Transit Cooperative Research Program

Sponsored by the Federal Transit Administration

RESEARCH RESULTS DIGEST

November 2001—Number 44

Subject Areas: VI Public Transit and VII Rail

Responsible Senior Program Officer: Christopher W. Jenks

Consensus Standards for the Rail Transit Industry

This digest provides the results to date of TCRP Project G-4 and its extension, G-4A, both of which are titled, "Developing Standards for System and Subsystem Interfaces in Electric Rail Passenger Vehicles." The digest was written by Thomas J. McGean, P.E., the principal investigator for the project.

INTRODUCTION

This digest provides information on the successful implementation of a comprehensive standards process for the rail transit industry using American National Standards Institute (ANSI) consensus procedures under the aegis of the Institute of Electrical and Electronic Engineers (IEEE) and the American Society of Mechanical Engineers (ASME). This effort, supported by the Transit Cooperative Research Program (TCRP), has established, for the first time in the United States, a permanent and ongoing process for developing rail transit standards using the consensus process. After 5 years of work by 19 working groups and more than 300 professionals, the practicality and workability of the process has been firmly established. Nine standards have successfully been balloted, approved, and published; 11 standards are under development; and 3 are under active consideration.

This digest discusses findings from work performed under TCRP Project G-4 and its extension, G-4A. The objective of the projects was to design a process for developing physical, logical, and electrical consensus standards for system and subsystem interfaces for elements of light rail, heavy rail, and commuter rail vehicles. In addition, the process was to be demonstrated through the production of one or more standards.

MAJOR ACCOMPLISHMENTS

Together, the IEEE and ASME standards activities developed under this TCRP program now provide the institutional framework for undertaking any needed rail transit vehicle standardization using ANSI-accredited consensus standards organizations. Nine standards have been published. In addition, nine IEEE and two ASME standards are currently under development, and an additional three standards are under active consideration. This project has assembled a team of highly qualified professionals from the rail transit community to develop standards needed to save money, promote safety, and make possible the migration of transit vehicle systems to integrated microprocessor-based control.

Approximately 300 individuals have volunteered their time and organizational resources to participate. Eighteen rail transit agencies (90 individuals) have participated in the process, along with approximately 50 suppliers (100 individuals), 30 consulting firms (70 individuals), and many governmental and other interested organizations (40 individuals).

Participation in professional society committees is voluntary, and either the members or their companies donate time to attend meetings and to work on the standards. The result is a good example of public-private cooperation. It is estimated that every public dollar spent by TCRP Project G-4 on standardization is matched by another eight dollars of private money spent by suppliers, transit agencies, and others on committee work (1). This matching not only effectively leverages limited federal research-and-development money, but also measures public support for the standards effort. If the effort ceases to be perceived as cost-effective, then private-sector support will probably be withdrawn.

CONTENTS

IEEE Standards

When the TCRP project was launched in 1996, industry experts created a list of critically needed standards. All of these standards have since been developed by the IEEE committee. These formally approved standards are as follows:

- **IEEE Standard 1477-1998, IEEE Standard for Passenger Information System for Rail Transit Vehicles.** This standard specifies the physical and electrical interfaces of the passenger information system for rail transit vehicle systems and subsystems. Lance Cooper, then of Washington Metropolitan Area Transit Authority, served as working group chair.
- **IEEE Standard 11-1999, IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles.** This standard applies to rotating electric machinery, which forms part of the propulsion and major auxiliary equipment on internally and externally powered, electrically propelled rail and road vehicles. It defines ratings, tests, and calculation procedures to permit comparison among machines for similar use and to enable evaluation of the suitability of machines for a given use. (This standard was already under development when the TCRP effort was initiated. The TCRP project assisted with obtaining final IEEE approval for publication, but was not directly involved in its preparation.)
- **IEEE Standard 1473-1999, IEEE Standard for Communications Protocol Aboard Trains.** This standard defines the protocol for intercar and intracar serial data communications between subsystems aboard passenger trains. Robert Anderson of GE Harmon served as working group chair.
- **IEEE Standard 1474.1-1999, IEEE Standard for Communications-Based Train Control Performance and Functional Requirements.** This standard establishes a set of performance and functional requirements necessary for enhancing performance, availability, operations, and train protection using a communications-based train control (CBTC) system. Alan Rumsey of Parsons Transportation Group served as working group chair.
- **IEEE Standard 1475-1999, IEEE Standard for the Functioning of and Interfaces Among Propulsion, Friction Brake, and Train-Borne Master Control on Rail Rapid Transit Vehicles.** This standard prescribes the interface functionality among propulsion, friction brake, and train-borne master control, including performance parameters, communications methods, and the means for measurement and verification of performance. David Phelps of the American Public Transportation Association (APTA) served as working group chair.
- **IEEE Standard 1482.1-1999, IEEE Standard for Rail Transit Vehicle Event Recorders.** This standard applies to event recorders, which are on-board devices with crashworthy memory that record data to support accident/incident analysis for rail transit vehicles. Functions, parameters, signals, systems, and subsystems to be monitored and recorded are identified, and diagnostic features or self-test options are described. Linda Sue Boehmer of LSB Technology served as working group chair.
- **IEEE Standard 1476-2000, IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces.** This standard delineates the electrical interface between the components comprising the auxiliary power system and other train-borne systems. Claude Gabriel of LTK Engineering Services served as working group chair.
- **IEEE Standard 1483-2000, IEEE Standard for the Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control.** This standard provides a set of verification tasks for processor-based equipment used in safety-critical applications on rail and transit systems. James Hoelscher of Alstom Signaling served as working group chair.
- **IEEE Standard 1478-2001, IEEE Standard for Environmental Conditions for Transit Car Electronic Equipment.** This standard specifies the baseline environmental conditions under which transit railcar electronic equipment shall both operate and survive, including temperature, humidity, atmospheric pressure, water, corrosive elements, and vibration or shock. Charles Elms of Lea+Elliott served as working group chair.

As the project progressed, additional standards activities were initiated at the request of the transit industry. As a result, the following standards are presently under development by the IEEE committee.

- **IEEE P-16, IEEE Draft Standard for Electrical and Electronic Control Apparatus on Rail Vehicles.** This standard will prescribe design, application, and test requirements for electrical and electronic control apparatus on rail vehicles. James Dietz of LTK Engineering Services serves as working group chair.
- **IEEE P-1474.2, IEEE Draft Standard for User Interface for Communications-Based Train Control Systems.** This standard will provide for consistent user interfaces that take advantage of the characteristics of CBTC systems to enhance service effectiveness. Alan Rumsey of Parsons Transportation Group serves as working group chair.
- **IEEE P-1482, IEEE Draft Standard for Rail Vehicle Monitoring and Diagnostic Systems.** This standard will apply to systems that monitor, collect, process, and present operating status and fault information for transit vehicles and trains of vehicles. It will identify functions, parameters, signals, systems, and subsystems that should be monitored. Robert McHugh of British Columbia Rapid Transit Company (BCRTC, or SkyTrain) serves as working group chair.

- **IEEE P-1536, IEEE Draft Standard for Rail Transit Vehicle Battery Physical Interface.** This standard will apply to the physical dimensions of a battery tray for a specified number of cells and battery-capacity rating. The standard is intended to facilitate multiagency joint purchases of batteries. Stanley Kwa of the Metropolitan Transportation Authority (MTA) New York City Transit (NYCT) serves as working group chair.
- **IEEE P-1544, IEEE Draft Standard for Transit Communications Interface Profiles for Rail Applications.** This standard will provide clearly defined message structures and content for intratrain communications. It will permit interoperability between disparate systems and equipment. Through consistent use of this standard, functional entities on rail vehicles will be able to communicate seamlessly with each other. Fred Woolsey of LTK Engineering Services serves as working group chair.
- **IEEE P-1558, IEEE Draft Standard for Software Documentation for Rail Equipment and Subsystems.** This standard will establish uniform minimum requirements for documentation of application software throughout the software development life cycle. It will apply to software for rail equipment and systems, including associated test and maintenance equipment. Paul Jamieson of Wabtec serves as working group chair.
- **IEEE P-1568, IEEE Draft Recommended Practice for Electrical Sizing of Nickel-Cadmium Batteries for Rail Passenger Vehicles.** During development of IEEE 1476, the auxiliary power standard, it became clear that a standard was needed for sizing nickel-cadmium batteries used in mobile applications, such as rail transit. IEEE P-1568 will meet this need by providing methods for electrical sizing of such batteries. Alex Sinyak of Bombardier serves as working group chair.
- **IEEE P-1570, IEEE Draft Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection.** The working group for this standard was formed in response to a request from the Federal Railroad Administration (FRA) to develop highway rail intersection standards in cooperation with the American Railway Engineering and Maintenance-of-Way Association (AREMA) and highway engineering groups. This working group has received additional funds from the FRA. The standard will define the logical and physical interfaces and the performance attributes for the interface between the rail subsystem and the highway subsystem at a highway rail intersection. The standard will be compatible with new National Transportation Communications for ITS Protocol (NTCIP) standards. William Petit of Safetran Systems serves as working group chair.
- **IEEE P-1582, IEEE Draft Standard for Environmental Requirements for Rail Transit Automatic Train Control Systems Wayside Equipment.** This standard will establish baseline environmental requirements for transit automatic train control (ATC) system wayside equipment. Environmental requirements include temperature, humidity, vibration, and electromagnetic interference. Harold Gillen of Union Switch and Signal serves as working group chair.

In addition to the aforementioned standards now being developed, two IEEE standards are being actively considered. Plans are underway to develop a standard communications protocol and technology for communications between rail vehicles and wayside and central. In addition, a subcommittee to develop standards for overhead catenary power distribution, led by Paul White of the Massachusetts Bay Transportation Authority, has been formed.

ASME Standards

The TCRP project also instituted a rail transit standards committee as part of ASME. The charter for the ASME Rail Transit Standards Committee was approved by the ASME Council on Codes and Standards in April 1998. The first activity of this group, led by Stan Canjea of New Jersey Transit, has been to develop new crashworthiness standards for light rail cars. A draft standard has been prepared, and the fourth draft is presently under committee review, with balloting expected later in 2001.

Recently, the ASME committee also agreed to develop similar crashworthiness and structural standards for rapid rail cars. This effort is being led by Keith Falk of MTA NYCT. In addition, negotiations are underway with the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) to develop a railcar heating, ventilation, and air-conditioning performance standard.

Use of Standards

The transit industry is using many of the consensus standards that have been published. New Jersey Transit has committed to using both the IEEE 1473 Communications Protocol and the data elements now being standardized by IEEE 1544 on its order of 24 locomotives and 230 Comet 5 cars. Beyond this order, the IEEE standards will be followed in the future to ensure interoperability for the New Jersey Transit fleet. IEEE Standard 1473 has also been specified by the Washington Metropolitan Area Transit Authority for its new Series 6000 railcars and will be used on the Sumitomo/ Nippon Sharyo commuter railcars being supplied to Chicago's Metra.

The Massachusetts Bay Transportation Authority (MBTA) specifications for the MBTA's blue/orange line cars require auxiliary power compliance with IEEE Standard 1476. The Chicago Transit Agency has ordered event recorders per IEEE Standard 1482.1 for its new railcars.

IEEE Standard 1474.1, the CBTC standard, has already been used for the Southeastern Pennsylvania Transportation Authority (SEPTA) CBTC procurement. In addition, the

Long Island Rail Road has specified compliance with both IEEE Standard 1474.1 and the new IEEE P-1474.2 in its specifications for the Babylon-to-Montauk CBTC. The same procurement also specifies compliance with IEEE Standard 1483, which governs critical safety software. This standard was also used in FRA Rules and Regulations Governing Railroad Signal and Train Control Systems Draft Part 236, Subpart H, as one of the acceptable standards for verification of safety, and by Lockheed-Martin as part of the Product Safety Plan for the North American Joint Positive Train Control Project. The Republic of Korea has used both IEEE Standard 1475 for propulsion and braking and IEEE Standard 1474.1 for CBTC in specifications for new cars.

Recently released technical specifications for the MTA NYCT R160 car (Section 16.5.1) specify that software documentation shall be consistent with IEEE P-1588, which remains in draft form at this time. The MTA NYCT also has incorporated IEEE Standard 16 into the R160 specifications (2).

KEY ISSUES RELATING TO STANDARDS

Key issues that have led to the need for standards include controlling capital and operating costs; improving passenger safety, equipment reliability, and the health of the supply industry; reducing the cost of spare parts and the cost of training maintenance personnel; and facilitating the introduction of complex electronic and computer systems. Constraints that limit the potential of standardization include the small annual volume of railcars sold and the worldwide nature of the railcar marketplace.

Reasons for Standards

The following are key reasons why standards are needed today:

- **Safety.** Transit standards are needed to improve and maintain safety. There are more than 2.5 billion light rail and subway passengers carried each year, more than four times as many persons as are carried by all U.S. airlines combined (3, 4). Until the standardization effort was initiated, no standards-development process existed to establish safety standards for these modes. As a reflection of how important this standards activity is to safety, the National Transportation Safety Board (NTSB) named event recorders for transit vehicles as its "most wanted" transportation safety improvement (5). Reacting to this high NTSB priority, this project's IEEE committee mounted a major effort to develop an event recorder standard for the transit industry. The standard has now been published as IEEE Standard 1482.1-1999.
- **Controlling costs.** The increasing cost of railcar procurement and maintenance has become a serious industry problem. Since the 1960s, railcar purchase costs have increased considerably faster than the rate of inflation has. The cost of car maintenance has also been growing rapidly. It cost less than 10 cents per car mile to maintain rail equipment in the 1960s; today, the cost is $1.20 per car mile (6). Lack of standardized interfaces also leads to single-source spare parts procurement, which results in noncompetitive prices and unpredictable parts availability, which in turn require transit agencies to stock a greater spare parts inventory. A 1982 study estimated the value of this inventory at over $250 million, and the value is probably close to twice that today (7).

  The "custom engineering" approach to railcar procurement has been identified as a major reason for these high costs. Standards save money spent to purchase, operate, and maintain equipment; purchase and inventory spare parts; and train personnel. It is estimated that railcar standards being drafted under this project can save a third of a billion dollars annually, an amount nearly three times the total federal operating grant approvals for urbanized areas for both bus and rail in FY 1999 (8, 9). Transit currently faces a major budget limitation, and standardizing interfaces is a readily identifiable way to save a lot of money. For example, James Kemp, the manager of Advanced Public Transportation Systems for New Jersey Transit, estimates that the IEEE Standard 1473, "Standard for Communications Protocol Aboard Trains" (which was developed under this TCRP project), would save New Jersey Transit $420,000 per year (10).

- **Information age concerns.** Modern computer technology offers both a new opportunity and new challenges to the industry. The opportunity is to significantly improve performance and reduce costs, and the challenges are to maintain complex new electronics and to deal with the possibility of increased costs due to customized, one-of-a-kind designs. These one-of-a-kind designs are especially problematic if they limit subsystem reprocurement to a single supplier.

  There is a serious risk of losing the modest degree of interoperability and standardization that has existed historically. This loss would result in designs that cannot be replaced or even be properly supported after the brief life cycle of the microprocessor-based technology. For example, the miles of expensive copper wiring onboard current railcars are being replaced with microprocessor systems, which are interconnected with local area network architectures. The hundred pin connectors transmitting discrete signals from car to car are being replaced with multiplexed, optical, or radio frequency connections. But unless these systems use common communications protocols, data elements, architectures, and hardware interfaces, cars purchased from one supplier under one car order will not be able to be coupled

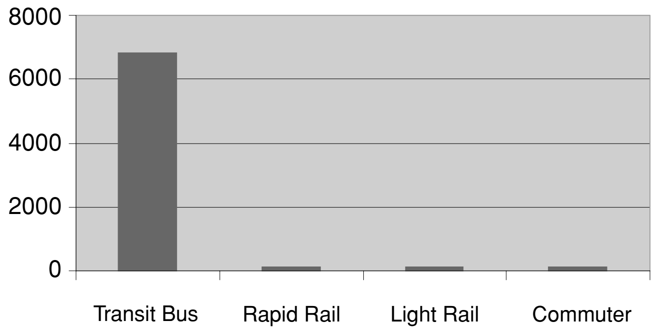

Figure 1. Sales of transit buses versus railcars in 1999. Note: Statistics taken from the American Public Transportation Association, Public Transportation Fact Book *(Washington, D.C.: March 2001, p. 96).*

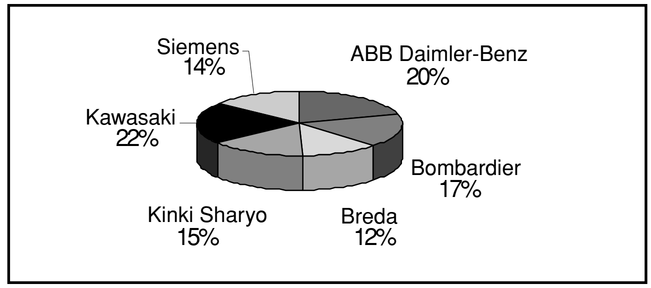

Figure 2. Railcar suppliers to the United States in 1999. Note: Percentages taken from the American Public Transportation Association, Public Transportation Fact Book *(Washington, D.C.: March 2001, p. 103).*

into a train with cars from another order and supplier. In other words, the ability to interchange cars within the fleet, which has existed on most rail transit properties for many years, could be lost. Recently, interoperability problems have been encountered despite the transit agency's specifying a common protocol for its cars because of a lack of standardization of data elements.

- **Training maintenance personnel.** Lack of standardized interfaces complicates the training of maintenance personnel because troubleshooting techniques for the various suppliers' equipment are often completely different.
- **Equipment reliability.** Lack of standards fosters a custom engineering approach that prevents the supply industry from developing equipment in the normal, orderly evolutionary manner that is customary in other industries. Estimates from 1982 indicated that reduced failure rates from standardization could have saved the industry up to $10 million per year (11).

Key Constraints

Constraints limiting the standards process for rail transit include the following:

- **Low sales volume.** The rail transit industry is vastly smaller than other ground transportation industries are. In 1999, the United States bought 8.7 million passenger cars, 8.7 million trucks, and 6,815 transit buses. Figure 1 contrasts the number of transit buses with the 122 rapid rail cars, 123 light rail cars, and 132 commuter railcars purchased by the U.S. rail transit industry in the same year (12, 13). Typical order size is also small, with railcar order sizes of 30-100 cars, light rail orders ranging from a few to about 20 cars, and commuter rail orders typically between those extremes. Because of the low volume of U.S. transit railcar sales, it is important that any standards effort keep open the possibility of worldwide standards, where the larger market size makes greater savings possible.
- **High unit price.** Although, in 1999, U.S. passenger car unit sales were 23,000 times that of rail transit cars (including rapid rail cars, light rail cars, and commuter rail cars), the unit price of a railcar is roughly 100 times greater than that of an automobile. As a result, the small unit volume of railcar orders still adds up to $1.25 billion per year in the United States (14).
- **Reliance on worldwide marketplace.** Because of the small volume and high unit price, transit suppliers seek to sell to the world market. All of the railcars built for the U.S. market in 1999 were from multinational or overseas suppliers, including ABB Daimler-Benz (Now Bombardier), Bombardier, Breda, Kawasaki, Kinki Sharyo, and Siemens (15). (See Figure 2.)

Implications of Needs and Constraints

Three important requirements for a successful standards process flow from the previous key issues (16). First, the standards must be of mutual benefit to both supplier and users. Second, the standards must be developed by consensus. Third, the standards must be voluntary. These requirements also lead to consideration of the consensus-based, voluntary ANSI process. ANSI procedures are intended to ensure a balanced committee that represents all interests. The procedures (a) provide supermajority voting requirements to ensure consensus, (b) require that negative comments be addressed, and (c) set forth a period for public comment before standards take effect. By ensuring that standards represent true consensus, the ANSI procedures make standards more forceful in litigation and in the government regulatory process.

STANDARDS PRINCIPLES, GOVERNING BODIES, AND U.S. LAW

The voluntary standards system in the United States consists of many standards developers who write and maintain one or more national standards. Among these developers are representatives from professional societies, trade associations, and other organizations. Thousands of individuals, companies, government agencies, and other organizations voluntarily contribute their knowledge, talent, and effort to standards development.

ANSI Standards

Most standards developers and participants support ANSI as the central body for identifying a single consistent set of voluntary standards. ANSI approval signifies that the principles of openness and due process have been followed and that a consensus of parties directly and materially affected by the standards has been achieved. ANSI is the U.S. member of international standards organizations, such as the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the Pacific Area Standards Congress (PASC). As such, ANSI coordinates the activities of U.S. participants in these groups.

The TCRP G-4 research project required that the consensus standards process follow ANSI guidelines. The approach taken used the standards processes of the IEEE and ASME, which are ANSI-accredited organizations that have all necessary rules and procedures in place to ensure ANSI compliance.

National Technology Transfer and Advancement Act

The National Technology Transfer and Advancement Act (Public Law 104-113), passed by Congress and signed into law in March 1996, enhances the importance of consensus standards in the legal and regulatory structure of the United States (17). Following the bill's passage, federal agencies must use, wherever possible, technical standards developed by consensus organizations, such as the IEEE, rather than develop their own regulations. In addition, federal agencies must consult with and, if possible, participate with voluntary, private-sector consensus standards organizations in developing technical standards. This act gives the force of law to prior Office of Management and Budget (OMB) directives, such as OMB Circular A-119, encouraging government agencies to adopt private, voluntary standards and to participate in the standards' development (18).

The Federal Transit Administration (FTA), in its annual report to the OMB on the implementation of OMB Circular A-119 and Public Law 104-113, has cited its participation in the development of the IEEE standards supported by this TCRP project (19).

Consensus Principles

Five imperative principles drive the standards process (20):

- **Due process.** Due process means having procedures, making them publicly available, and following them. This principle ensures that the process is rational and consistent and that the process is not being run arbitrarily or inconsistently to suit the desires of a particular person, group, or situation.
- **Openness.** Openness means that everyone with a legitimate interest has access to the standards process. This principle ensures that all materially interested and affected parties can participate in the standards development activity and ensures that the results of the deliberations are publicly available. The latter guarantee is usually achieved through having readily available minutes of the meetings. The objective of openness is to avoid the possibility of collusion or the appearance of obstructing anyone from participating. Openness also provides protection against antitrust situations. All working group meetings are open, and anyone may attend. This principle must be employed for every official standards meeting.
- **Consensus.** Consensus means agreement among the majority. It does not mean uniformity. For example, according to IEEE rules, 75 percent of balloting group members must return their ballots, and 75 percent of the ballots not abstaining must approve the standard. If these requirements are met, consensus has been achieved according to IEEE procedure (21).
- **Balance.** The balloting group (i.e., the group that votes on the standard) must consist of a balance of interests, with no domination by any one group or company. In the IEEE, balance is achieved by placing potential balloters into one of three categories: producers, users, and general interest. Producers are parties that make the product being standardized (in this case, rail transit suppliers). Users are parties that buy and operate the product being standardized (in this case, transit agencies). General interest includes parties that neither make nor use the product being standardized (in this case, general interest people are likely to be members of the FTA, the U.S.DOT, or state DOTS; APTA officials; members of regulatory agencies, such as the California Public Utilities Commission; or academics). To achieve balance, the IEEE requires that no category other than general interest can contain more than 50 percent of the balloting group membership. In addition, the procedures for the IEEE Rail Transit Vehicle Interface Standards Committee require that there be no more than two people from any single organization. (Note: The balance requirement does not apply to the working group [i.e., the group that prepares the draft standard], which can consist entirely of members from a single company.)
- **Right of appeal.** There are typically two types of appeals: procedural and technical. Appeals can be made at any point in the process, but, prior to standards approval, they are usually handled by the working group, which prepares the standard. After the standard is approved, if there is still a concern, an appeal can be made to the

governing Standards Board. There are specified time limits for appeals.

Advantages of Using ANSI-Accredited Engineering Societies

TCRP Project G-4 uses ANSI-accredited engineering societies as the vehicle for its standards activity because they offer a number of advantages in developing consensus standards:

- **Adherence to openness, due process, balance, and consensus.** The engineering societies that are accredited members of ANSI are audited for adherence to the principles of openness, due process, and balance, which are needed to achieve a consensus of those directly and materially affected by the standard.
- **Guaranteed use in federal regulatory activities.** ANSI accreditation also ensures that any standard developed will be considered a voluntary consensus standard by OMB Circular A-119. This consideration, by Public Law 104-113, requires federal agencies to use the standard in their regulatory activities. Any industry attempting self-regulation should consider using an ANSI-accredited process to ensure that the industry's significant investment results in consensus standards that are recognized as such by federal regulatory agencies.
- **Global reach.** Another advantage of ANSI accreditation stems from ANSI's role as the U.S. member of international standards organizations, such as the ISO, the IEC, and PASC (22). Developing standards under ANSI becomes especially important if future adoption by any of these international standards groups is considered a possibility. Although any group can apply for ANSI accreditation, using an already-accredited engineering society is faster, simpler, and less expensive than using an unaccredited agency.
- **In-place procedures and expertise.** Another advantage of using ANSI-accredited engineering societies for standards activities includes the societies' well-established procedures. ANSI-accredited societies have operating procedures, bylaws, balloting procedures, and appeal mechanisms established and in place and have experienced professional staff to answer questions and to help familiarize the volunteers developing standards with these rules.
- **Legal stature.** Another advantage of using ANSI-accredited engineering societies is that engineering society standards offer an extensive body of court precedent. Standards, unlike many other technical papers and reports, are quasi-legal documents. Standards are used as evidence to either substantiate or refute points in courts of law. Standards also become legal documents as they are adopted by various government and regulatory agencies. When this adoption happens, the content and decisions in a standard carry more weight and the process by which they are developed falls under much more scrutiny. Because engineering society standards have been widely used in building codes for many years, there is a large body of case law governing the use of these standards (23, 24). On the other hand, the requirements of Public Law 104-113 regarding citing standards in federal regulations have been in effect for only a couple years. It is reassuring to have the extensive body of court precedent available from engineering society standards.
- **Liability protection.** Another advantage of using ANSI-accredited engineering societies is liability protection. If an industry operates under an accredited engineering society and follows the society's rules and procedures, all professionals involved will usually be released from liability through an "umbrella of indemnification." This umbrella of indemnification legally protects the involved professionals from liability of any actions taken creating the standard and ensures that, if personal actions are called into question, the engineering society will defend the involved people in court (25). (Note: The engineering society protection is in addition to the significant new legal protection afforded to standards volunteers under the recently passed Volunteer Protection Act of 1997 [24]. This new law exempts volunteers of nonprofit corporations [such as engineering societies] from civil liability for harm caused by an act or omission of the volunteer on behalf of the organization. To obtain this exemption, the volunteer must have been acting within the scope of his or her responsibilities and must have been properly licensed or otherwise authorized for the activity. In addition, the harm must not have been caused by willful or criminal misconduct; gross negligence; reckless misconduct; or a conscious, flagrant indifference to the rights or safety of the individual harmed. This new law provides significant added protection to professionals involved in standards activities.)
- **Credibility.** Because standards developed by ANSI-accredited engineering societies are developed by consensus among people with a material interest, can be adopted worldwide, and have legal standing, they will be used. No one writing transit specifications is likely to assume the legal risk of ignoring an approved engineering society standard because errors and omissions insurance requires using accepted engineering practices.

PROJECT APPROACH

This project's approach leveraged its TCRP research funds to create self-supporting, industry-sponsored rail transit standards committees under the auspices of the IEEE and ASME. The IEEE and ASME are both accredited by ANSI and so offer all of the previously cited benefits of the ANSI process. The project spent no time developing standards committee procedures and petitioning for ANSI certification because the IEEE and ASME already have rules and procedures in place.

The approach to implementing the standards process was as follows:

1. The research team identified rail transit system and subsystem interfaces that were attractive candidates for the development of standards. Interfaces included both those within the vehicle and those between the vehicle and wayside equipment.
2. IEEE and ASME standards committees were formed, which, in turn, established working groups to prepare draft standards in areas of interest to committee members. This formation of committees involved working with IEEE and ASME officials to obtain needed approvals, preparing a mailing list of people to invite to join the two committees, and publicizing the committees, in transit industry publications and at conferences.
3. A "kickoff" meeting was conducted to initiate the standards committees. At this "kickoff" meeting, committee members selected the candidate standards they wished to implement, formed working groups to draft these standards, and appointed volunteer working group chairs. Formal documents required to establish standards projects within the IEEE and ASME were prepared and submitted, and all necessary approvals were obtained.
4. Periodic meetings of the sponsoring IEEE and ASME standards committees were held three or four times per year to monitor progress of the working groups, to review in detail the standards being produced, and to establish new standards efforts where needed by the rail transit industry.
5. After standards received preliminary approval from the sponsoring committee, they were submitted to a formal ballot process using ANSI-approved procedures. After all negative comments received from the ballot process had been addressed, the standard was then submitted to review boards within the engineering societies for final approval and publishing.

The following sections describe these steps in detail.

STEP 1: IDENTIFY CANDIDATES FOR STANDARDS

Candidate interfaces for standardization were identified by the project team at an intensive 2-day workshop and summarized in a working paper, TCRP G-4 Task One Working Paper, "Rail Transit Vehicle Standardization Options" (25). The workshop consisted of the principal investigator, an expert in conventional rail vehicle interfaces, and an expert in new microprocessor-based systems. Ideas for standards were generated using both bottom-up (or synthetic) techniques and top-down (or analytical) techniques. For the bottom-up approach, lists of suggested ideas prepared by each participant based on personal experience were used as the raw material. For the top-down approach, a comprehensive rail transit vehicle interface checklist was prepared using three source documents: the table of contents from the FTA-developed "Core Spec" for rapid rail cars, a list of commuter railcar elements assembled for the APTA Rail Standards Committee, and a light rail specification subsystem and component listing developed to assist with FTA review of procurement documents. The checklist reminded workshop participants of all aspects to consider during the team working session.

The heart of the workshop centered on a set of data forms generated in spreadsheet format. Standardization ideas generated during both the top-down and bottom-up work sessions were entered directly onto these forms in real time during the workshop. The forms included the name of the concept, a file number, and identification of the modes impacted (i.e., rapid rail, light rail, commuter rail, or a combination). Other information entered included a brief description of the concept and its pros and cons, identification of people or organizations active in the area, and identification of any known ongoing efforts at standardization already underway.

To estimate the potential benefits of each concept, the group made a very rough order-of-magnitude estimate of the annual dollar-cost impact that could accrue from implementing the proposed standard. To protect against misuse of the estimates, the simple assumptions on which the cost estimate was based were entered on each form. The listing of assumptions enabled users to judge the validity of the estimate or make adjustments based on their own judgements. The group also estimated for each standard concept the likelihood that the standards effort would be successful. To make this estimate, the group relied on its knowledge of the railcar industry and considered possible market, institutional, and technical obstacles. In each case, the concept was assigned as having a high, medium, or low likelihood of success.

To generate an expected value for the ideas, the expectation of annual savings needed to be multiplied by the probability of success. To make this calculation, it was assumed that concepts with a high likelihood of success had a probability of 80 percent, concepts with a medium likelihood of success had a probability of 50 percent, and concepts with a low likelihood of success had a probability of 20 percent. By multiplying this probability by the annual dollar impact, the group obtained an annual expected savings for each standardization concept. (Data on the rail transit fleet was taken from the 1994 Passenger Vehicle Fleet Inventory [26] and the 1994-1995 APTA Transit Fact Book [27]. To estimate capital recovery, an interest rate of 7 percent was assumed.)

The workshop generated 26 standardization concepts. The three highest-benefit concepts all involved new microprocessor

TABLE 1 Workshop recommendations

Concept	Probability of Success	$ Millions Per Year Expected Value
Communications-Based Train Control	High	116.0
Health-Monitoring Systems	High	77.7
Communications Protocols on Trains	High	56.2
Adopt ARR Standards for Commuter Rail	High	37.0
Accessibility Requirements	High	20.9
VOBC/Propulsion Controller/Motor/Brake	Medium	14.5
Auxiliary Power System	High	8.6
Wheel & Tread Dimensions	Medium	6.5
Coupler Standards	Medium	6.1
Vehicle Passenger Information	High	4.3
Conducted Emissions Limits	Low	3.9
Crashworthiness	Low	3.4
Standard Brake Actuator	Low	2.6
LRT Buff Load Standard	Low	2.0
Locomotive Systems Integration	High	1.5
Wheel Temperature Standard	High	1.5
Door Obstruction Sensing	Medium	0.9
Low Floor LRV Floor Height	Low	0.8
Wheel Slip System Requirements	Low	0.5
Grounding & Traction Return	Low	0.4
Tech Spec. Org. & Format	Medium	0.3
Brake Shoe/Pad Standards	High	0.2
Ratify/Reactivate IEEE and IEC Standards	High	0.2
Exterior Illumination	Medium	0.2
Car HVAC Requirements	Medium	0.2

technology. These concepts were CBTC, health-monitoring systems, and communications protocols on trains. A workshop report documenting the assessment was then prepared for submission to the newly formed rail transit standards committee. Table 1 shows the workshop recommendations.

STEP 2: FORM AN IEEE STANDARDS COMMITTEE

This section discusses the establishment of the IEEE Rail Transit Vehicle Interface Standards Committee (RTVISC) and the formation of active working groups to draft standards.

Every IEEE standard requires a sponsor. The IEEE Standards Board Bylaws define the sponsor as "a group of individuals who have a professed interest in the development of standards (either by direct participation or by the process of review) in technological areas that fall under the general scope of interest to the IEEE" (28). Sponsors of IEEE standards projects are committees that are responsible for the development and coordination of the standards project and the maintenance of the standard after its approval by the IEEE Standards Board. The IEEE Standards

Board Bylaws state that the sponsor may be a standards committee of an IEEE society.

Under the TCRP G-4 project, the RTVISC was formed within the IEEE Vehicular Technology Society to serve as the sponsor for all IEEE rail transit standards. The RTVISC was also set up to be the balloting group for all IEEE rail transit standards.

Working groups were also formed to prepare IEEE standards. IEEE working groups are open to anyone; whereas joining a balloting group requires having an interest in the subject and IEEE or affiliate membership (or a waiver for the IEEE membership), anyone can join a working group. Working group meetings are run according to an announced agenda distributed in advance of the meeting. Working groups seek to achieve consensus on controversial issues prior to balloting of the standard.

To initiate formation of the RTVISC, the IEEE committee contacted the president of the IEEE Vehicular Technology Society (VTS). The president established the RTVISC, duly notified the VTS Board, and appointed the chair pursuant to the president's authority under the Constitution of the Vehicular Technology Society. The chair contacted IEEE standards staff and, at the staff's request, prepared policy and procedures for operation of the RTVISC. A biographical sheet to be completed by people applying for membership on the committee was also prepared. IEEE staff also circulated the proposal to form the committee to the IEEE Transportation Systems Standards Coordinating Committee for comments. Copies were obtained of the IEEE Standards Board Bylaws, the IEEE Standards Operations Manual, the IEEE Standards Style Manual, and the IEEE Standards Companion, which gives advice on establishing a standards committee (29).

As a result of these efforts, the RTVISC was officially formed as an IEEE standards committee under the Standards Committee of the VTS. The committee officially reported to the IEEE vice chair of land transportation.

Formation of RTVISC Steering Committee

With the RTVISC established, the next step was to form a steering committee to assist the chair in organizing the committee. To ensure balance, the steering committee comprised three representatives of transit agencies, three representatives of transit suppliers, two general interest members, the RTVISC chair, and the president of the VTS. Figure 3 shows the makeup of the initial steering committee.

Chair:
Tom McGean, TCRP G-4 Principal Investigator

VTS President:
Linda Sue Boehmer, LSB Technology

Transit Agencies:
Yehuda Gross,* MTA (Maryland)
Gene Sansone, NYCT (New York City)
Russ Jackson,* SEPTA (Philadelphia)

Suppliers:
Ron Lawrence,* Adtranz
Claude Gabriel,* Bombardier
Robert Pascoe, Union Switch & Signal

General Interest:
Lou Sanders, APTA
Ron Kangas,* FTA

*Company affiliations are those at the time the committee was formed. The affiliation of this member has since changed.

Figure 3. Initial RTVISC Steering Committee membership.

Initial Meeting

The steering committee first met on March 25, 1996, in New York City for the purpose of organizing the full committee. In addition to the steering committee members, Walter Keevil (chair of the TCRP G-4 Project Panel) and Jim Dietz (a member of the TCRP G-4 project team) were present.

Mailing List for the RTVISC

Each member of the steering committee was asked to recommend people for a mailing list for invitations to apply for RTVISC membership. A tentative list was composed using these suggestions. At the meeting, the steering committee members reviewed the list and suggested additional names. Each steering committee member was asked to review the tentative list and check off people who, in the member's opinion, would be valuable members of the committee. Review and processing of the steering committee recommendations produced a mailing list with 53 names of people well known to be active in areas important to rail transit vehicle interfaces.

Organization of Full Committee

Letters inviting people to apply for membership on the RTVISC were mailed to all people on the mailing list. Each letter included an application form.

General Publicity

Because membership on consensus standards committees is open to all interested people, relying solely on a prepared mailing list for publicity is insufficient. To make sure that all interested people had the opportunity to join the committee, formation of the RTVISC was widely publicized in industry circles as follows:

- Formation of the committee was announced at a session on standards development efforts held at the sixth annual meeting of the Intelligent Transportation Society of America in Houston, Texas, April 15-18, 1996.
- Formation of the committee was announced at the first meeting of the ITS America Advanced Public Transportation Systems Working Advisory Group 8. This group advises ITS America on issues related to the U.S. position before ISO Technical Committee 204, Transportation Information and Control Systems. In addition, direct contact was made with the ITS American Working Group 8 chair, the director of systems integration for ITS America, and the head of the IEEE Standards Coordinating Committee on ITS.
- An article announcing formation of the committee was published in the April 1996 issue of *Railway Age*.
- An article announcing formation of the committee was published in the May 6, 1996, issue of *Passenger Transport*.
- Formation of the committee was announced in a speech to the monthly luncheon meeting of the IEEE and ASME in Washington, D.C.
- Press releases announcing formation of the committee were sent to the editors of *Railway Age, the VTS Newsletter, TR News, Passenger Transport, and TransitPulse*.
- Formation of the committee was announced on the electronic bulletin board for Communications Based Signaling (cbs@tsd.org).
- Formation of the committee was announced in a paper given May 2 at the 1996 ASME/IEEE Joint Railroad Conference in Oak Brook, Illinois, and a copy of the paper was published in the conference proceedings.
- Formation of the committee was announced in a paper given June 4, 1996, at the 1996 APTA Rail Conference in Atlanta, Georgia, and a copy of the paper was published in the conference proceedings.
- Formation of the committee was announced at the annual meeting of the IEEE Land Transportation Division on May 1, 1996, in Oak Brook, Illinois.
- The chair of the APTA Rolling Stock Committee was contacted and notified about the formation of the RTVISC.
- Direct contact was made with the chair of the ASME Rail Division, the manager of division affairs for the ASME Rail Division, the vice president of the ASME Environmental and Transportation Group, and a representative of the ASME Rail Transit Division Washington, D.C., Chapter.
- Direct contact was made with the FRA.
- Formation of the committee was announced at the MTA NYCT Specifications Peer Review meeting held in New York City, March 25-27, 1996.

Application forms for committee membership were sent to all people requesting membership as a result of hearing about the committee through these or other channels.

Formation of Committee

A record was kept of the date of receipt of all applications for membership, and members were admitted in the order of application receipt (subject to the following restrictions).

Although one need not be an IEEE or affiliate member to join the RTVISC, the IEEE Standards Operations Manual, Section 5.4.1, requires that the RTVISC be balanced among users, producers, and general interest members (30). Users are parties that use the product being standardized (in this case, transit agencies or their consultants). Producers are parties that supply the product (in this case, vehicle or vehicle subsystem suppliers and their consultants). General interest members are everybody else, including people from regulatory agencies and federal and state DOTs, academics, and members of advocacy groups. To achieve balance, no one group may constitute more than 50 percent of the membership.

TABLE 2 Ranking of standards

Concept	Panel Score
Communications Protocols on Trains	89
Communication-Based Train Control	88
Health-Monitoring Systems	54
VOBC/Propulsion/Brake/Controller	25
Safety Standards for Signaling Systems	17
LRT Buffing Load Standard	10
Auxiliary Power Systems	9
Vehicle Passenger Information Systems	9
Door Obstruction Sensing and Safety	8
Adapt AAR Standards for Commuter Rail	8
Coupler Standards	8
Side and Buff Strength, Crashworthiness	7
Accessibility Requirements	7
Locomotive Systems Integration	7

In establishing committee policy and procedures, two other requirements were established. First, no more than two people should be on the committee from any single organization. Second, to keep the committee manageable, its size is limited to 50 people.

Subject to these restrictions, applicants were accepted in the order in which they applied. It should be stressed that these limits on size and balance do not apply to working groups formed to draft standards. There are no constraints on who may assist a working group.

STEP 3: LAUNCH THE STANDARDS EFFORT

The kickoff meeting of the RTVISC was held at APTA headquarters in Washington, D.C., on May 23, 1996. The purpose for the all-day meeting was to select areas in which standards were needed and to form working groups to draft standards in these areas. Forty-five people attended the meeting.

Standards Committee Rankings

At the kickoff meeting, the RTVISC was asked to evaluate the results of the project team workshop in order to arrive at its own industry consensus on which standards should be implemented.

Committee members were all provided with a copy of the TCRP G-4 Task One Working Paper, "Rail Transit Vehicle Standardization Options" (25), which documented the results of the project team workshop.

Committee members were asked to nominate and rank according to importance four of the task force-selected activities for committee action by completing a ballot. The area listed first was scored four points, the second three points, the third two points, and the last one point. Scores from all members submitting ballots were summed in a spreadsheet, and the raw scores were used to rank standards activities. The results of the ranking are shown in Table 2. It should be noted that there was close agreement between the rankings of the project team and those of the committee members. The top three areas were the same in both lists, although the order was slightly different. Of the top 10 areas suggested by the project team, only one area failed to rank within the top 14 suggested by the committee. Some of the top areas identified by the committee for standards efforts included the following.

Communications Protocols Aboard Trains

The trend in controls has been away from centralized control schemes and toward smaller, less expensive, local controllers that communicate over local area networks. Older control schemes used relays for logic purposes. At first, attempts to use microprocessors centralized the logic function in the central processing unit (CPU) of a programmable logic controller (PLC). This centralization replaced the extensive wiring and large number of relays that used to be required to generate even the simplest of control functions. Furthermore, when microprocessors were first used, changes in logic no longer required rewiring, but could be implemented by software reprogramming. Now, the transit industry is distributing control to smaller, local controllers, or "intelligent" input/output devices, that communicate with each other. A vast reduction in wiring is possible through locating the controlling device closer to the equipment it controls. The loss of a single device, such as the CPU module in a PLC, no longer disables the entire system. This new approach elevates the importance of the communications channel. Two important forms of communications are to be considered: intracar communications and intercar communications. Three mediums for communications are in use today: fiberoptics, twisted-pair copper wiring, and wireless (radio) technologies.

It was important to create a standard communications protocol for distributed controllers on each car, as well as for trainline communications between cars. When the committee first met, there was no industry-preferred communications standard for vehicle subsystems, and railcar specifications were not requiring suppliers to conform to a uniform standard. This lack of standards could have caused each supplier to design its own communications protocol. This concept has potential application to the entire North American fleet.

CBTC

When the committee first met, both the Bay Area Rapid Transit (BART) and MTA NYCT were actively considering new communications-based signaling systems using wireless communications and microprocessors to handle ATP, automatic train operation (ATO), and automatic train supervision (ATS). Other systems, such as the San Francisco Municipal Railway, were also using microprocessors to replace relays in a more traditional hardwired signaling system. This area was expected to transform ATC, and, unless proper steps were taken, transit agencies could be locked into a single supplier after they bought one of these new signaling systems.

Health-Monitoring Systems

Standards for on-board diagnostics and health-monitoring systems could promote interchangeability, eliminate the need for suppliers to custom design for each procurement, and drastically reduce the cost of these systems. Such an approach would be especially promising if done in conjunction with standardization of communications protocols onboard trains because it could result in a readily programmable plug-in unit.

Interface Between the VOBC and the Propulsion Controller, Motor, and Brake Systems

The following are typical of trainline signals needed to interface between the vehicle on-board control (VOBC) and the propulsion controller, motor, and brake systems:

- Torque-demand signal,
- Maximum-speed limit,
- Overspeed signal,
- Motoring-braking signal,
- Propulsion-enable signal,
- Forward-and-reverse signals,
- Propulsion-on signal,
- Brake-control signal, and
- Brakes-released-and-applied signal.

When the committee first met, some critical functions, such as direction and operating mode, were effectively standardized by default because they used either the presence or absence of standard-battery voltage impressed on discrete wire trainlines. Discrete trainlines for step-wise tractive effort control had been less common because analog "P" wire, current-loop control was introduced. The common European practice was to use a variable-width, pulsed-signal analog control. This control had also been supplied on a few light rail vehicle fleets in the United States.

Control interface standardization was expected to enhance the car builder's flexibility to mix and match major subsystems in a basic car design, thereby providing lower costs, better subsystem supplier support, or both. Control interface standardization would also establish an industrywide due diligence standard for safety design aspects. Finally, control interface standardization would facilitate subsystem upgrades at midlife overhauls by easing the replacement of obsolete subsystem hardware, as well as making possible the use of still-serviceable subsystem equipment from scrapped car bodies.

Safety Standards for Wireless Communications and Vital Software

Standards were needed to provide an agreed-upon means to verify that vital software achieved the intent of "fail-safe" performance. As vital controls have moved increasingly from hardware- to software-based systems, it has become increasingly important to have accepted methods for verifying that all identified functions have been implemented safely. A standard was needed to identify the functions that must be performed fail-safely or vitally and to verify that the design and its implementation perform these functions in a fail-safe manner and meet the system safety goals.

Side and Buff Strength and Crashworthiness

This area includes proposals for a light rail buffing load standard, proposals for side and buff strength, and crashworthiness standards in general. Members indicated that a standard was needed in this area, but that it was not an IEEE activity. Members recommended that this standard activity be pursued within an ASME rail standards committee. A number of highly publicized commuter train accidents had brought the issue of the side and buff strength of transit vehicles back into the public limelight. However, the area is controversial. Numerous foreign car-builders have been convinced that U.S. light rail buff loads, which are two to four times higher than in European or Japanese practice, are unnecessary and expensive. Conversely, because of the recent accidents, there was also pressure to maintain or even increase the strength of commuter railcars. One possibly satisfactory solution was to base requirements on crashworthiness, rather than structural strength, permitting the designer to use collapsing devices to absorb collision energy instead of simply using brute strength. A standards working group could rationalize the conflicting data and opinions and possibly reach a consensus that would achieve better safety for the passenger and also provide a lighter and less costly car. The advantage of using a consensus standards approach is evident when the liability risks of any changes in this area are considered.

Auxiliary Medium-Power Voltage and Frequency

Medium-power loads on rail vehicles are primarily for passenger comfort and equipment ventilation. Significant economies are available if the equipment designs reflect commercially available, good-quality industrial motors and controls. For example, a 480 VAC one-horsepower motor can be purchased for about $100, while an equivalent 600 VDC motor costs thousands of dollars.

Industrial electric equipment is available for 120-volt, 208-volt, 230-volt, and 480-volt 60 Hz supply. Except for 120 volts, three-phase alternating current is the common supply means. Motors, contractors, controls, lighting fixtures, lamps, and connection hardware are commercially available as commodity items with good quality. The National Electrical Manufacturers Association (NEMA) and Underwriters Laboratories have promulgated standards for applying motors, their controls, circuit protection hardware, and its sizing.

However, transit-specific standards were needed to specify uniform electrical input and output requirements for auxiliary power system components so that suppliers could design to a single set of interface requirements.

Vehicle Passenger Information Systems

This proposed area would develop standard interface requirements for the physical, electrical, mechanical, and logical interfaces associated with vehicle passenger information systems so that systems made by different suppliers could be interchanged. Physical interface refers to the size of the units. The electrical and mechanical interfaces refer to having compatible voltages, couplings, and wire terminations. The logical interface is the most complex and requires compatible communications protocols and data elements so that the microprocessor-based information used by these systems is compatible.

Door Obstruction Sensing and Safety

This proposed standards area would have defined the type of door obstruction that must be detected and the door re-open and recycle techniques. Although rated fairly highly initially, the panel did not reach agreement on the need for a standard in this area, and the area was ultimately postponed for consideration.

Adapt Association of American Railroads (AAR) Standards for Commuter Rail

Members also identified the adoption of AAR standards for commuter rail as of high importance. Working group chairs were advised to use AAR standards as input to activity when appropriate. Public Law 103-440 (the Federal Railroad Safety Authorization Act of 1994) had required the FRA to develop safety standards for passenger trains. Effective federal safety standards for freight equipment had long been in place, but equivalent standards for passenger equipment did not exist in 1996. The AAR set industry standards for the design and maintenance of freight equipment that added materially to the safe operation of this equipment. However, over the years, the AAR had discontinued development and maintenance of passenger equipment standards, and no other industry organization had yet stepped in to fill the void. The FRA had been enjoined by Congress to encourage informed, active participation of the industry to develop passenger train safety standards for commuter equipment and operations. The committee indicated that it would not be unreasonable for a standards effort to resurrect, modernize, and maintain the old AAR standards governing commuter rail. Such a standards activity would have immediate positive impact in an area of major public and regulatory agency concern and could be implemented fairly quickly because of the existing, though outdated, AAR standards material. This area was estimated to be among the top standards activities in terms of economic impact. This activity, identified by the task force in 1996, was subsequently and independently taken over by a joint FRA-APTA process, which resulted in the highly successful Passenger Rail Equipment Safety Standards effort (31).

Committee-Originated Standards Concepts

In addition to the areas identified in the Task 1 working paper, members were invited to nominate their own areas for standardization. Three additional areas were identified:

- **Environmental standards for rail transit equipment.** The first suggested area would specify standards for environmental conditions under which transit railcar electronic equipment must both operate and survive. Such environmental conditions could include temperature, humidity, rain, ice, and snow, corrosive elements, and vibration and shock. The goal would be to eliminate unnecessary variability in specifications so that manufacturers could provide consistent product lines, thereby saving cost and improving equipment reliability. The full committee showed considerable enthusiasm for this suggestion, which was boosted to the 11th position in Table 2 by consensus.
- **Envelope dimensions for light rail vehicles.** The second area suggested by members would develop recommended envelope dimensions for light rail cars to promote uniformity among operating agencies. The member submitting this suggestion calculated an expected value for annual savings of $15 million per year. This suggestion failed to garner any additional support from the full committee, so its panel score and ranking remained limited to the vote of the nominating member.
- **Trip management.** This suggestion would develop functional standards for the system management of the train trip, including route, stopping patterns, customer information, incident notification, and special instructions. The committee consensus was that, if needed, this area could be included in the health-monitoring activity. Therefore, the area's ranking also remained limited to the vote of its sponsoring member.

  The trip management suggestion was subsumed under the health-monitoring standard concept. The committee recommended against activity on envelope dimensions for light rail vehicles at this time. The committee recommended adding environmental standards as a candidate for a working group.

Working Groups

The committee then voted to establish eight working groups. These working groups were responsible for developing drafts of the proposed standard in their area. Working group chairs were appointed for all groups. These chairs were encouraged to reach out to involve all industry interest groups to ensure the future acceptability of their standards. The following working groups were established by the committee:

- Working Group 1, Communications Protocols on Trains;
- Working Group 2, Communications-Based Train Control;
- Working Group 3, Health-Monitoring Systems;
- Working Group 4, Safety Standards for Software Systems;

- Working Group 5, VOBC/Propulsion Controller/Motor/Brake;
- Working Group 6, Auxiliary Power Systems;
- Working Group 7, Vehicle Passenger Information Standards; and
- Working Group 8, Environmental Standards for Rail Transit Equipment.

The committee recommended the following regarding two other standards areas that it deemed important and that were outside of the IEEE's domain:

- Forming a sister ASME standards committee to handle crashworthiness and buff load standards and
- Adapting AAR standards to commuter rail (as noted earlier, this activity was undertaken by the APTA Passenger Rail Equipment Safety Standards activity).

STEP 4: DEVELOP THE STANDARDS

This section discusses the activities involved in preparing, balloting, and obtaining final approval of standards.

Working Group Effort

Immediately following the kickoff meeting of the RTVISC on May 23, 1996, working groups sat down together to draft the project authorization request required by IEEE procedures. At the same time, committee members began preparing draft standards. At full committee meetings of RTVISC, the committee periodically reviewed the progress of all working groups. Also, the balloting group (normally the full RTVISC) reviewed all draft standards in detail at open meetings prior to balloting. On the basis of progress made by the various working groups, one group's draft standard was selected to be the first to undergo full committee review and be submitted to ballot. The others were taken up in the order in which they became ready for review.

Standards Ballot

As has been noted, the RTVISC is the balloting group for all standards that it sponsors unless it chooses to delegate that right to another group. Ballots must be returned by at least 75 percent of the RTVISC membership, and 75 percent of ballots not abstaining must be affirmative. Affirmative votes may be accompanied by comments suggesting corrections and improvements. These comments must be taken up by the RTVISC and resolved at its discretion.

Negative ballots must be accompanied by specific reasons in sufficient detail so that the specific wording changes that will cause the negative voter to change his or her vote to "approve" can readily be determined. The RTVISC must obtain written confirmation from each voter indicating concurrence with any change in his or her vote. Written confirmation may be by letter, fax, or electronic mail. In the absence of adequate reasons for a negative vote, the ballot may be classified as "no response," in which case further steps to mitigate that voter's concerns are not required.

Members who do not wish to review the document because of conflict of interest, lack of expertise, or other reasons are permitted to abstain.

Resolution of Comments and Negative Votes

The RTVISC reviewed all ballots received and made every attempt to resolve substantive comments, objections, and negative votes favorably. Comments pointing out obvious mistakes, typographical errors, and improvement in punctuation, grammar, and composition that do not change the technical meaning are considered "nonsubstantive" and may be accepted, revised, or rejected.

Comments accompanying affirmative votes that advocate changes in the technical meaning of the document may be accepted, revised, or rejected. Changes may also be made to the document to resolve negative votes. In these cases, the RTVISC must obtain written confirmation from each negative voter (by letter, fax, or electronic mail) that indicates that the change meets his or her objection. If the negative vote is not satisfied, the negative voter must be informed of the reasons for the rejection and be given an opportunity to change his or her vote. All unresolved negative ballots and all substantive technical changes made in response to affirmative or negative comments or made for other reasons must be submitted to each member of the full committee, providing members with an opportunity to change their ballot if they no longer approve of the revised wording. Further resolution may be required if this change causes the approval to drop below the 75-percent threshold. However, once the 75-percent threshold is achieved with the modified standard, IEEE requirements for consensus have been achieved and the RTVISC can forward the proposed standard on to the IEEE Standards Board for review. The transmittal includes copies of all unresolved negative votes, in addition to reasons given by negative voters and the rebuttals by the RTVISC.

The IEEE Standards Board consists of 18-26 voting members, all of whom have IEEE membership. The board has overall responsibility for all standards developed by the IEEE and sole responsibility for appointment to and cooperation with other organizations on all standards matters. The board reviews all proposed IEEE standards to determine whether IEEE procedures have been followed and whether consensus has been achieved.

The board has two standing committees that play an important role in approval of standards: the New Standards Committee and the Standards Review Committee (32). The New Standards Committee is responsible for ensuring that proposed standards projects are within the scope and purpose of the IEEE, that standards projects are assigned to the proper society or other organizational body, and that interested parties are appropriately represented in the development of IEEE standards. The Standards Review Committee is responsible for reviewing new and revised standards to ensure that proposed standards represent a consensus of the parties having a significant interest in the subjects covered and that IEEE procedures have been followed.

Approval and Publication

After review by the IEEE Standards Review Committee and approval by the IEEE Standards Board, the standard is ready for publication.

Appeals

Appeals may have either a procedural basis or a technical basis. Technical appeals are resolved by the RTVISC. Appeals are reviewed and considered by the IEEE Standards Board only after appeal processes within the RTVISC have been exhausted. The appeals processes include hearings in which the appellant has a chance to state his or her case.

STEP 5: PUBLISH THE STANDARDS

As noted earlier, all eight working groups established at the kickoff meeting succeeded in developing IEEE standards. Details on their activities follow.

Working Group 1, IEEE Standard 1473-1999, Communications Protocols Aboard Trains

When the IEEE standards effort began, there was no preferred communications standard for microprocessor-based vehicle subsystems, and railcar specifications in the United States were not requiring suppliers to conform to a uniform standard. This lack of standardization could have caused each supplier to design its own communications protocols, frustrating the ability of different systems to intercommunicate over a common bus. Thus, one of the first orders of business was to establish a standards working group "to permit systems provided by a variety of suppliers performing different on-board functions to share a common communications facility" (33).

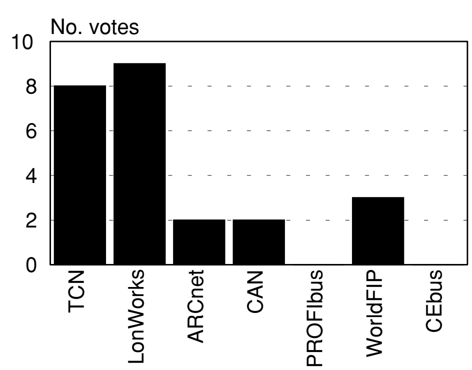

Figure 4. Protocol survey results.

Working Group 1 (which oversees IEEE Standard 1473, Communications Protocol Aboard Trains) was led by Robert Anderson, the manager of systems engineering for Harmon Industries and former senior director of subways technology for MTA NYCT. At its first meeting on July 26, 1996, the working group established nine key protocol criteria: must have redundancy, must include all rolling stock, must define maximum train length, must have no repeaters, must define baud rate versus bus length, must indicate maximum number of nodes, must check for errors, must have reliability, and must support multiple networks (34). The committee saw no need to develop another new protocol and, thus, evaluated potential existing protocols against these nine criteria. On the basis of the criteria, the working group selected seven protocols for further evaluation: ARCNET, CAN, WorldFIP, LonWorks, PROFIbus, Cebus, and TCN (the last of which is a protocol adopted by the International Electrotechnical Commission). A written survey of working group members showed a clear consensus developing around two of the protocols (35). Figure 4 shows the survey results. LonWorks (36) was preferred because of its large user base, low cost, and ease of programming. TCN (37) was preferred because it had been custom engineered for railroads and was designed to provide for time-critical messages. At a meeting of the full committee, the working group's decision to focus its standards effort on these two protocols received formal approval.

The approach taken by this working group was thus built around two widely accepted protocols designated in the standard as Type L and Type T. Type L is based on EIA 709, a general purpose control network developed by Echelon under the trade name LonWorks. Type T refers to IEC FDIS 61375, a train communication network (TCN) developed specifically for railways that addresses the need for deterministic, cyclic, time-critical data and provides other engineering features unique to train operations.

LonWorks is a U.S.-developed protocol familiar to most subsystem suppliers with a wide user base, extensive programming tools, and economies attributable to widespread use. The IEC TCN protocol has the advantage of extensive engineering and testing to handle the specific needs of railway applications, which can save engineering and development costs involved with intercar communications. The combined approach was intended to provide the user with the ability to tailor the best system for his or her needs while still providing for interoperability. Working group discussions focused largely on seeking consensus on recommended areas for use of these two protocols and on seeking agreement on standard connectors. Consensus was achieved that, where trains must be coupled or uncoupled with equipment not under the engineering and management control of the specifying authority, TCN would be required for the train bus. Additional effort beyond developing the standard anticipated by the working group included promoting the development of a gateway to permit communication between the two protocols.

Recent activities at New Jersey Transit have provided a unique window of opportunity to demonstrate the IEEE 1473 protocol. New Jersey Transit is currently converting its entire fleet to modern serial data communications and has mandated compliance with IEEE 1473. Part of this overall conversion effort will be to retrofit Comet II cars, linking them through an IEEE 1473 Type T wire train bus to communicate with Type L local sensors on-board the cars. Thus, this project will provide a platform to demonstrate a gateway between the Type L general-purpose control network and the Type T train backbone.

IEEE 1473 only covers protocols for communication on a vehicle or between vehicles in a train. Currently, the full committee is considering whether to form another working group to standardize the communication protocol to be used for train to wayside communication of nonvital data, such as diagnostic data. At a full committee meeting in Miami, February 11-12, 2001, a representative from the Union Pacific Railroad gave a presentation on the AAR Wireless Communications Task Force and its VHF Communications System using the Association of Public Safety Communications Officials APCO P25 digital radio platform (38). This platform is widely used for emergency services and provides voice and data encryption. Separately, a representative from Adtranz Switzerland gave the committee a presentation on his company's train-to-wayside communication system, which is known as "Date Via Internet," or "DAVINCI." Messages are sent from the vehicle by a radio link to a ground station, where they are then sent out over the Internet or an intranet (39). The committee is reviewing these and other approaches as it decides what course to pursue in this area.

In addition, discussions are underway within the committee about standards for a wider bandwidth protocol as a next-generation system for use on-board trains.

Working Group 2, IEEE Standard 1474.1-1999, Communications-Based Train Control

San Francisco's Bay Area Rapid Transit, MTA NYCT, Philadelphia's SEPTA, the Long Island Rail Road (LIRR), Port Authority Trans Hudson, and a number of other transit systems are prototype testing, actively planning, or considering CBTC. CBTC has been defined as a train control system that is based on continuous two-way communications between trains and that does not require the use of track circuits (40). These new signaling systems must preserve at least the degree of interoperability that presently exists for track circuit-based signaling systems. Accordingly, the original purpose of Working Group 2, Communications-Based Train Control, was to standardize individual functional requirements and information flow requirements (41) with regard to at least the critical ATP function.

For the first year, working group meetings concentrated on defining the critical train to wayside interface. This effort culminated in a special workshop attended by representatives of eight major signaling suppliers, MTA NYCT, APTA, and the FTA. The goal of this 3-day meeting was to define the interface requirements of a consensus standard for train-to-wayside and wayside-to-train communication of ATP information. The workshop was led by the then working group chair, Dave Rutherford, president of Rail Safety Engineering. At the meeting, complete interface data were provided by all eight suppliers, and a "best fit" hypothetical interface was defined (42). Table 3 summarizes the critical interface information.

The workshop was a landmark accomplishment, representing the first time that suppliers had shared critical interface information at a level sufficient to define a baseline interface as a point of departure for CBTC standardization. However, the workshop did not reach a final consensus on interface standards. At the time of the workshop, the MTA NYCT was planning a CBTC demonstration on the Canarsie Line (which runs from 8th Avenue at 14th Street in Manhattan to Rockaway Parkway in Brooklyn). The successful proposer on this program was to be tasked with developing "interoperability interface" specifications, and contracts would then be awarded to two additional contractors to design and demonstrate compatible systems. The approach was intended to generate at least three sources of supply for future CBTC contracts (43). In recognition of this ongoing effort, the workshop recommended that IEEE interoperability standards be put on hold until results from this project were available.

While deferring interoperability standards, the workshop participants concluded that IEEE performance standards could and should be developed. This suggestion was ratified by a meeting of representatives from 10 transit agencies active in the CBTC area, who all agreed to actively support the IEEE in developing such a standard and to "promote the use of a consensus standard in future CBTC procurements" (44). After formal approval by the full standards committee, a new project authorization request was submitted to IEEE Standards for P 1474.1 to establish "the minimum set of performance and functional requirements needed to establish an acceptable level of safety, performance, availability, and operations" for a CBTC system (45).

Leadership of this working group was assumed by Dr. Alan Rumsey, Manager of Systems Integration for the Parsons Transportation Group who also headed Parsons's effort in support of the MTA NYCT CBTC program. Since its inception, this working group has had the largest membership of any of the RTVISC working groups. At its first meeting, Tom Prendergast, president of the LIRR, described a $700 million "signal strategy" to modernize the LIRR sig-

TABLE 3 "Best Fit" composite message structure

Onboard Database	Wayside to Train (ATP)	Train to Wayside (ATP)
FIXED DATA	**PERIODIC (~1 sec/train)**	**PERIODIC (~1 sec/train)**
Train performance data -Acceleration rates -Safe brake rate -Maximum speed	Wayside identity	Wayside identity
ATP identities	Train ATP identity Onboard database version (+verification data per subset)	Train ATP identity Train limits that bound train position (including uncertainties and train integrity considerations)
	Absolute LOA -Sector (zone) ID -Segment ID -Offset (ft) Route information to LOA -No. of switches -Switch positions	-Train "front" position -Sector (zone) ID -Segment ID -Offset -Train "rear" position -Sector (zone) ID -Segment ID -Offset
	Traffic direction Traffic direction after LOA to next home signal (i.e., permission to proceed past LOA following loss of data communications) Emergency stop (set/reset)	Train stopped (zero speed)
	Data to ensure message integrity (e.g., sequence numbers, CRCs) - timestamp?	Data to ensure message integrity (e.g., sequence numbers, CRCs) - timestamp?
	Ancillary communications protocols	Ancillary communications protocols
DATA DOWNLOADED FROM THE WAYSIDE (ATP) - (For current zone as a minimum)	**DATA TRANSMITTED AS NEEDED**	**DATA TRANSMITTED AS NEEDED**
Topographical data -Stationing reference -Sector (zone) ID	Database downloads Slow speed order (set/reset, as database update)	
-Zone boundary -Zone west connect -Zone east connect -Segment ID -Segment length -Segment west connect -Segment east connect -Switch IDs -Converge connect -Normal connect -Reverse connect -Segment speed limit -Segment grade -Home signals -End of track -Station platforms (east connect, west connect, and orientation) -Transponders (ID, location, east connect, and west connect) Database version number	-Speed limits -Start position -End position -Route information Restricted speed (set/reset) Work zones (set/reset as database update) Data to ensure message integrity (e.g., sequence numbers, CRCs) - timestamp? Ancillary communications protocols	

continued

TABLE 3 continued

Onboard	Wayside
Calculated Data	**Calculated Data**
Train front position (including position uncertainties)	Maximum limit for each train
Train length	Train tracking -CBTC trains -Non-CBTC trains
Train integrity	Zone-to-zone transfer
Train rear position (including position uncertainties and train integrity considerations)	
Train speed (including speed measurement uncertainties)	
Train travel direction	
ATP (speed/distance) profile	
Train "berthed" at station platform	
Operating mode	
In/out CBTC territory	

Note: ATP = automatic train protection; CRC = cyclic redundancy code; ID = identification; LOA = limit of authority; CBTC = communications-based train control

naling system over the next 20 years and stressed that if effective IEEE CBTC performance standards were developed, LIRR was committed to supporting and using them (46).

IEEE Standard 1474.1 has been published and is proving a valuable resource in the CBTC arena. The large working group continues to meet and is now developing a new standard, IEEE P-474.2, which is developing user interface requirements for CBTC systems. This standard defines standards for CBTC graphical displays. In addition, the working group encouraged the development of an offshoot working group, Working Group 2B, headed by Harold Gillen of Union Switch and Signal, to develop environmental standards for wayside ATC equipment.

Working Group 3, IEEE P-1482.1-1999, Event Recorder

Originally, Working Group 3 was tasked to develop maintenance and diagnostic standards. However, in May 1998, the NTSB issued a "most wanted" list of transportation safety improvements (47). The first item on the list was automatic information recording devices, more commonly called "black boxes" or "event recorders" for transit vehicles. Reacting to this high NTSB priority, Working Group 3 deferred work on its maintenance and diagnostic standard, and prepared a new project authorization request to develop an event recorder standard for the transit industry. In a matter of months, the project authorization request was submitted to and approved by the IEEE and a draft standard was released for balloting. The standard has now been published as IEEE Standard 1482.1-1999, and the working group is back at work on its original maintenance and diagnostic standard.

Working Group 4, IEEE Standard 1483-2000, Safety Considerations for Software Used in Rail Transit Systems

As transit moves ever more rapidly into the age of microprocessors and computers and as these devices begin to be used for vital "fail-safe" applications, a standardized method for safety verification of processor-based equipment becomes increasingly essential. Conducting separate safety verifications for each application is a confusing, time-consuming, and costly process. Given the inevitable limitations of time and money, the process can also compromise the ultimate goal of safety. Without standards for this process, both suppliers and transit operators will see higher cost, slower acceptance, and increased uncertainty about the safety of processor-based systems (48). Thus, establishing a standards group in this area was a high priority for the Rail Transit Vehicle Interface Standards Committee.

Working Group 4 (which oversees IEEE Standard 1483, Safety Considerations for Software Used in Rail Transit Systems, and which is chaired by Jim Hoelscher, senior applied research engineer of Alstom Signaling) was formed to "provide a well-defined and well-structured set of analysis methods and documentation which fulfills the primary purpose of the verification process, is flexible enough to accommodate all viable design methods, and satisfies the safety requirements of the end user" (49). The standard includes an appendix with an example of practical application.

Normally, the parent IEEE Rail Transit Vehicle Interface Standards Committee, which sponsors these standards, serves as the official balloting group. However, because of the committee's large size and the specialized expertise involved, Working Group 4 requested and received permission to form its own balloting group.

This standard describes the "safety verification" process. "Safety verification" addresses the question, "Did we build the system right?" The standard does not address what is commonly called "validation." "Validation" answers the question, "Did we build the right system?" Thus, validation is a matter of identifying what the design must do to be a safe system, which hazards must be addressed, and which risk is acceptable. Verification shows that the design, as built, actually does meet the requirements identified by the validation process.

Working Group 5, IEEE Standard 1475-1999, Functioning of and Interfaces among Propulsion, Friction Brake, and Train-Borne Master Control on Rail Rapid Transit Vehicles

Working Group 5, which oversees IEEE Standard 1475, has the lengthy but descriptive title "Standard for the Functioning of and Interfaces among Propulsion, Friction Brake and Train-borne Master Control on Rail Rapid Transit Vehicles." Its standard prescribes the interface functionality among propulsion, friction brake, and train-borne master control and encompasses performance parameters, communications methods, and the means for measurement and verification of performance (50). The working group was chaired by Dave Phelps, manager of rail programs for APTA and former manager of transit sales for GE Transportation Systems.

Because of the diversity of technology presently in use, standards were established for three levels of complexity (51):

- **Type I interfaces** have signals primarily of the "off-on" form that are normally transmitted at the voltage level of the control battery system. Signal flow across a given interface is one-way. Fault annunciation to the operator is limited to simple indicator lights or similar means. Unless required by federal or other regulations, no data recording or fault logging is provided.
- **Type II interfaces** are more complex. Interface signals are a mix of digital and analog or proportional signals, usually at car battery voltage. Signal flow across a given interface remains one-way. Fault annunciation is still limited to indicating lights or similar means, but more indications, both local and trainlined, may be provided. Data recording or fault logging, if provided, is done either at the vehicle level or at the functional system level. Both levels may be provided, but there is no exchange of information between the levels.
- **Type III interfaces** are designed to be used with a serial communication link over a data bus using IEEE Standard 1473 protocols. Two-way signal flow and communication across interfaces is provided. Comprehensive system, vehicle, and train information displays are provided to the operator. Integrated data recording and fault logging are available with information shared among the train level, vehicle level, and functional system level.

IEEE Standard 1475 provides information for each interface, as well as information enabling the user to select a compatible set of Type I, II, and III interfaces for his or her vehicle design. Functional interface information is provided for the following interfaces: emergency brake, direction, mode selection, modulation, blending, load weigh, speed, penalty brake, spin/slide, no-motion, alertness monitoring, specialized brake functions, specialized propulsion functions, door status, and data and fault annunciation. Specialized propulsion and brake functions include track brake, sanding, "snow brake," and electric and regenerative brake cutout.

Working Group 6, IEEE Standard 1476-2000, Passenger Train Auxiliary Power Systems

Working Group 6 (which oversees IEEE Standard 1476, Passenger Train Auxiliary Power Systems) had the responsibility of developing standards for auxiliary power system interfaces. This group was led by Claude Gabriel (now with LTK Engineering Services and at the time manager of advanced engineering for Bombardier Transit) with help from Norm Vutz (also of LTK Engineering Services). The standard covers the battery, the battery charger, low-voltage power supply, and static inverters and converters. It includes equipment interfaces and equipment functional parameters. It does not cover the internal working of equipment, nor does it cover wiring, connectors, or mounting of equipment (52).

In addition to interface information, the standard provides guidance for conducting a loads analysis to properly determine and size auxiliary loads. As this effort proceeded, it became clear that existing nickel-cadmium battery standards-such as IEEE Standard 1115, Recommended Practice for Sizing Nickel Cadmium Batteries for Stationary Applications, which was written for stationary applications, were not suitable for sizing batteries for rapid transit use. IEEE Standard 1115 was geared for long standby periods (months to years) as opposed to short periods (hours) for rail transit. The standard did not take into account unique aspects of the rail duty cycle, such as interruptions caused by rail gaps or battery discharge at night when not connected to the power rails. Nor did the standard consider the short bursts of high energy that a rail transit battery must deliver, such as during application of track brakes. The issue was discussed with the chair of IEEE Standard 1115, and it was agreed that a new standard for rail applications was needed. This new standard is now being developed as IEEE P-1568.

Working Group 7, IEEE Standard 1477-1998, Passenger Information System for Rail Transit Vehicles

Working Group 7 (which oversees IEEE Standard 1477, Passenger Information System for Rail Transit Vehicles) was charged with developing standards "to establish the minimum interface requirements for passenger information systems in order to enable product interchangeability" (53). The group was led by Lance Cooper, at the time senior manager of operations support for the Washington Metropolitan Area Transit Authority. This standard was originally intended to cover physical, electrical, and logical interfaces of passenger information systems for rail transit vehicles. However, at a meeting of the full committee in Chicago on June 25-26, 1997, it was agreed that the logical portion of the standard would not be completed at that time. This logical portion has been reserved to be undertaken by a separate working group formed specifically to tackle message content and data objects. In the meantime, the portion of the standard covering the physical and electrical interfaces (54) was successfully balloted in October 1997. The portion was the first successfully balloted RTVISC standard.

Working Group 8, IEEE Standard 1478-2001, Environmental Conditions for Transit Rail Car Electronic Equipment

Working Group 8 (headed by Charles Elms, senior principal of Lea+Elliott) was responsible for specifying "standards for environmental conditions under which transit rail car electronic equipment shall both operate and/or survive" (55). Such environmental conditions include temperature, humidity, ice, snow, corrosive elements, and vibration/shock and may depend on equipment location. At the start of the Working Group 8 effort, a survey was conducted of approximately 80 suppliers to determine the values to which they normally design their electronic equipment. This survey formed the basis for subsequent development of the standard.

During development of the standard, a problem came up handling U.S. Department of Defense (U.S.DOD) Military Standards. A number of U.S.DOD environmental tests from MIL-STD-810E, Environmental Test Methods Guidelines (56), are cited in IEEE Standard 1478. However, as part of a general policy in U.S.DOD to get out of the standards business, the newly released MIL-STD-810F no longer included the tests for rain, salt, sand, and dust that were cited by Working Group 8. The matter was discussed with an IEEE project editor, who advised the committee to include the cited material, which is public domain, as an informative annex to IEEE Standard 1478. This material has been included, thereby ensuring that these valuable environmental tests, which have been used to design a number of environmental test chambers in wide use in the industry, will continue to be available.

As IEEE Standard 1478 was developed, it became clear that a standard was needed for wayside train control equipment. As a result, a new working group, Working Group 2B, was formed to develop these standards as IEEE P-1582. This situation is an example of a need for a new rail standard developing in the normal course of committee work.

RAIL TRANSIT STANDARDS WEBSITE

The IEEE's Rail Transit Vehicle Interface Standards Committee website (www.tsd.org/rsc) went on-line early in 1997 shortly after the committee's second meeting. Since its inception, the site has been hosted by Transportation Systems Design (of Oakland, California), which maintains and updates the website several times per month under a TCRP G-4 subcontract.

This standards website has proven popular both in the United States and in other countries. In addition to the main committee page, each working group has its own web page describing how to reach its chair, past and ongoing activities, next meeting information, agenda and minutes, draft standards, presentations, and other relevant information. Several journal articles about the work of the committee that have been published in popular rail transit magazines are also available on the committee's website.

The latest versions of all RTVISC draft standards can be immediately downloaded, but, as required by the IEEE, draft standards are password protected. Except for the draft standards, all information is unrestricted and immediately available to anyone with access to the Internet. This openness is consistent with the committee's philosophy to make its work readily available so everyone who desires can benefit from these industry efforts to provide open interface standards.

To increase the usefulness of the website, the use of graphics is minimized and no Java or other applets are used or required, resulting in fast presentation of information without the delay common to many other websites. Most agenda and meeting minutes can now be directly viewed from a browser without the need for external word processors or other viewers that slow down the presentation of similar information. This responsiveness is important not only to international visitors who often must view the information via a slow link, but also to the many volunteers who do committee work at home and who are frequently limited to a slow dial-up connection.

The website can easily be located over popular search engines. Thus, users who don't know the website address can easily find the website by typing a portion of the committee name or a standard name (such as "ieee-1473") or simply describing some of the committee's activities. Hundreds of thousands of "hits" have been received from professional institutions as far away as Australia, China, Korea, Singapore, Korea, and India, indicating that the work of this TCRP project is of keen national and international interest and that the decision to disseminate results via the web was good.

DEVELOPING ASME STANDARDS

Because of recommendations to develop standards in areas such as light rail crashworthiness, a sister standards group to the IEEE was established in ASME. ASME is a worldwide educational and technical society of mechanical engineers that develops mechanical engineering standards through its Council on Codes and Standards.

Meetings with ASME staff were initiated to secure approval for such a group. Separate presentations to the ASME Board on Safety Codes and Standards were made on September 10, 1997, and on March 18, 1998. At the latter meeting, the board voted to recommend to the ASME Council on Codes and Standards the formation of an ASME Rail Transit Vehicle Standards Committee. On April 3, 1998, the council approved the proposed charter. The committee is empowered to develop standards covering "safety, functional, performance, and operability requirements for rail transit vehicles, mechanical systems, and components and structural requirements" (56). The committee's scope includes subway or rapid rail cars and light rail cars, but specifically excludes freight, commuter, high speed, or any other rail vehicles already under the jurisdiction of the FRA. This exclusion was established to avoid any overlap with the activities of APTA's Passenger Rail Equipment Safety Standards (PRESS) effort, which is being undertaken with the support of the FRA.

A "kickoff" meeting to plan the committee was held on July 17, 1998, at the offices of New Jersey Transit. Twenty-six engineers and other specialists attended the meeting. Appointed as committee chair was Stan Canjea, light rail transit program manager for New Jersey Transit.

The committee has 27 members representing owner/operators, manufacturers, specialists, regulatory agencies, and general interest. Its first standards activity (RT-1) has been to develop standards covering carbody strength and crashworthiness for light rail cars. On July 17, 1998, ASME gave its final approval to undertake this standards activity, thus effectively launching the committee. Modern standards in this area could reduce the risk of passenger injury in a collision and also save more than $10 million per year in reduced energy consumption and more efficient vehicle design.

The first official meeting was held on November 13, 1998, at the SEPTA offices. The committee has held seven meetings to date, the most recent in Atlanta, Georgia, on March 21-23, 2001, and is presently reviewing the fourth draft of its standard.

At the request of the MTA NYCT and APTA, the committee has added a second RT-2 standards activity to develop structural and crashworthiness standards for rapid rail cars. That activity is being led by Keith Falk, director of car systems engineering for the MTA NYCT.

ASHRAE STANDARDS

The MTA NYCT requested that the ASME Rail Standards Committee develop standards for heating, ventilation, and air-conditioning systems for rail passenger vehicles. These performance standards would cover areas such as type of refrigerant, voltage and power supply, packaging, materials, determination, and verification of capacity requirements. Because of recent acquisitions and business reorganizations, the number of rail heating, ventilation, and air-conditioning suppliers has been reduced, lessening the pool of experience with the unique and demanding aspects of the North American mass transit environment. These aspects include the increased thermal load caused by operation in a confined tunnel with frequent passenger loading and unloading, vibration and shock loads unique to rail systems, and the rail electromagnetic interface environment. As a result of the shrinking pool of experience, a standard was needed to document heating, ventilation, and air-conditioning performance requirements unique to the railcar environment.

The problem of not having heating, ventilation, and air-conditioning standards has serious implications. When heating, ventilation, and air-conditioning systems fail underground, the stifling environment causes passengers to evacuate the vehicle. This evacuation induces hazards from potential exposure to high voltages, falls onto the track, and panic. The evacuation necessitates shutting off track power, which causes serious delays to propagate throughout the system, thus multiplying all of these problems.

When the matter was brought before ASME committee officers, the officers suggested that ASHRAE was better qualified to undertake this standard. Meetings and discussions were held with ASHRAE staff, the chair of the ASHRAE TC9.3 Transportation Technical Committee, and the chair of the Railcar Air-Conditioning Subcommittee. As a result, this standards effort has been transferred to ASHRAE, which is in the process of forming a standards committee to address the issue.

COORDINATION

In the case of transit standards, many organizations need to be coordinated with, including ITS America, the FRA, APTA, and international standards organizations. Coordination may include circulating draft copies of the standard, designating liaison representatives, or providing common members on both committees or groups.

This section discusses the myriad of organizations involved in transit-related standards activities with which coordination has been required during the development of IEEE and ASME rail transit standards.

In trying to make sense of ongoing standards efforts in the transit industry, it is useful to categorize the efforts into (a) activities accredited by ISO, ANSI, or both and (b) industry- or government-sponsored efforts operating outside of the ISO-ANSI system. (As has been noted, ANSI is the central body in the United States responsible for voluntary standards activities.)

While the ISO-ANSI system is widely used, there are also other organizations involved in transit standards activities. Some of these organizations are industry groups, which do not offer open membership to all interested parties. Others have been formed by public agency efforts, such as those of the FRA.

ANSI accreditation is, thus, one important way to classify the many transit standards activities now underway. Another useful way to classify transit standards is according to whether they are involved in the multibillion dollar Intelligent Transportation Systems (ITS) initiative. A key element of the ITS program has been standards to ensure interoperability of advanced microprocessor electronics applied to automobiles and highways.

National ITS standards are essential to achieving the interoperability and compatibility needed to enable ITS equipment to function consistently and reliably anywhere in the United States. The National ITS Architecture has been developed to serve as a master blueprint defining basic ITS interfaces. Standards that needed to support this architecture are being developed with funding from the U.S.DOT. This standards effort is built around the National Transportation Communication for ITS Protocol (NTCIP).

NTCIP is the backbone of this standards effort, intended to provide a standard protocol for the interchange of computer-based information throughout the transportation industry. The NTCIP protocol was originally conceived to be an extension of the NEMA TS-2 Controller Standard governing traffic controller communications. As the project developed, it grew to cover the more complex issues of systems interoperability and communications standards. A joint NTCIP committee was formed, consisting of members from NEMA, the Institute of Transportation Engineers, and the American Association of State Highway and Transportation Officials (AASHTO). This joint committee serves as a steering committee overseeing all NTCIP standards development efforts.

Because buses use the highway system, a transit component of NTCIP was needed. Transit Communication Interface Profiles (TCIP) represents this transit component. It augments the NTCIP with transit-related information and message formats to facilitate the exchange of information among traffic management centers, transit vehicles, and other transit facilities. The Institute of Transportation Engineers leads the TCIP program with funding from the U.S.DOT.

The national ITS effort has generated a great deal of standards effort, initially oriented to automobiles and highways, but gradually moving inexorably into the area of buses and ultimately even rail transit. Understanding the relationship of rail transit standards activities to overall ITS strategies is, thus, critical to understanding the big picture and has required continued coordination with ITS activities.

The following sections identify the various standards activities involving transit today. First, international standards activities are discussed. Next, ANSI-accredited activities are summarized. Finally, industry- and government-sponsored activities outside of ANSI are identified. Each section highlights the relationship, if any, to the ITS program. Within each section, organizations are in alphabetical order.

International, ISO/IEC Transit Standards Committees

There are at least two ISO/IEC committees directly involved in transit standards.

- **IEC TC9, Electric Traction Equipment.** IEC TC9 is an IEC technical committee that prepares international standards for electric train equipment. Among its activities has been the development of IEC 61375-1 1999 (Electric Railways Equipment-Train Bus), which defines a communications protocol for a TCN. The protocol has been adopted as one of the two complementary protocols accepted by IEEE Standard 1473-1999 for use on transit vehicles and trains.
- **ISO TC 204, Transportation Information and Control Systems.** ISO TC 204 was formed within the ISO to handle ITS. Its Working Group 8 has particular responsibility for public transport and emergency and is of the most importance to the transit industry. The Society of Automotive Engineers (SAE) has been designated as the international secretariat for the ISO 204 committee. The secretariat is responsible for providing technical and administrative services for the committee. ITS America, an industry group for ITS, serves as the U.S. Technical Advisory Group for ISO 204.

ANSI-Accredited Standards Development Organizations

There are at least five ANSI-accredited standards development organizations actively involved in transit standards activities.

- **The American Society of Civil Engineers (ASCE).** The ASCE is a professional society formed to advance professional knowledge and improve the practice of civil engineering. This society develops standards under its Codes and Standards Activities Committee. The key ASCE transit standards activity is led by the Automated People Mover Standards Committee. This committee, formed in 1992, is establishing minimum safety and performance requirements for automated people movers. It has published two standards: ASCE 21-96 (which governs train control, communications, safety, reliability, and environmental concerns) and ASCE 21-98 (which governs vehicle, propulsion, and braking systems). Additional standards activity is underway in guideway and stations, electrical power, operations and maintenance, inspection, testing, configuration control, and security matters.

- **ASHRAE.** ASHRAE is a 50,000-member organization whose purpose is to advance the art and science of heating, ventilation, and air-conditioning through research and development, standards, education, and publications. Its TC 9.3 Technical Activities Committee is responsible for transportation technology.
- **The American Society of Testing and Materials (ASTM).** The ASTM is developing ITS standards in the area of dedicated short-range communications physical and data links.
- **The IEEE.** The IEEE is the world's largest technical professional society serving the computing, electrical engineering, and electronics professions. The IEEE Standards Association develops standards in these areas. IEEE activities in transit standards are in two major areas: (a) the RTVISC serves as the sponsor and balloting group for all rail transit vehicle interface standards developed by the IEEE, and (b) the ITS Standards Coordinating Committee (SCC 32) coordinates all ITS activities in the IEEE. In addition to rail TCIP standards, these ITS activities include the ITS data dictionary and message set template, dedicated short-range communication message set, and incident management message set. To date, SCC32 has published (a) standards covering message sets for vehicle and roadside communications, (b) data dictionaries for ITS, and (c) a guide for microwave communication system development.
- **The SAE.** In addition to its role as secretariat of ISO TC 204, the SAE is very active in ITS, where it focuses on in-vehicle and traveler information. The SAE communications protocols used for buses (SAE J-1587 and SAE J-1708) are well known, and new standards activity is now underway in this area.

Government Organizations Involved in Transit Standards Development

The following are government-sponsored or related groups involved in standardization.

- **The FRA.** The FRA is a U.S. federal government agency that regulates mainline railroads. It is working with APTA on the PRESS activities to develop commuter rail safety standards. In addition, the FRA has convened the Rail Safety Advisory Committee (RSAC) to provide consensus recommendations for proposed and final FRA regulatory actions. The FRA is not bound to follow RSAC recommendations, but typically does. RSAC has representatives from the rail carriers, labor, and the Railway Progress Institute, representing suppliers. A major effort involves Positive Train Control, a program to develop communications-based signaling systems for mainline railroads. RSAC has formed a special Positive Train Control Working Group that has a standards task force charged to recommend potential revisions to federal regulations (49 CFR Part 236) to address processor-based technology and communications-based operating architectures. The task force is now considering rules for safety verification of processor-based systems.

  Another FRA activity is Highway-Rail Intersection Standards. In 1994, the Federal Highway Administration was asked to include highway-rail intersections as part of the ITS program. These intersections represent an interface between railroad signaling and highway traffic signal and traffic management and need to be included in the ITS architecture and standards efforts. Efforts in this area led by the FRA are now underway.
- **The FTA.** The FTA is becoming increasingly involved in standards efforts. The FTA works closely with the U.S.DOT Joint Program Office to help identify, encourage, and implement standards activities undertaken by the transportation industry that are related to ITS, including the TCIP standards effort. In addition, both through the TCRP program and directly, the FTA is supporting ongoing standards activities in the bus and rail areas.
- **U.S.DOT Joint Program Office for ITS.** The U.S.DOT has formed a joint program office for ITS to coordinate departmental and agency activities in ITS. A key standards activity has been the establishment of the TCIP development effort to address the transit component of ITS standards.

Private Organizations Involved in Transit Standards Development

The following are industry groups, not-for-profit organizations, or ANSI-nonaccredited engineering societies involved in standardization.

- **The AAR.** Standards for commuter railroad cars were first developed in the United States in 1867 by the Master Car Builders Association, the forerunner of the AAR. A new standard was normally proposed by the railroads or manufacturers and passed on to the car construction committee. The proposed standard had to pass a majority vote of both the committee and the full AAR membership. In 1984, the AAR discontinued maintaining standards for passenger rail equipment, leaving a void that has been filled by the APTA PRESS program.
- **AASHTO.** AASHTO consists of principal executive and engineering officers of the various state highway and transportation agencies and the U.S.DOT. AASHTO's main purpose is to develop and improve methods of design, construction, operation, and maintenance of highways. AASHTO serves on the Joint NTCIP Committee, which serves as a steering committee overseeing all NTCIP standards development efforts.
- **APTA.** APTA is an organization whose mission is to

serve and represent the transit industry. APTA operates PRESS, a task force to develop passenger rail equipment safety standards for commuter rail passenger cars. PRESS arose in 1996 when the nation's commuter railroads, acting through APTA, assumed development of safety standards, for commuter rail passenger cars, based on updating and modernizing the AAR standards. The standards cover vehicle speed, car body design, doors, windows, fuel tanks, braking and electrical systems, emergency exits, cab controls, fire safety, inspection, and maintenance. This industry action was taken at the request of the FRA in response to a directive from Congress to the FRA for additional regulation of passenger car safety.

APTA recently initiated an ambitious effort to develop additional standards for the rail transit industry. The effort is beginning with standards in four key areas: vehicle inspection and maintenance; rail transit system operating practices; grade crossing design, operation, and maintenance; and fixed structure inspection and maintenance. In addition, APTA is assisting the ASME in its rail transit vehicle crashworthiness standards.

In addition, APTA is developing technical specification guidelines for transit buses with the support of the TCRP. Through its participation in TCRP, APTA is also involved in the TCRP G-4 project developing electrical and mechanical railcar standards.

- **The American Railway Engineering and Maintenance Association (AREMA).** A professional organization of railway officers, engineers, and supervisors engaged in design, construction, and maintenance of railroad facilities, AREMA publishes a manual of railway engineering and various recommended practices and standards related to freight operations. AREMA was formed by the merger of several groups, most notably the American Railway Engineering Association (AREA). AREA, and now AREMA, issues and supports track and fixed-way standards for both mainline railroads and rail transit systems. AREMA and the IEEE are currently jointly working out responsibilities in the area of overhead contact system standards.
- **The Electrical Industry Association (EIA).** The EIA is an industry group that develops electrical standards. It maintains EIA 709.1-1998, Control Network Protocol Specification, one of the two complementary protocols adopted by IEEE Standard 1473-1999 for use on passenger rail vehicles and trains.
- **The Institute of Transportation Engineers.** The Institute of Transportation Engineers is an international scientific and educational association concerned with transportation and traffic engineering, which is leading the TCIP effort with the support of a large group of technical advisors and members of the transit community. The TCIP is the transit component of the NTCIP effort. It augments the NTCIP with transit-related information and message formats to facilitate the exchange of information among traffic management centers, transit vehicles, and other transit facilities. Message sets have been developed in a number of distinct business areas. During the course of the effort, it was determined that message sets would also be required for rail systems, which interface with TCIP in a number of areas. The IEEE Rail Transit Vehicle Interface Standards Committee was charged with the responsibility for this effort and formed a Working Group 9 for this purpose. In addition, the Institute of Transportation Engineers serves on the Joint NTCIP Committee, which serves as a steering committee overseeing all NTCIP standards development efforts. The Institute of Transportation Engineers also supports the Transit Signal Priority Working Group, which is concerned with the interfaces involved with providing signal priority to buses and light rail vehicles.
- **ITS America.** ITS America is an industry group for ITS. ITS America has a standards and protocols committee. It also serves as the U.S. Technical Advisory Group for the ISO TC 204 Committee.
- **LonMark Interoperability Association.** LonMark is an industry association formed to assist and quickly establish interoperable systems using the Echelon-developed LonWorks communication protocol (EAI 709.3-1998). This protocol has been adopted as one of the two complementary protocols accepted by IEEE Standard 1473-1999 for use on transit vehicles and trains. LonMark has recently formed a Transportation Group to facilitate standardization and interoperability of LonWorks-based systems in the transportation industry. Its initial emphasis will be on rail transit equipment.
- **The Object Management Group (OMG).** The OMG is an industry organization formed in 1989 whose mission is to create an interoperable world for exchange of information between microprocessor computers through development of the Common Object Request Broker Architecture (CORBA). The OMG serves somewhat as an industry alternative to the de facto Microsoft standards. The OMG has a transportation domain task force and has recently formed a transit domain group to develop transit application standards compatible with the overall OMG architecture. The NTCIP is using CORBA for its communications standard.
- **NEMA.** NEMA is an industry association of electrical equipment manufacturers. The NTCIP protocol was originally conceived to be an extension of NEMA's TS-2 Controller Standard governing traffic controller communications. As the NTCIP project developed, it grew to cover the more complex issues of systems interoperability and communications standards. NEMA now serves on the Joint NTCIP Committee, which serves as a steering committee overseeing all NTCIP standards development efforts.

RECOMMENDATIONS FOR THE FUTURE

Over the past 5 years, a great deal has been accomplished to transform consensus standards for the U.S. rail transit industry from an idealistic dream to an everyday reality. Active and functioning standards efforts involving much of the transit community are flourishing within the IEEE and ASME.

To sustain this effort over the long term, a permanent source of funds is needed to facilitate and manage this basically volunteer effort. The APTA Rail Transit Standards Policy and Planning Steering Committee, meeting at the APTA annual rail conference in Boston in June 2001, has made an initial commitment to seek such support and to share in the cost. This commitment promises to put the engineering society consensus standards effort on a solid foundation for the future.

Another area requiring additional attention is the international arena. With virtually all railcar suppliers operating globally, increased coordination with and participation in international standards activities, including those of the International Electrotechnical Commission and the International Organization for Standardization, is unavoidable. More effort will need to focus on this increasingly important area. The "one country, one vote" policy used in these organizations currently gives an influence to European Common Market nations disproportionate to that of the three members of NAFTA. Over the long term, changes at the treaty-making level may be necessary to address this issue, which goes beyond the immediate concerns of the transit industry.

ACKNOWLEDGMENTS

The work described in this report was accomplished by more than 300 volunteers from the transit industry developing standards sponsored by the IEEE and ASME. Particular acknowledgment is due to the chairs of the working groups that actually develop these standards, many of whom are mentioned by name within this report. In addition, the research team would like to specifically acknowledge the assistance and support of Linda Sue Boehmer, who, when serving as president of VTS, was directly responsible for establishing the IEEE Rail Transit Vehicle Interface Standards Committee. The research team would also like to acknowledge the tireless support of Robert Brownstein, the APTA vice chair for research and development, and of Lou Sanders, the APTA director of research and technology, who have supported this standards effort from the beginning. TCRP Project G-4 has been under the direction of Chris Jenks of the Transportation Research Board, with the assistance of a panel of eight transit experts led by Walter Keevil, chief rail equipment engineer of the Chicago Transit Authority. Paul Jamieson, chief engineer of WABCO, has also been very active, chairing a working group, maintaining a database of technical definitions, and supporting the efforts as a member of the APTA Rail Transit Standards Policy and Planning Steering Committee. The research team would also like to acknowledge the continued support of Edward Thomas and Jeffrey Mora of the FTA Office of Research and Technology and Ron Kangas (retired, formerly of FTA). The research team has also received outstanding support from the IEEE, led by Tricia Gerdon. The website has been maintained under a subcontract by Tom Sullivan of Transportation Systems Design.

GLOSSARY OF ACRONYMS

AAR: The Association of American Railroads.
AASHTO: The American Association of State and Highway and Transportation Officials.
ANSI: The American National Standards Institute.
APTA: The American Public Transportation Association.
AREA: The American Railway Engineering Association.
AREMA: The American Railway Engineering and Maintenance-of-Way Association.
ASCE: The American Society of Civil Engineers.
ASHRAE: The American Society of Heating, Refrigeration, and Air-Conditioning Engineers.
ASME: The American Society of Mechanical Engineers.
ASTM: The American Society of Testing and Materials.
ATC: Automatic train control.
ATO: Automatic train operation.
ATP: Automatic train protection.
ATS: Automatic train supervision.
BART: The Bay Area Rapid Transit.
CBTC: Communications-based train control.
CORBA: The Common Object Request Broker Architecture.
CPU: Central processing unit.
EIA: The Electrical Industry Association.
FRA: The Federal Railroad Administration.
FTA: The Federal Transit Administration.
IEC: The International Electrotechnical Commission.
IEEE: The Institute of Electrical and Electronic Engineers.
ISO: The International Organization for Standardization.
ITS: Intelligent Transportation Systems.
LIRR: The Long Island Rail Road.
MBTA: The Massachusetts Bay Transportation Authority.
MTA: The Metropolitan Transportation Authority.
NEMA: The National Electrical Manufacturers Association.
NTCIP: National Transportation Communications for ITS Protocol.
NTSB: The National Transportation Safety Board.
NYCT: New York City Transit.
OMB: The Office of Management and Budget.
OMG: The Object Management Group.
PASC: The Pacific Area Standards Congress.
PLC: Programmable logic controller.
PRESS: Passenger Rail Equipment Safety Standards.
RSAC: The Rail Safety Advisory Committee.
RTVISC: The Rail Transit Vehicle Interface Standards Committee.
SAE: The Society of Automotive Engineers.
SEPTA: Southeastern Pennsylvania Transportation Authority.
TCIP: Transit Communication Interface Profiles.
TCN: Train communication network.
TCRP: The Transit Cooperative Research Program.
U.S.DOD: The U.S. Department of Defense.
U.S.DOT: The U.S. Department of Transportation.
VOBC: Vehicle on-board control.
VTS: Vehicular Technology Society.

REFERENCES

1. "Applying Engineering Society Standards in Mass Transit." *TR News*, No. 202, May-June 1999, p. 13.
2. This information is based on information collected by the IEEE Rail Transit Vehicle Interface Standards Committee from its members and maintained on its website at www.tsd.org.
3. The American Public Transportation Association, *Public Transportation Fact Book*. Washington, D.C., March 2001, p. 63.
4. U.S. Department of Transportation, *The Changing Face of Transportation*. Washington, D.C., 2000, Figures 2-16, pp. 2-19.
5. "Slants and Trends." *Urban Transport News*, Vol. 26, No. 15, July 29, 1998, p. 113.
6. *Public Transportation Fact Book,* op. cit. Table 88, p. 138.
7. McGean, T. J., D. B. Eldredge, and W. Frost, *Benefits of Railcar Standardization*. Urban Mass Transportation Administration, U.S. Department of Transportation, UMTA-IT-06-0229-82-2, Washington, D.C., February 1982, pp. 2-6.
8. McGean, T. J., *Rail Transit Vehicle Standardization Options*. TCRP G-4 Task 1 Working Paper, April 1996, p. 7 (assumes expected value of top six standards).
9. *Public Transportation Fact Book*, op. cit. Table 21, p. 56.
10. Kemp, James, *Economic Benefits of Transit Standards*. The American Public Transportation Association Annual Meeting Proceedings, Orlando, Florida, 1999.
11. *Benefits of Railcar Standardization*, op. cit. p. 2-8.
12. U.S. Census Bureau, *Statistical Abstract of the United States-2001*, Table 1023. U.S. Department of Commerce, Washington, D.C., 2001.
13. *Public Transportation Fact Book*, op. cit. Table 56, p. 96.
14. *Public Transportation Fact Book*, op. cit. Table 16, p. 49.
15. *Public Transportation Fact Book*, op. cit. Table 59, p. 103.
16. Cihak, Frank J., *Transit Standardization Efforts*. The American Public Transit Association, Washington, D.C.
17. *Public Law 104-113, 104th Congress, National Technology Transfer and Advancement Act of 1995*, Section 12(d), "Utilization of Consensus Technical Standards by Federal Agencies; Reports." Signed into law March 13, 1996.
18. *Notice and Request for Comments on Proposed Revision of OMB Circular No. A-119*, "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities." *Federal Register,* December 27, 1996, Vol. 61, No. 250, pp. 68,312-68,317.
19. "Annual Report to the Office of Management and Budget on the Implementation of OMB Circular A-119 and P.L. 104-113 Covering the Period October 1, 1998, through September 30, 1999." U.S. Department of Commerce, National Institute of Standards and Technology, Gaithersburg, Maryland, pp. A47-A50.
20. The Institute of Electrical and Electronic Engineers, *IEEE Standards Companion,* First Edition. New York, New York, 1995, pp. 4-6.
21. The Institute of Electrical and Electronic Engineers, *IEEE Standards Operations Manual*. New York, New York, 1997, pp. 17-18.
22. The American National Standards Institute, *Procedures for the Development and Coordination of American National Standards*. New York, New York, March 1997, p. iv.
23. Administrative Committee on Building Codes, *Introduction to Codes and Standards Development*. The American Society of Civil Engineers, Reston, Virginia, April 1991, pp. 21-26.
24. "Protecting Volunteers from Lawsuits." *Washington Window, Mechanical Engineering*, August 1997, p. 32.
25. McGean, T. J., "Rail Transit Vehicle Standardization Options." *TCRP Project G-4 Task 1 Report,* April 1996.
26. The American Public Transit Association, *1994 Transit Passenger Vehicle Fleet Inventory*. Washington, D.C., April 1994.
27. The American Public Transit Association, *1994-1995 APTA Transit Fact Book*. Washington, D.C., February 1995.
28. The Institute of Electrical and Electronic Engineers, *IEEE Standards Board Bylaws*. New York, New York, 1997, p. 9.
29. This section has provided an overview of the IEEE standards process followed by the Rail Transit Vehicle Interface Standards Committee. Complete details of the standards procedures summarized in this working paper are found in the *IEEE Standards Board Bylaws* and the *IEEE Standards Operations Manual*. Other useful references are the *IEEE Standards Style Manual*, which describes editorial aspects of IEEE standards, and the *IEEE Standards Companion*, which provides general information and guidance on the standards process.
30. The Institute of Electrical and Electronic Engineers, *IEEE Standards Operations Manual*. New York, New York, 1997, pp. 15-16.
31. "Commuter Railroads to Develop Passenger Car Safety Standards." *Passenger Transport*, Vol. 54, No. 18, April 29, 1996, p. 1.
32. *IEEE Standards Companion*, First Edition, op. cit. p. 6 and 31.
33. "Communications Protocol Aboard Trains." *Project Authorization Request Form P1473*, approved September 19, 1996.
34. Anderson, Robert, "IEEE Rail Transit Vehicle Interface Standard Communication Protocol on Trains" (minutes of July 26, 1996, IEEE meeting). August 9, 1996.

35. The Institute of Electrical and Electronic Engineers, "Minutes of Committee Meeting, IEEE Rail Transit Vehicle Interface Standards." Pittsburgh, Pennsylvania, October 23, 1996, Attachment 4, p. 34.
36. Global Engineering Documents, "Control Network Protocol Specification." *EIA 709.1-1998*, Englewood, Colorado, 1998.
37. International Electrotechnical Commission, "Electric Railways Equipment-Train Bus-Part 1: Train Communications Network." *IEC 61375-1: 1999*, Geneva, Switzerland, 1999.
38. Kemp, Edwin F., "WCTF Presentation to the IEEE Rail Transit Vehicle Interface Standards Committee." Union Pacific Railroad, Omaha, Nebraska, February 12, 2001.
39. Steiner, Rene, "Mitrac Remote" (presentation to the IEEE Rail Transit Vehicle Interface Standards Committee). Adtranz Switzerland, February 12, 2001.
40. "Communications Based Train Control Standards, Working Group 2, Summary Minutes of Meeting #3." Indianapolis, Indiana, September 26, 1996, p. 1.
41. "Communications Based Train Control." *Project Authorization Request From P1474*, approved September 16, 1996.
42. "Minutes of Committee Meeting, Rail Transit Vehicle Interface Standards Committee." Washington, D.C., October 8-9, 1997, pp. 4-5.
43. Glickenstein, Harvey, "Transportation Systems." *IEEE Vehicular Technology News*, August 1997, p. 25.
44. "Minutes of Committee Meeting, Rail Transit Vehicle Interface Standards Committee." Washington, D.C., October 8-9, 1997, Attachment 5B.
45. "Communications Based Train Control Performance Requirements." *Project Authorization Request Form P1474.1*, approved March 19, 1998.
46. "IEEE Developing Rail Train Control Systems Standards." *Passenger Transport*, December 8, 1997, p. 6.
47. "Slants and Trends," op. cit.
48. Hoelscher, Jim, and Rutherford, Dave, "IEEE Safety Verification Standards for Fail-Safe Processor Based Signaling Equipment." AAR Communication and Signal Section, 1997 Annual Technical Conference, Nashville, Tennessee, August 25-27, 1997, pp. 3-4.
49. "Safety Considerations for Software Used in Rail Transit Systems." *Project Authorization Request Form P1483*, approved September 16, 1997.
50. "The Functioning of and Interfaces Among Propulsion, Friction Brake, and Train-Borne Master Control on Rail Rapid Transit Vehicles." *Project Authorization Request Form P 1475*, approved December 10, 1996.
51. "IEEE Standard for the Functioning of and Interfaces Among Propulsion, Friction Brake, and Train-Borne Master Control on Rail Rapid Transit Vehicles." *IEEE Std. 1475-1999*, Institute of Electrical and Electronic Engineers, New York, New York, p. 9.
52. "Passenger Train Auxiliary Power Systems Interfaces." *Project Authorization Request Form P1476*, approved September 16, 1998.
53. "Passenger Information System for Rail Transit Vehicles." *Project Authorization Request Form P 1477*, approved September 19, 1996.
54. "IEEE Standard for Passenger Information System for Rail Transit Vehicles." *IEEE Standard 1477-1998*, Institute of Electrical and Electronic Engineers, New York, New York, 1998.
55. "Environmental Conditions for Transit Rail Car Electronic Equipment." *Project Authorization Request Form P 1478*, approved September 19, 1996.
56. "Standard for Environmental Conditions for Transit Rail Car Electronic Equipment." *IEEE Standard 1478-2001*, Institute of Electrical and Electronic Engineers, New York, New York, 2001.