRACT No.: __________

REVIEW LEVEL: __________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
4.5.1.A	Passenger vehicle materials shall be selected on the basis of their resistance to graffiti and vandalism, their ability to be cleaned, and their ability to meet fire, smoke emission, and toxicity standards.			
4.5.1.B	Passenger vehicle seat cushions shall be of vandal-resistant material without compromising comfort. Those sections of the seat where comfort is a primary consideration shall be of modular design and easily replaceable with the proper tools.			
4.5.2.A	Passenger vehicle glazing shall be made of clear, impact resistant, hard-surfaced material which is further defined in Vol. I, Section 3.5.5, Safety Criteria.			
4.5.2.B	Between-vehicle visibility shall be provided by windows at each end of the vehicle.			
4.5.3	A means of reliable communication that permits direct communication between the passengers and the train operator shall be installed in each passenger vehicle. The device shall be vandal resistant.			
4.5.3.B	A communication capability between the Rail Control Center and the train operator and between the Rail Control			

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METRO RAIL PROJECT DESIGN REVIEW CHECKLIST

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REVIEWER: ______________________

DISCIPLINE: SECURITY - PASSENGER VEHICLE

REVIEW REFERENCE: METRO RAIL PROJECT SYSTEM DESIGN CRITERIA AND STANDARDS, VOL. 1, SECTION 4 CONTRACT No.: ______________

REVIEW LEVEL: ______________

REQ. I.D.	REQUIREMENT	YES	NO	COMMENT
	Center and the onboard patrons shall be provided.			
4.5.3.C	Exterior distress signals that identify the origin of an alarm shall be incorporated in the design.			
4.5.3.D	Vehicles shall be uniquely numbered to provide for positive identification.			