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U. S. Department of Transportation
Federal Transit Administration

FIRE SAFETY COUNTERMEASURES FOR URBAN RAIL VEHICLES

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe
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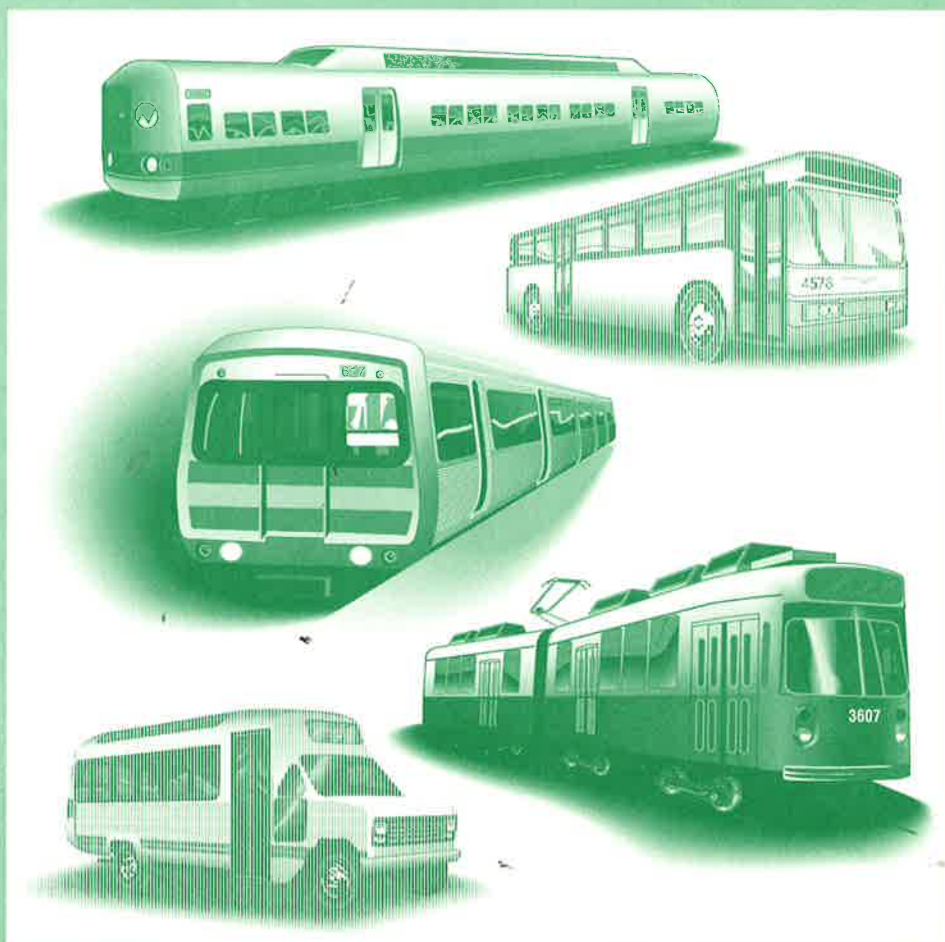
Cambridge MA 02142

July 1992
Final Report



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13. ABSTRACT (Maximum 200 words)

The Volpe National Transportation Systems Center (VNTSC) has analyzed transit system fire statistics to learn how often fire and smoke incidents occur on rail transit systems. While the threat of fire accounts for only a small percent of all rail transit incidents, the potential exists for loss of life and significant damage to property. This report identifies those countermeasures necessary to prevent and reduce the severity of transit fires.

To identify the necessary countermeasures, the system safety approach was used. This method used (1) fault trees that graphically represented in a sequence of events how a fire develops, (2) an expert in transit safety who examined each sequence of events, and (3) another expert who examined the countermeasures for reducing and preventing transit fires.

The system safety approach allowed the VNTSC to examine the relationships between the various physical components and operating procedures of the entire transit system. In addition, potential problems relating to the construction and operating stages of the transit system could be identified.

This report identifies five major areas of countermeasures: vehicle/equipment, procedures, human factors/training, environment, and information management/data analysis.

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PREFACE

While the safety record of mass transit has been very good and few major fires have occurred, it cannot be assumed that the many minor fires that do occur will not develop into life-threatening events. The Federal Transit Administration (FTA) has recognized the need for transit systems to address the issue of fire protection. This document presents fire safety countermeasures that may be implemented to prevent ignition, or slow down and contain the fire once ignition occurs.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in.) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

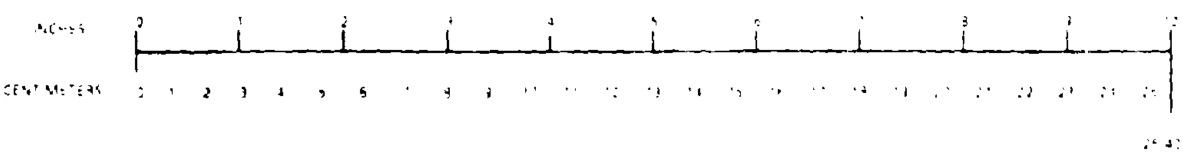
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

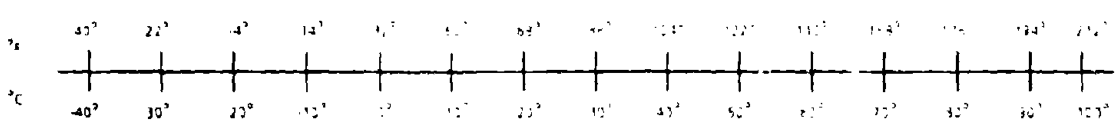
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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1. INTRODUCTION

1.1 BACKGROUND

The Federal Transit Administration is sponsoring an ongoing research program to address the issue of fire safety in urban transit systems. This program consists of a series of work tasks directed at the identification and mitigation of the potential fire hazards affecting transit passengers and personnel.

Figure 1 presents an overview of the program addressing the fire threat associated with transit vehicles. The six basic tasks of this program are:

1. Assessment of the current state of transportation fire safety;

2. Identification of the fire threat in transit vehicles;

3. Identification of countermeasures which are defined as "any actions or set of actions that may be taken to minimize the fire threat";

4. Evaluation of the countermeasures;

5. Development of R&D programs to support countermeasure evaluation and implementation; and

6. Implementation of selected countermeasures.

Tasks 1) and 2) have been completed; findings are reported in references 1 and 2, respectively. In task 2, the system safety concept was employed to assist in the identification of fire and smoke hazards. Two analysis techniques were employed in this identification effort: 1) data analysis, and 2) fault tree analysis. The data analysis covered statistics and case study or scenario data to identify the major hazards. The fault tree analysis provided a better understanding of fire propagation and human involvement with the fire events. This effort forms a foundation for the work presented in this report.

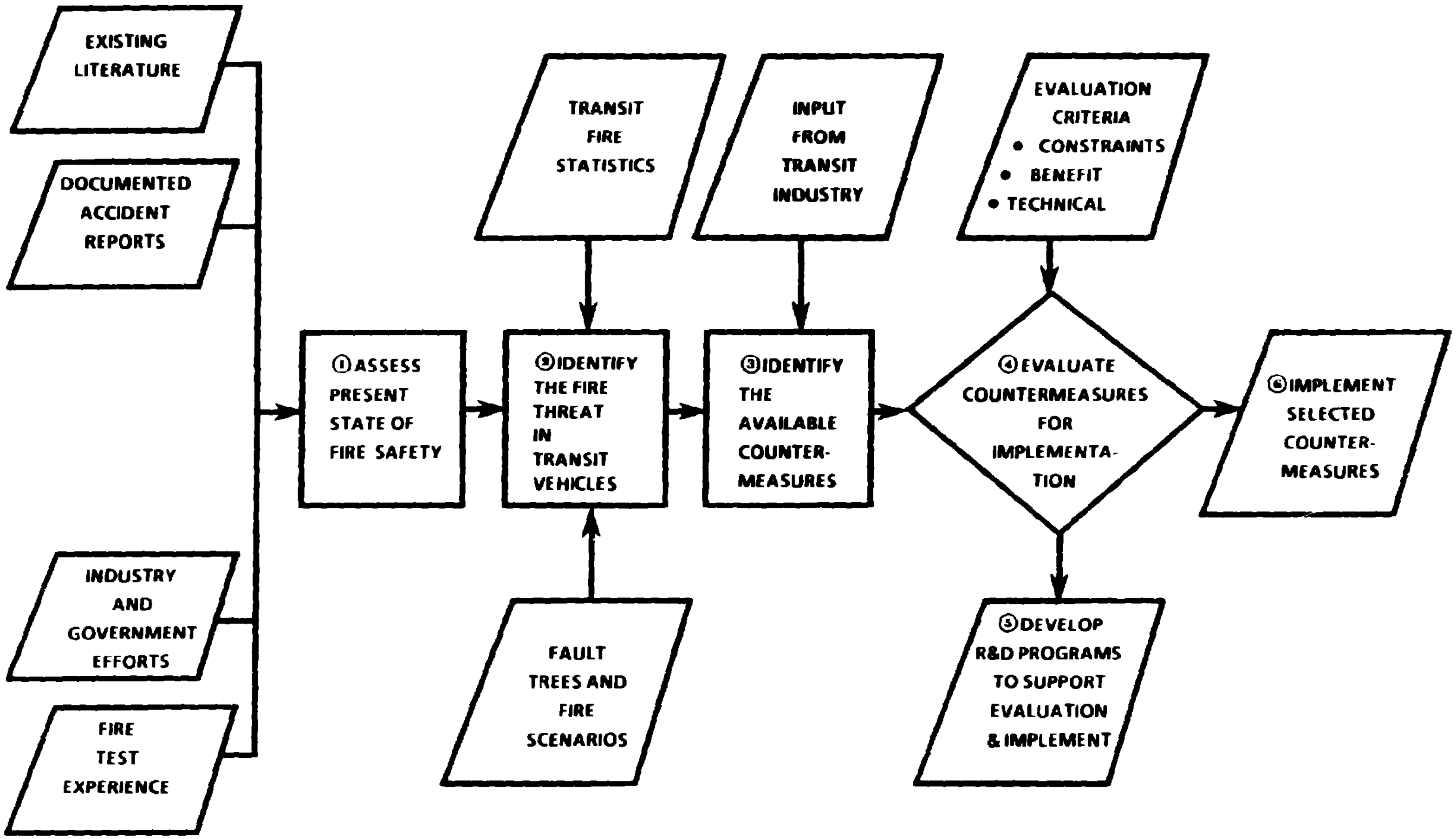

FIGURE 1. FIRE SAFETY IN TRANSIT SYSTEMS-PROGRAM OVERVIEW

This report presents the results of task 3, the identification of countermeasures for rail transit systems. Tasks 4-6 will be addressed in future reports.

An analysis of transit system fire statistics performed by the Volpe National Transportation Systems Center (VNTSC) indicated that the rate of occurrence of fire and smoke incidents is a small fraction (1-5 percent) of all incidents.[2] Data on vehicle fire and smoke incidents presented in the "Safety Management Information Statistics (SAMIS) 1990 Annual Report"[3] reveals 854 rail vehicle fires occurred and resulted in 2 deaths and 231 injuries. While the majority of these do not develop into serious incidents, many minor incidents have the potential to escalate into situations where loss of life and significant damage to property may occur.

The judicious application of the countermeasures described in this report may, in some instances, prevent the occurrence of the initial fire incident entirely. In addition, these countermeasures should serve to reduce the likelihood of minor fire incidents developing into major conflagrations. Finally, certain countermeasures could increase the effectiveness of emergency evacuation by delaying the onset of non-survivable conditions in burning vehicles, and by ensuring that evacuation-related equipment is in operating order.

1.2 OBJECTIVE

The objective of this report is to identify fire safety countermeasures that may be implemented to prevent ignition, slow down or contain the fire once ignition occurs, and facilitate passenger evacuation in existing and new rail transit vehicles. These countermeasures represent a series of changes in the design and operation of transit vehicles to minimize the fire threat to occupants, vehicles, and equipment to the fullest extent possible.

1.3 SCOPE

This report addresses countermeasures that can be implemented on vehicle/equipment, procedures, human factors/training, and information management/data analysis. The countermeasures would promote:

- fire prevention
- early detection

- fire hardening, suppression and containment
- effective passenger evacuation

The redesign of fundamental vehicle components such as motors, switches, and brakes is not considered in this report, but rather the focus is on component replacement, construction materials, maintenance procedures and schedules, etc. Similarly, the focus of countermeasures related to fire prevention/suppression and evacuation is on the installation of appropriate equipment and its appropriate use.

Both preventive and reactive phases of transit safety are covered, focusing on countermeasures that can be implemented on the rail cars by the rail transit authorities. (Reactive phase-type countermeasures are also addressed in FTA's "Recommended Emergency Preparedness Guidelines for Rail Transit Systems"[4] which covers other elements of the rail transit system such as passenger station, trainway and central control, as well as coordination of municipal emergency crews such as fire department personnel.)

1.4 APPROACH

The system safety concept was utilized to develop the countermeasures presented in this report. This concept involves a "planned, disciplined, systematically organized, before-the-fact process" of identifying, analyzing, and controlling hazards. This is in contrast to the after-the-fact investigations of accidents or problems to determine possible modifications in procedures or equipment.

There are two major advantages to using the system safety approach. First, this systematic approach encourages the examination of the interrelationships between all elements of the system. For example, equipment and facility elements are considered in conjunction with the operational/maintenance procedures as they exist within the transit system as a whole. This is essential because the failure of a particular component or procedure can cause an initial fire or allow a minor fire to escalate into a major fire emergency.

Second, potential problems are identified prior to the construction and operation stages of the transit system. Thus, necessary modifications to control hazards may be designed into the system prior to losses. Furthermore, these modifications can usually be implemented in a more cost-effective manner by their initial integration into the system, rather than being incorporated as a later addition.

This system safety approach was implemented in three steps and designed to ensure that most of the important countermeasures are identified. First, the fault trees presented in reference 5 were drawn upon to describe in a systematic manner, the development of fire threats including human elements, and material and environmental factors. Second, each event or sequence of events was examined by an expert in transit safety to identify appropriate countermeasures with the potential for minimizing or eliminating a fire threat. Third, each countermeasure was discussed and reviewed by another expert to ascertain its appropriateness.

Because of the reliance on fault trees as a starting point in this report, a brief review follows of the fault tree analysis methodology and the source of the fault trees used.

A fault tree is a graphic representation of the relationships between certain specific events and an ultimate undesired event (which in this analysis is a transit fire and related casualty). Its key virtue is to illustrate the logical progression of events from a low order cause to the main undesired event. Thus, countermeasures or intervention and remedial actions can be identified at each step in the fault tree.

The fault trees utilized were obtained from a previous FTA-sponsored VNTSC study, entitled "Identification of the Fire Threat in Urban Transit Vehicles."[2] The technical data used in the construction of the fault tree diagrams in that report were obtained from several sources. Statistical and historical data, although limited, provided an indication of the frequency of fire occurrence, location of ignition, and components of the transit vehicle involved. This information was obtained from published accident reports, transit system reports, newspaper clippings, transit system personnel and VNTSC staff. Because such information did not usually contain the detailed causal data necessary for fault tree analysis, it was essential to study the construction of the rail transit vehicles in order to determine potential as well as known fire hazards. Additional technical information was obtained from a review of vehicle construction specifications and maintenance manuals, and discussions with transit system staff and other technical people. This information was combined with the historical and statistical data and then used in developing fault tree diagrams for rail vehicle fire incidents.

Note that each transit authority uses vehicles built to its own specifications. As such, transit vehicles built at the same time by the same manufacturer may differ since each authority may specify the structure, equipment, materials and operational procedures for its particular transit cars.

To account for these differences in a current transit vehicle fleet, the fault tree diagrams were developed in as generalized and nonspecific a way as possible without sacrificing the accuracy needed to describe the ignition and propagation of the fire. Every effort has been made to identify all possible ignition sources on the transit vehicles. Correspondingly, the countermeasures identified in this program may be considered as general and nonspecific to particular transit systems. These countermeasures should be reviewed by each transit authority and tailored to its actual system.

Furthermore, for each type of activity in the rail transit system, the countermeasures identified in this report are classified depending on the phase of the fire threat cycle they are intended to intercept, namely:

1) *Fire Prevention*

2) *Fire Detection*

3) *Fire Suppression*

4) *Occupant Evacuation*

Note that intervention at any of these phases can interrupt the progression of the fire threat; and that intervention at all phases ensures maximum safety in view of the uncertainties in the level of success of a countermeasure at any specific phase. Such organization of the countermeasures (in this report) paves the way for their evaluation in future studies, and the implementation of the most cost-effective countermeasures.

A notable advantage of the methodology used in this study is that a high level of detail can be generated for use in understanding the relationship between events and causes leading to a particular undesired event and how they can be mitigated by the countermeasures. This high level of detailing ensures that no major countermeasure has been overlooked. Furthermore, it can be used as a starting point for carrying out tradeoffs between the various countermeasures in future studies.

1.5 OUTLINE OF REPORT

The countermeasures identified in this report are organized into five major areas or activities:

1) Vehicle/Equipment

2) Procedures

3) Training/Human Factors

4) External Factors/Environment

5) Information Management/Data Analysis

In each area, system characteristics are first described to provide a framework against which countermeasures are identified. Then, when the identified countermeasures are numerous, they are organized (for each area and its sub-headings) into categories describing the phase of the fire threat cycle they are intended to intercept. This further highlights the rationale for each countermeasure. On the other hand, when the number of countermeasures is small, they are lumped together without breakdown by category.

The four categories used (and presented as italicized headings throughout the report for highlight) are:

1) *Fire Prevention*

2) *Fire Detection*

3) *Fire Suppression*

4) *Occupant Evacuation.*

An additional category, R&D is used to cover countermeasures that should be studied in future research and development work.

2. VEHICLE/EQUIPMENT

This chapter discusses the major characteristics of vehicle/equipment pertaining to fire safety as well as the type of problems that might occur and potential countermeasures. The chapter is organized into three sections covering:

1. Undercar equipment (where major fire incidents have originated, historically)
2. Materials
3. Fire protection equipment

2.1 UNDERCAR EQUIPMENT

The undercar of a transit vehicle contains the major mechanical and electrical equipment required for transit vehicle operation, including traction motors, friction brakes, and current collectors. This section provides a detailed review of equipment considered vulnerable to ignition. Each item is described in terms of its design, operation, and function. Potential sources of fire are identified, and recommendations are made on ways to eliminate or minimize the possibility of ignition. When the elimination of these hazards is not possible, recommendations are provided on fire detection and suppression techniques. Finally, when applicable, the report suggests potential R&D for components and materials. In some instances, transit systems have investigated the suggested R&D.

The following paragraphs will cover:

1. Propulsion system
2. Low-voltage power
3. Brakes
4. Air conditioning system

2.1.1 Propulsion

The major propulsion systems of interest are:

1. Propulsion Controller
2. DC traction motor
3. Motor/braking resistors
4. Current collection
5. Train control

2.1.1.1 Propulsion Controller - The function of the propulsion controller is to control traction motor operation with regard to speed, direction, braking, etc.

In doing this, it connects the traction motors, usually, four per car, for acceleration and dynamic or regenerative braking. The propulsion controller adjusts the resistance in the traction motor circuits to control the operating mode and speed of the car, as directed by the reverser and by the position of the master controller in the cab or the train control system from signals transmitted along the wayside.

The current state-of-the-art propulsion control system is either a cam controller with its related contactors, relays, and plug-in cards; or a solid-state system, utilizing banks of capacitors, transistors, thyristors, heatsinks, and plug-in circuit cards.

The cam controller device itself can be either electromagnetically or electro-pneumatically operated. If the cam controller is electro-pneumatically operated, its vital circuit power devices, such as line switches, transfer switches, mode switches and reversers, are usually electro-pneumatically operated.

Some of the electromechanical controllers have their vital circuit power devices (such as the reversers) operate directly as a function of the cam controller itself.

A. Cam Controller

Any malfunction or improper operation of the cam controller itself may create a condition where arcing can occur, resulting in ignition. Some examples are listed on the next page.

1. Poor adjustment of the controller notching mechanism of the electromechanical cam controller or sluggish operation of control valves of the electro-pneumatic cam controller can cause the controller to notch out of sequence, so that a cam switch under load might not be making positive contact. If this occurs, an arc could be drawn across the contact tips, resulting in a flashover that could weld the tips and thereby create problems for other components in the propulsion system.

2. Defective, worn or broken parts of cams, cam switches, or notching devices can either position the controller improperly or jam the controller and draw an arc or weld the contact tips of a cam switch under load.

Malfunction or improper operation of the cam controller may not result in ignition within the confines of the propulsion controller compartment, but could result in ignition in other sections of the vehicle where propulsion equipment is located. Some examples are listed below.

1. A welded controller cam switch can prevent the controller from advancing, and cut out motor resistance. With the controller welded in the position corresponding to all the resistance in the circuit, the resistors will overheat and possibly cause ignition.

2. A welded controller cam switch, in addition to preventing the controller from advancing and cutting out resistance, also prevents the traction motors from accelerating, which may result in the traction motor (especially a self-ventilated one) overheating, and causing ignition.

3. Welding of the line switch contact tips due to the sluggish operation of this device, or to worn or misaligned contact tips, can set up a multitude of conditions for ignition, especially if a ground or short should appear in the propulsion system at the same time.

4. Controller malfunction could position the controller in a braking mode during acceleration, or in an acceleration mode during braking. This could create a regenerative condition where the traction motor and motor resistors could overheat and cause ignition.

B. Cam Controller Power Devices

Propulsion system power devices, such as series-parallel switches, or power-brake change-over switches of the electro-pneumatic cam controller system, have long been suspected of being the source of electrical arcing within the propulsion controller compartment. The power-brake change-over switch is the most likely source, since the high ground cable is usually connected directly to this switch. Any malfunction of this switch which results in arcing could create a flashover to this high ground and cause ignition.

By the same token, the high ground cam switch on electromagnetic cam controllers has experienced arcs caused by malfunction or poor adjustment of the controllers. Line breakers in electromagnetic or solid-state controller systems have also been known to bind. If this occurs, and the breakers are unable to contain the arc, tips could weld or a flashover develop and induce ignition.

C. Solid-State Controller

Breakdown of solid-state components may create a condition that results in ignition due to the establishment of a short circuit or ground condition. Insufficient cooling of the solid-state components and subsystems may create an overheat condition and bring about ignition.

Prevention

1. Inspect propulsion controllers and related contactors and relays periodically.
2. Ensure that all moving parts of the controller system are properly adjusted.
3. Periodically sequence the cam controller to be assured of proper operation.
4. For solid-state devices, inspect heatsinks and remove any dirt or obstructions from the area of the cooling fins.

5. For electro-pneumatic controllers, install velocity fuses to shut off the flow of air in a propulsion control compartment should an air line at the controller rupture during a fire in this compartment.

6. Install indicators on the cab console to identify the mode (acceleration or braking) that the propulsion controller is in.

7. Replace all parts and components that show indications of wear.

Detection

Reference 6 contains the results of a study to identify and evaluate potential undercar fire detection and suppression systems.

Suppression

Since propulsion controllers are usually mounted under the car in closed compartments where windage and direction of travel of the car have no effect on fire propagation, a fire suppression system can be installed in the controller compartment. The system should have a heat-sensing device in each vital area of the controller to activate the system should a predetermined level of overheat occur. Reference 5 provides information on fire detection and suppression systems.

If a suppression system is used, caution is advised in the selection of a suppression system and suppression agent. Reference 6 should be reviewed and, if necessary, research should be undertaken to determine the most efficient system and most effective suppression agent.

Possible R&D

1. Develop more reliable solid-state components that can sustain higher temperatures.

2. Develop a fire suppression system for the propulsion controller compartment. The suppression agent used must have a chemical composition that will suppress a fire without creating a by-product which, due to heat, could support combustion, become toxic, or be in anyway hazardous to health and life.

2.1.1.2 DC Traction Motor - The traction motor used for dc transit operation is usually a series wound motor. These motors are, in general, mounted in a truck either in a bimotor configuration, where one motor is coupled to one axle by means of a right angle or parallel drive unit; or a monomotor configuration, where one motor is coupled to both axles of the truck through right angle drive units. These traction motors are either self-ventilated by a built-in fan, or are force-ventilated by means of an external blower system.

The state-of-the-art in transit vehicle design requires that the traction motor performs two functions. The first is to propel the car in the direction selected, and the second is to retard the motion of the vehicle by acting as a generator and dissipating the generated energy either in the resistors carried on the car, or by returning the generated energy to the power system. The traction motor, drawing high currents and voltages in the functions described above, has a high percentage of recorded fires.

The combination of brushes and commutator on a dc traction motor is actually a high-speed, high-current, multiple-contact rotary selector switch. Contact between the brush and commutator must be continuous and positive, or problems may result. Brushes worn beyond their established wear-limit will not have sufficient pressure against the commutator to make good contact, since brushholder spring pressure will be reduced considerably at this level of brush wear. With this light pressure, arcing and an overheat condition may result, with subsequent flashover and ignition. A new brush combined with a defective or improperly adjusted brushholder spring can create the same results.

Surface contact problems may also result if a commutator is rough or worn. Under these conditions, a brush riding over the commutator segments will, at some point, arc as the armature rotates from one segment to another, and produce a fire ring or overheat condition. Due to the heavy current draw, this could result in ignition of the commutator.

Defective armature or field coils may create excessive arcing or an above-normal current draw, overheat the coils, and result in ignition.

Dirt accumulating within the shell of the motor can alter the air gap between the armature and fields and cause an overheat condition with resultant ignition. This same dirt, carrying conductive particles or becoming damp or moist due to environmental conditions, can create a current creepage path and a flashover.

A worn or defective bearing can create enough friction to start a fire in the bearing lubricants which will then spread to other parts of the motor.

In addition to the fact that the traction motor can cause ignition on its own, a malfunction of the propulsion controller may cause an excessive current draw through the motor, establish an overheat or flashover condition, and lead to ignition.

Motor leads are connected to traction motors by either a clam shell, spark plug or split-pole configuration. When a motor lead breaks, in most instances, the break occurs where it is crimped or soldered to the connector. With the spark plug type of connection, however, the connector on the motor itself may break. In either case, once the lead or connector breaks, the lead may sway about the truck area and come in contact with ground. It may then draw an arc that can cause ignition and set fire to flammable material under or outside the car.

If motor leads are not clamped properly, they can chafe against those parts of the truck or undercar equipment to which they are clamped. Under these conditions, the insulation can be worn through and a circuit-to-ground established which can result in flashover and ignition.

Prevention

A. Conduct regular inspections of traction motors. The inspection should include:

   1. Insulation resistance check;

   2. Removal of dust and dirt from motor interior;

   3. Replacement of worn brushes;

   4. Inspection of commutator for roughness or wear;

   5. Inspection of motor leads for damage; and a

   6. Check for bearing wear.

B. Institute periodic rehabilitation of traction motors. This rehabilitation should include:

   1. Re-insulation of armature;

   2. Re-insulation of field coils;

   3. Trueing of commutator;

   4. Replacement of bearings; and

   5. Replacement of brushholders.

Detection

1. Install a ground fault detector that will remove power from the propulsion system if a ground fault is sensed by the detector.

2. Install temperature sensors that will remove power from the propulsion system if the temperature reaches a predetermined level.

3. Install indicators on the motorman's console that are connected to these devices to inform him of the problem.

Suppression

Due to the location of the traction motor on the truck and the compactness of the motor itself, it would be difficult to install a suppression system for every traction motor on a transit car. However, should a fire occur in a motor, the limited quantity of flammable material nearby and the steel shell of the motor itself would prevent extended combustion. The vent openings are not large enough to allow an arc or flame of any magnitude to cause damage outside the shell.

Potential R&D

1. Develop an AC propulsion system which, as one of its attributes, will utilize AC traction motors and eliminate the need for commutators, brushes, and brushholders, which are major sources of fire in the DC traction motor.

2. Develop a better insulating material for the motor.

3. Develop a more rugged insulating material for motor leads that addresses the requirements of the FTA Guidelines for Flammability, Smoke Emission, and Toxicity.

4. Develop an on-board diagnostic system to monitor the traction power circuits and alert the train crew to a potential problem and allow them sufficient time to take corrective action before ignition occurs.

2.1.1.3 Motor/Braking Resistors - The motor/braking resistors on present transit cars are commonly mounted under the car and open to the atmosphere. On some cars, where undercar space is limited, the resistors are mounted on the roof. On some older cars, they are mounted in sealed compartments, under the car, through which air is blown. In the winter months, the heat dissipated from these resistors is channeled into the body of the car as main body heat.

In cam controller service, the resistors are used to vary the speed of the car during acceleration when the controller, as it advances in response to the commands of the master controller or wayside train control, shorts out segments of resistance. In dynamic braking, the resistors are used to dissipate the energy generated by the traction motor.

In solid-state control, resistors are not used in acceleration since the solid-state devices control the speed of the traction motor directly. Braking resistors are normally used in solid-state service to dissipate the energy generated by the traction motor. They are usually found on cars that utilize regenerative braking, but are only used when the traction power line is saturated and is not receptive to additional power.

Operating a cam-controlled transit vehicle under power, for an extended period, at a restrictive speed, will heat the resistors to a point where the resistors or adjacent combustibles could ignite.

Foreign matter or debris lodged between sections of resistors can short out that particular section of resistance, overheat the remaining sections, and ignite combustibles in the surrounding area. The foreign matter or debris itself can ignite also.

A broken motor/braking resistor cable swaying around in the resistor area can make contact with ground, draw an arc, and ignite combustibles.

Prevention

1. Instruct operating personnel not to operate cars for an extended period at a restrictive speed. A period of "coast" should be used during this period to cool the resistors.

2. Inspect the resistors regularly and remove foreign matter or debris from the area.

3. Inspect the right-of-way periodically and remove foreign matter and debris to insure that they do not lodge in the resistors.

4. Secure resistor cables properly to insure that they cannot touch ground should they break.

5. State in the specification for the car that all undercar wiring, exclusive of resistor cables, be directed away from the resistor area to insure that they would not be damaged should the resistors overheat.

Detection

Some transit systems have installed over-temperature devices to detect overheat conditions at the motor/braking resistors.

Suppression

Due to the exposed nature of the installation and the motion and variable direction of the car, it is almost impossible to design an effective suppression system for the resistor area.

Possible R&D

1. Develop a resistor material that can sustain higher temperatures.

2. Develop a heat-sensing device that can be inserted in the resistor area, under the car, to accurately detect an overheat condition in that area, compensating for ambient temperature and airflow over the resistor.

2.1.1.4 Current Collection - Current collection for electric-powered heavy rail transit cars usually utilizes a third rail contact shoe assembly mounted on an insulated beam/block. This combination, in turn, is mounted on both sides of each truck. Vehicle power is collected when the spring-loaded contact shoe pad makes contact with the power rail by riding on top of or under the rail. The contact shoe assemblies are connected in parallel to insure continuity of power when running through special work, rail gaps, etc.; where there are breaks in the third rail; or where the third rail changes sides.

The beam/block is usually made of a laminated fiberglass-reinforced material or impregnated wood for strength and insulation resistance.

By virtue of its location on each side of each truck, the current collector is a prime area for fire ignition on a rapid transit car. The only separation between the current collector and the truck frame, which is ground, is the insulated beam/block. This separation is usually the thickness of the beam/block. With all four current collectors connected in parallel and alive at all times, even if only one collector is making contact with the power source, there is potential for ignition at any of the four current collector areas.

With the amount of brake shoe dust, environmental debris, and road grit churning along the right-of-way and collecting on exposed areas (current collector, mounting beam/block, truck frame, etc.), creepage between the current collector and truck frame can be established, thereby creating a path to ground. By virtue of the current collector's location on the car, there is usually no fuse protection except for the section breaker in the substation, which is set to trip at a predetermined high current overload or fault. An arc, festering at a low current at the outset, will increase in intensity as the creepage path becomes more positive, burn the block/beam, and arc over to the truck frame and severely damage it. This arc, as its intensity increases, can ignite undercoating or road grit accumulated along the underside of the car, and then spread along its length.

Due to its exposed nature, the current collector assembly is vulnerable to the elements and the operating environment of the transit system, which are both factors in the rate of deterioration of the insulated beam/block. Damaged, cracked or worn insulated beams/blocks can create pockets where conductive materials accumulate, with an end result that creepage is established, creating a path to ground, with possible ignition following.

With all four collectors in parallel and each collector alive, and at least one collector shoe making contact with the third rail, a broken current collector cable, or a cable with its insulation chafed due to rubbing against a hard grounded object under the car, can result in an arcing condition and subsequent ignition if the broken cable touches ground or the cable insulation chafes to bare wire and grounds.

Debris and foreign matter along the right-of-way, especially in stations where objects are thrown onto the roadbed, can be a catalyst for ignition. This debris can lodge between the third rail and the running rail, or between the current collector and the truck frame or car body as the car passes by, and if of a conductive nature, can result in arcing and ignition on the vehicle as well as on the right-of-way.

Transit systems in the snow belt encounter an added fire hazard with the presence of sleet or ice on the third rail during inclement winter weather. The current collector, as it moves along the third rail, cannot make positive contact and draws a heavy arc between the third rail and the contact shoe. This, in turn, can flashover to the truck or car body, or carbonize the insulated beam/block and create a creepage path to ground. Any of these conditions can result in ignition.

Prevention

In view of the difficulty of designing a fire suppression system in the area of the current collector, a greater effort must be made to prevent initial arcing and ignition. This effort must begin in the specification and design stages. Here, in the wording of the specification and on the drawing board design, maximum protection can be built into the car. Once the car is placed in revenue service, proper maintenance of the current collector assembly and its mounting beam/block is essential. Such maintenance involves the following:

1. The current collector must be inspected daily to check for hanging or damaged assemblies or parts of assemblies.

2. The beam/block must be checked periodically. Any beam/block found to be cracked or deteriorated must be replaced. Insulation resistance

readings must be taken at this time, and the beam/block replaced if the insulation resistance cannot be made to meet a predetermined level.

3. The beam/block must be washed periodically with an approved washing solution and, where appropriate, painted with an approved insulating paint.

4. The current collector cables must be properly clamped to reduce the possibility of the cables breaking or chafing.

5. The height of the current collector shoe must be adjusted periodically to prevent excessive arcing or damage as it rides on and off the third rail.

6. The height of the third rail must be checked and adjusted periodically to insure proper contact by the current collector.

7. The right-of-way, especially the roadbed at stations, must be inspected periodically and any debris removed to reduce the chances of an object becoming lodged between the third rail and ground, or the current collector and ground.

Detection

It is difficult to detect an ignition problem in the area of the current collector. Due to the exposed nature of the installation, and the motion and variable direction of the car, it is virtually impossible to design a fire detection system for this area of a transit car. Visual detection is problematic due to the number of personnel on a train (usually no more than two). Ignition in this area is only likely to be detected when the section breaker in the substation is tripped; when personnel on a passing train notice smoke and fire emanating from the area of the current collector or from under the car and notify Central Control; or when passengers in the car see flames or smoke, or react to extreme heat coming through the floor, and notify train personnel.

Potential R&D

1. Develop an insulated beam/block material to which environmental debris cannot adhere and which will be impervious to environmental and weather conditions.

2. Develop a more flexible current collector cable to reduce the possibility of breakage due to flexing.

3. Develop a means to prevent the accumulation of sleet or ice on the third rail during inclement winter weather.

2.1.1.5 Train Control Compartment - Many transit systems operate on train control. The degree of train control and the complexity of the control system varies from site to site. Some transit properties have their train control equipment mounted in compartments inside the car, usually in the cab, while other properties mount this equipment in compartments under the car.

Vital and nonvital relays, plug-in logic cards, governors, speed regulators, and power supplies are enclosed within this compartment.

This compartment also contains the solid state and electromagnetic components that operate the train control system. The number of components that are contained in this compartment depends on the complexity of the system and the amount of train control used.

There is usually no high-voltage in this compartment. The most serious fire threat is from a high-voltage flashover in another area of the car entering the train control circuitry, destroying the system, and igniting the apparatus in this compartment.

Prevention

Most of the wiring in this compartment is hard-wired to receptacles, making inspection difficult.

Inspect the apparatus in the compartment to insure that they are securely fastened.

Suppression

For train control equipment mounted under the car in closed compartments where windage and direction of travel of the car have no effect on fire propagation, a fire suppression system can be installed in the compartment. The system should have a heat-sensing device in each vital area of the assembly to activate the system should a predetermined level of overheat occur.

If a suppression system is used, caution is advised in the selection of a suppression system and suppression agent. Research should be undertaken to determine the most efficient system and most effective suppression agent. It should be kept in mind that the train may be in the subway much of the time.

Possible R&D

1. Develop more reliable solid-state components that can sustain higher temperatures.

2. Develop a fire suppression system for the train control compartment. The suppression agent used must have a chemical composition that will suppress a fire without creating a by-product which, due to heat, could support combustion, become toxic, or be hazardous in any way to health, life, or environment.

2.1.2 Low-Voltage Power

2.1.2.1 Storage Battery - The storage battery of a transit car is the low-voltage source for:

1. The operating control functions of the propulsion controller;

2. Lighting;

3. Lighting control;

4. Door control and operation;

5. Train control;

6. Communications; and

7. Any other electric function requiring low-voltage.

The battery voltage ranges from 32.0 to 37.7 volts.

In the past, most batteries used in transit cars were of the nickel-iron alkaline type. In recent years, however, nickel-iron alkaline batteries have been unobtainable in this country, so nickel-cadmium alkaline or lead-acid batteries are being substituted.

The storage battery is usually mounted under the car in its own compartment.

In fleets of single unit cars, each car has its own battery. With married pair or other captive configurations of cars, the battery is usually one of the items delegated to a specific car of the consist, with low-voltage power going from the battery-equipped car through the electric couplers or jumpers at the end of the car to the other cars in the captive consist.

Overcharging, heavy load cycling, lack of water in the cells, shorted cells or improperly matched battery chargers can be responsible for high electrolyte temperatures, and create conditions where an explosion or ignition could occur.

A broken battery wire can sway around the battery box area, touch ground, generate an arc and cause ignition.

Prevention

1. Assure that the battery is matched for the load requirements of the low voltage system and that the battery charger is matched for the load requirements of the battery.

2. Periodically test each cell of the battery to ensure that there are no shorted cells.

3. Periodically check the output of the charging system to ensure that the charging voltage is correct.

4. Inspect battery box wiring to ensure that all wiring is secured in such a way that if a wire breaks, it will not touch ground.

5. Periodically inspect each cell of the battery to ensure that the level of electrolyte is sufficient.

6. Design undercar conduit and cable layouts so that they do not pass over the battery box. This will prevent damage and fire in the wiring should an explosion occur.

7. Properly vent the battery compartment to prevent build-up of explosive gases.

Detection

1. Install an over-voltage sensing device in the battery charging circuit to open the charging circuit and alert the train operator should an over-voltage condition occur.

2. Install an over-temperature sensing device in the battery box to open the charging circuit and alert the train operator should an over-temperature condition occur.

Suppression

With properly working over-voltage and over-temperature sensing devices, the need for suppression apparatus should be minimal, since the two sensing devices would theoretically prevent ignition.

Possible R&D

Develop an improved battery that has less fire and explosive potential than present batteries.

2.1.2.2 Motor Generator - The motor generator is a rotating device that is employed to supply low-voltage power and charge the battery. It is usually contained in a single housing, with the motor on one end of the shaft and the generator on the other end. The motor is usually designed to operate from the high-voltage source.

In single car fleets where each car has its own battery, each car will also have its own motor generator (if used). With married pair or other captive configurations of cars (where equipment is delegated to various cars of the consist), the motor generator is usually installed in the same car as the battery.

The motor generator, properly sized for its load requirements, will provide adequate low-voltage power for the rail transit vehicle(s) while operating within acceptable temperature limits.

Should additional loads be added to the low-voltage system, so that the motor generator reaches its output limits, it could overheat the armature and cause the armature coil insulation to become brittle and break off. A short or ground could result, leading to ignition.

Worn brushes, defective brushholders, rough or worn commutators could cause a flashover, ground or overheat condition and could result in ignition.

Worn bearings can create enough friction to ignite the lubricant in the bearings. Lack of lubrication can cause the bearing to overheat, and could result in ignition.

Prevention

A. Conduct regular inspections of motor generators. The inspection should include:

   1. Check of insulation resistance;

   2. Removal of dust and dirt from motor generator interior;

   3. Replacement of worn brushes;

   4. Inspection of commutator of both motor and generator for roughness or wear; and

   5. Inspection of motor and generator leads for damage.

B. Institute periodic rehabilitation of motor generators. This rehabilitation should include:

   1. Reinsulation of the motor and generator armatures;

   2. Reinsulation of motor and generator field coils;

   3. Trueing of motor and generator commutators;

   4. Replacement of motor end and generator end bearings; and

   5. Replacement of motor and generator brushholders.

Detection

   1. Install a ground fault detector that will remove power from the motor generator once a ground fault is sensed.

2. Install temperature sensors that will remove power from the motor generator once the temperature reaches a predetermined level.

3. Have indicators on the operator's console connected to these devices to inform him of the problem.

Suppression

It would be difficult to provide an effective suppression system for a motor generator mounted in an exposed manner under the car. Since the cars can travel in either direction, the airflow, especially in a tunnel, could dissipate the suppression material in such a manner as to make it ineffective.

If the motor generator is used as part of a recaptured heat system, it may be mounted in a compartment. It would be inadvisable to install a suppression system in this compartment, since the suppression material could be blown into the car by the blowers attached to the motor-generator shaft, causing a breathing problem or panic among the passengers.

Potential R&D

1. Develop a better insulating material that can withstand higher temperatures.

2. Develop an on-board diagnostic system to monitor the motor generator and alert the train crew to a potential problem, allowing them sufficient time to take corrective action before ignition occurs.

2.1.2.3 Equipment Enclosures, Climate Control Compartment, Electronic Control Compartment, and Solid State Low-Voltage Power Supply Compartment - The equipment enclosures usually contain the contactors to energize the air compressor, motor generator/solid-state low-voltage power supply, lights, transfer switch for auxiliary power, and fuse panel.

The climate control compartment usually contains the heat and vent control contactors and relays.

The electronic control compartment usually contains the control apparatus, either solid-state or electromagnetic, for the propulsion controller.

The solid-state low-voltage power supply compartment usually contains the solid-state components that make up the low-voltage power supply (if used). In fleets of single cars, each car has its own battery. If a solid-state low-voltage power supply is used, each car will have its own power supply. With married pair or other captive configurations of cars (where some equipment is delegated to various cars of the consist), the solid-state low-voltage power supply is usually installed in the same car as the battery.

The components contained in these compartments are either electromagnetic, electro-pneumatic, or solid state.

A malfunction of these components can cause an overload, short or ground, and create a condition for ignition. Overloading or insufficient cooling of solid state components may cause an overheat condition and result in ignition.[2]

Since these compartments house apparatus of both high and low voltages, broken wires swaying about these compartments can touch ground and flashover, creating an ignition condition. In addition, a flashover from a broken high-voltage wire to a low-voltage circuit can create an ignition condition in any part of the low-voltage circuit (including the cab of the car) since the low-voltage apparatus may not be insulated for high voltage, and consequently, could blow up.

Prevention

1. Inspect the various compartments periodically to ensure the proper operation of moving parts, where applicable.

2. Inspect wiring to insure the integrity of connections and connectors, and wire security.

Suppression

Same as for propulsion controller (p. 2-5).

Possible R&D

Same as for propulsion controller (p. 2-5).

2.1.3 Brakes

Major systems include the:

1. Friction brake/handbrake;

2. Hydraulic pump; and

3. Air compressor.

They are discussed below.

2.1.3.1 Friction Brake/Handbrake - Friction brake subsystems are designed in several ways, according to transit agency preference:

1. Tread brakes, where a brake shoe is forced against the tread of a wheel with various degrees of pressure to retard the motion of the car. This can be accomplished by means of a brake unit or package and shoe at each wheel, or by means of levers actuating brake beams to which brake shoes are attached.

2. Disc brakes, where one or two discs are attached to each axle, with shoes or pads making contact with the rotating disc to retard the motion of the car.

3. Drum brakes, where a brake drum is attached to the drive shaft of each motor, with shoes making contact with the rotating drum to retard the motion of the car.

Friction brakes are actuated either pneumatically, hydraulically, or electrically as specified by the transit agency.

In any of these friction brake subsystems, if the brakes are not fully released while the vehicle is in motion, the wheels, discs, or drums will become extremely hot and could ignite combustibles in the area.

A handbrake (sometimes called a parking brake) is actuated independently of the main friction brake control. This brake mechanically or hydraulically actuates all or part of the friction brake system when applied, as specified by the operating agency.

Should the brake not release properly, the friction from the applied brake will generate heat and may cause ignition.

Prevention

1. Design into a new car, or install into an existing car, a handbrake or parking brake interlock that will indicate to the train operator that this brake is not completely released and will prevent power from being applied to the propulsion system until this brake is completely released.

2. Establish a friction brake inspection schedule (no less than once a day) to insure that all friction and parking brakes are functioning properly.

Potential R&D

1. Develop overheat detectors for overheated wheels.

2. Develop feedback mechanisms to indicate when friction brakes are not fully released.

2.1.3.2 Hydraulic Pump - The hydraulic pump charges the hydraulic lines and provides the pressure required to operate the friction brakes on those cars equipped with a hydraulic friction brake system. Most hydraulic brake systems utilize the disc brake concept, which is the most practical for this type of system. Hydraulic fluids are not train-lined through the drawbar; consequently, each car has a self-contained closed hydraulic system with its own pump and related apparatus.

On those transit cars that utilize a hydraulic friction brake system, leaks in the hydraulic lines or hydraulic apparatus can saturate the area with hydraulic fluid which, under a flashover condition, or because of hot brake discs, could result in ignition or in the generation of acrid smoke that is detrimental to health and life.

Prevention

1. Periodically inspect the hydraulic system for leaks.

2. Periodically replace hydraulic seals in vital apparatus to prevent leaks.

3. Arrange hydraulic lines such that potential leaks will be shielded from hot surfaces.

Detection

Install pressure indicators in the cabs of the cars to alert the operator of a reduction in hydraulic pressure due to a leak.

Possible R&D

1. Explore the use or development of a type of hydraulic fluid with lower flame/smoke/toxic properties.

2. Design the hydraulic system to minimize the inventory of fluid on each car.

2.1.3.3 Air Compressor - In a pneumatic system, an air compressor provides the air to operate the friction brakes and all other systems specified by the transit system to be air operated, such as door operation, propulsion control, and air suspension. The compressor is either belt-driven or gear-driven by a motor usually powered from the high-voltage source. The compressor and its motor are normally mounted in a frame under the car, together with the compressor's governor, dryer, cooling fans, and safety valve.

On fleets of single unit transit cars, each car has its own compressor. With married pairs or other captive configurations of cars (where some equipment is delegated to various cars of the consist), the compressor is usually one of these delegated items, with the air lines running from the compressor-equipped car through the train lines to the drawbars, and through the drawbars to the other cars of the captive consist.

An air compressor, properly designed and sized for the operation intended, will have a duty cycle that will keep the operation temperature within acceptable limits.

Should air leaks materialize, or the governor become defective and not shut off, the compressor would run continuously and could overheat and create a condition for ignition of any debris or dirt/oil properties that has accumulated on the compressor housing.

Should the oil level in the compressor become low due to a leak or defective seal, the compressor could overheat and create a condition for ignition.

Prevention

1. Periodically check the air system for leaks.

2. Periodically check the governor for proper operation.

3. Periodically check the oil level in the compressor.

Possible R&D

Develop an overheat detector that is ambient-temperature compensated to alert the train crew should an overheat condition occur at the compressor area.

2.1.4 Air Conditioning

The main elements of this system are:

1. The compression/condensor unit;
2. Evaporator/blower unit overhead; and
3. A number of motors.

2.1.4.1 Compressor/Condensor Unit - During the air conditioning cycle, the compressor takes the refrigerant vapor that leaves the evaporator, compresses it to higher temperature and pressure levels, and discharges it into the condensor. The compressed vapor is liquified in the condensor and returned to the receiver.

Transit cars that are air conditioned usually have the compressor/condensor unit mounted under the car and the evaporator unit(s) mounted in the ceiling area. There are some cars that have modular air conditioning units mounted under the car that are self-contained, with the evaporator unit as part of the undercar package.

The air conditioning compressor/condensor unit, when properly designed and sized for the environmental conditions of the area of operations, will have a duty cycle that keeps the operating temperatures within acceptable limits.

Should the refrigerant level be reduced due to leaks in the line or apparatus, the compressor would run continuously and possibly overheat, thereby creating conditions for ignition.

Prevention

1. Periodically check the system for refrigerant leaks.

2. Periodically check the liquid level in the receiver.

Possible R&D

Develop an overheat detector that compensates for ambient temperature to alert the train crew and/or shut down the A/C system should an overheat condition at the compressor/condensor unit occur.

2.1.4.2 Compressor/Condensor Motor, Air Compressor Motor, and Forced Ventilated Blower Motor for Traction Motor Cooling - The motors that drive the air conditioning compressor/condensor/fan and the air compressor are mounted in the same frame as their respective compressors, connected to them by a belt drive configuration or a shaft drive configuration with a coupling. These motors are usually designed to operate from the high-voltage source. The entire unit is usually mounted in an unenclosed fashion on the undercar.

Traction motors on transit vehicles are either self-ventilated, with a fan built into the motor itself, or forced ventilated, where the motor is cooled by air from an external blower. Driven by a motor usually operated from the high voltage source, this blower unit is mounted under the car. The air is directed to the traction motor by means of ducts.

Properly designed for their intended operation, the air conditioning compressor/condensor motor, the air compressor motor, and the forced ventilated blower motor, will operate their respective devices at their required duty cycles, while keeping within acceptable temperature limits.

Worn brushes, defective brushholders, rough or worn commutators could cause a flashover, ground or overheat condition and could result in ignition.

Worn bearings can create enough friction to ignite the lubricant in the bearings. Lack of lubrication can cause the bearings to overheat and result in ignition.

Prevention

A. Conduct regular inspections of air conditioning compressor/condensor motor, air compressor motor and forced ventilation blower motor (if used). The inspection should include:

   1) Check of insulation resistance;

   2) Removal of dust and dirt from motor interiors;

   3) Replacement of worn brushes;

   4) Inspection of motor commutators for roughness and wear; and

   5) Inspection of motor leads for damage.

B. Institute periodic rehabilitation of air conditioning compressor/condensor motors, air compressor motors and forced ventilation blower motors (if used). This rehabilitation should include:

   1) Reinsulation of armatures;

   2) Reinsulation of field coils;

   3) Trueing of commutators;

   4) Replacement of bearings; and

   5) Replacement of brushholders.

Detection

1. Install a ground fault detector that will remove power from these motors should a ground fault be sensed by the detector.

2. Install temperature sensors that will remove power from the motor when temperatures reach a predetermined level. Install indicators on the operator's console to alert the operator of the problem.

Suppression

Since these motors are located under the car and are relatively exposed, it would be difficult to design and install an effective suppression system.

Potential R&D

1. Develop an insulating material that can withstand higher temperatures.

2. Develop an on-board diagnostic system that can monitor these motors and alert the train crew to a potential problem, allowing them time to take corrective action before ignition occurs.

2.1.5 Materials

2.1.5.1 Wire and Cable - For the most part, wire and cable are installed under a transit car in conduit, ducts, or troughs. Wire and cable bring in the high-voltage power from the current collector to the propulsion controller and high-voltage auxiliary circuits, as well as low-voltage power to the control circuits of the propulsion controller and any other low-voltage system under the car.

The insulation of the wire and cable is cited in reference 7, and performance data is available in the UMTA Report "Combustibility of Electrical Wire and Cable for Rail Rapid Transit Systems," Vol. I Flammability & Vol. II Toxicity.[8,9]

Breakdown of wire and cable insulation on a transit vehicle is caused by high temperature exposure, overloaded circuits, chemical contamination or deterioration over time, and can cause shorts, grounds, or arcing with resultant ignition.

Prevention

1. Inspect wire and cable periodically and replace any that shows signs of deterioration or breakdown of insulation.

2. Design wire and cable layouts under the car to limit the number of areas where visual inspection would be difficult.

3. During the specification writing process, specify smooth edges on trays (where applicable) to prevent chafing.

4. Periodically conduct an insulation resistance and "hi-pot" test to determine the integrity of the wire insulation.

Possible R&D

Develop an insulating material that is rugged, does not chafe when pulled through conduit, will not break down, and meets all the requirements of the latest FTA guidelines.

2.1.5.2 Undercoating - The undercoating used on transit cars is applied to protect the undercar structure, compartments, and exposed apparatus from the elements. Today's state-of-the-art specifies that all undercoating be of non-asphalt type, nonflammable and nontoxic, with a low smoke emission index.

Until recently, undercoating material used on transit vehicles was usually made from an asphalt base. This material is highly flammable and ignition can result from an arc or flashover.

Prevention

Remove asphalt-base undercoating and replace with a non-asphalt-base material, or fire harden the asphalt-base material.

2.1.5.3 Fuses - Most high voltage fuses used in transit service are of the one-time cartridge type rated between 600 to 1000 volts that are mounted on a panel in a closed compartment under the car. Fuses protecting rotary apparatus, such as motor generators and air compressor motors, are usually dual element fuses to keep the fuse from blowing during normal high inrush currents at start-up.

One exception to the cartridge-type fuse is the ribbon fuse used by many transit systems in the current collector assembly. The fuse is mounted in a fuse holder at each current collector assembly to protect against faults between the current collector and the propulsion system or auxiliary circuits.

Most transit vehicles have fuses rather than circuit breakers in their high-voltage circuits. For low-voltage circuits, however, most vehicles use circuit breakers.

Where fuses are used, they should be rated properly, allowing for line and circuit surges. Where high inrush currents are experienced during start-up of rotating apparatus, dual element fuses should be used.

Fuse clips that do not make positive contact with the fuse may arc or overheat and cause ignition.

Fuses not rated specifically for dc that are used in dc circuits may not control the arc of a blown fuse, especially higher current fuses. The fuse can explode, scatter fire, or arc to surrounding fuses and apparatus and ignite the area.

Prevention

1. Use only fuses properly rated for the proposed circuit.
2. Inspect fuse clips regularly to make sure that they are not pliable.
3. Insert barriers between high-voltage fuses where practical to prevent scattering or arcing should a fuse explode.
4. Use fuses rated for DC service only.
5. Use fuse clip clamps for all high voltage fuses to assure positive contact of the fuse in the fuse clip.

Possible R&D

Develop a dc fuse applicable to transit use.

2.2 PROTECTION SYSTEMS

Within the interior and underside of rail transit vehicles, many devices can be utilized to minimize the effects of fire and smoke, reduce the time for detection, inhibit the propagation of the incident, and protect the passengers in the vehicle. Such systems are described in this section.

An intercommunication system that allows direct access to the train crew would be appropriate for early warning of a fire incident within the interior of the vehicle by a passenger during revenue service. The train crew would advise Central Control of the situation and allow them to take appropriate action relative to alerting emergency response organizations. Also, the train crew would be able to take the proper action relative to the movement of the train, assist in the suppression of the fire, and assist in the evacuation should it become necessary.

Detection/Suppression

Smoke/fire detectors would be appropriate within the confines of the interior of the vehicle. However, in a storage yard which may not be within close proximity to yard or shop personnel, it would be necessary to employ an external source or the radio within the train in order to monitor the detection system while the train is in storage.

Automatic fire suppression systems within the confines of the interior of the vehicle would be inappropriate, since the suppression ingredient would be released onto passengers should the system be activated while the vehicle is in revenue service. This system would be appropriate for the interior of the vehicle while the vehicle is unattended in a storage area. However, the system would have no way of differentiating between revenue service and unattended storage. It would then be dependent on human resources to activate the system in storage and deactivate it when the vehicle is returned to revenue service.

A more appropriate means of fire suppression within the confines of the vehicle interior while in revenue service would be by manually operated fire extinguishers located in each vehicle accessible by passengers and train crew alike. The transit system would post signage indicating the location of the extinguishers and the means and methods to gain access to them in time of need.

Certain undercar equipment, as described above and in reference 6, would be adaptable to suppression and/or detection systems, while others, due to location, exposure to windage and direction, would not be realistically adaptable to these systems.

Occupant Evacuation

With the safety of passengers the first priority in any emergency, most especially in a fire emergency where visibility may be hampered by smoke, adequate signage that directs passengers in methods of evacuation and direction of exits is most essential.

These signs would be required in the vehicle, along the right-of-way, and in the station areas.

Lighting/emergency lighting should be provided within these areas with sufficient intensity to illuminate areas of exiting under smoke conditions. References 4 and 10 provide a more in-depth discussion of this. Other occupant evacuation issues are as follows:

Evacuation/R&D

1. Design emergency lighting in stations and terminals to provide maximum illumination and to be protected with its power source from damage and vandalism. This would:

    - Reduce the possibility of dark areas in subway stations and terminals
    - Improve passenger safety
    - Reduce the possibility of vandalism
    - Reduce evacuation time

2. Provide emergency lighting at doors of the vehicle. This would:

    - Reduce the prospect of panic in an evacuation
    - Reduce the prospect of confusion
    - Reduce the prospect of injury of passengers

3. Provide public address systems in all stations and terminals with speakers so located that announcements can be heard from any area of the station or terminal. This would:

    - Improve passenger safety
    - Reduce the prospect of panic
    - Reduce confusion during an emergency
    - Reduce evacuation time

4. Provide public address system in all vehicles. This would:

   - Provide passengers with information relative to evacuation
   - Reduce the prospect of panic
   - Reduce evacuation time
   - Reduce the prospects for confusion

5. Provide signs in subway stations, terminals and vehicles which give instructions for reporting unusual occurrences and procedures for emergencies. This would:

   - Reduce the time necessary to evacuate in case of emergency
   - Reduce confusion during emergencies
   - Reduce hazard exposure by early reporting of the problem

6. Provide early warning of emergency. This would:

   - Reduce the time for emergency response personnel to respond
   - Reduce evacuation time

2.3 CAR MATERIALS

In the construction of a transit car, a variety of plastic materials are used for seating, panels, flooring, insulation, etc. Such materials can ignite and fuel a fire inside wall cavities or the passenger compartment. Fire safety countermeasures can be taken by selecting materials that are fire-hardened, i.e., that are difficult to ignite when exposed to flame or heat; that are self-extinguishing (or at least easily-extinguishable), if ignited; and that produce a slow fire propagation if they continue to burn, along with little smoke, heat, or toxic output.

These considerations have been covered in the "Recommended Fire Safety Practices for Rail Transit Materials Safety."[7] Each transit authority should review the materials on its fleet, and improve the flammability and smoke characteristics of its materials according to the recommended FTA practices. Reference 11 provides an insight into how one transit system fire-hardened their veh. le.

3. PROCEDURES

The proper operation of any complex system requires the formulation of detailed procedures to coordinate the actions of the various people involved and minimize the possibility of human errors. Many of these procedures are essentially fire safety countermeasures intended to ensure fire prevention, quick detection and suppression, and effective and smooth emergency response.

This chapter presents recommended fire safety countermeasure procedures for rail transit systems. The procedures are organized into three categories: maintenance/inspection, operations, and emergency response.

3.1 MAINTENANCE/INSPECTION

To meet schedules and prevent breakdowns, rail transit systems are obliged to develop and perform comprehensive maintenance/inspection programs based on time and mileage. These programs will provide for the timely replacement of expendable items and the interval replacement/overhaul of components, sub-systems, and systems. In addition, they will also provide for the visual inspection of the vehicle as a whole and for the systematic testing and adjustment of car borne equipment. By performing these functions, potential ignition sources can be uncovered and corrected and the risk of fire greatly reduced.

Prevention

1. Evaluate maintenance programs; develop realistic goals for performance and costs of maintenance programs. This evaluation will aid in establishing a meaningful preventative maintenance program which in turn reduces the probability of fire ignition.

2. Institute strict maintenance programs for the inspection and replacement of the following: high voltage (motors and resistors) and low voltage (battery, etc.) components, wiring and cables, HVAC equipment, journals, wheels, gears, collector shoe assemblies, and catenary. By a strict maintenance program and periodic inspection of vital pieces of apparatus

and components, downtime of the vehicle is reduced and the sources of fire and fire propagation are controlled.

3. Institute programs to keep vehicles clean on exterior, interior, undercar, etc. The program for the removal of rubbish and/or combustible material eliminates this source of fuel for fire caused by overheat conditions, vandalism or other sources.

4. Conduct regular sweep and clean maintenance of stations and trainways so that debris does not accumulate. Keeping stations and trainways free of debris removes a potential fuel source for fires caused by overheat conditions or vandalism.

5. Conduct a daily walkaround inspection of all vehicles to check for hanging or damaged equipment or covers, and the condition of current collector and current collector mounting beams etc. This will enable transit system personnel to discover potential fire/safety hazards on a more immediate basis.

6. Involve the train operating crew in preventative maintenance by requiring a daily walkaround general inspection of the vehicle. This inspection provides an additional "check" to ensure that equipment is in proper operating condition and provides the means to discover and correct potential fire/safety hazards on a more immediate basis.

7. Keep accurate records of the condition of components mentioned in item 2 above at the time of each inspection, and record those components replaced. Records reveal patterns for failure and/or fires which can be controlled.

8. Assign responsibility for specific maintenance programs which bear on fire safety to specific inspectors or supervisors. This provides for better control of maintenance and fire safety by segregating this responsibility.

9. Inaugurate a program to periodically remove and rehabilitate all rotating apparatus including traction motors. This procedure reduces the cause of failure due to time and/or mileage.

10. Inspect, clean, and service cam controller contacts, relays, cams, and switches at regular intervals. This maintenance reduces the cause of failures due to time and/or mileage.

11. Inspect the cam controller cover gasket and the logic circuit cover gasket at regular intervals and replace as necessary. This inspection reduces the possibility of dirt ingestion into the cam controller and logic circuit compartments.

12. Inspect the friction brakes on a daily basis to ensure that all brakes are functioning properly. This inspection insures the proper operation of friction brakes and reduces the possibility of friction brake failures.

13. Inspect, test, clean, and paint the collector shoe assembly at frequent, regular intervals. This process should be implemented at shorter intervals during snow plowing and salting periods in snowbelt areas. Adjust the collector shoe height. Frequent attention paid to this assembly reduces the possibility of leakage, creepage or shorting of the current collectors to ground, or damage to the collector shoe and reduces potential downtime of the vehicle.

14. Inspect the third rail at regular intervals for erosion, faults, degree of flatness, and proper height. Frequent inspection will maintain the integrity of the third rail and reduce the potential for arcing and reduce the potential for damage to the third rail and /or the current collector.

15. Clean debris and metal dust from the track area at frequent, regular intervals. This cleaning removes a catalyst for potential shorts and grounds of the third rail current collector and removes a catalyst for potential fires along the right-of-way caused by arcs from the third rail.

16. Inspect the catenary wire and pantograph at regular intervals for faults, degree of wear, proper height, and offset. This inspection reduces the possibility of the pantograph fouling with the catenary and tearing it down and possibly creating a fire situation.

17. Follow appropriately scheduled maintenance of rotating and non-rotating apparatus, brushes and bearings. This maintenance verifies the

integrity of the apparatus, protects against malfunctions and environmental ingestion, and reduces potential downtime of the vehicle.

18. Clean and inspect the general condition of the equipment, electrical contacts and connections, insulation, and covers. This protects against malfunctions and environmental ingestion.

19. Check and adjust all electrical equipment to insure that it is properly grounded. This safety check protects the integrity of the circuitry and protects personnel from electrical shock.

20. Inspect and service batteries and charger at regular intervals. This procedure reduces the possibility of overcharging, undercharging, and batteries functioning without water, and reduces the possibility of fires caused by defective batteries.

21. Check all wiring and cables periodically for protection against vibrations, tight connections, adequate tie downs, and missing grommets. Inspect the condition of wiring and cables after maintenance operations. Check all wiring and cables to insure that they are rerouted around heat-generating areas or are protected by heat shields. Time devoted to this function protects the integrity of wire insulation and wiring installation from grounding or heat.

22. Evaluate wiring, circuits, and fusing for adequate operation and protection whenever any equipment changes are made. As a safety check, this protects the integrity of the equipment and circuitry.

23. Avoid the possibility of fires started by vandals by keeping station platforms, stairways, concourses, etc., free of trash. This undertaking eliminates trash as a source of ignition and reduces safety and health hazards.

Detection/Suppression

All fire protection equipment should be inspected and tested on a routine basis to ensure its integrity and to familiarize transit personnel with their locations and operations. Specific countermeasures include:

- Routinely test and inspect smoke and fire detectors, automatic and manual fire alarms and suppression systems in stations, terminals, maintenance facilities and along the right-of-way and, if applicable, on vehicles.

- Inspect fire extinguishers on a daily basis and test on a semi-annual basis.

- Test and inspect standpipes in stations terminals, trainways, and maintenance facilities semi-annually to ensure proper operation.

- Test ventilators, dampers or blowers in stations and along the trainways (tunnels), and maintenance facilities for proper operation.

Evacuation

1. Inspect and test emergency lighting systems in terminals at regular intervals to reduce the possibility of their failure in time of need and to verify the performance criteria for each system.

2. Clean and inspect light fixtures in terminals, busways, and maintenance facilities at regular intervals and replace as necessary. This would improve the lighting intensity and reduce the possibility of light failures.

3. Inspect periodically, all terminal, tunnel, and busway emergency exits and walkways to ensure that they are safe, free of debris, properly marked and lighted. This would ensure rapid egress in time of emergency and reduce the possibility of injury to passengers during an evacuation.

4. Test terminal public address, vehicle radios, and other communication equipment on a daily basis to ensure the operation of communication equipment for use in evacuation.

5. Inspect and test periodically, the emergency power systems in terminals to ensure their integrity in time of need.

3.2 OPERATIONS

The majority of activity for the movement of vehicles and people lies within the jurisdiction of an operations department of a rail transit system. Its responsibility is not only for the actual operation of the vehicles, but also for the operation of the Central Control and station and line personnel who must deal with the riding public. The operations department must ensure that schedules are met, vehicles are safe to operate and facilities are safe to operate in. With the responsibility that the operations people must assume, they must be alert to the hazards that are inherent to the industry, most importantly, fire. They must take every effort to reduce the potential for this hazard within the system.

Key operation - type countermeasures are presented below:

1. Each transit system should, if possible, engage fire safety support to oversee all aspects of fire safety and fire prevention. Activities of fire safety support personnel would reduce the possibility of fire on the vehicle and improve overall fire safety.

2. Extensively test prototype transit cars for propulsion system performance under actual operating conditions prior to revenue service. This course of action could correct deficiencies in propulsion system performance prior to revenue service and provide experience in operations and maintenance for transit system personnel.

3. Pretest repaired or replacement electrical components and/or subsystems to insure proper operation and integrity of parts. The performance of these functions reduces the possibilities of malfunctions of repaired/replacement components that can result in fires. Also, it assures proper calibration of those parts/components that require calibration.

4. Increase visibility of transit personnel on trains, in stations, etc., to discourage vandalism.

5. Enforce No Smoking regulations in cars and in stations and maintain good housekeeping practices to reduce the amount of debris on vehicles and in stations and the resulting potential for fires.

3.3 EMERGENCY RESPONSE

Establish procedures to be followed during an emergency response to a fire accident. These procedures will include:

- Identifying the duties and the responsibilities of the train crew, the emergency response crew of the authority, and local fire department, police, ambulance, etc.

- Providing communication channels between those various groups involved in the rescue.

- Outlining procedures for the train crew as to reporting a fire, fighting it with a manual extinguisher, and passenger evacuation from the train.

- Communicating with the passengers to inform them of the fire, how to evacuate the train (if needed), and where to go after leaving the train. This should be done without producing any confusion or panic in as short a time as possible.

- Outlining special procedures for helping the elderly and handicapped during evacuation.

Additional pertinent information can be found in the "Recommended Emergency Preparedness Guidelines for Rail Transit Systems"[4] and "Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers"[10] and the section on training/human factors in this report.

4. TRAINING/HUMAN FACTORS

Extensive training and frequent retraining of personnel is essential to the safe operation and proper maintenance of any rail transit system. Part of this training should provide the experience needed to identify, prevent, eliminate, or correct unsafe conditions, such as fire. Also, this experience would be essential in protecting the system and its passengers should an unsafe condition develop into an emergency. Reference 12 provides an insight into the training needs of rapid transit system and fire service personnel.

Key countermeasures are presented below:

Prevention

1. Develop public education and public relation programs (posters, school visits, etc.) to increase public awareness concerning the consequences of vandalism and fires.

   Although the benefits of such programs might be questioned, it:

   - Provides potential to reduce fire and vandalism in a vehicle.
   - Improves the relationship between the transit system and the public.

2. Conduct periodic retraining of operations personnel and training of new transit system personnel with emphasis on fire prevention and emergency preparedness. The time and funds expended in this program would:

   - Provide experience to operating personnel in fire safety and emergency preparedness.
   - Reduce potential for fires to propagate from a small fire to a major conflagration.
   - Reduce injury to passengers due to lack of direction of personnel.

3. All vehicle maintenance personnel should be carefully trained in testing, repairing, and inspection procedures. Regular training and retraining sessions should be scheduled for inspection and maintenance personnel. Such an on-going program works to:

- Improve vehicle reliability.
- Reduce premature failures of components and sub-systems.
- Improve expertise of maintenance personnel.
- Improve employee-management relationship.
- Improve mean time between failures.
- Reduce out-of-service time.

4. Conduct retraining of train operators on operation of train to prevent traction motor, resistor, or friction brake overheating. The results of this retraining should:

- Reduce the potential for fires in these areas.
- Improve vehicle reliability and availability.

5. Maintain public relations effort to reduce vandalism; include a reward mechanism for information leading to the apprehension of vandals. Although this effort could be considered psychological it would:

- Reduce the possibility of vehicle vandalism.
- Improve the relationship between the transit system and the public.

6. Instruct train operators on how to deal with smokers (i.e., announcements) to:

- Reduce smoking in vehicles.
- Improve the relationship between the transit system and non-smoking passengers.

- Reduce the possibility of fire on trains.

7. Use graphics on vehicles to inform passengers that the transporting of flammable materials is not allowed on vehicles as to:

   - Reduce fire and explosion hazards on vehicle.
   - Improve the relationship between the transit system and public.

8. Hold seminars on flammable materials such as gasoline, propane, etc., and instruct operating and supervisory personnel on the restrictions relative to transporting these items on trains as to:

   - Expose operating and supervisory personnel to the hazards of these materials on trains.
   - Inform operating and supervisory personnel as to the identification and handling of these materials.

Detection/Suppression

1. Conduct a formal training program in fire prevention and fire suppression of the rail vehicle for newly hired rail vehicle operating personnel. This program should be conducted in conjunction with local fire departments as to:

   - Provide proper training in emergency procedures for rail vehicles for operating personnel.
   - Reduce the possibility of confusion and delays during an emergency.
   - Reduce the risk of injury to passengers and operating personnel.
   - Improve the operating personnel morale.

2. Conduct refresher courses for operating personnel in fire detection and fire suppression of rail vehicles as to:

- Insure dissemination of up-to-date information and procedural changes.
- Maintain high reliability and close coordination in the evacuation and fire safety of rail vehicles.
- Improve operating personnel morale.

3. Periodically conduct actual fire drills, incorporating fire suppression procedures for operating personnel, fire fighters, and Central Control personnel utilizing rail vehicles in tunnels, subways, elevated locations and shared train and busways as to:

   - Provide actual experience in fire suppression procedures.
   - Provide the opportunity and mechanism to correct, improve, or change procedures from experience gained from drills.
   - Improve working relationships between agencies and departments involved.

4. Conduct seminars for operating personnel in the reporting of fires in trains and in decision-making on initial fire suppression as to:

   - Reduce time in decision-making relative to the notification of Central Control and initial fire suppression.
   - Provide operating personnel with insight in evaluating and reporting fires in trains.
   - Reduce time for the evacuation of passengers.

5. Conduct seminars for Central Control personnel in the evaluation of fire reports, their response to the reporting personnel, and the procedures for notifying the fire department as to:

   - Provide Central Control personnel with experience in handling emergencies.

- Reduce tension of Central Control personnel.

- Improve the relationship between the transit system and the local emergency organizations.

6. Initiate and maintain a program which effectively informs the riding public of emergency notification devices and fire extinguisher locations in terminals, stations, and in vehicles.

7. Inform all personnel, fire fighters, and Central Control personnel as to the location of suppression and communication equipment in terminals and stations including fire hoses, standpipes, extinguishers, telephones, etc. Conduct personnel walking tours for view of the locations of the equipment. This would:

   - Familiarize emergency and transit system personnel with locations of suppression and communications equipment.

   - Reduce time to put emergency equipment into operation.

   - Reduce time to extinguish fires.

8. Conduct a training program in the use of suppression equipment such as fire extinguishers and standpipes as to:

   - Insure direct access to equipment in time of need.

   - Insure proper operation of equipment in time of need.

   - Provide trained personnel for approaching and handling emergencies.

9. Instruct appropriate personnel in the proper methods relative to using fans, dampers, etc. on vehicles in order to inhibit smoke from entering passenger compartments as to:

   - Reduce hazard to life.

   - Prevent panic among passengers.

- Reduce smoke damage to equipment.

Evacuation

1. Conduct seminars for operating personnel in the reporting of fires in trains and decision-making on evacuation of passengers as to:

    - Reduce time in decision-making relative to the evacuation of passengers.

    - Provide operating personnel with insight in evaluating and reporting fires in trains.

    - Reduce time for evacuation of passengers.

2. Conduct seminars for Central Control personnel in the evaluation of fire reports, their response to the reporting personnel and the procedures for notifying the fire department. This would:

    - Provide Central Control personnel with experience in handling the emergencies.

    - Reduce tension of Central Control personnel.

    - Improve the relationship between the transit system and the local emergency organizations.

3. Conduct a formal training program for newly hired operating personnel in emergency evacuation of passengers from disabled trains and in fire safety. This program should be conducted in conjunction with local fire departments. The program would:

    - Provide the proper training in emergency procedures for operating personnel.

    - Reduce the possibility of confusion and delays during an emergency.

    - Reduce the risk of injury to passenger and operating personnel.

- Improve the operating personnel morale.

4. Conduct refresher courses for operating personnel in emergency evacuation of passengers from disabled trains and in fire safety as to:

   - Insure dissemination of up-to-date information and procedural changes.

   - Maintain high reliability and close coordination in evacuation and fire safety.

   - Improve operating personnel morale.

5. Periodically conduct actual fire drills that incorporate emergency evacuation procedures and fire safety for operating personnel, fire fighters, and Central Control personnel utilizing trains in tunnels, tubes, elevated locations, and shared train and busways. This would:

   - Provide actual experience in emergency evacuations, fire safety and fire suppression procedures.

   - Provide an opportunity to correct, improve, or change procedures from experience gained from drills.

   - Improve working relationships between agencies and departments involved.

6. Establish procedures and conduct training in the movement of a train on fire to the next station for passenger evacuation or to an area for ease of evacuation. This would:

   - Determine the best and safest means of movement of trains under fire conditions.

   - Allow for the establishment of specific areas for evacuation.

   - Provide experience for operating and supervisory personnel in the movement of trains under fire conditions.

7. Establish procedures and conduct training in the transfer of passengers from a train on fire to a rescue train as to:

   - Reduce the time for the transfer of passengers.
   - Reduce the confusion during the transfer of passengers.
   - Reduce the possibility of panic among the passengers.
   - Provide trained personnel for approaching and handling emergencies.

8. Inform all operating personnel, fire fighters, and Central Control personnel as to the location of emergency exits in tunnels and subways. Conduct personnel walking tours for actual views of the areas. This would:

   - Reduce the time to evacuate passengers through emergency exits.
   - Familiarize emergency and transit personnel with the locations of emergency exits.

9. Conduct a training program in the use of emergency rescue equipment and inform all operating personnel, fire fighters, and Central Control personnel as to the location of this equipment. This would:

   - Ensure direct access to equipment in time of need.
   - Ensure the proper operation of equipment in time of need.
   - Provide trained personnel for approaching and handling emergencies.

10. Initiate and maintain a program which effectively informs the riding public of emergency routes and procedures as to:

    - Improve the relationship between the transit system and the public.
    - Improve the evacuation of passengers during an emergency.

11. Inform all operating personnel, fire fighters, and Central Control personnel as to the location and operation of devices on the vehicles that will open side and end doors in an emergency. This would:

- Reduce the time to evacuate passengers.
- Familiarize the emergency and transit personnel with the location and operation of emergency devices for door operation.
- Reduce the prospect of panic.

Potential R&D

1. Perform human factors research on management and labor force attitudes and procedures in order to identify and correct unsafe practices and attitudes of operations and maintenance personnel. Performing these functions will lead to the reduction of incidents due to personnel action or inaction.

2. Conduct research on the psychology of vandals and develop ways of detecting and deterring them. Understanding this would be worth its cost in funds and time. This would:

   - Reduce vandalism on the vehicle.
   - Improve passenger-authority relationships.

3. Reference 13 provides an overview of the Automated Emergency Response System (AERS). This is a decision-making tool that should be further developed to assist transit systems in responding to emergency situations.

5. EXTERNAL FACTORS

The external factors discussed in this section are those not under the direct influence of the transit authority. However, they may still affect fire safety on the system. Such factors are too numerous to incorporate in this report; for example, what might happen at a right-of-way crossing which may involve other vehicles. Thus, this report will only address the two external factors that have impacted fire safety historically:

- Vandalism
- Weather conditions

5.1 VANDALISM

To lessen the impact of vandalism, a number of countermeasures can be adopted:

- Replace frequent arson target materials with materials that are difficult to ignite. This will reduce sources for ignition and help prevent vandalism/arson.
- Protect seat cushion undersides and seat backs from access by vandals. This will reduce the potential for arson.
- For those transit properties not so equipped, provide a coverboard of non-conductive material over the third rail to reduce the potential for grounds and/or short circuits caused by objects thrown onto the third rail that can cause ignition.
- For those systems that operate with trolley wire or catenary, provide non-conductive shields over wires at bridge or station platforms, where applicable, to reduce the potential for ignition from grounds and/or short circuits caused by objects thrown onto the wire.
- Provide intrusion alarms at fenced areas along the right-of-way to alert system personnel that the integrity of the right-of-way has been compromised. Alarms may also provide early warning should a fire in those areas materialize.

- Install smoke and fire detection apparatus within the interior of rail transit vehicles to alert train personnel should ignition materialize due to action by vandals. This would reduce the time for discovery of the fire, reduce damage to the vehicle, and provide timely warning so that sufficient time will be available to evacuate the vehicle should it become necessary to do so.

- Install smoke and fire detectors in station and subway/tunnel areas to alert system personnel should ignition materialize due to vandalism or other reasons. This would reduce discovery time, reduce damage to the facility, and provide a timely warning with sufficient time to evacuate passengers or Authority personnel should it become necessary to do so.

5.2 WEATHER CONDITIONS

Weather is a major consideration in the operation of a rail transit system. Wind, water, and temperature are serious concerns in maintaining service on the system and in fire security.

During a wind storm, systems that use trolley wire or catenary may be damaged by the force of the wind or broken by objects coming in contact with it. When the wire is severed, it could make contact with ground, arc, and cause ignition. The contact could be with a vehicle, should a vehicle be in the area at the time the wire falls. For those transit systems that utilize a third rail, high water may inundate the right-of-way and cause a conductive path through the water and arc, causing ignition.

Hot temperatures can cause the wire to expand and cause problems, and cold temperatures can cause the wire contact to snap. In those areas where rail transit systems experience sleet and ice, operating under these conditions with trolley pole or pantograph can cause arcing of such intensity that the wire could heat and melt, fall onto the roof of the vehicle, and cause ignition.

There is very little that a transit system can do about the environment. However, from the past experiences of individual transit systems, they can be prepared for rapid response to an environmental incident. For those systems utilizing trolley wire or catenary that are in an area that experiences sleet and ice storms, they can equip a portion of their fleet with ice scrapers on the trolley pole or pantograph. This would scrape the wire of sleet or ice. However, these vehicles would be required to operate within short headways in order to prevent buildup of this condition.

Relative to heavy rail vehicles operating on the third rail, sleet scrapers should be readily available for clearing the third rail of sleet and ice. Operating with sleet scrapers with short headways will aid in the prevention of ice or sleet on the third rail which, if not controlled, could create considerable arcing and cause ignition.

Relative to wind and flood, transit systems that have had previous experience with these Acts of God should have emergency response groups available. These groups, such as line crews and pump crews, can be dispatched within a short space of time and contain the incident before it does extensive damage, causes ignition and shuts down the system thereby creating a situating that would require rescue and evacuation of passengers from stalled vehicles.

6. INFORMATION MANAGEMENT/DATA ANALYSIS

One of the most important functions of a transit system is to provide safe and adequate service to the patrons within its operating areas. To accomplish this, the transit system must provide safe and reliable vehicles to cover the routes and headways.

In order to keep these vehicles in revenue service, serious considerations must be given to those problems that contribute to the downtime of the vehicle, the subsequent reduction in its availability, and the ultimate loss of service. Record keeping and data analysis can contribute to the reduction in downtime of a rail transit vehicle. With databases and information programs available to record and store information for each system and subsystem of the vehicle, transit management can retrieve and analyze the past history of incidents, scheduled and unscheduled maintenance, and make a determination as to the cause. Further analysis will aid in the determination of a method to prevent the recurrence of the incident.

With respect to fire and smoke incidents, complete and concise reporting of these incidents and complete data entry into the system will allow management to evaluate the information, establish a pattern for these incidents, focus on the cause, and develop a prevention criteria. Any piece of information about these vehicles, individually or collectively, no matter how inconsequential it may appear, should be recorded. In an analysis of fire incidents, a minute piece of information may be the key to the fire. Once the analysis has determined the cause of the fire, means can be taken to eliminate the cause.

Information from these databases can be used by transit system management in the design of the fire incident safeguards for new vehicle procurements and for the rehabilitation of older vehicles.

In any rail transit system, the collecting and recording of information relative to its vehicles (in terms of performance and fire incidents) is vital. Such information can be used in preventing fires, ensuring quick detection and suppression, and effective evacuation. Specific examples include:

1. Improving fire threat analysis by improving fire incident reporting to indicate a detailed description of ignition source, flammable material, and reason for failure (e.g., equipment, operator, maintenance, etc.). This information should be computerized for ease of retrieval, and analysis should include cost and downtime data. This will:

   - Provide a data bank to aid in establishing criteria for new vehicle design and older vehicle rehabilitation.

   - Aid in deterring fire risk and fire prevention areas of the vehicle.

2. Computerizing maintenance data including scheduled inspection and component replacement on specific vehicles to allow review of maintenance or inspections performed as well as unscheduled repairs. This will:

   - Insure that the complete history of vehicle maintenance is available. This would be beneficial in determining patterns of vehicle failures which could lead to fire propagation.

   - Derive causes of fires for which corrective action can be taken.

7. CONCLUSION

In closing, the ability to identify potential hazards and then address these hazards (by eliminating, controlling, or possibly accepting them) has and will provide the highest practical level of safety. The outcome of such a fire safety analysis is very transit system specific, and thus, it should be carried out for each authority. Still, one can make a few generalizations as presented below.

From discussions held with the transit community, it is necessary to recognize the fact that fires on transit systems will continue to occur. However, the numbers of fire incidents can be greatly reduced or their effects minimized if prevention, detection, and suppression measures, as recommended, are adopted.

From the information presented in this document, it should be recognized that the underside of a rail transit vehicle, with all of its equipment and subsystems, is the most vulnerable area for the occurrence of fire when compared to other areas of the vehicle. In addition, an undercar fire has the potential of being life-threatening should a fire erupt and the vehicle becomes immobilized within the confines of the subway, tunnel, or aerial structure. Accordingly, special care must be taken to preserve the integrity of the undercar equipment and subsystems and minimize the potential for fire ignition by performing proper preventative maintenance.

Since most fires on transit systems are unique in themselves, each fire must be thoroughly investigated and its cause determined. With the high volume of human life exposed in a transit system fire, a special type of expertise is necessary to reduce the hazard of loss of life. A means of obtaining this expertise is through training and retraining those people exposed to fire fighting and fire prevention. Documentation of each fire investigated would become a learning tool for these training periods.

Finally, it is apparent that many of the countermeasures identified in this report can be implemented with relative ease and at a minimal cost, but others will require extensive research and development to provide the protection described. Adopting as many as possible of the countermeasures on any transit system should greatly enhance the overall fire safety of rail transit vehicles, and, in turn, not place in jeopardy, the lives of the passengers and operating personnel within the vehicle.

8. RECOMMENDATIONS

Given the sensitivity relative to fires on transit systems, each system should commit itself to developing and implementing a program for the countermeasures that are applicable to its respective system. Where a particular countermeasure would require additional research and development efforts, the system should undertake the efforts at the earliest possible time frame in order to provide the protection needed to reduce the causes or ignition points of fires.

The individual transit system must assign an urgency factor to countermeasures. This urgency factor would define the timetable for implementation. It would define whether implementation would take place during new construction where the cost of even the most difficult-to-implement countermeasure would be relatively little or, during normal rehabilitation where, again, the costs would be relatively low. On the other hand, retrofit of the vehicles to incorporate countermeasures would require a substantial investment of funds.

It is called to the reader's attention, that in some cases, the technology may not exist for the implementation of some countermeasures and the cost would make this exercise exorbitant.

Once the reader has completed a review of this document, it will become apparent that most of the suggested countermeasures can be implemented by existing technology with labor cost being the chief restraint. The most predominant countermeasure that will require more than existing technology to implement is the use of wire insulation that has a low index of flammability, smoke emission, and toxicity. Although extensive research and development previously performed has produced guidelines and recommendations, more improvement in wire insulation is necessary. Several other countermeasures may not be able to be implemented with existing technology alone; some redesign and/or modification will be necessary.

These prospective countermeasures include:

- The design of an under-vehicle fire extinguishing system which can be activated automatically or manually.

- The installation of an indicator to inform the train operator when the rail transit vehicle is in the accelerating or braking modes of operation, and open power circuits if the rail car is not in the desirable mode of operation.

- The determination of the causes of propulsion controller fires and the modification of circuits/components to correct these causes.

- The installation of overheat sensor devices to alert the train operator of high temperature conditions.

- The design of a current collector shoe which would completely break off upon impact with objects along the trainway.

- The design of an improved ice scraper to remove ice from the third rail.

- The performance of full scale fire tests to evaluate flammability, smoke emission, and toxicity characteristics of interior materials.

- The development of the capability to use computer models to assess the impact of the flammability, smoke emission, and toxicity characteristics of interior materials on the threat to life and property.

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