U.S. Department
of Transportation
**Federal Railroad
Administration**

Railroad Communications and Train Control

Report to Congress

Office of Safety

July 1994

U.S. Department of Transportation
Federal Railroad Administration

Administrator

**400 Seventh St., S.W.
Washington, D.C. 20590**

JUL 8 1994

The Honorable Albert Gore, Jr.
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

Pursuant to the authority delegated to me by the Secretary of Transportation, the Federal Railroad Administration (FRA) submits the enclosed report on "Railroad Communications and Train Control," as required by the Rail Safety Enforcement and Review Act, Public Law 102-365. This report responds to the Congressional mandate to assess safety requirements relating to radio communications, existing advanced train control systems (ATCS), and potential Federal regulations requiring ATCS compatibility and positive train control (PTC) to prevent collisions in the railroad industry.

During the preparation of this report, FRA began discussions with railroads, rail labor, and suppliers, in a cooperative approach to address the real safety challenges confronting the industry. These discussions have already produced positive action on the testing of PTC systems, and I am confident that such cooperative effort will be able to move PTC technology forward towards FRA's high-priority goal of combining private and public sector efforts to foster deployment of contemporary PTC systems on high-risk rail corridors by the year 2000.

On behalf of the FRA, I am pleased with the encouraging vision for the future outlined in this report. I look forward to working with Congress to advance our shared objective of improving safety in the railroad industry.

A copy of this report has also been sent to the Speaker of the House of Representatives.

Sincerely,

Jolene M. Molitoris

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Enclosure

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JUN 8 1994

The Honorable Thomas S. Foley
Speaker of the House of Representatives
Washington, D.C. 20515

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INTRODUCTION

Recent tragedies in the railroad industry have again focused attention on the prospects for improving railroad safety through enhanced radio communication and implementation of advanced train control systems (ATCS). ATCS has the potential to prevent future accidents such as the collision between multiple-unit commuter trains at Gary, Indiana, on January 18, 1993, in which seven passengers died, and the collision between trains of the Union Pacific and Burlington Northern railroads at Longview (Kelso), Washington, on November 11, 1993, in which five employees lost their lives.

The Clinton Administration is strongly committed to improving safety on all modes of transportation, and this objective is one of the seven core goals of the Department of Transportation's Strategic Plan announced by Secretary Federico Peña in January 1994. In this report, the Federal Railroad Administration (FRA) expands on a Congressional mandate to evaluate ATCS and enhanced radio communications and finds that positive train control (PTC)--which, as a component of ATCS, can enforce speed and movement restrictions--is nearing a point at which it can begin to be used on railroads to eliminate injuries and deaths caused by train-to-train collisions. FRA recommends a series of steps to encourage the implementation of PTC systems on high-risk rail corridors by the year 2000.

Both through the Association of American Railroads (AAR) and through individual companies' efforts, the railroad industry has made great strides towards the development of ATCS over the last twelve years. The AAR has developed technological standards to ensure that equipment from different suppliers will be compatible, and certain railroads have implemented basic ATCS technologies for purposes such as replacement of landline communications. However, ATCS systems are not yet available in off-the-shelf form, nor is much of the research and development necessary to full implementation completed.

In a departure from the past, FRA is working with railroad management, labor, and suppliers in a collaborative effort that does not at this time require a formal regulatory proceeding but still advances FRA's safety agenda. Consultations leading to this report have already fostered concrete action on PTC: in May, the Burlington Northern Railroad and the Union Pacific Railroad announced a joint venture to pilot-test a basic PTC system on their high-density lines in Washington and Oregon, including the site of the Longview, Washington, collision. FRA will monitor and support this effort, and AAR will work with the railroads to ensure that the new system will work with other ATCS-type train control systems.

FRA reviewed the costs and benefits of PTC, using accident prevention estimates developed with the AAR and the Brotherhood of Railroad Signalmen and cost estimates provided by the AAR. That analysis reveals that a requirement of *universal* PTC cannot be justified at the present time based on accident avoidance alone. However, implementing PTC on major corridors is an important safety objective. FRA's near-term goal is to identify corridors--such as those which carry high traffic levels, passenger service, or hazardous materials--on which PTC is important and justifies the cost. Should the results of this work indicate that application of PTC to certain corridors would be cost beneficial, FRA would propose to require its implementation on those routes.

Development of ATCS and PTC provides an important opportunity to improve railroad safety, increase railroad productivity, and promote the development of new technologies with commercial applications. FRA will continue its collaborative effort to ensure that the safety technology of PTC and ATCS evolves and moves closer to full implementation. FRA is confident that this new partnership will produce real advances towards PTC implementation. In addition, FRA will progress its corridor risk analysis to determine if PTC is warranted on particular categories of rail lines and propose any needed regulatory action to ensure this is accomplished.

THIS STUDY

In September 1992, as part of the Rail Safety Enforcement and Review Act (PL 102-365), Congress required the Secretary of Transportation to conduct an inquiry into the Department's railroad radio standards and procedures. The Act required an investigation into the effectiveness of radios in emergency situations; the effect of interference on safe operation; ways in which technologies such as digital radio can be implemented to enhance safety; and the status of ATCS. Congress also required an assessment of potential regulations mandating that locomotives be equipped with radios allowing crews to communicate with dispatchers and crews on other trains, and that radios be made available at intermediate terminals; and a review of the potential for ATCS to provide positive train separation which would be compatible nationwide.

On behalf of the Secretary, FRA conducted an inquiry which included extensive field surveys, lengthy consultation with railroad management, labor, and suppliers, a review of ATCS by the Institute for Telecommunications Sciences, and opportunity for public comment.

POSITIVE TRAIN CONTROL SYSTEMS

Over the last decade, ATCS has been seen as the ultimate extension of the use of radio in rail operations. Under ATCS, dispatchers would communicate with road crews via digital radio signals to an on-board computer terminal, eliminating the need for voice-communicated orders. The on-board terminal would be continuously updated with information including speed limits, work in progress on the right-of-way, the location of the preceding and following trains, and road and motive power conditions. ATCS would provide capability for positive train control (PTC), through use of an on-board computer and communications links to a control center. Under ATCS, the brakes would be applied automatically if necessary to keep trains apart, enforce a permanent or temporary speed restriction, or stop the train short of a switch not properly lined for that train or other known obstruction (such as on-track maintenance equipment). At some point after much development and implementation, ATCS could replace existing signal and train control systems and facilitate the more efficient use of existing rail lines.

It is possible to develop PTC technology that provides varying levels of operation, depending on how much or how little of the current signal and control system is to be retained. It is also important to ensure that PTC equipment is interoperable--that different systems installed on different railroads can be used together, due to modern practices in which many locomotives operate over other railroads' lines. A PTC system that is overlaid on existing signal systems and provides enforcement of occupancy and speed restrictions can be referred to as "basic PTC." A PTC system that is "vital" (has failsafe characteristics), and is capable of replacing fixed block signal systems, can be referred to as "enhanced PTC."

Beginning in 1982, the AAR and the Railway Association of Canada (RAC) began investigating ATCS and formulating standards for ATCS throughout the industry. The FRA has found that the AAR is well advanced in its pursuit of standardized ATCS goals and specifications, and that those specifications are at a high state of readiness.

As conceived by the AAR and RAC, "ATCS" is much broader than train control. The ATCS communication platform can be used to replace landlines (pole line elimination), carry work orders for placing and picking up cars at shipper locations, report information on the "health" of an en-route locomotive to a maintenance facility, and perform other nonsafety functions. However, many of these beneficial aspects of ATCS have already been implemented through lower-cost separate systems, none of which has the capability to include positive train control.

The Potential of Communication-Based PTC

Contemporary PTC systems have the potential to improve management of train operations in a variety of ways and at lower cost than conventional automatic train control systems. Depending upon the technology employed, PTC technologies can:

1. Ensure positive train control. This capability would override the engineer's controls by braking the train when necessary to enforce speed restrictions, avoid collision with other trains, or ensure that the train will stop short of a known obstruction. In ATCS, an on-board computer would compare the location and speed of the train with a constantly-updated database of train orders, work orders, and speed restrictions, and would apply the brakes to stop or slow the train if the engineer made an error.

2. Maintain flexible blocks. With advanced PTC capabilities, railroads will not have to rely on fixed-length blocks and signals to keep trains separated safely. Different trains have different stopping requirements, and routes that carry mixed traffic (heavy commodity traffic; light, fast, intermodal traffic; or high speed passenger trains) currently require all trains to maintain the minimum separation of the trains that take

the longest distance to stop. Trains can be more closely spaced without impairing safety, because each train's braking capacity is taken into account.

3. <u>Enhance train management</u>. Under an advanced PTC system, train location is known at all times at the central dispatching center. As a result, train pacing, planning of meets and passes, and dispatching of trains from terminals can be managed with greater precision, improving fuel and crew utilization and gaining valuable time available for roadway work between trains.

4. <u>Improve accuracy in train communications</u>. Some forms of advanced PTC would be implemented with on-board computers and digital radio contact. Through this system, train orders and track warrants that are now sent by voice radio--spoken by the dispatcher and copied down by the crew--would be transmitted from the central dispatch computer directly to the displays of the on-board terminal, without the potential for misunderstanding or miscopying.

5. <u>Maintain constant communication</u>. Certain forms of PTC technology will require a virtually seamless digital radio contact (current radio contact still has some gaps caused by terrain and other factors), and this capability together with digital transmission of movement authorities will facilitate more efficient operation of trains. An important side benefit is the availability of another means of sending emergency messages, should voice radio communications not be established.

6. <u>Provide information to the locomotive engineer</u>. In certain PTC technologies, the on-board computer would give road crews a complete, continuously updated picture of the track ahead, including switch positions, work in progress, and speed limits. Like automatic cab signals, which would also be displayed, this kind of information will assist the engineer in sound train handling.

<u>The Cost/Benefit Analysis of PTC</u>

Working together, the AAR, the Brotherhood of Railroad Signalmen, and FRA developed an estimate of accidents preventable through PTC systems. FRA and AAR then utilized AAR estimates of cost as a basis for cost/benefit analysis of requiring the universal application of PTC. These reviews indicated that the savings from PTC would not cover the costs of installation.

FRA, AAR, and labor representatives identified 116 accidents between 1988 and August 1993 (5.67 years) which could have been prevented by a PTC system. Using the agreed-upon assumptions and the standard values that FRA uses to evaluate avoided fatalities, FRA estimated that the savings from PTC would be approximately $34.5 million per year.

AAR has estimated the cost of universal PTC at $843 million for a system providing only a warning to the crew (without automatic braking) to $1.1 billion for a system replacing current signals altogether. A PTC system providing enforcement of movement limitations using information largely gathered from existing signal systems (where available) was estimated at $859 million.

While a *universal* PTC requirement could not at present be warranted on the basis of cost and safety benefits alone, the benefits of PTC may justify the costs in certain corridors with certain characteristics, including the presence of passenger trains, hazardous materials, or higher levels of congestion. Similarly, further development of PTC technology may result in cost reductions or increases in benefits that may make universal application practical in the future. Thus, FRA will continue to support PTC research, development, and implementation in a number of ways.

Positive Train Control and FRA's Technology Goals

Secretary Peña has made promotion of technological development one of the seven core goals of the Department of Transportation. Assisting and leading the development of PTC technology is a major way in which DOT can make use of technological innovation to improve the Nation's infrastructure and increase American economic competitiveness.

Enhanced PTC technology can advance each of the three primary goals of the FRA's Research and Development program:

1. **Improve railroad safety.** PTC enforcement capability promises virtually to eliminate main line collisions, overspeed derailments, and accidents involving roadway workers and their equipment operating under specific authorities.

2. **Improve railroad productivity.** After decades of downsizing to avoid the costs of excessive track capacity, recent growth in rail traffic has begun to strain the capacity of certain high-traffic rail corridors. Enhanced PTC makes possible more precise scheduling of train movements, effectively increasing capacity. Increased capacity will make possible additional rail commuter service in regions where freight traffic is heavy and excess rail lines are not available for dedicated use, and reduce delays to the host railroad's freight operations, holding down the costs passed on to commuter service funding agencies. Freight railroad companies will also have additional flexibility to accommodate the growth of time-sensitive intermodal freight service.

3. **Facilitate the introduction of high speed ground transportation in the United States.** By continuously maintaining automatic oversight of train movements, increasing track capacity, and allowing dispatchers safely and efficiently to handle trains going at vastly different speeds, PTC will improve the financial feasibility of upgrading existing corridors to handle high speed service safely.

Development of next-generation PTC technologies will also provide opportunities for defense-related industries to team with established rail suppliers and convert defense technology to commercial production. Once demonstrated and accepted, communication-based PTC technology will have a potential market including every railroad in North America and elsewhere in the world, and related technology will have applications for every mode of transportation and the military.

__FRA Actions__:

This study has determined that the AAR/RAC ATCS specifications provide a sound basis for further development. Although cost/benefit analysis does not presently support requiring the installation of basic or advanced PTC on all railroads, this study has found significant potential benefits of PTC systems and advanced PTC research and has identified the need to take several actions. Specifically, FRA will--

- ***Conduct a risk assessment to determine which conventional rail corridors may warrant application of PTC technologies; and develop proposed safety standards consistent with the findings.***

  FRA will begin a risk assessment study to determine which corridors could benefit most from PTC. For FY 1995, FRA has requested $400,000 for the first year of a two-year effort to develop a model to evaluate PTC safety needs on major rail corridors. While requiring universal application of PTC would not be cost beneficial under present conditions, certain corridors may reap greater benefits from PTC application than the national rail system as a whole. For instance, lines carrying heavy passenger or hazardous materials traffic may experience greater risk with respect to frequency or severity of a preventable accident.

- ***Monitor and provide technical support for implementation of a basic PTC system test bed on heavily used freight and Amtrak lines in the States of Washington and Oregon.***

  FRA will take an active role in monitoring and providing support for the test of basic PTC technology by the Union Pacific Railroad (UP) and Burlington Northern Railroad (BN) on approximately 600 miles of railroad in the States of Washington and Oregon, some of which is jointly operated. This system will use radio communications to integrate PTC into current traffic control systems and automatic block systems. Unlike ATCS, however, it will use the Global Positioning System to determine train location, and both UHF and VHF data radio will be employed.

- ***Support Amtrak's enhancement of its automatic train control system for the Northeast Corridor (NEC); issue performance criteria for operations to 150 miles per hour.***

Beginning with NEC territory from New Haven to Boston, Amtrak is modifying its cab signal/automatic train control system to provide additional cab signal aspects, enforce civil engineering speed restrictions, and enforce positive stop at key control points. The Amtrak system differs from ATCS in three crucial ways: it will be an enhanced cab-signal system, using nine signals to authorize movement, rather than orders transmitted to an on-board computer; it will be based on electronic codes transmitted through the rails, rather than by radio; and the positive train stop and civil engineering speed enforcement features will be based on passive wayside transponders. One of FRA's main interests in this application of PTC technology will be its impact on safety and traffic capacity in a high-speed passenger corridor that also handles large numbers of commuter trains and some freight. FRA is the funding agency for the Northeast Corridor Improvement Project, which will support this signal system enhancement.

FRA is also responsible as a regulator for the safety of signal and train control systems and must specially approve such systems for high speed operations. FRA will commence a proceeding to specify performance criteria for the new NEC signal system incorporating PTC technology.

- ***Promote and develop advanced PTC technology as an element of the Next-Generation High Speed Rail Program.***

  Working in partnership with State and private interests, FRA will invest strategically in a demonstration of advanced PTC technology on a specific high speed rail corridor. The demonstration project will apply communications-based technology that is interoperable with PTC systems planned for freight rail corridors to mixed freight and high speed passenger service, verifying safety performance characteristics and refining system features that can enhance corridor capacity and traffic flows.

  The first phase of this effort will be the demonstration of communication-based PTC enforcement, and improved on-board information delivery and display, suitable eventually to permit high speed operations, and initially involving parallel operation of an existing signal system with suitable attributes. In later phases of the project, flexible block capabilities may be explored.

- ***Work with other DOT agencies and the Advanced Research Projects Agency (ARPA), Department of Defense, to promote integration of defense technology into PTC systems.***

  FRA will aggressively pursue opportunities for partnership among ARPA, DOT agencies, the railroad industry, rail suppliers, and defense industries to explore and help advance innovative technologies that can enhance the capability and affordability of interoperable PTC systems.

- ***Work closely with the AAR to ensure that AAR's open architecture approach for universal compatibility remains effective and that standards meet safety needs.***

  In today's railroad industry, where many locomotives and trains run across company boundaries, the safety benefits of PTC will be lost if incompatible systems are applied by different railroads. FRA will promote the use of flexible industry standards so that all systems will improve safety on all railroads.

  FRA will continue to work with AAR committees and task forces considering further development of ATCS or successor industry standards.

- ***Extend FRA's partnership with the Federal Highway Administration (FHWA) on highway-rail grade crossing safety to work together more closely in planning for interoperability between PTC technology and Intelligent Vehicle Highway Systems (IVHS).***

  PTC technology can and should be made compatible with IVHS technology so that trains and road vehicles can use the same equipment to detect each other at grade crossings as they do to detect other trains and vehicles. The Vehicle Proximity Alerting System (VPAS), being developed as part of IVHS by FHWA, has this potential to interface with ATCS. The VPAS is intended primarily for use by priority vehicles such as school buses and emergency vehicles, at passively equipped grade crossings; it would also provide reinforcement to standard warnings at crossings equipped with active warning devices.

  FRA and FHWA will seek to combine IVHS and ATCS research on this subject. The FRA's Office of Railroad Development and FHWA are working to evaluate proximity alerting technologies, and are planning to use the Transportation Test Center to evaluate invehicle train warning technologies at grade crossings. For FY 1995, the Department's budget request of $12.5 million for technology development in the area of positive train control and grade crossing technologies (under the appropriation for next-generation high speed rail) includes an emphasis on linking IVHS and ATCS for use on high speed rail systems.

- ***Analyze and evaluate developing technology pertinent to PTC to determine its impact on safety.***

  As railroads and suppliers have already begun to develop technology related to ATCS, FRA should evaluate these emerging technologies and analyze their impact on safety. For FY 1995, FRA has requested $250,000 for the analysis of microprocessor-based train control, and $400,000 for the analysis of ATCS technology already in place. A clear focus on software and hardware issues will help lay the foundation for performance standards and support development of PTC technology.

Time Line:

The FRA's goals for PTC research and implementation are as follows:

FY 1994:

- Monitor and support development of BN/UP test bed.

FY 1995:

- Initiate a project to test enhanced PTC technology that is interoperable with industry-standard technology on a high speed rail corridor. Select corridor, determine technical approach, and begin system implementation.

- Begin two-year project to evaluate which conventional rail corridors are prime candidates for implementation of PTC by developing a risk assessment model.

- Initiate and complete a proceeding for an order or rule of particular applicability for NEC system cab/signal automatic train control system with added PTC features.

- Evaluate results of the AAR findings and report on ATCS (expected in December 1994); provide assessment to AAR Board of Directors.

- Complete initial evaluation in conjunction with FHWA of VPAS using the Transportation Test Center to perform evaluation of candidate technologies.

- Study the safety impact of PTC technology and microprocessor-based train control.

- Provide continuing support for AAR standards development to ensure interoperability.

FY 1996:

- Continue development of project to test enhanced PTC technology on a high speed rail corridor, completing basic safety verification of enforcement features linked to existing signal system.

- Complete two-year project to evaluate which conventional rail corridors are prime candidates for implementation of PTC.

- Complete evaluation of BN/UP test bed, report on the lessons of those tests, and work with the AAR to incorporate promising approaches into AAR positive train separation framework (ATCS or successor specifications).

- Continue partnership with FHWA to ensure proper interface of IVHS and PTC technology.

- Continue technical evaluations of PTC technology and systems.

- Provide continuing support for AAR standards development to ensure interoperability.

<u>FY 1997</u>:

- Complete demonstration of an enhanced PTC system on the selected high speed corridor. Implement in revenue service in FY 1998.

- Review conventional rail corridor risk analysis and, as appropriate, commence rulemaking to require PTC on identified categories of rail lines. Include development of generic performance criteria for improved train control systems applicable to high speed and conventional rail service. Complete rulemaking in FY 1998.

- Demonstrate IVHS and PTC interface for highway-rail crossing safety in cooperation with selected railroads and trucking companies.

- Provide continuing technical support for the development and implementation of PTC technologies nationwide, including development of AAR industry standards to ensure interoperability.

By forming partnerships within the Federal Government and with industry, development and demonstration of PTC technology can be achieved. As the technology becomes operational, its value will be recognized. With wide deployment, PTC systems should become more affordable, and barriers to further deployment should fall.

FRA believes that private and public sector efforts can be combined to foster deployment of contemporary PTC systems on high-risk rail corridors by the year 2000. ***FRA will make it a high agency priority to accomplish this objective.***

RADIO COMMUNICATIONS

FRA found that railroad radio communications are generally good and have been improving since FRA's last major review of this issue in 1987. However, compliance with FRA standards and procedures for voice radio communications is poor, and the inflexibility of

FRA regulations may discourage compliance. Further, employee representatives continue to report problems with radio equipment; and railroad companies fail to treat communication systems as an integral part of safety planning and execution, resulting in lower levels of maintenance.

FRA Actions:

As a result of the findings of this study, FRA will--

- ***Revise the Radio Standards and Procedures to make the regulations more flexible and to promote improved compliance.***

- ***Include in the proposed rule requirements that railroads provide suitable communications capabilities between trains and dispatchers, and between locomotive engineers and ground employees, and that back-up systems be established for critical functions.***

- ***Propose as a part of that rulemaking that each lead locomotive be equipped with an operative radio or suitable alternate communication equipment.***

- ***Work with a major railroad and its employees to implement transmission of movement authorities by digital data radio, in lieu of voice radio communications.***

Time Line:

FY 1995:

- Initiate negotiated rulemaking to revise the radio standards and procedures, including requirements for communication plans and compliance with those plans.

- Work with a major railroad and its employees to pilot-test the transmission of movement authorities from the central dispatch computer to the on-board terminal.

FY 1996:

- Complete rulemaking to revise the radio standards and procedures.

- Complete system implementation of data radio to transmit movement authorities on a major railroad.

FY 1997:

- Conduct compliance reviews on major railroads to verify compliance with revised requirements.
- Identify additional opportunities for transmittal of movement authorities by more secure means.

These steps, taken together, will help ensure that radio communications are treated as an integral part of railroad safety planning and execution.

THE MANDATE

Section 11 of the Rail Safety Enforcement and Review Act (Public Law 102-365; September 3, 1992), entitled "Railroad Radio Communications," provided as follows:

(a) SAFETY INQUIRY.--The Secretary shall, within 18 months after the date of enactment of this Act and in consultation with the National Railroad Passenger Corporation, freight and commuter railroads, rail equipment manufacturers, and railroad employees, conduct a safety inquiry regarding the Department of Transportation's railroad radio standards and procedures. At a minimum, such inquiry shall include assessment of --

(1) the advantages and disadvantages of requiring that every locomotive (and every caboose, where applicable) be equipped with a railroad voice communications system capable of permitting a person in the locomotive (or caboose) to engage in clear two-way communications with persons on following and leading trains and with train dispatchers located at railroad stations;

(2) a requirement that radios be made available at intermediate terminals;

(3) the effectiveness of radios in ensuring timely emergency response;

(4) the effect of interference and other disruptions of radio communications on safe railroad operations;

(5) how advanced communications technologies such as digital radio can be implemented to best enhance the safety of railroad operations;

(6) the status of advanced train control systems that are being developed, and the implications of such systems for effective railroad communications; and

(7) the need for Federal standards to ensure that such systems provide for positive train separation and are compatible nationwide.

(b) REPORT TO CONGRESS.--The Secretary shall submit to Congress within 4 months after completion of such inquiry a report on the result of the inquiry along with the identification of appropriate regulatory action and specific plans for taking such action.

CHAPTER I

Introduction

Preface

This report responds to the mandate of the Congress, contained in section 11 of the Rail Safety Enforcement and Review Act, to conduct a safety inquiry on railroad communications and train control and to report the results of that inquiry. The statutory mandate specifically references the "... radio standards and procedures," FRA's regulations for voice radio communications (49 CFR Part 220). The scope of those regulations is defined as the use of radio communications in connection with railroad operations. Based upon this reference and the specific areas identified by the Congress for assessment, FRA has focused this effort on the safety of train operations.[1]

Railroads provide approximately 37 percent of the freight transportation service in the United States, logging over one trillion ton miles each year. Railroads also provide about 14 billion annual passenger miles of intercity and commuter service each year. Despite occasional, individually significant accidents, the railroad companies provide this service with a high degree of safety.

As America becomes more densely populated and its existing highway system struggles with limited capacity, the Nation will need rail transportation even more in the next century. Whether the railroad companies are able to meet this challenge will depend on a wide variety of factors, two of which are central to the subject of this report: First, the railroad companies must provide service safely. Second, the railroad companies will need to direct capital investments to purposes that permit them to earn a reasonable return.

Although these two objectives may conflict, FRA does not believe that this conflict is inevitable. Rather, FRA believes that strategic investment in highly capable technology will benefit both railroad safety and railroad profitability.

In particular, the railroads' ability to serve the Nation depends on investment in technologies that will facilitate effective flows of information and preserve critical safety margins even under worst-case conditions. Rail transportation has several characteristics that have historically caused railroads to place a premium on effective and secure communications:

- The size and weight of rail equipment impart destructive potential.

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[1]Radio and other means of communication also have safety value with respect to other aspects of railroad work, particularly the coordination of maintenance and inspection of railroad track and structures and railroad signal and train control systems with on-track movements. The fact that the present study did not address all of these issues in detail should not be taken as an indication that they are unimportant.

- This potential is magnified by the long stopping distances inherent in operation of heavy rolling stock using the steel wheel and steel rail.

- Operations are conducted over an extensive network of rail lines spanning lightly developed rural and wilderness areas as well as highly developed urban and suburban areas.

- Railroads must contend with over 280,000 highway crossings at grade and countless other locations where pedestrians and vehicles may come into conflict with rail movements.

- Like other modes of transportation, the railroad companies face challenges presented by natural disasters and often rapidly changing weather conditions.

In recent decades, the need for more highly capable communications has increased as --

- The number of railroad employees has declined (e.g., elimination of train order operators), including a major reduction in the number of railroad officers available to provide direct supervision.

- Train speeds have risen in response to service requirements, particularly for highly competitive intermodal service.

- Density of track occupancy has risen due to downsizing of plant and unexpectedly strong demand for rail service.

- Elements of prior systems, such as pole lines, have outlived their useful life and required replacement by alternatives that require less cost to maintain.

Railroad communications pertain to safety functions and business purposes. Although this report will address only the former, a great many railroad functions that rely on effective communications are in fact safety-relevant.

Safety Inquiry Approach; Report Objectives

Section 11 of the Rail Safety Enforcement and Review Act (RSERA), enacted September 3, 1992, required the Secretary, in consultation with the National Railroad Passenger Corporation, freight and commuter railroads, and rail equipment manufacturers, to conduct an inquiry and provide a report to the Congress regarding "the Department of Transportation's railroad radio standards and procedures...." The report mandate addressed the use of three technologies: voice radio communications, digital data communications, and advanced train control technologies.

In order to address these objectives, FRA --

- Conducted a field investigation of current railroad voice communications technology and practice, including assessments at dispatching offices, observations while train riding and, visits to yards are terminals.

- Held three Roundtable discussions on advanced train control technologies as part of the Administrator's outreach program. Participants included railroad management and employee representatives, rail suppliers, and other Department of Transportation agencies involved with communication and navigation technologies.

- Followed up the Roundtable discussions by meeting with representatives of the Association of American Railroads and the Brotherhood of Railroad Signalmen to examine train accident data for the purpose of identifying those events that might be prevented by positive train control (PTC) technologies.

- Published a notice of special safety inquiry (59 FR 11847; March 11, 1994), conducted a public hearing on March 29, 1994, which focused on voice radio communications, and received written comments (comment closing date: April 11, 1994).

- Contracted with the Institute for Telecommunications Sciences (ITS), Department of Commerce, for a technical evaluation of Advanced Train Control Systems under development by the Association of American Railroads/ Railway Association of Canada.

- Met with various parties interested in this issue to gather information and views.

- Consulted with other agencies within the Department of Transportation and with staff of the Federal Communications Commission regarding pertinent issues.

FRA's approach to preparation of this report was collaborative and benefitted greatly from the time and effort invested by all participants. The conduct of this study resulted in acceleration of deliberations by the major railroads, through the Association of American Railroads, regarding future investments in next-generation, communication-based train control technologies. Further, the impetus created by the roundtable process has helped to spur development of a test bed for "positive train separation" technology by two major western railroads. These developments are reviewed in Chapter IV.

Report Structure

This chapter introduces the approach and objectives of the report and describes functional safety requirements that are pertinent to the scope of the congressional mandate. ***Chapter II*** is devoted to historical background that describes (i) the origins, characteristics, and uses of communication and signal systems within the framework of railroad operating rules, and (ii) the role of the Federal Government in regulating those systems for the purpose of safety. ***Chapter III*** describes current voice radio capabilities, deployment, and uses and identifies related issues. ***Chapter IV*** describes the need for more capable train control systems (incorporating "positive train control" or "PTC"), and recounts the efforts of the industry to develop them. ***Chapter V*** estimates costs and benefits of positive train control. ***Chapter VI*** suggests conclusions and future actions regarding the future of communications technologies in the safety of railroad operations, including the role of Federal regulation and investment policy.

Safety Requirements

In the contemporary operating environment it is essential that railroads have available effective means of communication and that they use those means wisely. Sometimes, however, merely communicating information is not sufficient. In those instances where it is critical that operational commands or authorities be acted upon in a timely and precise manner, it may be appropriate to provide back-up systems that provide "enforcement" if the human recipient is unable, unwilling or insufficiently motivated to act properly. Advanced train control technologies unite features of digital data communication with attributes of present signal and train control systems. They permit enforcement of movement authorities and instructions from compatible wayside detectors.

Depending upon whether the information communicated is an instruction, warning, display of track occupancy, indication regarding switch position, or other message, etc., and depending further on the technology employed, a contemporary railroader might refer to the medium as "track warrants" (paper copy), "fax," "radio" (voice radio), telephone (line or cellular, commercial or private), wayside signal system, cab signal system, or "OBT" (on-board terminal of a data communications network).

It is important to recognize that all communications media must be considered when railroad communications and train control functions are evaluated. Only by recognizing this inter-relatedness can railroads make decisions that will ensure optimum use of capital; and, only by recognizing this interrelatedness can Federal policy properly determine minimum safety criteria for railroad communications and train control that should be applicable to different types of railroad operations.

Table I-1 describes some of the most important communication and train control functions that are relevant to safe operations on the railroad and involve communication of information or instructions. The table indicates the means by which communication can be effected using the means most commonly employed in the industry today: voice radio, and signal and train control (S&TC) systems. In addition, entries are provided for digital data radio--a rapidly emerging technology. For purposes of this "data" entry in the table, we assume that the train's controlling locomotive is equipped with an interactive terminal.

TABLE I-1

COMMUNICATIONS MEDIA AND FUNCTIONS

Legend: Y = Yes (the function is supported)
N = No (the function is not supported)

COMMUNICATIONS FUNCTION	VOICE	DATA	S&TC	COMMENT
DISPATCHER TO TRAIN				
Train movement authorities	Y	Y	Y	Data communication may be more reliable than voice, due to direct input from a computer-aided dispatching system and elimination of misunderstandings; during 1994 or 1995, the first use of digital data radio to transmit train movement authorities will be implemented. In automatic train control systems, information regarding switch position and track occupancy is used to display appropriate signal indications and to enforce them. Advanced features include positive stop and enforcement of temporary speed restrictions.
Obstruction and other emergency warnings from third parties (fires, impending floods, objects on the track, objects fouling the track)	Y	Y	*	*In centralized traffic control territory, the dispatcher could set the signal system to stop a train short of problems in distant "blocks." The same capability does not exist in automatic block territory.
FIELD TO TRAIN				
Wayside detector warnings (hot wheel, hot bearing, slide, high water, dragging equipment, etc.)	Y	Y	Y	Wayside detector readings can be communicated through the signal system, a prerecorded transmission over the voice radio, or through data transmission.

COMMUNICATIONS FUNCTION	VOICE	DATA	S&TC	COMMENT
LOCOMOTIVE TO GROUND CREW				
Switching movements	Y	N	N	Conductors and brakemen rely heavily on voice radio communication with the locomotive engineer during switching operations. FRA radio rules require that movements be stopped if radio continuity is lost.
TRAIN TO DISPATCHING CENTER / EMERGENCY RESPONDERS				
Emergency warning (e.g., train derailed and fouling adjacent track; shifted lading; problem with passing train; fallen tree)	Y	Y	N	Operating rules require train crew members to inspect their train and passing trains in route and to provide information concerning other unsafe conditions. Currently, voice radio is the only means available to communicate this kind of information.
Security concerns	Y	Y	N	Trespassers endanger themselves, and vandals endanger both themselves and others. Having available a ready means of communication will permit train crews to pass information through the dispatching center or other channels to railroad police and local law enforcement.
Emergency request (e.g., crew member or bystander injured, train derailed, hazardous materials release, collision with highway vehicle)	Y	Y	N	Very often, the first notice of a serious accident or casualty is provided by voice radio, which may be the most flexible medium for eliciting and providing information necessary for emergency response.

Safety Performance

Though the rate of progress has been neither steady nor uniform, the railroad industry has made enormous strides in preventing serious human factor accidents--particularly those involving collisions of trains. These advances have resulted from a variety of sources, including more capable signal systems, tighter operating rules, computer-aided dispatching (CAD), improved voice radio communication, reductions in use of alcohol and drugs, and the increasing professionalism of railroad operating employees.

FRA train accident data is available in comparable form since 1975, when the current reporting system became effective. A reportable "train accident" is one exceeding the current threshold for railroad property damage (since 1991, $6,300). Figure I-1 illustrates the decline in reportable collisions, most of which occur during low-speed yard switching operations. Figure I-2 displays the much smaller number of main line collisions, which tend to be the most hazardous to persons.

Figure I-3 displays fatalities in collisions. The increase in 1987 resulted from the accident of January 4 at Chase, Maryland, in which one crew member and 15 passengers died. The total for 1993 is strongly influenced by the collision between two commuter passenger trains at Gary, Indiana (7 fatalities) and the collision between two freight trains at Longview (Kelso), Washington (5 fatalities).

Figure I-4 shows fatalities in collisions on main tracks. These are the collisions responsible for most fatalities and those most likely to be preventable by positive train control technology (discussed in Chapter IV).

COLLISIONS BY YEAR
ALL TRACK TYPES

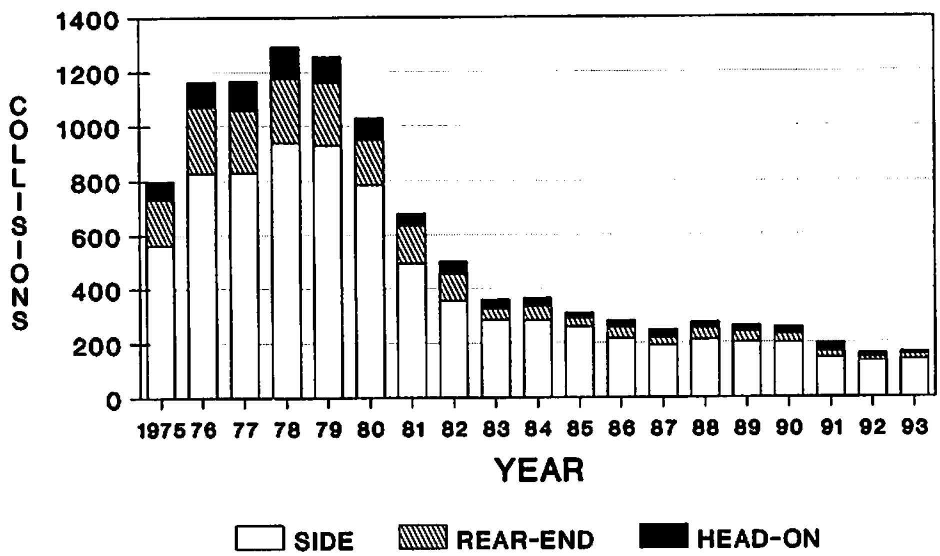

Figure I.1

COLLISIONS BY YEAR
MAIN TRACK

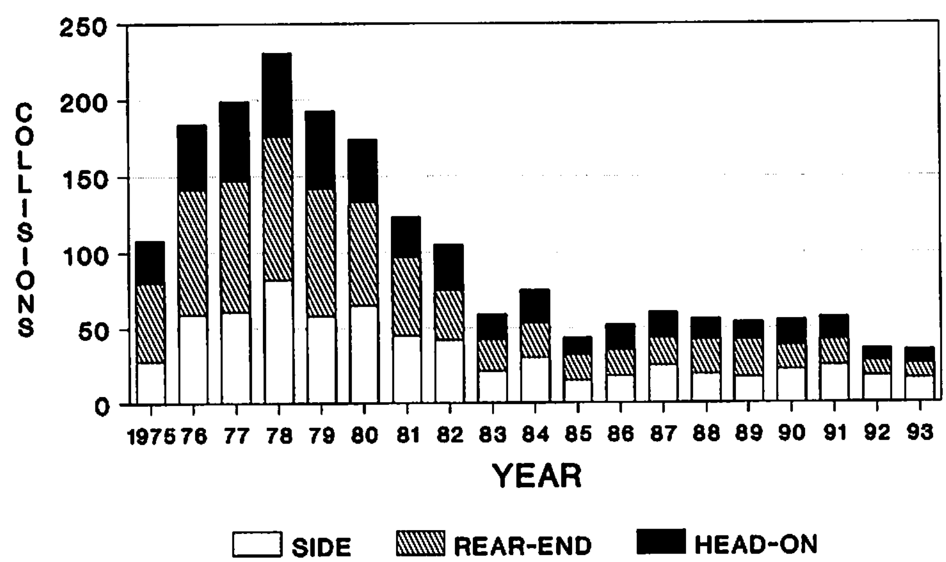

Figure I.2

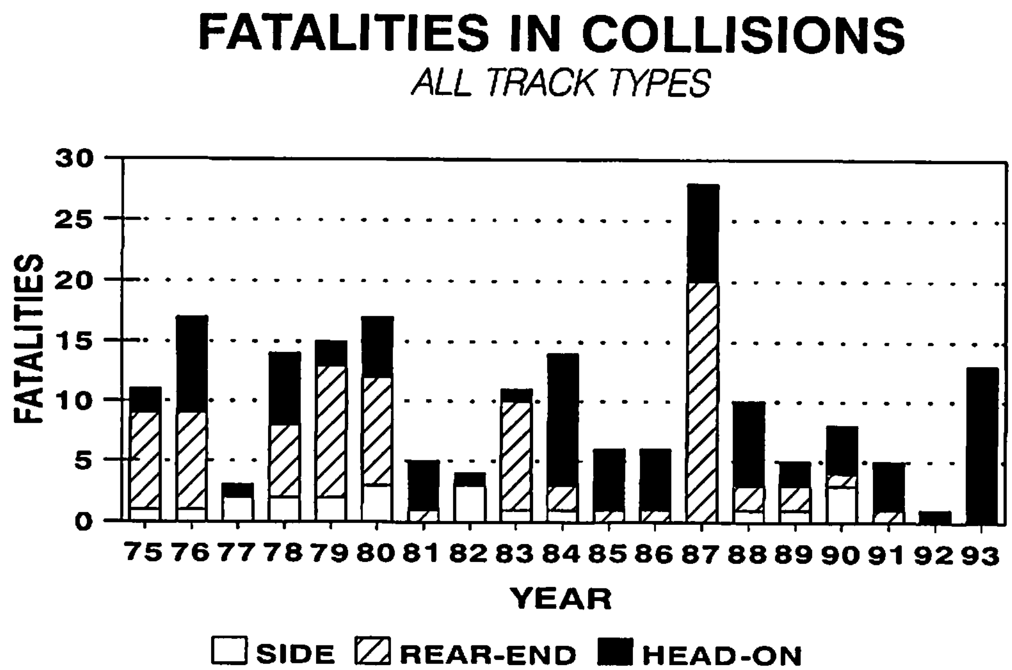

Figure I.3

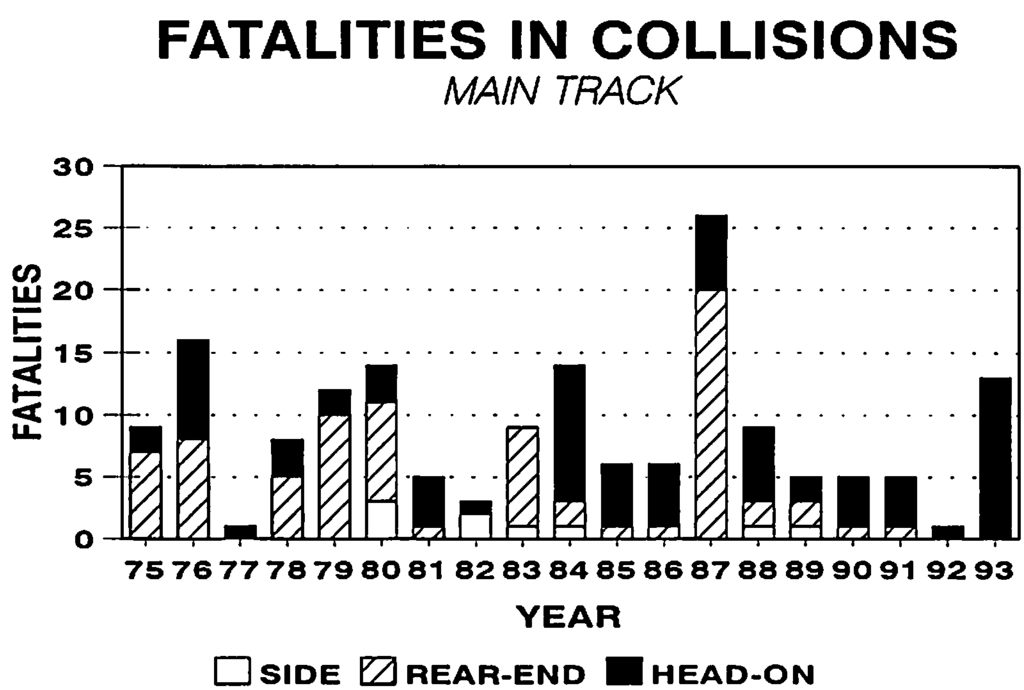

Figure I.4

CHAPTER II

Development of Railroad Communications and Train Control

This chapter briefly describes the development of railroad communication technologies, signal and train control systems, and operating rules. It also traces the development of pertinent Federal statutory and regulatory requirements and outlines the residual safety risks associated with current methods of operation.

The Early 20th Century

At the turn of the century the railroad industry was rapidly expanding, and experimentation prevailed. Faster, more powerful locomotives were being introduced to meet the demands for high speed passenger trains and the hauling of heavier tonnages. Greater use of the telegraph as the primary means of communication was being made to eliminate the costs of closely spaced stations to control the movement of trains and to cope with higher speeds and train densities, changing schedules and traffic patterns, and competitive pressures. Operating rules were primitive, often adopted as the result of tragic accidents.

In 1906, the Congress passed the Block Signal Resolution which directed the Interstate Commerce Commission (ICC) to investigate and report on the use of block signal systems and appliances for the automatic control of trains. Thus began the initial Federal effort at curbing train accidents caused by human error. For the next 14 years, the ICC studied existing trainstop and train control systems and submitted its findings in reports to each Congress. On the basis of these findings the Congress enacted legislation in the Transportation Act of 1920 that authorized the ICC to require the installation of trainstop and train control systems where found necessary in the public interest.

In issuing the first order for trainstop and train control systems, the ICC summed up the accident experience as follows:

> The accident reports made by the railroads show that from January 1, 1906, to December 31, 1921, there were 26,297 head-on and rear-end collisions. These resulted in death to 4,326 persons and injury to 60,682. The damage to railroad property alone amounted to $40,969,633. The annual average of these collisions amounted to 1,643; the average number killed, 270; and the average number injured 3,792. The average damage to railroad property alone amounted to $2,560,603 per year.[2]

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[2]69 I.C.C. 258, 272 (Docket No. 13413; decided June 13, 1922).

The trainstop and train control devices of the early 1900s were mainly mechanical and electromechanical devices of a crude design compared to modern engineering. Several systems required wayside structures of inductors, ramps or trips to activate mechanical or electrical devices installed on steam locomotives. The harsh environment of steam locomotives and increasing train speeds were punishing to the onboard devices necessitating daily inspections, maintenance and repair. Failures were frequent.

The wayside block signal systems were of a wide variety--mechanical, pneumatic, hydraulic, electromechanical and electropneumatic. Few systems had continuous track circuits.[3] Technology in the application of electricity to signal and train control systems was in the developmental stage. The reliability of the interconnection of onboard devices with wayside equipment was poor.

There was an intensive search for a means of operating trains safely and efficiently. As a result, thousands of patents were applied for to cover railroad equipment, particularly signal and train control devices. The ICC reviewed and reported its findings on 85 trainstop and train control devices. Some railroads had as many as three incompatible systems. There was even more disparity in the types of block signal and interlocking systems.

The prevalent methods of operation were by timetable and train orders or timetable schedules only. Train orders required a thorough understanding of a complex set of rules involving the rights of trains, and orders were often misinterpreted. Timetable schedules were based on a time interval scheme which was heavily dependent on accurate time and flag protection when a train was delayed.

The organizational structure of the typical railroad further complicated this situation. Railroad management and employees were initially antagonistic toward signal systems. Mechanical departments saw little value in proper maintenance of trainstop and train control devices on locomotives. Communication engineers tasked with the installation and maintenance of wayside signal systems generally viewed the responsibility as burdensome. In general, railroad companies had not yet recognized that signal systems can increase track capacity, improve safety, save fuel and expedite train movements.

Efforts to Improve Technology and Rules

In 1895, a group of young signal engineers formed a signaling club in Chicago, Illinois, to share experiences and standardize signal equipment. Among their first undertakings were the preparation and adoption of a standard and uniform set of rules and practices for interlockings in the Chicago area. Using sound engineering principles, various committees also set standards for signal aspects and indications and automatic block signal systems (ABS). As a result, train collisions, which frequently occurred at crossings-at-grade, were

[3]Contemporary signal systems utilize the rails as conductors, a design that permits detection of trains and broken rails.

significantly reduced. The success of the signaling club did more than any other group in dispelling antagonism toward signal systems. The club became widely recognized and respected, and subsequently was accepted into the American Railway Association (now the Association of American Railroads) (AAR) as that organization's Signal Section.

The primary duty of the Signal Section was to develop recommended practices for equipment and materials for signal systems. However, within the AAR it was better able to influence the various committees of the AAR's Operation and Mechanical Divisions, resulting in a higher standard of recommended practices for operating rules and maintenance of trainstop and train control devices installed on locomotives.

Over time, the AAR's Standard Code of Operating Rules, prepared and adopted by the Operating Rules Committee that was composed of member railroads' top rules officers, was revised to provide succinct rules for train operations at interlockings and in various types of signal, trainstop and train control systems. Each railroad had its own book of operating rules and rules officers could adopt an AAR rule or modify it to their railroad's needs. The effect of the AAR's improved Standard Code of Operating Rules resulted in an overall improvement of its member railroads' rules. The AAR even provided written responses to rules officers who made inquiries for interpretations of special situations, further standardizing acceptable rules practices.

The AAR's member railroads' Chief Mechanical Officers (CMOs) focused seriously on trainstop and train control devices for locomotives. Beginning in 1920, the CMOs played a major role in setting standards for the design, construction, installation and maintenance of those systems. Working in conjunction with the signal engineers, the application of electrical technology in trainstop and train control devices was improved--even a vacuum tube-driven electronic amplifier was introduced that was used for more than 30 years until replaced by solid state equipment.

By 1920, the telegraph was widely used in the industry for issuing train orders. The telephone was rapidly expanding, and voice transmissions of train orders commenced, with the telegraph being relegated to other communication purposes. Train order stations were becoming further apart as the railroad companies realized the economic benefits from the application of dependable signal systems, communications and operating rules. Still, the failure of train crews to interpret train orders properly, obey speed limits, comply with signal indications, and the failure of railroads to enforce compliance with operating rules, plagued the industry with frequent and sometimes catastrophic accidents.

Federal Intervention in Train Control

In 1922, under authority of the Transportation Act of 1920, the ICC issued Order 13413 requiring 49 respondent railroads to install either a trainstop or train control system on at least one division over which passenger trains were operated. The Order was expanded in 1924 to include an additional passenger division on each railroad.

The ICC set minimum standards that required ***trainstop*** systems to operate automatically, upon the failure of an engineer to acknowledge a restricting signal, to apply the brakes until the train was brought to a stop. A ***train control*** system was required to apply the brakes until the train was brought to a stop in the event an engineer failed to take action to control the speed of the train in accordance with signal indications. (Train control systems by design do not operate to enforce signal indications when the speed, under control of the engineer, has been reduced below 20 MPH to Restricted Speed, a feature found acceptable on the theory that train movements are safe when all trains are operating prepared to stop in one-half the range of vision.)

Many of the railroad companies objected to the Order and filed appeals, mainly on the basis of poverty. Some argued successfully and were waived from the requirements. A few railroads saw the value of trainstop or train control and made installations systemwide. Other railroads made more than the required number of installations but most railroads met only the requirements of the Order.

Certain railroads elected to install trainstop systems; others installed train control systems; and a few installed systems that had the features of both. Five railroads sought and obtained ICC approval to install trainstop or train control devices only on passenger locomotives. All other railroads installed them on both passenger and freight locomotives used in the equipped territory.

The Pennsylvania Railroad pioneered the development of a four-aspect cab signal system with an audible alarm that sounds when the cab signal changes to a more restrictive indication. The railroad petitioned the ICC for approval to install the automatic cab signal system (ACS) on its line in lieu of a trainstop or train control system. After investigation, the ICC approved the cab signal system in 1930. Subsequently, two other railroads also adopted the cab signal system.

The reliability of cab signal, trainstop and train control devices are dependent not only on the quality of maintenance and repair performed by mechanical department employees, but also by the quality of installation, maintenance and repair of wayside signal equipment. While the affected railroads complied with the ICC's order to install the systems, many railroads did not install or maintain the wayside systems in a manner to assure the cab signal, trainstop and train control devices functioned as intended. The ICC had no authority to require safe and proper installation, maintenance and repair of interlockings and block signal systems with the result that cab signal, trainstop and train control installations frequently functioned with less than the desired results expected by the Government.

Acting on the basis of reports from the ICC, in 1937 the Congress passed the Signal Inspection Act giving the ICC almost plenary authority over signal and train control systems. In 1939, the ICC promulgated rules, standards and instructions (RS&I) governing the installation, maintenance and testing of block signal, interlocking, cab signal, trainstop and train control systems. The impact of the RS&I resulted in the wayside and onboard equipment becoming highly reliable operating tools for the safe movement of trains. In addition, in order to meet the requirements contained in the RS&I, carrier operating rules pertaining to train operations in these systems were revised to clearly indicate the actions to be taken.

Post-World War II Developments

Traffic control systems were developed in the 1930s and successfully utilized during World War II to increase track capacity and expedite train movements. The post-war years confronted the railroad companies with the need to downsize as the volume of traffic diminished. One means of reducing plant was by the expansion of traffic control systems.

A traffic control system (TCS) is controlled from a machine operated by one person, usually the dispatcher. Frequently used switches, such as siding switches, are power-operated and also positioned from the control machine. The method of operation is by signal indication, eliminating the need for train orders and train-order situations.

By 1954 there were over 17,000 miles of railroad equipped with automatic cab signals (ACS), automatic train stop (ATS) or automatic train control (ATC). The industry began to petition for removal of equipped territory and installation of TCS, resulting in more than 7,000 miles of equipped territory being discontinued.

The expansion of traffic control systems signaled the demise of traditional methods of operation whereby train orders were issued using the telephone and telegraph. Significant returns on the capital investment for traffic control was earned by the closing of train order stations, remote control of manual interlockings and the reduction of multiple tracks to fewer or single main tracks. Operating rules in traffic control systems are much more succinct than train order rules, which improves operating safety.

In addition, the railroad companies began to introduce radio to railroad operations as a means of communication. In territory where signal systems were not in use, and in automatic block signal territory, radio was increasingly relied upon as an adjunct to telegraph and telephone for the purpose of delivering the text of movement authorities (initially train orders).

As the use of the radio expanded, the railroad companies began to adopt rules for its use. As a result of incidents that occurred and the disparity of radio rules among the carriers, the FRA, the successor to the ICC in matters concerning railroad safety, promulgated rules in 1977 for the use of the radio (49 CFR Part 220). The rules provided --

- Standard protocols for radio discipline;
- Procedures for sending movement authorities; and
- Rules for use of radio during switching operations.

Radio technology continued to develop and its reliability grew as new installations were made and existing installations were updated. Today on many carriers almost 100 percent coverage exists along their lines.

As a result of almost complete coverage, in 1974 one railroad pioneered Voice Control Radio System operating rules in which directives were given to train crews (through block or "relay" operators) authorizing limits of authority to operate, including whether to hold the main track or take sidings for the purpose of meeting other trains. After investigation and examination, the Voice Control Radio System received the approval of FRA for three primary reasons: (1) radio communications across the line involved were excellent; (2) instructions were presented simply, reducing the risk of human error about actions to be taken in the movement of trains; and (3) maintenance-of-way personnel were brought under the same protection as trains which greatly enhanced the safety of those employees.

In 1983, several western railroads also received the approval of FRA for the use of a radio-based operation termed "track warrant control" for the same reasons. Track warrant control differed from the Voice Control Radio System in that dispatchers communicated directives directly to train crews rather than to a relay operator to do so. While the check and balance of the relay operator was eliminated, FRA still favored implementation of track warrant control for the above reasons. However, full protection of maintenance-of-way employees was never implemented mainly because of the workload imposed on dispatchers.

Present Methods of Operation

Track warrant control systems, under various names, are now widely established in the industry. The security of track warrant operations is enhanced through the use of computer-aided dispatching systems. CAD systems utilize computers to verify movement authorities against one another and (in traffic control system territory) against occupancy and switch position information. Properly configured and employed, they can also ensure against mistaken routing of a train onto a track subject to repair by maintenance-of-way forces.

Railroad signal systems continue to play a very important role in the safety and efficiency of the railroad industry. Under the current signal and train control regulations (49 CFR Part 236), signal systems are mandated based on train speed as follows:

	Speed (MPH)	
Signal system	Freight	Passenger
None required	to 49	to 59
Block signals or manual block	50-79	60-79
Automatic cab signal, train stop or train control	80-110	80-110

(Under the Track Safety Standards, operations are permitted up to 110 miles per hour. A railroad seeking approval to operate at greater speeds must receive special approval from the FRA, and the application must include information on signaling of the territory (49 CFR sec. 213.9(c)).)

The Signal Inspection Act and implementing regulations (49 CFR Part 235) bar discontinuance of signal systems without FRA approval. FRA regulations also requires reporting with respect to methods of train operation (49 CFR Part 233). Reports as of January 1, 1993 revealed the information displayed in Table II-1 for railroads in the general system of rail transportation.

Table II-1

METHODS OF OPERATION

Method of operation	Track miles	Road miles
Track warrant (direct traffic control)	48,735	48,183
Train order (timetable)	25,589	24,953
Total dark territory	**74,324**	**73,136**
Automatic block signals	28,506	21,626
Traffic control systems	60,313	49,031
Total signal territory	**88,819**	**70,657**
Total miles operated	**163,143**	**143,793**

The total miles of signal territory listed above include several thousand miles of railroad where wayside signals are supplemented by automatic cab signals and/or where wayside or cab signals are supplemented by automatic train control or automatic train stop systems. These systems are deployed on some of the highest density lines in the United States; and, as noted above, one or more of these systems are required for operations at greater than 79 miles per hour. Automatic cab signals provide warning when the signal aspect becomes more restrictive, and ATC and ATS provide enforcement where the engineer fails to respond properly.

FRA conducts inspections to determine compliance with signal system regulations. The agency also investigates "false proceed" reports (indicating an unsafe malfunction of a system) for which cause or remedial action may be in doubt. Actual signal system malfunctions are responsible for fewer than one percent of reportable train accidents each year. This record is a great credit to the fail-safe design of the systems and the skilled work of railroad signal maintainers.

Remaining Safety Risk

Capable signal and train control systems, improved radio communication, strengthened operating rules, and CAD technology, along with committed employees, have contributed greatly to railroad safety. Accidents involving train collisions continue to occur mainly at lower speeds.

However, train collisions with significant consequences have occurred sufficiently often to raise public concern for employee and passenger safety and damage to the environment as a result of hazardous materials spills. Although most of these accidents continue to be attributed to "human error," they also represent failures of safety systems that seek to provide, where possible, multiple layers of safety assurance.

Table II-2 describes, in summary form, the principal methods of operation currently in use on U.S. railroads and their vulnerabilities with respect to collision risk. Similar comparisons can be made for overspeed derailment risk or for events involving maintenance-of-way personnel and equipment. Note the interrelationships among railroad operating rules, signal systems, and other communications media.

TABLE II-2

SAFETY RISK FACTORS AND COUNTERMEASURES UNDER DIFFERENT METHODS OF OPERATION

RISK FACTOR	CURRENT COUNTERMEASURE	COMMENT
TRAIN ORDER/TRACK WARRANT (NO SIGNALS) Description: Trains are operated in accordance with written authorities, which may be transmitted directly, via FAX or telegraph, or by voice (radio, telephone) and transcribed by the receiving employee.		
Improper authority (e.g., "lap order")	CAD	Increasingly capable CAD systems are in use
Incomplete orders	Rules require comparison of orders with a clearance document; may not act on orders unless all are received	Clearance document must be the final, pertinent document, must be complete, and must be carefully reviewed by conductor and engineer
When passed by voice, misstated by dispatcher	Rules require read-back; dispatcher should catch error	Dispatcher may not catch error
When passed by voice, misunderstood by crew	Rules require read-back; dispatcher should catch error	Dispatcher may not catch error
When passed by voice, mistranscribed	Rules require read-back; dispatcher should catch error	Dispatcher may not catch error
Correctly transcribed, but misunderstood by engineer or conductor	Conductor and engineer required to have copy of all orders; entire crew required to discuss, resolving conflicts before proceeding	Usually effective, not always

RISK FACTOR	CURRENT COUNTERMEASURE	COMMENT
TRAIN ORDER/TRACK WARRANT W/ AUTOMATIC BLOCK SIGNALS (ABS) Description: Trains move in accordance with train orders or track warrants subject to restrictions imposed by signal indications.		
As a result of risk factors listed above under train orders, crew is provided erroneous order or misunderstands	Automatic block signals will indicate presence of train in block ahead, permit train to stop or slow	Ineffective if signals are not observed
TRAFFIC CONTROL SYSTEM Description: Trains are routed by signal indication from a dispatching center.		
Engineer fails to note, misperceives, or wrongly recalls signal indication	Other front end crew members, if any, are required to call signals and intervene with use of emergency brake valve if necessary; control operator may detect an overrun signal and radio train to stop, divert train to another track, or divert/stop conflicting movements	Higher risk than under ABS with train order/track warrant, since reliance is exclusively on wayside signal indication; intervention by traffic control before an accident cannot be depended upon in all situations
Risks common to the following methods of operation: TRAIN ORDER/TRACK WARRANT TRAIN ORDER/TRACK WARRANT WITH AUTOMATIC BLOCK SIGNALS TRAFFIC CONTROL SYSTEM		
Single crew member incapacitated, inattentive, or distracted	Other crew members, if any, are required to note and call signal, use emergency brake as necessary	Residual risk is related to distraction or lack or alertness by other crew member(s), if any Danger is greatest during early morning hours
All crew members incapacitated, inattentive, or distracted	Alerting device, if any	Engineer may reset reflexively

RISK FACTOR	CURRENT COUNTERMEASURE	COMMENT
AUTOMATIC TRAIN CONTROL WITH CAB SIGNALS Description: Trains are routed by signal indication, with continuous display in the cab. Failure to control train within speed range dictated by the signal system will result in enforcement (full service brake application).		
Engineer acknowledges warning but fails to stop train short of control point or other train	Other crew members, if any, are required to note and call signal, use emergency brake as necessary	Low risk of occurrence, but possible if engineer acts reflexively and other crew member (if any) is distracted and fails to intervene in time

Table II-2 is not a complete listing of risk factors within the scope of this report.[4] For instance, a signal system may function properly but the train crew may fail to observe operating rules that would have provided protection (e.g., failure to wait prescribed time after requesting signal at rail-rail grade crossing interlocking, failure to secure freight cars standing on sidings and industrial spurs, leaving hand-throw switches providing access to the main line misaligned). In addition, the actions of vandals may result in collisions or derailments.

Overspeed operation is also responsible for many train accidents, such as the Amtrak accidents at Back Bay Station, Boston, Massachusetts, on December 12, 1990 and at Palatka, Florida on December 17, 1991. Injuries and fatalities have also occurred when the presence of roadway workers or their on-track equipment was not properly accounted for by dispatchers or train crews, or where roadway workers operated their equipment outside of assigned limits.

The railroad companies, their employees and rail suppliers have greatly reduced the number of collisions, overspeed derailments, and other life-threatening events through prudent

[4]This report considers risks that can be avoided or controlled through enhanced communications and train control. Track and equipment-caused accidents are not the only type of risks beyond the scope of the report. For instance, there is no doubt that improper train handling (e.g., proper management of in-train forces taking into consideration grade and curvature, train make up, proper use of brakes and proper use of throttle) is a "human factor" responsible for train accidents. But there is no automated system, existing or planned, as competent as a well trained and experienced engineer to ensure proper train handling.

application of railroad operating rules (including radio rules) and through advances in contemporary signal and dispatching technology. The continuing challenges and opportunities associated with intelligent use of radio communications, including the prospects for cost effective advanced train control technologies in the near future, are the subjects of the chapters that follow.

CHAPTER III

Voice Radio Communications

Background

In the context of railroad operations, communications historically concerned two major areas: train movement authorities and intracrew directives (i.e., crewmember to crewmember on when to go, stop, backup, slow down, etc.).

- **Train Movement Authorities:** Railroads traditionally depended on hand-printed or typed orders to convey important information to employees engaged in the movement of trains. Train order operators copied orders transmitted by train dispatchers over land lines and then hand delivered them to the engineers and conductors. The telegraph was used initially, followed by dedicated railroad owned telephone lines (dispatcher lines), which linked the dispatchers with the various block operators. To complement this system, wayside telephones were installed so that train crews could communicate with dispatchers and operators in the event of accidents and other unexpected circumstances.

- **Intra-Crew Directives:** Over the years a number of hand and lantern signals evolved which enabled operating crews to communicate with each other. While some of these signals varied slightly from railroad to railroad, the majority were similar enough to be recognized by railroaders throughout the country. Railroads typically formalized and published the hand and lantern signals in operating rule codes.

Voice Radios: The utilization of two-way radio communications was a significant technological advancement for railroads that began in the 1950s. Radios provided a means of reliable communication between the dispatcher and crews and enabled the elimination of thousands of wayside dispatcher telephones.

When railroads began utilizing radio systems, operating divisions were generally much smaller than they are today. Train dispatching districts were also smaller and the dispatching offices located more closely to each other. There were usually several train order and interlocking operators located along any given route. Although a railroad might have a few remote radio base stations linked to a train dispatching office, the number of remote base stations did not provide complete radio coverage.

During the early era, radios limited to two-channel capability were installed on locomotives. Normally, one channel was utilized for road communications with operators and dispatchers, while the other was used for yard switching operations. About 1970, railroads began installing four- or eight-channel radios on locomotives. The industry also began purchasing portable radios for use by conductors, trainmen, and maintenance employees. For the past several years, the recommended standard of the AAR has been to equip new locomotives with 97 channel radios. This standard ensures good communication in joint operations and in the event of mergers. Many railroads have underway a comprehensive program of replacing older radio hardware installed on existing locomotives.

Safety-Relevant Uses of Voice Radio

The railroad industry has experienced significant changes during the last decade. Technology has rendered many traditional railroad operating methodologies obsolete, leading to substantial changes in structure and organization.

As conventional practices changed, the attributes of voice radio communications became increasingly important. For example, several years ago a standard train crew consisted of up to five employees: An engineer, conductor, head brakeman, rear brakeman, and flagman. Today, the standard road train crew is commonly composed of an engineer and conductor. Where once hand/lantern signals provided adequate means of communicating from crewmember to crewmember, radios are now a vital necessity rather than a convenience. In today's railroad environment, track warrant control (or "direct train control")[5] is the most commonly accepted operational method. With the advent of this approach, voice radio has developed into a critical railroad safety component.

Train movement authorities. Traditional issuance of train movement authorities utilized private communications systems (telegraph/telephone). Today, railroads use voice radio to transmit movement authorities from the dispatcher directly to the crew in the cab of the locomotive. The stopping of the train, renewal of pole lines that carried communications wire lines along the railroad, and the associated installation and maintenance expenses inherent in the older systems are no longer incurred. Additional benefits result from the ability of train dispatchers and train crews to maintain contact throughout the trip.

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[5]This is an umbrella term for a method of operation derived from traditional timetable/train order methodology. Adopted to varying degrees by most of the major railroads over the past 10 years, these methods of controlling train movements have simplified operations by eliminating timetable schedules, train orders, superiority, train registers, operators, and the attendant array of complicated operating rules. These systems are predicated upon the train dispatcher having direct radio contact with all trains and on track equipment, hence the informal name "radio train dispatching." In place of the train order, there is a written document known variously as a "track warrant," "DTC clearance," "OCS clearance," "RCBS clearance," "track permit," "Form D," etc. There are two basic track warrant control or "direct control systems" presently in use on today's railroads: One that uses fixed blocks (f) (i.e., the limits are constant and are identified both in the timetable and by wayside signs); and, one that uses variable blocks (v) (i.e., the limits are not constant and are created by the train dispatcher for each train).

Persons not familiar with railroad operating rules sometimes assume loss of communications will create an unsafe situation because a train could not be told to stop short of another train. That is not the case. Loss of communications during the transmission of a movement authority renders the authority void. Under the rules, a dispatcher would not be permitted to issue a potentially conflicting authority to another train until the antecedent authorities issued to other trains had been executed or canceled. Thus, under most circumstances, no hazard would be presented by a train crew proceeding as specified under a valid authority without an operative radio. Nor would a train crew be authorized to move its train beyond the limit of the authority previously provided without another valid authority.

However, a wide variety of events can occur on the railroad that may render execution of an otherwise valid authority hazardous (see., e.g., Table I-1). The withdrawal of train order operators and other communications media from the rights of way, together with the reductions in train crew size and lengthening of crew districts, places a premium on availability of voice radio (or other means of communication not heretofore provided) for communication with the train dispatcher.

Switching Operations. As a result of reduced crew sizes, voice radio has emerged as a crucial element in intracrew communications, as well. Where once several crewmembers enabled the relaying of hand/lantern signals when required by the task (e.g., setting out a long cut of cars, shoving cars around a curve out of sight of the engineer, etc.), today radios must provide the means for crew communications.

The use of radio communications to transmit and receive switching related information otherwise conveyed by hand signals has produced significant gain in efficiencies for the railroad companies. Likewise, the need for trainmen to pass signals from the tops and sides of moving rail cars with the attendant risks, has been eliminated.

Communication of Wayside Detector Information. Reliance on radios to transmit automatic detector warnings for hot journal detection, high-wide or shifted loads, dragging equipment, etc., has become the norm. The safety importance of such devices has increased with elimination of manned cabooses, and railroads employ "talking" detectors on nearly all major corridors across the country.

Before introduction of automatic warning detector technology, notice of impending problems was dependent primarily upon crew observation. Even with crew members positioned in the caboose, reliability was not assured as evidenced by numerous derailments due to burned-off journals, undetected dragging equipment, etc. The advent of automatic detector technology enhanced crew awareness of impending problems. This application of radio technology has contributed significantly to the enhancement of safety through the timely and reliable information provided. The major limitation is that automatic detector placement is an inexact science in some applications. As such, the formula for determining precise detector locations leaves some track segments with less coverage than other track segments. Further, exclusive reliance on recorded voice transmission to provide warning in nonsignal territory raises issues of effectiveness, since locomotive radios may not be tuned to the channel on which the warning is broadcast.[6]

Emergency Response. Ideally, voice radio provides a means whereby trains in distress can summon help instantly. In many situations this is the case. The advantages of such instant notification are manifold. Not only can emergency responders be notified, but other trains approaching the distressed train can take necessary precautions (e.g., slowing or stopping until it is ascertained that adjacent tracks are clear). The use of voice radio expedites the flow of information in emergency circumstances.

Casualties on the railroad are unfortunately not infrequent. For instance, each year almost 5,000 collisions occur between trains and vehicles at highway-rail crossings, resulting in about 600 fatalities and almost 2,000 nonfatal injuries.

Further, roughly 500 times each year train accidents occur involving trains carrying hazardous materials. Although hazardous materials are actually released in only about 30 such accidents each year, prudence dictates careful evaluation of the situation by railroad and public authorities in a great many of the other instances.

Railroad operating employees also suffer significant injuries while working around moving equipment. In 1992, trainmen on duty sustained 1,707 injuries in train incidents, 163 of which were amputations and 463 of which were fractures.[7] Such injuries may occur on line of haul, at industry sidings, or in portions of railroad yards and terminals several miles from railroad offices. In some cases, promptness of emergency response may be critical.

Just as radio communications can be employed to save life after a train accident or incident, radio can be used to prevent serious accidents. Where automatic means of warning are not feasible or not provided (e.g., for broken rails, dangerously high water, fallen trees, derailed equipment fouling an adjacent main track, bridge damage from barge operations, etc.), radio communications may provide the last opportunity for accident avoidance. Although "near accident" data are not collected in the railroad industry, FRA is aware of numerous occurrences where use of voice radio has permitted accident avoidance or has significantly mitigated the severity of an accident.

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[6]Where the broadcast is made on the dispatcher channel, FRA found that detectors often interfered with dispatcher-train crew communications. Whenever interference is encountered, the risk increases that employees will take expedient actions, rather than following mandated procedures. The most effective solution to these problems would be the integration of detectors into a positive train control system.

[7]Accident/Incident Bulletin No. 161, Calendar Year 1992 (Federal Railroad Administration, July 1993), Tables 47 and 49.

The Railroad Communication Project

FRA has approached the safety inquiry on railroad radio communications in a consultative manner, involving Amtrak, freight and commuter railroads, rail equipment manufacturers, and railroad employees. A public meeting was conducted in March 1994 to enable interested parties to comment on voice radio communications. In addition, FRA has conducted a field assessment that has permitted FRA to verify actual conditions in the railroad operating environment while gathering information and views directly from working railroad employees.

Field Assessment

During the course of routine inspections, FRA inspection forces visit dispatching centers, ride trains, observe switching operations and conduct other monitoring of railroad operations on a daily basis. However, these activities are directed at a variety of compliance purposes. In order to provide a proper focus for this report, FRA conducted a special radio communications assessment during 1993, in conjunction with the Train Dispatcher Follow Up Assessment.

The scope of the field review involved FRA presence on most major railroads in the United States. FRA formulated an inspection plan which involved --

- On-site audits of 20 representative railroad dispatching offices where over 150 train dispatchers were monitored;
- Riding dozens of trains over every major traffic corridor in the country; and
- Spot visitations to local yard switching operations and yard offices.

FRA conducted on-site inspections involving teams of inspectors as well as inspectors working alone. An inspection methodology was provided to field inspectors to ensure that the information gathered was standardized and in a format consistent with project goals as outlined in Section 11. All data collected during the assessment were analyzed by FRA's Office of Safety headquarters technical staff in Washington, D.C.

Railroads audited were selected based upon a matrix which provided review of varying operational methodologies, dispatching technologies, and geographical differences. Major passenger and hazardous materials traffic routes weighed heavily in determining audit sites. Inspection methodology included the monitoring of radio traffic in the presence of railroad employees during normal operations, interviews with employees and officers, on-site observations in various terminals and yards, record reviews, and selective dispatcher desk auditing on each duty shift.

Prior to initiation of the field portion of the review, FRA contacted the American Train Dispatchers Department of the Brotherhood of Locomotive Engineers (ATDD) to obtain local labor contacts. At offices where ATDD represented train dispatchers (some train dispatchers are exempt employees), FRA's team chief visited local union officials to discuss respective concerns and recommendations. At the conclusion of each site visit, FRA conducted a detailed exit meeting with responsible railroad managers to advise them of FRA findings and recommendations. Copies of inspection reports were provided to respective officials at those meetings.

Findings

In general, FRA found railroad voice radio capabilities much improved since FRA's last programmatic review in 1987. Most major railroads have worked with suppliers and committed significant financial resources toward procurement of contemporary radio equipment. As a result, coverage, availability, and reliability of railroad voice communications have been improved. During the field study, FRA found that:

- Most trains inspected by FRA inspectors during the project were equipped with operative radios on the lead locomotive.

- Radio equipment appeared to be fairly reliable based upon employee comment and inspector observation during the project.

However, FRA found lingering issues that need resolution. Some radio-related problems remain in both hardware application and proper utilization in accordance with rules and regulations. For example, congestion of radio frequencies continues to be a concern in some dispatching districts. Sources of congestion include nonessential transmissions by a variety of officers/employees as well as improper use of assigned frequencies.

FRA also noted that on numerous occasions train dispatchers and officers/employees in the field did not comply with required radio standards and procedures. These deficiencies included improper transmission of mandatory directives in accordance with Federal requirements. Specific FRA concerns include the following:

Hardware Concerns:

- Radios at some dispatcher desks still experience "bleed-over" from neighboring dispatcher districts. In addition, some dispatchers related frustration with automatic wayside detectors which override their frequencies and interrupt radio transmissions with trains.

- There exist diverse and sometimes incompatible communication systems in some dispatchers offices. For example, FRA noted a few offices where "open speaker" systems are used, resulting in a need for constant monitoring by train dispatchers. This monitoring process created interference when dispatchers had to listen for verbatim readback of mandatory directives and critical information.

- Several dispatcher offices did not have a dedicated emergency channel. Additionally, some communication systems did not have capability to prioritize incoming calls as routine and emergency.

- In some offices, chief and assistant chief dispatchers could not monitor the shift dispatcher's radio communications from their workstation.

- Dispatchers related that reliability of locomotive onboard radios had improved considerably, but there were instances where crew communications were inhibited by weak or inoperative radios.

- Problems with the reliability of some systems were of continuing concern. Desk audits disclosed several specific locations where communications could not be initiated between the dispatcher and field personnel despite upgraded and modern systems. Similar concerns were experienced with mobile and cellular telephone systems. It appears the problem is rooted in peculiar atmospheric or terrain conditions rather than equipment malfunctions.

<u>Human Interface Concerns</u>:

- FRA found that some railroads continue to underutilize available frequencies. This exacerbates congestion on key channels required for safety-related communications. Specifically, during the 1993 review FRA found the following sources of interference:

  - Channels intended for road train use were used by yardmasters and terminal switching crews.

  - Channels intended exclusively for use to communicate with dispatchers were used by road crews engaged in such duties as adding or removing cars from their trains or to handle other communication of no value to the train dispatcher or other trains.

  - Maintenance-of-way employees frequently used the dispatching channel to communicate with each other, even though separate channels were available for this purpose.

  - Supervisors, administrative personnel, clerks, and even railroad taxi drivers used the dispatching channel for purposes not related to the safety of train operations.

- At most offices assessed, FRA noted frequent radio rule noncompliance. Many exceptions were extremely serious in nature, to include failure of the dispatchers and train crews to comply with 49 CFR §220.61 (transmissions of train orders by radio), and failure to assure on-track authorities are properly transmitted and repeated. These deficiencies also included occasional failure of train dispatchers and employees in the field to properly identify their stations, failure of the train dispatcher to require employees to use proper identification, and failure to use the words "over" and "out" when required.[8]

- In several instances FRA observed train dispatchers issue critical train movement authorities without obtaining proper identification and/or location of involved trains, a violation of the FRA radio regulations.

- In violation of radio standards, a few dispatchers were observed issuing mandatory train movement directives to employees operating the controls of moving trains (i.e., no attempt was made to identify the receiving employee).

- While the majority of train dispatchers utilized proper radio procedure, there were some who did not. Additionally, the radio procedures used by employees in the field, including supervisory personnel calling train dispatchers, were seldom in compliance with Federal radio standards. Most train dispatchers took no action to remedy the noncompliance by setting an example or openly requesting proper compliance.

Public Comments

FRA solicited both oral and written comments regarding railroad radio communications in its March 11, 1994, Notice of Special Inquiry. The Notice directed the attention of the public to seven core issues and invited comment on supplementary matters as well. At the March 29, 1994, hearing testimony was given by a rail labor panel, the Association of American Railroads, and the American Short Line Railroad Association (ASLRA). Written comments were accepted until April 11, 1994. FRA received eight written comments for inclusion in the official docket expressing general concerns, specific complaints, and addressing the seven issues outlined in the notice.

A transcript of the special inquiry has also been included in the official docket. Significant testimony by all three groups from the inquiry is summarized in this report. The rail labor panel was comprised of representatives from the Brotherhood of Locomotive Engineers (BLE), the United Transportation Union (UTU), the Train Dispatchers Department of the Brotherhood of Locomotive Engineers, and the Brotherhood of Railroad Signalmen (BRS). The panel collectively concluded that very little had changed regarding radio communications in the railroad industry since the last inquiry in 1987. The labor panel cited examples of accidents where radio communication breakdowns of some sort were contributing causes of the accident.

In general, the rail labor representatives said they believe that FRA should enact rules covering the use, maintenance and availability of voice radios. Citing a similar recommendation made to FRA in a 1987 safety inquiry on railroad communications, the

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[8]The safety necessity for use of these terms is disputed by some of the participants in the safety inquiry. Nevertheless, their use is currently required.

labor representatives said radio communications have not improved and in some situations have gotten worse.

The railroad companies affirmed the importance of voice radio communication to railroad operations. For instance, the AAR stated that "[t]he advantage of radio voice communications is that they permit running today's efficient and productive operation in a safe manner." Nevertheless, with respect to specific risks, the railroad companies generally denied that the availability of radio communications is of significant value with respect to maintaining reasonable margins of safety in train operations. The railroad companies stressed, instead, the importance of adherence to railroad operating rules.

Rail management and the short line railroads noted that they have spent millions of dollars upgrading communications systems. Rail management took the position that the railroads did not need Federal regulations in this area. The railroad companies said they are committed to quality radio communications as a matter of good business and do not need governmental intervention to continue improvements.

The BLE representative played a recording of a radio transmission to illustrate the poor quality of communication that exists in the industry today. The train dispatchers suggested improving radio communications by using a separate radio channel for dispatchers. The BRS reiterated their specific concern that effective radio communication is not enough to save the lives of signalmen. According to BRS, watchmen and flagmen along with good radio communication are necessary to protect workers along the right-of-way. The firm position of the rail labor panel was for FRA to require the use of radios in the rail industry.

The ASLRA and the AAR testified at the inquiry and submitted written comments. In so doing, the AAR and ASLRA essentially addressed the core issues listed in the notice. The ASLRA emphasized the need to tailor communication systems to fit the needs of a particular railroad. For example, short lines often find cellular phones, allowing the crew to contact customers as well as make emergency phone calls, more cost effective and more practical than elaborate radio systems.

The ASLRA supplemented the oral testimony by submitting written comments. In these comments, the ASLRA recognized the benefits of radio use on the railroad, but found no compelling justification for a blanket mandate requiring such use. The consensus among the short lines is that a two-way communication system such as a radio, is not essential for the safe operation of trains. Therefore, any requirement that railroads use radios as their communication system would stifle their ability to choose systems best suiting their individual needs and impede technological progress by preventing railroads from experimenting with other forms of communication.

Requiring replacement radios at intermediate terminals was also not favored by the ASLRA, because such a requirement would be burdensome and an inefficient expenditure of time and money. The ASLRA emphasized that radios assist in emergency situations, but do not ensure a timely emergency response. Regulating interference and disruption during radio communications would only impair the development of solutions, as interference is really a technology problem not one of compliance.

Lastly, the ASLRA addressed Advanced Train Control Systems, concluding that any mandate of a particular system, such as digital radios, would be unwise because it would further limit technological developments. The short lines' approach to operation is low but serviceable technology which contributes to low costs. Short lines should, therefore, not be forced to employ unnecessary and expensive technology. The ASLRA concluded that they are committed to safety and progress, but do not believe that increased regulation of railroad radio communications is necessary to achieve those goals.

The AAR's testimony at the inquiry essentially highlighted the issues listed in the notice. They urged that railroad safety is dependent on compliance with operating rules and Federal regulations, not radio use. In so doing, they acknowledged that radio use is an integral component of efficiency, but stressed that the absence of radios does not make the operation of trains unsafe, just as the use of radios does not ensure safe operation.
The AAR utilized the written comment forum to address the Federal Communications Commission's (FCC) proposed spectrum refarming (Docket No 92-235). Although this refarming is not the main emphasis of the safety inquiry, the tangential concerns are noteworthy. Essentially, the FCC proposes to convert channels from present band centers of 15 kHz to a narrow bandwidth of 5 kHz thereby reducing channel congestion. The AAR estimates such a conversion will cost railroads approximately $1.2 billion to purchase replacement equipment. Consequently, the AAR urged FRA to support its "offset overlay" plan, designed to achieve the same benefits at a reduced cost to the rail industry.

The written comments submitted by the AAR also answered questions that had been addressed to them by the FRA panel at the inquiry. The AAR was asked what type of investment railroads had made into their radio systems. Since FRA's inquiry into voice radio in 1987, the industry has invested over $100 million in improved radio communications. All Class 1 lead road locomotives are now equipped with radios, costing on average $3,950 for the entire package installed and with an average useful life of 10 to 12 years. Radio units for replacement in equipped locomotives cost $2,350. The average useful life for a locomotive radio is 10 to 15 years. Significantly, the AAR indicated that 90 percent of Class 1 railroad locomotives are now equipped with all-channel radios--a requirement for good communications in joint operations.

In response to FRA's concern regarding the reliability of portable radios under adverse conditions, the AAR found that most hand-held portable radios are reliable except after being totally submerged in water. Finally, the AAR addressed the FRA panel's concern regarding radio effectiveness. Common problems such as bleed-over from neighboring dispatcher districts, dead spots, and channel congestion are not unique to the railroad industry. All users of major radio systems face similar problems. A variety of methods are used by railroads to alleviate this problem including frequency leap-frogging, dedicated dispatcher and road channels, Dual-Tone-Multiple-Frequency (DTMF), tone encoding, and adding new base stations. The AAR suggested a working meeting at which interested parties would work on streamlining existing rules and regulations.

Six other written comments were submitted. General comments were expressed by the American Public Transit Association (APTA) and two of its members, the Northeast Illinois Regional Commuter Railroad Corporation (METRA) and the Port Authority Trans-Hudson Corporation (PATH). APTA, representing all of the current U.S. Commuter Rail operators, concluded that safety regulations requiring the presence of radios and replacement of radios failing in route would have adverse consequences for commuter operations. APTA agreed with the views that the AAR expressed at the March 29, 1994, hearing. Essentially, both groups contend that railroad safety is dependent on compliance with the underlying operating rules adopted by each railroad and not the required presence of radios.

The United Transportation Union (UTU) National Legislative Department utilized the inquiry as an opportunity to air grievances from local organizations. These complaints specified incidents that occurred due to railroad radio communication failures including, insufficient broadcast range, radio transmissions from the yardmaster and control tower over the employee's hand-held radio, and the flooding of the air waves. In a separate submission, the UTU, Montana State Legislative Board, expressed concern about radios with insufficient power and suggested using cellular phones as an alternative. Finally, they suggested the use of two speakers located on both sides of the locomotive cab to ensure that all radio transmissions are heard.

The Brotherhood Railway Carmen Division Transportation Communications International Union (BRC) submitted written comments. BRC's general position was that all locomotives and cabooses must have radio equipment and that replacement equipment must be available at intermediate terminals. They stressed the necessity of radio equipment for emergency situations. BRC also felt that FRA should evaluate sources of interference affecting radio performance, enforce current standards and clarify the use of current technology. Lastly, BRC emphasized their opposition to any reduction in the use of voice radio communications on the Nation's railroads.

The final two comments were from the New York State Department of Transportation's Railroad Safety Staff (NYDOT) and Metro-North Commuter Railroad (MNCR). NYDOT acknowledged one significant disadvantage of requiring radios would be increased air clutter and overuse of the radio. NYDOT felt that regulatory monitoring should be established by FRA. MNCR emphasized the importance of radios on lead locomotives, but could not establish a justification for such a requirement.

The special safety inquiry served as an opportunity to poll the railroad community regarding radio use in the rail industry. This summary of testimony and written comments merely highlights significant information. As noted above, the transcript and the written comments are available for review in the public docket.

Analysis

When used in the context of a railroad operations, voice radio communications provide economic and safety enhancement opportunities when hardware is reliable and users comply with established standards. During the field investigation FRA safety inspectors encountered few locomotives with inoperative radios. Interviews with train and engine employees, train dispatchers, and other interested employees revealed that voice radio reliability has improved dramatically over the past few years. The problems that were identified involved occasional inoperative or weak radios on locomotives and frequency congestion around terminals (which is, to a large extent, a product of improper channel utilization rather than equipment shortfalls).

Adequate communications equipment. Effective communications among crew members, and to and from the dispatching center, is an important factor in safe train operations. Given the operating environment today with heavy reliance on voice radio and direct train control, and given the need to communicate emergency warnings and emergency requests, FRA believes it essential that adequate communications capability be provided on all trains. FRA also believes that a suitable level of safety redundancy should be built into the railroads' communications systems.

One important solution to the problems with voice radio no doubt resides in data communications associated with advanced train control technologies. This concept is already in use in some applications in the railroad industry. For example, through upgraded computer-assisted train dispatching systems and on-board locomotive receivers, some railroads have experimented with transmission of movement authorities electronically. This eliminates the potential for misunderstanding and miscommunication. FRA supports the move toward data communications as a means to reduce potential human "hearback-readback" errors which have contributed to several fatal collisions over the past several years. These issues are discussed further in the chapter that follows.

The need for voice radio, however, will apparently persist at least as long as railroad switching operations are conducted on long cuts of cars using two or three-person crews. Radio communications provide the only practical means of exchanging information and instructions in switching moves; and continuity of communication is important to safety.

Good procedures and radio discipline. Availability of communications hardware alone will not ensure sound communications. FRA accident data clearly reveal that, despite some shortcomings in radio systems, it is user noncompliance with radio standards that is most likely to create an unsafe situation, not inoperative radio equipment. For example, over a recent 4-year period, 83 train accident reports were submitted by railroads attributing the cause to radio/communication problems. These reports included 4 employee fatalities, 16 employee injuries, and $12 million in property damage. In each of these events, noncompliance with existing rules and standards (49 CFR Part 220) was evident.

Better radio rule compliance will occur only when railroads make it clear to their employees that compliance is expected and when dispatchers and operating officers set the example. The railroad companies have suggested that the formality of the present FRA radio rules makes enforcement of radio discipline more difficult. FRA agrees that the time has come to reexamine the rules to determine if they can be simplified to be less directive and more performance oriented.

Better utilization of capacity. The Federal Communications Commission has allotted channels in the VHF band which are dedicated to railroad radio communication. Part of the reason for this allotment of scarce radio frequency capacity to the railroads is the safety interest of the railroad companies and the public. The AAR plays a useful role in managing channel allocation to reduce interference.

Yet many railroad users continue to misuse available channels, particularly the dispatcher channels, resulting in congestion. Further, some railroads have not elected to employ contemporary technology that facilitates giving automatic priority to emergency communications. Finally, railroads have made only limited use of data communications capacity available in the UHF band in the 900 mhz frequencies. (For many purposes, digital data communication employing radio and hard wire paths is a far more secure and effective medium than voice radio.)

Railroads should enforce proper use of allotted channels to avoid to the extent possible interference with dispatcher-to-train communications and locomotive-to-ground-crew (conductor, brakeman) communications. Where radio traffic warrants and alternative means of emergency communications are not available, means should be provided to give automatic priority to emergency calls.

Summary. FRA recognizes the vast strides that the railroad companies have made in recent years to enhance their radio communications systems and the considerable contribution those efforts have made to safety. However, FRA is concerned that railroads participating in the safety inquiry have not expressly recognized the value radio communications can contribute to railroad safety. Although FRA understands the reluctance of rail management to shoulder further regulatory burdens, failure to credit the value of good communications to safety is an attitude that may inadvertently be expressed within the railroad organization, as well as in filings with the regulator.

Determining the best use of voice radio technology as part of system safety requires functional analysis, consideration of alternative or supplementary measures, and delineation of the number of layers of safety redundancy that may be deemed acceptable for the function. Deployment of the digital data communications systems used in certain advanced train control technologies constitutes one important measure that may satisfy certain safety requirements. *Chapter IV* describes the emerging potential of such systems and the uneven progress of the railroad industry in realizing that potential.

CHAPTER IV

Positive Train Control and Digital Data Communications

Section 11 of the Rail Safety Enforcement and Review Act requires an assessment of how advanced technologies such as digital radio can be implemented to enhance the safety of railroad operations, the implications of advanced train control systems for railroad communications, and the need for Federal standards to ensure that such systems provide for positive train separation and are compatible nationwide. This chapter describes emerging technologies that can provide for positive train separation while achieving other safety objectives. With regard to potential for application across the breadth of the national rail system, the most promising of these technologies are founded on digital data communications platforms. As those platforms are put in place-- but before the systems are fully deployed-- railroads can begin to realize safety benefits, as data links replace the more error-prone voice radio systems for transmission of train movement authorities.

Terminology and Objectives

Positive train control. This report uses the term "positive train control" or "PTC" to refer to highly capable technologies for preventing train accidents and casualties. PTC is preferred for this purpose over positive train separation (PTS), "advanced train control systems," Advanced Train Control Systems (ATCS), or other possible formulations.

The term "positive train separation" is very useful to denote collision avoidance, but it is not sufficiently broad. Next-generation train control systems should be capable of keeping trains apart, but they should also be capable of preventing violation of permanent and temporary speed restrictions, including restrictions that protect roadway workers and their equipment. Further, the "PTS" acronym has now been adopted for a specific test bed application (described below).

Fully deployed ATCS, as conceived by the AAR and the Railway Association of Canada, includes all PTC elements, but ATCS also includes several nonsafety elements, such as work order reporting and locomotive health monitoring. Essentially all of the ATCS features thus far deployed by North American railroads have little safety relevance *as presently utilized*. Further, fully deployed ATCS offers advantages with respect to plant capacity that may not be realized using alternative technologies (advantages that are of great economic value where needed, but, again, not necessarily representing a major advance in safety).

Thus, PTC[9] refers to a set of safety objectives, rather than a specific technology. Specifically, positive train control should --

- Prevent train-to-train collisions (positive train separation);

- Enforce speed restrictions, including civil engineering restrictions and temporary slow orders; and

- Provide protection for roadway workers and their equipment operating under specific authorities.

PTC should accomplish these objectives by intervening only in the rare instance when the human operator (e.g., locomotive engineer) errs. The PTC system should be secure from tampering and should function as an integral part of cab electronics so that it cannot simply be "cut out" for reasons of expediency by an engineer.

Intelligent discussion of PTC must begin with the understanding that there is no current or planned technology that is capable of replacing the human operator.[10] Rather, PTC would be implemented to assist and protect the operator through enforcement of key, safety-critical limitations on train operation. The most advanced PTC technology would also provide the operator with all critical information required to operate the train without intervention.

Interoperability. In order to be affordable by North American railroads, PTC technology should be interoperable; on-board locomotive equipment will be equally responsive to the PTC system on each railroad. This is especially critical because locomotives often run through railroad boundaries and some of the most dense traffic is found in major terminal areas where multiple carriers operate over the same trackage. In practice, if systems are not interoperable, the regulator will be presented with many situations where it is not cost effective to require that certain trains (e.g., detour movements, freight movements for short

[9]PTC is used here as a generic term and is not intended to refer to any proprietary technology.

[10]During the development of the industry's Advanced Train Control Systems program, consideration was given to the possibility of automatic control of road trains. However, as freight railroad operations are currently configured this is not practical. For instance, engineers are required to respond with warning and, where possible, mitigating measures, to a wide range of obstructions on the right of way (including pedestrians and vehicles at highway-rail crossings). Some heavy rail transit systems (e.g., BART, Washington Metro) are capable of fully automated operation. However, they operate trains of standard sizes over standard routes on protected rights-of-way. All such systems which operate at significant speeds continue to place an operator capable of assuming control of train operation on each train.

distances in joint operations, etc.) be equipped with on-board equipment responsive to PTC commands. When trains are not equipped, the value of PTC is lost.

Compatibility. From a commercial standpoint, compatibility of components from a wide variety of manufacturers should be ensured through "open architecture" specifications. This will help hold down the cost of components while permitting further technological advances within a flexible framework.

Digital data radio.[11] "Digital data," as applied to safety-relevant communications systems, refers to electronic data passed between computers over a wide variety of paths (short-range radio, microwave, fiber optics, conventional pole lines or cables, commercial telephone, etc.). Digital data communication has the potential to enhance safety by virtually eliminating miscommunication (though not necessarily misapprehension) of safety-critical information. Digital data radio promises to communicate safety-relevant information and commands across rail systems. It is also a key element in emerging PTC systems.

As the discussion below will demonstrate, the means to accomplish both positive train control and more secure communication of safety-relevant information may be integral parts of the same system. Compatibility of components and interoperability of systems from railroad to railroad then become prime planning objectives.

Background: Train Control Enforcement Systems

PTC is not a theoretical construct or distant vision. Where historical traffic patterns have warranted, railroads have been required to install relatively expensive train control systems incorporating warning and/or enforcement features, such as automatic cab signals, automatic train control (ATC) or automatic train stop (ATS).

There are 6,212 miles of automatic train stop and automatic train control installed on railroads in the U.S. An ATS system is arranged so that its operation will automatically result in the application of the brakes until the train has been brought to a stop if the engineer fails to acknowledge the more restrictive signal. There are two general types of ATS systems; namely, intermittent inductive ATS (which verifies compliance only at certain locations, such as approach and home signals) and continuous inductive ATS (which is interfaced with the track circuit).

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[11]Section 11 of the Rail Safety Enforcement and Review Act referred to "digital radio," and some commenters have taken this to mean digital transmission of voice, in place of today's analog systems. Certainly digital voice technology offers the promise to improve clarity and utilize frequencies more efficiently. However, there is no commercially accepted standard protocol for this function at the present time, and merely transmitting voice messages in a different way would not have a fundamental effect on safety of railroad operations. This report addresses radio transmission of digital *data* (in effect, from computer to computer) via radio.

An automatic train control system is arranged so that its operation will automatically result in the application of the brakes until the train is brought to a stop, or--under control of the engineer--until the train's speed is reduced to a predetermined rate or the condition that caused the restrictive signal ceases to exist. ATC is required to apply the brakes when the train exceeds the predetermined rate, until the speed is reduced to that rate.

Automatic cab signals provide warning when signal aspects change to more restrictive aspects. Cab signals also provide a continuous display of signal aspects, further reducing the possibility that wayside signals will be misperceived (or missed entirely).

Impetus for Change

It has long been recognized that features of PTC systems, such as those incorporated in ATC, ATS, and the developing technologies described below, can improve safety. Indeed, this was the reason that the Interstate Commerce Commission, during the peak years of the Nation's dependence on railroads for passenger service, required installation of ATC/ATS on portions of the national system.[12] However, the cost of installing and maintaining this equipment was high, and the Commission allowed exceptions even to the limited installations initially required. Some ATC/ATS systems were later discontinued, in some cases because of facility consolidations and in others because discontinuance was permitted by the Commission due to changing traffic (particularly, following the Second World War, as passenger traffic precipitously declined).

The physical damage and carnage associated with train collisions during the period just after the First World War can profitably be compared with the current situation with respect to benefits and costs of safety technology. In its first train control order, the Commission stated --

> The matter of cost is the basis upon which the carriers have raised objection to an order requiring the installation of automatic stop or train-control devices....Yet the compensation from a financial standpoint, which will result from ... securing added safety in train operations should not be overlooked. In the hearings before the Committee on Interstate and Foreign Commerce when Section 26 [the precursor to the Signal Inspection Act] was under consideration certain statistics gleaned from our accident reports were presented showing that from 1909 to 1917, both inclusive, there were 13,339 head-on and rear-end collisions resulting in damage to railroad property alone of over nineteen million dollars. These collisions resulted in death to 2,454 persons and injury to 37,724.[13]

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[12]See *Interstate Commerce Commission Activities 1887-1937* (Bureau of Statistics, ICC, 1937); *Reports and Orders of the Interstate Commerce Commission: In the Matter of Automatic Train Control Devices,* Docket No. 13413 (1931).

[13]Ibid. at 74.

As reflected in Chapter I and the Appendices, contemporary safety experience reflects tremendous advances since those times. For instance, during no year since 1975 have as many as 20 persons died in train-to-train collisions on the Nation's railroads.

In recent years, advances in safety have not reduced interest in affordable technology that could eliminate entirely those human factor accidents, such as collisions and accidents involving excessive speed, which tend to be most likely to cause fatal injury. As it has become increasingly evident that even higher levels of safety are possible, interest in closing the remaining gaps has risen. That interest has been spurred by each successive fatal accident for which train control technology might have made the critical difference.

The National Transportation Safety Board (NTSB) has made a series of recommendations to FRA concerning automatic train control and positive train separation.

In 1971, the NTSB recommended that FRA develop a comprehensive program for future requirements in signal systems which would require as a minimum:

a. That all mainline trains be equipped with continuous cab signals in conjunction with automatic block signals; and

b. That all passenger trains be equipped with continuous automatic speed control (train control).

In 1973 the NTSB recommended that FRA, in cooperation with the Association of American Railroads, develop a fail-safe device to stop a train in the event that the engineer becomes incapacitated by sickness or death, or falls asleep. Regulations should be promulgated to require installation, use, and maintenance of such a device. (Note: contemporary alerter technology comes close to meeting this objective, and FRA continues to seek fully fail-safe answers through research.)

In 1976, NTSB recommended that FRA promulgate regulations to require an adequate backup system for mainline freight trains that will insure that a train is controlled as required by the signal system in the event that the engineer fails to do so.

In 1987, NTSB recommended that FRA promulgate Federal standards to require the installation and operation of a train control system on mainline tracks which will provide for positive separation of trains.

In 1991, NTSB recommended that FRA, in conjunction with the Association of American Railroads and the Railway Progress Institute, expand the effort now being made to develop and install advanced train control systems for the purpose of positive train separation.

Finally, in 1993, in its report on the Ledger, Montana, accident of August 30, 1991, the NTSB made the following recommendation to FRA:

In conjunction with the Association of American Railroads and the Railway Progress Institute, establish a firm timetable that includes, at a minimum, dates for final development of required Advanced Train Control System hardware, dates for implementation of a fully developed Advanced Train Control System, and a commitment to a date for having the Advanced Train Control System ready for installation on the general railroad system.

As the drumbeat of NTSB and other public advocacy has swelled, the central issue has continued to be that of affordable technology. In 1991, FRA estimated a cost of $16 billion for 91,000 route miles merely to install automatic train control (ATC) systems, a figure that was many times greater than expected safety benefits over the systems' useful life.[14]

The railroad industry has responded to this dilemma, and to other business needs, by planning a communications-based train control system for the future.

North American ATCS

In the early 1980s, the Railway Association of Canada (RAC) began actively to explore the feasibility of a radio-based train control system that would eliminate human error in the operation of trains. During 1982, the RAC first convened meetings of senior railroad officials in Canada and the United States to explore this possibility. Subsequently, committees composed of the department heads of several railroads met and developed the concept of Advanced Train Control Systems. For the first time a method of operation was being preplanned for universal application. In 1983 a project chairman was designated. In early 1984, the Association of American Railroads assumed responsibility for project staffing and the AAR and RAC pledged funding.

On behalf of the RAC and AAR, a report of the Operating Requirements for ATCS was published in April 1984. The report forecasted the requirements for a series of comprehensive and advanced radio-based electronic systems essential for safety, productivity and efficiency in all aspects of on-track operations. The specifications contained in the requirements were purposely generic to accommodate a variety of hardware and software from different sources that would achieve industry-wide compatibility. The report recognized that some functions would require research and development of new systems.

As conceived in the specifications, ATCS is an enhanced train control system that utilizes microprocessors (computers) and digital data communications to connect elements of the railroad, locomotives, track forces, and wayside devices to the dispatcher's office. Additionally, it will link data to key managers of a railroad, through information management systems. The communications system that links all of the systems together is

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[14]*Advisability and Feasibility of Requiring Automatic Train Control Systems on Each Passenger and Hazardous Materials Rail Corridor* (Report to the Congress pursuant to the Rail Safety Improvement Act of 1988) (Federal Railroad Administration, 1991).

the key to ATCS. ATCS currently has six pairs of digital data communications channels available for exclusive use in North America. (For territory not equipped with data radio, cellular telephone communications are being studied.) The communications system can utilize components made by different companies, providing for modularity of the system and promoting competition among vendors.

The ATCS Operating Requirements envisioned the optimum system -- eliminating dependence on human compliance with signal indications, operating rules, and written instructions to achieve safe speeds and separation; obtaining increased traffic capacity and equipment utilization; and controlling operations for maximum savings in fuel and labor. Specifications were established for system-enforced movement authority, speeds, and positive separation. The system would ensure route integrity with the functional status of wayside equipment, including defect detectors and highway-rail grade crossing devices, communicated to each train and the control center. Specifications were established for --

- on-board displays that would identify track profile, route authority and conditions;
- work order reporting (car pick ups and set outs);
- locomotive health monitoring;
- interface with maintenance-of-way forces;
- predicted braking distances; and
- train operation management for crew identification and hours of service.

The specifications also included automatic stop protection that would preclude a train exceeding its limits of authority. Finally, the specifications required the system to be modular, with hardware and software capable of industry-wide operation of a locomotive moving from one type system to another automatically without hindrance, and compatible with all existing control systems, especially traffic control systems.

Subsequently, under the umbrella of the AAR, Aeronautical Radio, Inc. (now "ARINC") was selected as the consultant to provide technical and engineering services for the development of specific design specifications. Working committees composed of representatives from Canadian and United States railroads were formed to develop the specifications for ATCS. FRA also participated in the process.

The AAR's Communications and Signal Division, working with ARINC, developed the communications architecture for the system, using accepted procedures that assure transmission and receipt (handshake) of data, security and reliability. In addition, specifications for datalink operation of wayside apparatus (wayside interface units (WIUs)) were developed.[15] WIU specifications cover signals, switches (both hand-operated and power-operated), highway-rail grade crossing devices, defect detectors, and various detection methods for determining rail continuity.

The AAR's Mechanical Division developed specifications for a locomotive on-board computer (OBC). The OBC was designed constantly to monitor the locomotive's health (fuel, fuel consumption, water, oil, temperatures, main reservoir pressure, etc.); operation (speed, throttle position, brake position, brake pipe pressure, horn, bell, location, train profile, tonnage, etc.); train control (authority, route, block and interlocking conditions, highway-rail crossing device conditions, defect detector conditions, track integrity, etc.); management of operations (identification of crew, hours of service, work orders, projections, predictive conditions, conflict resolutions, etc.); and train handling requirements (limits of authority, speed restrictions, speed instructions, etc.).

The AAR's Operating Rules Committee, with input from representatives of FRA, drafted the rules for operations in ATCS territory. The work of this committee is yet to be finalized. Efforts to develop operating rules identified the disparities of the concept of ATCS that exist within the industry. It became evident that some carriers were seeking the optimum system in which all trains would be ATCS equipped; some carriers proposed equipping only passenger and manifest freight trains; and some carriers were opposed to the train control features. In some quarters, the objective was to eliminate all block signal systems in ATCS. In order to accommodate these differences, ATCS evolved into four categories -- Levels 10, 20, 30 and 40.

Level 10 would provide the equivalent of track warrant operations by visually displaying limits of authority and work orders.

Level 20 added to Level 10 locomotive health and predictive calculations for pacing, train meets and crew management.

Level 30 added to Level 20 communications with wayside interface units (WIUs) and PTC enforcement.

Level 40 was conceived as the optimum system interfaced with a centralized, computer-aided dispatching function. At this level, ATCS might replace the existing signal system (or provide the capability to operate trains in "dark territory" with the same or greater competency as if a traffic control systems were in place). Level 40 offers the potential that fixed blocks[16] might be eliminated in favor of flexible block length, resulting in significant

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[15]A WIU includes the hardware and software necessary to provide interface between new and existing wayside devices and ATCS.

[16]A "block" is simply a segment of track--in signal territory a segment of track between wayside signals. Since signal spacing must be set at a distance approximating the stopping distance of the heaviest and fastest train permitted to use the railroad, a fixed-block

increases in capacity in some cases (as more trains are permitted to use the same track, with reduced headways).

Since the specifications are modular, delineations among the levels of ATCS are not clearly defined; and many of the specifications written for ATCS are optional in the first three levels.

An ATCS locomotive display shows the mileage, speed limits, actual train speed and grade. ATCS differs from conventional train control systems in that all train movement authorities and operating instructions are displayed in the locomotive cab.

In the ATCS concept, transponders are located along the rail line to provide precise train location information. Between transponders, interpolation is by wheel rotation count (tachometer). The on-board computer integrates the location information from the transponder with the authorities provided from central control and determines enforcement parameters.

As the main body of the specifications was developed, ARINC coordinated all the working groups to assure the technical specifications were uniform, modular in construction with interoperable datalink communications. ARINC conducted several exercises to prove the flowcharted specifications in which representatives from the railroad companies, FRA and the supply industry acted out specific roles of the components, devices and computers being designed for ATCS. The role-playing exercises were tedious, intensive and precise. Design flaws were corrected and the handshake for data communications refined. From the flowcharts actual specifications were derived for electronic design of ATCS using concepts from the aerospace program, especially the National Aeronautics and Space Administration. According to an evaluation by Draper Laboratories, the failsafe factor of the electronic design is 10^{-17}, the equivalent of one hazardous failure in 64 years, which meets or exceeds the failsafe factor in current signal circuitry design.

In the ATCS development program, various railroads in both Canada and the United States conducted tests of ATCS components. Several railroads began a long-term restructuring of their communications systems to enable future radio transmissions required to implement ATCS. As a result, the industry has developed and proven many subsystems of the ATCS technology, particularly those elements integral to the communications platform. Many components are now available off the shelf for implementing ATCS.[17]

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arrangement tends to limit "throughput" of trains more than an arrangement that considers the speed and tonnage of the trains actually using the railroad.

[17]An extensive discussion of ATCS topics is contained in *Advanced Train Control Systems*, Transportation Research Record No. 1314 (Transportation Research Board, National Research Council 1991).

"Business" Applications of ATCS

ATCS is far more than a planning process. Nonsafety applications of ATCS have been undertaken by several railroads. In the United States, the Union Pacific Railroad has implemented ATCS work order reporting program system-wide. The work order reporting system enables the conductor to receive work requests (pick-ups and set-outs) and to report work completed in "real time", using data links between locomotives and UP's Transportation Control System. Work order reporting is designed to serve as an element of a integrated service management plan that will increase the quality of service to shippers, defined in terms of predictability and speed.

Burlington Northern Railroad (BN) has a pilot program for monitoring locomotive performance, by equipping 100 locomotives with ATCS-compliant health monitoring systems.

The Norfolk Southern Railroad is considering a pilot project for a work order reporting program using ATCS. CSX Transportation and The Atchison, Topeka and Santa Fe Railway are currently using ATCS communications technology for replacing pole line.
In Canada, the Canadian National Railroad (CN) and the Canadian Pacific are advancing their ATCS projects. CN has operated a prototype ATCS installation that includes "real world" and simulation testing, though this effort is not presently active.

ARES

Simultaneous with development of ATCS, the BN developed a similar system designated Advanced Railroad Electronics System (ARES). The BN, with Rockwell International its prime contractor, implemented a test bed for ARES in northern Minnesota. The characteristics of ARES functions included those of ATCS with an additional feature that permitted emergency stopping of trains from the control center.

One significant difference between ATCS and ARES is the method utilized for train location. ATCS specifications employ transponders located at designated locations that will identify each train as it passes that location and transmit the data to the locomotive and central computer. ARES utilized the Global Positioning System (GPS) to monitor and calculate the location of each train periodically.[18]

Another difference concerned the communications platform. ARES utilized VHF frequencies (which are favored, among other things, for the greater distances that can be accommodated between radio base stations), while ATCS utilizes assigned frequencies in the 900 MHz range of the UHF spectrum (which may be less affected by interference from other radio frequency traffic in more congested areas).

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[18]In GPS, radio transmissions from communications satellites owned and operated by the U.S. Department of Defense are compared to determine location.

BN demonstrated ARES on a test bed in northern Minnesota (the "Iron Range") during the period 1988 through 1993. Although BN and Rockwell technical teams judged ARES ready for system-wide application, BN did not fund the project. Instead, in 1993, BN placed the fate of ARES in the hands of the AAR Board of Directors, which determined that ATCS technology should remain the industry standard for planning purposes. Although BN discontinued work on the train control aspects of ARES, BN elected to continue development of a digital data radio capability using VHF frequencies that is similar to the ARES communications platform.

Evaluation of ATCS

Under an interagency agreement, FRA asked the Institute for Telecommunications Sciences, Department of Commerce, to review the ATCS specifications to determine the readiness of the industry to achieve PTC objectives through ATCS and to outline the steps that would be required to bring the train control aspects of ATCS on line. ITS has extensive experience in the development and evaluation of telecommunications technologies.

Based on review of the ATCS specifications and consultations with the AAR, ARINC, and other sources, the ITS report to FRA (reproduced as Appendix 3) reached the following conclusions:

(1) The ATCS Specifications have been developed to ensure compatibility and interoperability. The specifications are written to ensure compatibility between system components produced by different manufacturers. They are written to ensure interoperability between railroads. Such compatibility and interoperability is needed to provide positive train separation throughout the North American rail system.

(2) The ATCS Specifications apply sound engineering techniques to ensure the proper delivery of data from source to destination. Data communications systems must rely on automated techniques to ensure that data arrive at the intended destinations, that errors are detected and corrected, that data have been protected, and data arrive within established time constraints. The data communication system must have the ability to detect and recover from faults. In the event of failure, the data communication system must allow a graceful and safe return of control to a secondary system, in this case voice communication between the dispatcher and locomotives or track maintenance vehicles. The ATCS accomplishes these tasks well.

(3) The ATCS has the components to provide positive train separation. Positive train separation refers to the capability to detect and prevent impending collisions between trains. Within the ATCS, the access of trains and track forces to any section of track is strictly controlled by authorities issued by a dispatcher. The speed and location of trains and track forces are continually monitored. If violation warnings are not heeded by the operator, speed restrictions of the limits of movement authorities are enforced through automatic brake application.

(4) The ATCS Control Flow Specifications need further testing and validation. The ATCS Control Flow Specifications provide functional descriptions of certain aspects of railroad operating logic, and define how hardware and software elements of the system should interact in order to execute railroad operations. For example, one of the ATCS control flows describes the process by which central dispatch would issue a movement authority to a locomotive, and defines the associated messages that would be exchanged between various system processors.

A major revision of the Control Flow Specifications was completed in 1993. The control flows have become increasingly complex as system development has progressed, and ARINC is working on further documentation to aid ATCS software developers.

Because of the complexity of the control flows and because correct control flows are essential to safety, ITS recommends independent modeling and validation of the ATCS control flows under a variety of operating scenarios to ensure that the system functions as intended.

(5) A coordinated field test of a full implementation of the ATCS is needed. Various railroads and railroad equipment manufacturers have implemented only portions of the ATCS Specifications, or have conducted only limited tests of ATCS applications and equipment. A coordinated effort is required to field test a full implementation of the ATCS on a section of track with typical environmental conditions. A more comprehensive field test or pilot demonstration would be required to show the ATCS can properly function in more severe environments such as the Chicago hub or the Northeast Corridor.

(6) A migration plan and a timetable for implementation of the ATCS are needed. A migration plan provides for an orderly transition from one system to another. The migration plan ensures that safety measures already in place are not removed before all trains that pass through the territory have fully-equipped ATCS locomotives. Older systems and the ATCS will probably have to be operated in parallel while the ATCS becomes fully operational.

The implementation timetable accounts for the acquisition of funding, the installation and testing of ATCS equipment, and training for users of the new system. The timetable should seek to accommodate all railroads to encourage widespread use of the ATCS.

ITS also recommended evaluation of the UP/BN PTS project (described below) as an important means of gaining some of the knowledge referred to in the fifth and sixth findings, above.

Northeast Corridor (NEC) North End

In connection with the improvements on the NEC between New Haven, Connecticut and Boston, Massachusetts, the National Railroad Passenger Corporation (Amtrak) is upgrading the signal system to a traffic control system and proposing the conversion of the present 4-aspect single frequency cab signal/ATC system to a 9-aspect dual-frequency system with an intermittent train stop system. These changes will provide for centralized dispatching, permit increased speeds between intermediate signals, provide enforcement of civil engineering speed restrictions,[19] provide means of protecting roadway workers, and implement positive train stop at key control points. The proposed system will allow maximum speeds of up to 150 mph and speeds of 80 mph through crossovers.

The proposed intermittent train stop system is a transponder-based system, passive in operation, being a fixed "overlay" system, designed to locate the actual braking points and capable of supervising curve speeds and other civil restrictions in increments of 5 mph.

The existing 4-aspect, 100 Hz, 3-code system will be expanded to a 9-aspect, dual frequency, 8-code system by adding 250 Hz to 100 Hz as a second power frequency carrier and by adding 270 code to the traditional 180, 120, and 75 codes. The 250 Hz and the 270 code rate will be added in a way that minimizes the impact upon the existing equipment using the NEC.

The FRA supports Amtrak's project, and has advised Amtrak that the proposed system should meet the following requirements:

1. The system must enforce both permanent and temporary civil speed restrictions.

2. All trains operating over the trackage of the proposed system must be equipped to respond to this system.

3. No conflicting aspects or indications shall be displayed in the locomotive cab.

4. The system must enforce the most restrictive speed at any location associated with either the civil restriction or cab signal aspect.

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[19]"Enforcement of civil engineering speed restrictions" means limiting speeds at curves, stations and other points where the speed allowed by the signal system (based on track occupancy and rail integrity) exceeds the timetable speed restriction at the site. At FRA's request, the existing cab signal/ATC system has already been modified at several critical points on the NEC to provide this protection against overspeed operation, but the proposed system would provide an additional margin of safety at numerous additional locations.

5. The system must defeat any action by an engineer (e.g., as might occur should an engineer be on the verge of sleep and reflexively acknowledge a cab signal warning) that could allow a train to proceed past a key control point.

Amtrak submitted a block signal application seeking approval of the proposed modification of the automatic block signal system between New Haven, Connecticut and Cranston, Rhode Island. Approval was granted on October 28, 1992. This modification included the removal of the intermediate wayside signals in connection with the installation of a traffic control system and the expansion of the existing four aspect cab signals to include five additional aspects and speed control for high speed operation. However, this approval does not permit operation in excess of 110 miles per hour, and FRA expects to consider the matter of higher speeds in an appropriate public proceeding.

Currently all main tracks between New Haven, Connecticut and Boston, Massachusetts, 155 route miles and 338 track miles, have been signaled for reverse movement (bi-directional). This provides for flexibility for operating Amtrak, commuter, and freight services during construction, as well as increased traffic when high speed train operation is implemented.

The signal work is the first of two phases required to support 150 mph operation. The second phase will build on the first phase, by installing the additional equipment necessary for the operation and for upgrading the maximum speed to 150 mph. Three of the five new "high speed" interlockings have been placed in service, permitting 80 mph cross-over moves for the first time in the United States. Twenty diesel locomotives have been equipped with an interim 5 aspect cab signal featuring the additional speed command necessary to operate existing trains at 80 mph on these crossovers. This is an interim step until all locomotives and cab control cars can be equipped with the new 9-aspect cab signal and speed control system that Amtrak has developed.

Amtrak is developing the new system under the name "Advanced Civil Speed Enforcement System" (ACSES). It is designed to build on existing systems and to be compatible with application to electrified territory.

ACSES will use a carefully constructed blend of transponder scanning, radio, and microprocessor technology to meet specific needs of Amtrak's multiple-track, high-speed corridor. Prototype testing and final specification for procurement of the ACSES system will be completed in 1995.

ACSES will supplement the new continuous 9-aspect cab signal and speed control system by enforcing civil speeds at 5 mph increments up to 150 mph and by enforcing a *positive stop* at interlocking home signals where an overrun stop signal could compromise an adjacent high speed main track. It is being designed with an eye toward ultimately equipping the entire Northeast Corridor as well as the emerging high speed corridors throughout the country.

Both the 9-aspect cab signal and speed control system and the ACSES system will use proven, highly reliable technology to achieve Amtrak's and FRA's safety goals with the least possible impact on other railroad users of the Northeast Corridor. Both have been developed to accommodate the "incremental" or "building block" approach to upgrading the emerging high speed corridors in practical stages as funding is made available. The design ensures that each stage will contribute significantly to increased protection and to decreased trip times.

PTC Alternatives

Amtrak's ACSES--a signal-based ATC enforcement system--offers an effective PTC alternative to ATCS. The Florida East Coast Railway Co. (FEC), which operates a high-density railroad between Jacksonville and Miami, Florida, at freight speeds to 65 miles per hour, recently installed a modern ATC system that incorporates most PTC attributes (with the exception of direct data links to, or supplementary automatic protection for, roadway workers).

However, the Amtrak and FEC approaches, while cost effective in their particular operating environments, involve investments that are likely not sustainable over the national rail system. As such, they do not appear to be affordable alternatives to ATCS for much broader applications.

During roundtable discussions on PTC issues, and in discussions with suppliers, FRA developed information regarding alternative PTC concepts that might be no more costly, or less costly, than ATCS. Suppliers identified a variety of approaches, such as --

- Augmentation of existing signal systems with ATCS-compliant components that might communicate locally with an on-board computer;

- Use of range-finding technology with on-board computers to provide safety and facilitate flexible block lengths;

- Use of "spread spectrum" radio to track and manage trains on a very localized basis between signal system control points, potentially facilitating very short headways.

- Radio-based control that places all intelligence in the field, such that key route and traffic information is downloaded to the on-board computer for determination of movement authority, again providing for flexible blocks and short headways.

FRA is satisfied that a reasonably wide range of technologies could be employed with a high degree of effectiveness to achieve PTC. Selection of technology should rest with the railroad industry based upon all pertinent safety and non-safety requirements, cost, interoperability, and adaptability to changing requirements and technology.

AAR Strategic Planning

As FRA began the inquiry leading to this report, the AAR had in progress a strategic planning effort designed to determine the industry's course with respect to ATCS technologies, including positive train control. The timetable for that review had already been extended, and no resolution of any of the critical issues was expected prior to December 1994. At the request of the Federal Railroad Administrator, AAR accelerated its review of ATCS and provided briefings regarding preliminary findings to FRA at the final roundtable in late March 1994, with further refinement in early May 1994.

AAR believes that positive train control elements of ATCS must be supportable on their own merits if they are to be implemented. The AAR stated that the expected "business benefits" of ATCS are being achieved by "timely, more cost effective technologies." Example: implementation of work order reporting through use of "cellular-grid pad[20]" systems on Conrail, CSX Transportation, and the Southern Pacific Lines.

The AAR judged that developing technologies may in some cases be more cost effective than certain other ATCS features. For instance, the Class I railroads are developing a dynamic Automatic Equipment Identification (AEI) tag for use in offloading locomotive health data.

According to the AAR, other previously forecasted business benefits of ATCS exist, if at all, only in particular applications. Again, in many cases carriers are finding alternative means to achieve the same benefits. For instance, benefits associated with automatic train management and moving block could be realized only on those lines where capacity is at issue. Benefits associated with pole line elimination are being realized on some properties through use of reserved fiber optic capacity.

Speaking for the major freight railroads, the AAR continues to agree that "positive train separation" demands industry interoperability but notes that it has applications for transit, commuter and passenger rail operations, as well as freight. This raises the question of appropriate roles for the Federal Government, and State and local governments, as well as freight railroads and suppliers.

In summary, AAR stated that "positive train separation, if cost justified, will most probably be done on a carrier/corridor specific time table in phased increments."

The AAR committees studying ATCS also considered technical choices, risks associated with PTC, and cost and benefits (discussed in Chapter V, below); and they identified unresolved issues. The AAR noted that existing PTC systems such as Amtrak's ATC system are signal-

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[20]Commercial cellular telephone can be used either to send voice messages or data. A "grid pad" is a type of hand-help microcomputer that permits entry of data on a touch-sensitive screen. A "cellular grid pad" uses a commercial cellular radio telephone link to transmit the entered data.

based, very effective, and costly. Emerging communication-based PTC systems were projected to be less costly, equally safe, and capable of more applications (e.g., speed and capacity enhancements).

The AAR signaled new flexibility with respect to radio data paths, noting the availability of VHF, UHF, cellular, and spread spectrum options. Similarly, both transponders and GPS merited interest as location systems.

In reviewing the risks associated with PTC development and implementation, the AAR stated that software development and delivery risk was low to moderate, following verification of industry specifications. The AAR committees feared unstable requirements leading to cost overruns. Operating reliability was identified as a critical characteristic of any PTC system, both to serve the system's safety goals and to provide for operating efficiency.

As the major railroads continue to develop recommendations for the future direction of PTC, they will be attempting to identify a specific, flexible building-block approach that can be pursued by individual railroads according to available resources and operating requirements. The AAR suggested that the most likely migration path is as follows:

- Warning -- system warns of exceeding authority limits or speed limits and warns of approaching maintenance-of-way (MOW) work limits.

- Enforcement with existing signal systems -- positive train separation enforcement overlaid on existing systems with enforcement of authority, speed and MOW limits.

- Enforcement without existing signal systems -- adding wayside interface units and enhanced control software.

The preceding outline of a migration path is notably non-specific. It does, however, suggest a merging of existing signal system functions with PTC functions during the intermediate period before all advanced technology features associated with ATCS Level 40 are deployed.

This concept of "enforcement with signals" is relatively easy to imagine in the context of a traffic control system. Data regarding block occupancy and remote-control switch position, which is already received through nonvital paths and utilized to plan dispatching, would be provided by data communications link to the on-board computer, which would add train location information to determine enforcement parameters consistent with movement authorities communicated through the same data path. Very likely, these enforcement parameters (as opposed to the movement authority) would not be displayed to the engineer, since the quality of this data would be just slightly less than the quality of information provided by the vital signal circuits themselves. It would not be wise to invite the engineer to use this information to speculate regarding upcoming signal indications, etc.[21]

It is much less evident how the "enforcement with signals" option would work in automatic block territory (let alone dark territory). Presumably placement of WIUs would be necessary at key points, and the value of the enforcement system would be proportional to the comprehensiveness of WIU installation (e.g., at switches, wayside detectors, and signal houses).

As this report entered review, the AAR had once again reconstituted its committees addressing ATCS. In place of the "ATCS Steering Committee," a new "PTS Tactical Development Team" was appointed. The team will establish minimum requirements for PTS, define industry and individual railroad development responsibilities, develop a detailed migration path, define management structure for industry development ("if any"), address unresolved issues and report to the PTS Strategic Planning Committee. By November 1994, the Strategic Planning Committee is to report to the AAR Board of Directors with recommendations.

BN/UP Test Bed

The Union Pacific Railroad has put in place the most extensive ATCS communication infrastructure of any major railroad to support its work order reporting program. The Burlington Northern Railroad recently launched a major data radio network installation for pole line elimination, and BN's development of ARES provided the railroad with extensive knowledge of the challenges posed by communication-based PTC. Together, BN and UP are well situated to advance communication-based PTC.

On April 29, 1994, the two railroads announced a joint project to apply PTC to a large-scale test bed in the States of Oregon and Washington. The territory involved includes a north-south main line from the Canadian border at Blaine, Washington, through Seattle to Portland. (BN and UP share trackage between Tacoma and Portland.) Also included would be the carriers' parallel east-west main lines from Vancouver, Washington, to Pasco, Washington, on the BN and from Portland to Hinkle, Oregon, on the UP.[22] The territory comprises

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[21]The quality of an enforcement system of this type could never be greater than the quality of the signal and train control system whose data it utilized. For instance, in cab signal territory if a cut of cars rolled out of a siding onto the main in the next block ahead of an oncoming train, shunting the signal system, the train crew would immediately become aware of the obstruction and could begin to take preventive action. In traffic control territory without cab signals, this information would not be known until the train came within sight distance of the wayside signal.

[22]The railroads' initial announcement suggested that a BN branch line from Wishram, Washington, to Bend, Oregon, would also be included in the test bed. However, this line

over 700 miles of railroad. Most is governed by traffic control systems, with the remainder operated by track warrant control and automatic block signals. The two railroads have joint operations over 193 miles of this territory.

The railroads' electronic train monitoring and control system will be referred to as "PTS." The PTS system will be a central communication-based, enforcement technology integrated with existing signal systems (TCS, ABS). Although technical details were open as this report entered review, it appeared likely that both railroads would use GPS for location. However, UP planned to employ its UHF ATCS communications platform, while BN planned to use its VHF Rockwell data radio network. Thus, on-board units will be required to be equipped with dual-band transceivers.[23]

Over a decade after the North American railroads first sought to achieve a consistent approach to advanced train control, and more than 12 months after the BN allegedly terminated its competing ARES program, it is ironic that the first large-scale test bed for PTC will use GPS (ARES) train location technology. Further, it appears that UP and BN will address interoperability in the same basic way Amtrak has operated over disparate train control systems for some years (i.e., by equipping its locomotives with all systems and selecting the appropriate system upon entering a new equipped territory).[24]

Track Warrants by Digital Data

Even as PTC systems continue to be deployed, direct traffic control or "track warrant" operation will likely continue for some time over much of the national rail system, particularly on lines where density is low. To the extent digital data communication is available on these lines, railroads should develop software and establish procedures so that movement authorities are communicated by the CAD system directly to an on-board computer.

Issuing track warrants by data radio will result in significant advances in safety and significant reductions in voice radio congestion. Advances in safety will result from the secure means of transmission--errors that can arise as the dispatcher reads the authority aloud and the train crew attempts to hear and transcribe the authority will not arise. Since data communications are much more efficiently transmitted than voice, radio congestion will be

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was deleted based on minimal traffic levels.

[23]Interoperability could be achieved with contemporary electronics utilizing any number of radio frequencies; however, there are penalties in cost and complexity that must be overcome. The penalties increase where more than one communications software package is used, as will be the case with the BN and UP systems.

[24]This is a greatly simplified view, and optimistically the two railroads will develop technical approaches that make transitions relatively transparent from the point of view of safety objectives, while holding down costs.

reduced. Further, advances in technology should make it possible to provide onboard printing of movement authorities, both for immediate use in operating the train and as a subsequent record of information received.

FRA believes that, over the next year, one or more railroads using data radio communications from train to central office will launch an experiment involving transmittal of track warrants by this means. FRA will assist any such an effort by working with the railroad's rules officers to ensure proper consideration of sound operating procedures.

CHAPTER V

Benefits and Costs of Positive Train Control

The immediate future of PTC implementation is, as suggested by the mandate for this study, tied closely to the progress of ATCS. As described in the previous chapter, ATCS is a system of technologies covering a broad range of railroad functions.

The benefits of ATCS to any railroad will depend upon which functional elements are chosen for implementation, how implementation is carried out, how the capabilities of ATCS are used, and the extent to which alternate means may have been elected to achieve the same benefits. Fuel and labor savings, safety, and improved equipment utilization are examples of tangible benefits--expenses are reduced or capital outlays are avoided. ATCS would also generate detailed information about railroad operations which could be used to improve service quality.

The safety features of ATCS address (1) collision prevention, (2) speed control, and (3) protection of roadway workers and their on-track equipment--the central objectives of PTC as described in this report. The AAR has begun to refer to technology designed to achieve these objectives as "positive train separation."[25]

During the development of this report, the major railroad companies have contended that, from the point of view of public policy development, there is no merit to consideration of nonsafety benefits of advanced communications technology that might be realized in connection with PTC investments. At the end of the chapter, FRA examines the value and limitations of that perspective.

Safety Benefits and Costs: AAR Positive Train Separation

Analysis of accident/incident data shows that virtually all collisions and overspeed accidents preventable by PTC result from human factors. This is not surprising, since by definition the area of inquiry is one for which the final margin of safety is presently provided by the human operator; and, after many decades of development, existing signal and train control

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[25]The full significance of this new name was not clear as this report was prepared. Certainly using "positive train separation" to refer to PTC attributes of new technology properly distinguishes train control from other systems. However, as indicated by the the innovations included in the UP/BN pilot project, use of the term may also indicate that the major railroad companies view the ATCS specifications as only one of the available paths toward achievement of train control objectives.

hardware is extremely reliable. In reviewing options for what the industry now calls "positive train separation," the AAR and its committees have assumed that the technology deployed under that rubric would be fully competent to achieve all PTC objectives--or very nearly so.

Appendix 1 shows major train accidents which would have been preventable through the use of PTC. PTC systems could virtually eliminate these types of accidents, as well as events of lesser magnitude that occur with somewhat greater frequency.

In order to quantify the potential benefits from PTC, representatives from FRA, AAR and rail labor reviewed accident data from the period 1988 through the first eight months of 1993 (5.67 years). All reportable[26] collisions and overspeed derailments (there were 220 such accidents during the study period) were examined to determine the extent to which each would have been prevented by PTC. After several discussions as to the principles which should be applied to determine whether PTC would have prevented particular accidents, the FRA, AAR and rail labor reached basic agreement on a list of 116 accidents that all participants agreed would have been prevented with a PTC system.

The 116 accidents included 35 derailments, 21 head-on collisions, 39 rear-end collisions, 15 side collisions, and 6 other accidents that, after examination of the individual accident report, were judged to have been preventable by PTC. These accidents resulted in 420 injuries, 30 fatalities, and $70 million in reported railroad property damage.

The prevention of these types of accidents in the future is the potential safety benefit of PTC. Assigning a dollar value to these potential benefits involves both estimation and judgment, and different selections will produce a range of answers. Depending on the estimates used and judgment employed, the potential benefits range between about $27 million and $53 million annually.

The key factors in determining the high and low estimates are (1) the extent to which it is estimated that the elements of property damage required to be reported by the railroad companies underrepresent total adverse economic impacts, and (2) the monetary values assigned to the avoidance of casualties and fatalities. Railroad property damage required to be reported by the railroad companies does not include loss of lading, wreck clearance, environmental clean-up, and incidental costs (delay of operations resulting in extra train crew costs, etc.), therefore a reasonable adjustment factor is useful to avoid undervaluing accident avoidance. Assigning monetary value to fatality and injury avoidance is necessary as a tool in benefit/cost analysis in order to examine alternative uses of public or private funds fairly.

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[26] "Reportable" accidents are those which result in damage above the FRA reporting threshold. The current threshold is $6300. Collisions and overspeed derailments which resulted in less than $6300 in railroad property damage would not have been reported to FRA and are not included in this analysis.

Below are three estimates of the annual potential benefits of PTC based on the 116 preventable accidents referred to above. The lowest estimate, $26.6 million per year, was produced by the AAR and represents their best estimate of the likely annual benefits of PTC. The highest estimate, $52.9 million per year, was AAR's highest estimate, and represents very liberal assumptions as to both the extent of underreporting and the monetary value of casualties. The estimate in between was produced by FRA using the agreed-upon underlying data, but applying the values for avoided fatalities that FRA usually uses in its regulatory analysis of proposed safety regulations.

The calculations for each of the three estimates are shown in Table V-1:

Table V-1

ESTIMATED BENEFITS OF POSITIVE TRAIN CONTROL

ESTIMATE 1 (LOW) (AAR)		
Reported Property Damage (5.67 years)	$70.0m	
Additional Damage (56.25% of above)[27]	$39.4m	
FELA[28]	$40.8m	

	$150.2m	($26.6/yr)
ESTIMATE 2 (FRA)		
Reported Property Damage (5.67 years)	$70.0m	
Additional Damage (56.25% of above)	$39.4m	
Injuries (420 at $20,000 each)[29]	$ 8.4m	
Fatalities (30 at $2.6m each)[30]	$78.0m	

	$195.8m	($34.5m/yr)
ESTIMATE 3 (HIGH) (AAR)		
Reported Property Damage (5.67 years)	$70.0m	
Additional Damage (100% of above)	$70.0m	
Casualty Costs (Equal to ALL damages)	$140.0m	

	$280.0m	
Round up	$300.0m	($52.9m/yr)

Note: Comparable figures for the North American rail system including Canada are slightly higher (cf. Table V-2).

[27] The damages currently reported to FRA do not include loss of lading, wreck clearance, or environmental cleanup. AAR surveyed its members and reports that, on average, these other costs constitute an additional 56.25 percent of the reported damages.

[28] AAR's estimate of casualty costs stated in terms of Federal Employers Liability Act recoveries.

[29] $20,000 is the value used by FRA to represent the amount society would be willing to pay to avoid an average injury to a railroad employee.

[30] FRA uses $2.6m as the amount society is willing to pay to avoid a fatality to a railroad employee.

AAR Cost/Benefit Analysis

Responding to FRA's request that ATCS planning be expedited, an AAR committee considered the cost implications of major technical options for PTC. In April 1994, AAR prepared a cost/benefit analysis of requiring U.S. and Canadian Class I railroads to install PTC.[31] The AAR's analysis did not quantify nonsafety or "business" benefits to be derived from such systems. Instead, the AAR estimated the costs and safety benefits to be derived from a "safety only," government-required PTC system.

The AAR's analysis assumed a U.S.-Canadian system of 149,000 route miles (85,700 miles equipped with TSC/ABS and 63,300 miles dark territory). The AAR analyzed three system architectures: (1) signal control-based, (2) field control/communication-based, and (3) central control/communication-based.

PTC investment cost estimates for each of these architectures is shown in Table V-2. Signal control-based PTC was viewed as the most expensive approach, with an estimated investment cost of over $2 billion.[32] Field communication-based PTC was estimated to exceed $1.2 billion in cost.[33] The AAR estimated central communications-based PTC to be the least costly.

Signal control-based PTC systems are used in this country by Amtrak (e.g., as planned for the north end of the Northeast Corridor) and in European countries. Signal control systems are extremely effective in safety-related PTC. The AAR estimates signal control-based system investment costs for Class I railroads to be $2.1 billion, a figure well below previous estimates for automatic train control systems, but still well above other alternatives. No annual maintenance expenses were estimated for this option. Signal control-based systems are only capable of routing and protecting trains. There are presently few business benefits that would justify the freight railroad industry's investment in this type of PTC.

The two remaining PTC architectures are field control communication and central control communication. Communication-based systems are less costly than signal-based systems and potentially offer safety and PTC attributes that are equal to signal-based systems.

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[31] Railroad classifications are established by the Interstate Commerce Commission are based on indexed operating revenue levels. Effective January 1, 1992, a Class I railroad has operating revenues equal to or exceeding $250 million; a Class II railroad has operating revenues of less than $250 million but in excess of $20 million; and a Class III railroad has operating revenues of $20 million or less. By Commission definition, all "switching and terminal" railroads are classified as Class III, regardless of operating revenue levels.

[32]It was not clear from the AAR presentation what type of technology was contemplated.

[33]Again, the AAR did not specify what technologies were deemed least expensive.

Communication-based systems (particularly those involving central office functions) are also capable of far more applications than PTC, many with economic benefits to railroads.

In evaluating communication-based systems AAR made the following assumptions:

(1) The installation of specialized on board computers and communication equipment in 15,335, of 20,289 locomotives--about 76 percent of the U.S.-Canadian Class I fleet;

(2) A transponder train location system; and

(3) A communication system utilizing UHF (900 MHz) technology.

The two communication-based systems can be constructed under three levels of PTC--"warning," "enforcement with signals," and "enforcement without signals." Depending on which level of PTC is selected, the AAR estimates field communication-based system investment costs of Class I railroads for a safety-only system to range from $1.2 billion to $1.5 billion for initial hardware and start-up costs. No annual maintenance expenses were estimated for this option.

According to the AAR, the least costly of the PTC architectures is central communication based. The cost of a safety-only PTC central communication-based system for all Class I railroads range from $843 million to $1.137 billion for initial hardware and start-up costs.[34] On a per route mile basis, the initial hardware and start-up costs would range from $5,660 - $7,630. Annual maintenance expenditures for this system are estimated to range from $176 million to $236 million ($1,200 - $1,600 per route mile).

By comparison, U.S. Class I railroads reported $28.8 billion in revenue, $4.3 billion in net revenue from operations, and $2.5 billion in net railway operating income in 1993.

The AAR's study estimated the safety benefits of PTC using the data evaluated by AAR, rail labor, and FRA, and adjusted to consider Canadian exposure. Depending on which of the three PTC scenarios was adopted, the U.S.-Canadian Class I railroads would reduce up to 23 accidents, lower injuries and fatalities by up to 83 and 7, respectively, and reduce payouts due to PTC-preventable accidents by up to $30 million. A synopsis of this data is presented in Table V-3 (on page 65).

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[34]Based upon the break-down of costs discussed with the AAR, it appears that the less costly central communications-based systems would utilize data from existing signal systems, where available. Depreciation or maintenance of those existing systems is not included in the AAR cost estimates.

Business Case Benefits

As reflected in this report, ATCS offers significant potential business benefits to railroads with pertinent needs not otherwise addressed through alternative technology. These include fuel savings, better utilization of track and equipment (such as work order reporting, locomotive health monitoring, and traffic control), reduced wear on track and equipment, on-board hot bearing detection, car/trip scheduling, more precise scheduling of employee deployment, reduced job stress for train dispatchers, and better service for customers (such as more reliable schedules and decreased transit time). All of these potential benefits offer possibilities for additional cost savings and managerial efficiency through increased network intelligence and enhanced information flows.

AAR and the freight railroad companies' strong message to FRA during the process of consultation leading to this report is that "business case" benefits of ATCS cannot be estimated at the national industry level. Therefore, they reason, these benefits should not be credited in the overall benefit/cost computation for PTC, and that this computation should focus on the safety improvements expected alone.

AAR and the freight railroads state first that the business benefits of ATCS are rapidly being implemented with separate, need-specific systems. For example, pole line elimination can take place without ATCS if a railroad has granted use of its right-of-way for fiber optic cable and has reserved for itself a certain amount of the cable's communications capacity; similarly, a railroad will not need a work order reporting system if it is able to determine car location and status through cellular telephone data links. This type of technology substitution is becoming widespread.

Secondy, they contend that different railroads will realize different levels of benefits (and costs) from ATCS. A finding that railroads will benefit by a certain amount "on average" would mean very little to the individual companies because railroads differ significantly in their operating structure, facilities, business requirements, markets, and profitability. For example, the capacity-increasing potential of ATCS would prove profitable to those railroads adding second main tracks or additional passing sidings, but would have no value to the major western railroad removing its second main track over a major route. In addition, railroads vary in their capacity to make investments in new technology.

The railroads have been analyzing the benefits of ATCS since first developing the concept, and found that those benefits were difficult to predict even on specific railroads. The Burlington Northern (BN) stated that its ARES project (described in Chapter 4) promised "improved service, with higher revenue potential, and cost reductions [and] the elimination of train accidents caused by violations of movement authority." However, BN's consultants (SDG) concluded that "the potential benefit of ARES is large but highly uncertain. . . . The benefits depend greatly on implementation success: The system design must be sound, a strong implementation plan must be developed, and functional groups across the BN system must be committed to using it to full advantage." As previously stated, BN decided not to continue with the project, primarily because the benefits were so uncertain.[35]

Accordingly, to determine the extent to which PTC should be implemented--whether through the voluntary action of a railroad or a Federal mandate--consideration must be given to each specific application. Although incidental business benefits should be taken into consideration, nonsafety benefits must not be assumed in a speculative way.

In the long term, the development of an integrated and interoperable communications network such as ATCS, which will produce safety benefits, is likely. Commercial needs are growing; high quality service is essential to market growth in many sectors, as shippers increasingly demand precision with respect to both pick up and delivery schedules. The rapid increase in intermodal service using containers, trailers, and other intermodal options places a premium on higher average train speeds, which requires better use of plant capacity and increasingly competent signal systems (as reflected by continuing investments in new traffic control systems on high density routes). As service requirements become more demanding on railroad plant, equipment, and personnel, the business benefits of flexible, interoperable, communication-based PTC should become more evident and more readily quantifiable.

Just as the freight railroad industry's need for competent and flexible communications is growing, so too is the industry's use of cutting-edge communications technology. Freight railroads are sharing traffic data with their shippers and one another using electronic data interchange (EDI). They are tracking rail cars over their main lines using AEI; and, with cooperation from trucking and maritime interests, similar tracking of containers and trailers is possible. In 1992, the rail industry launched an effort to bring all of these systems together. Known as interline service management (ISM™), this undertaking is to develop and foster the implementation of business processes and supporting information systems that will allow interlining carriers to provide reliable, competitive, seamless service. Communication-based PTC systems should fit well with that series of initiatives.

Public sector benefits can also be expected from the implementation of interoperable PTC. Rail commuter service is a growth industry due to the saturation of urban highways and the high cost of heavy rail transit starts. Enhanced PTC systems can help reduce the cost and improve the quality of commuter rail expansion. With Amtrak's Northeast Corridor service leading the way, high speed passenger service has emerged as a favored planning option for certain congested corridors among major U.S. cities. Highly capable, interoperable PTC systems can provide necessary safety features while holding down costs associated with mixed freight and high speed passenger service.

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[35] Burlington Northern: The ARES Decision (A), Copyright 1991 by the President and Fellows of Harvard College. Report 9-191-122, dated 2/21/91.

To the extent PTC is deployed over major freight routes used by Amtrak, conventional passenger service reliability might increase, and in some cases trip times might be improved (though speed is generally not a major competitive issue for Amtrak service outside of high-speed corridors).

Additional impetus for concerted railroad industry action will come from external forces. The Intelligent Vehicle Highway System (IVHS), now under development through the leadership of the Federal Highway Administration, promises a plethora of technologies, some of which may have direct implications for the railroad industry. For instance, should IVHS offer innovative approaches to enhance safety at highway-rail crossings, the need for a new communications interface could be presented at 170,000 public crossings nationwide. Should the railroad companies find it necessary to respond individually to this challenge, the cost implications of PTC would likely pale by comparison.

The basic thrust of the AAR/RAC ATCS program has not been rendered obsolete; however, technological opportunities and business demands have grown at a faster pace than ATCS planning had proceeded. The need remains for an accelerated, industry-level effort to integrate telecommunications systems, guiding investments in technology by ensuring the forward compatibility of software and interoperability of related systems.

Analysis

The AAR and major railroads are justified in insisting that the PTC debate include a clear focus on safety costs and benefits. However, the architecture identified by AAR as least costly for safety purposes (central communication-based) is also the architecture most likely to yield nonsafety benefits. Should ATCS architecture prove insufficiently flexible to meet emerging needs, railroads will find ways to lend it new flexibility. That is already happening in the BN/UP positive train separation project. It is imperative that such efforts be coordinated at a wider industry level in order to ensure maximum efficiency and thus promote broader application.

Previous rail industry technological advances produced benefits that were also difficult to estimate; the benefits of dieselization far exceeded predictions. FRA believes that the benefits of a central communications system--or flexible networks capable of functioning as a single system--can be expected to exceed the modest expectations of those advocating individual subsystems. Investments in safety and efficiency can produce synergies that result in unexpectedly high returns.

As indicated previously, the application of PTC to all rail lines has not been shown to be cost beneficial at present based on safety alone. Business advantages to the railroad industry from such universal implementation can be expected, but the specific extent and nature of such advantages will differ greatly, depending on the particular circumstances. In the final chapter, the report considers whether, and under what conditions, individual line segments should be considered ripe for PTC implementation.

Table V-2

Estimated Investment Costs
Positive Train Control
Signal Control-Based Versus Communication-Based
Class I Railroads--United States and Canada

(Dollars in Millions)

SIGNAL CONTROL BASED			
SIGNAL CONTROL-BASED		$ 2,064	

COMMUNICATION BASED	WARNING	ENFORCEMENT WITH SIGNALS	ENFORCEMENT WITHOUT SIGNALS
FIELD COMMUNICATION-BASED	$ 1,196	$ 1,212	$ 1,490
CENTRAL COMMUNICATION-BASED	$ 843	$ 859	$ 1,137

Source: Association of American Railroads *Interim Report of Railroad Industry ATCS Strategic Planning Committee*, April 1994.

Note: Figures vary slightly from those in the narrative because Canadian railroads are included.

Table V-3

Estimated Cost and Benefits of
Central Communication-Based Positive Train Control
Class I Railroads -- United States and Canada
(Dollars in Millions)

COSTS[36]	WARNING	ENFORCEMENT WITH SIGNALS	ENFORCEMENT WITHOUT SIGNALS
One-Time Costs			
Railroad Industry	$ 30	$ 50	$ 50
Individual Railroads	803	809	1,087
Total One-Time Costs	$ 843	$ 859	$ 1,137
Annual Operating Costs[37]			
Individual Railroads	$ 176	$ 180	$ 236
BENEFITS (Annual)			
Monetary Savings	$ 23 [38]	$ 30	$ 30
Reduction of Accidents	14 [37]	23	23
Reduction in Injuries	65 [37]	83	83
Reduction of Fatalities	6 [37]	7	7

Source: Association of American Railroads *Interim Report of Railroad Industry ATCS Strategic Planning Committee*, April 1994.

[36] All costs have been identified on an industry-wide basis. Individual railroads were not analyzed--too carrier specific and variable in application.

[37] Includes amortized capital expense and annual maintenance.

[38] Maximum annual benefits. True experience may be less due to crew inaction following warning.

CHAPTER VI

Conclusions and Future Actions

Railroad communication systems and signal and train control systems serve important safety purposes while playing a critical role in the efficiency of railroad operations. The safety relationships between the two systems have been addressed through railroad operating rules, supplemented by Federal radio standards and procedures. Working together, today's signal systems, voice radio communication, and railroad operating rules provide for good safety performance and low safety risk.

Further reductions in risk can be achieved with PTC systems. PTC systems with enhanced features can also increase rail system capacity, facilitate the growth of high speed passenger service and commuter service, and help position freight railroads to compete and form additional partnerships in an intermodal marketplace. As the railroad companies are making investments that will permit full PTC capabilities, opportunities should be exploited to use data communication paths to transmit critical movement authorities, in lieu of voice radio.

Even as technology becomes more sophisticated, however, investment should be scaled to safety need and, secondarily, other business requirements. Federal regulations and railroad rules should maintain a clear focus on the functional requirements that communication and control systems are intended to fufill. Where technology of lesser cost will do as well as more sophisticated and costly technology, suitable flexibility should be provided.

Based on this study and its findings, FRA will take the following actions, detailed later in this chapter:

- Revise radio operating rules to be more flexible and to include requirements regarding the presence of radios as safety equipment.

- Seek to test transmission of orders via digital data radio in place of voice radio on a major railroad.

- Identify high-risk rail corridors which may warrant mandatory PTC application.

- Maintain an interest in all ongoing tests of PTC-related technology, and include PTC technology in the Next Generation High Speed Rail Program.

- Promote continued effort by the AAR to ensure compatibility and interoperability in specifications for PTC systems.

- Establish as a priority agency objective the deployment of PTC technolgy on major high-risk rail corridors by the year 2000.

RESPONSE TO CONGRESSIONAL MANDATE

In addition to reviewing the broader issues of railroad communications and train control, section 11 of the RSERA required the Secretary to assess specific issues related to railroad radio standards and procedures.

"(1) the advantages and disadvantages of requiring that every locomotive (and every caboose, where applicable) be equipped with a railroad voice communications system capable of permitting a person in the locomotive (or caboose) to engage in clear two-way communications with persons on following and leading trains and with train dispatchers located at railroad stations...."

Current practice among major railroads provides for equipping lead locomotives with all-channel radios (generally with transmitters rated at 35 watts and equipped with an effective externally-mounted antenna which is necessary both for effective tranmission and reception).[38] Radio communications are established between trains and the dispatching center. The quality and reliability of this communications link is important to ensure that movement authorities are clearly understood (if applicable), to provide a means of requesting emergency assistance in the event of an accident, to provide a means of transmitting and receiving emergency and security warnings, and to ensure receipt of messages from wayside detectors (particularly in non-signal territory).

The lead locomotive of any consist should be so equipped upon departure from a terminal. If the radio should fail en route, a standby radio or radio in another locomotive (or an alternative means of communication, such as a work order station or cellular phone) would be important to provide an emergency communications link from the train to the dispatch center. Reasonable provision should also be made for the crew to receive warnings of unsafe conditions that might affect the operation of the train.

On balance, there is no supportable safety rationale for requiring train-to-train communications if an effective link exists from each train to a operational dispatching office. Currently, locomotive radios and retransmission facilities are not designed to ensure train-to-train communications for extended distances. It is true that train crews listen for and to other train communications avidly; however, train crews do not receive track warrants or signal indications from one another. They should not be engaged in casually passing information that, if relied upon, could cause them to operate in excess of their authority. A

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[38]Cabooses are rapidly disappearing from service, but where used they are generally equipped with 25- or 35-watt radios. This would appear to be prudent to ensure good front-to-rear and dispatcher-to-caboose communications.

major danger in this regard is that train crews of following trains will rely upon voice radio communications rather than observe rules for restricted speed.

When train crews become aware of developing safety or security concerns, that information may be passed through the dispatcher to other train crews. To the extent there is insufficient time for an emergency message to be passed through the dispatcher, in the great majority of cases train-to-train communication will be available over the short distances involved as an adjunct to train-to-dispatcher communication capability.

It should be emphasized that railroad operating rules, rather than any communications system, provide the first line of defense for the integrity of movement authorities. While many territories trains are "run by radio," it would never be proper to create a trap in which safety of operations depends on the ability to reach a train to cut short its previously granted movement authority. Rather, orders may be issued only if not in conflict with orders previously issued and still in effect. If it becomes expedient to change orders, all prior orders must be canceled prior to issuing fresh orders that might in any way conflict with previous orders.

"(2) a requirement that radios be made available at intermediate terminals...."

This requirement would provide replacement radios for trains whose radios fail en route, so that crews not be required to operate without a functioning locomotive radio unnecessarily. As stated above, each train should be equipped with an operating radio. Should the voice radio of the lead locomotive fail, several factors should be considered:

- What other communications capability is available to the crew? (Operative radio in trailing locomotive, on-board work order computer, cellular telephone, portable low-power radios, etc.)
- What is the length of haul to the train's final terminal or other known repair point?
- What work will the crew perform along the way? (Switching may be performed using only low-power portable radios ("handitalkies"), but total absence of radio communication may render the work too hazardous, including unplanned switching to set out defective equipment.)

Railroads should have in place communications plans that consider the safety communications requirements outlined above and that address these concerns, ensuring appropriate redundancy.

"(3) the effectiveness of radios in ensuring timely emergency response...."

Information available does not provide a basis on which to quantify the extent of reliance on radio communications to summon aid in emergencies. However, FRA is aware that railroad dispatching centers maintain extensive listings of emergency responders in all of the jurisdictions through which railroads operate. Further, given the vast distances over which railroads operate, radios very frequently offer the only immediate means of summoning assistance.

In most cases, FRA and NTSB reports reflect that radios function as intended following serious accidents. However, when that is not the case, critical delays can ensue. Railroads should include communications strategies in their emergency preparedness plans; in most cases, those strategies will require heavy dependence on voice radios.

> *"(4) the effect of interference and other disruptions of radio communications on safe railroad operations..."*

In FRA's field review of railroad radio communications and train dispatching offices, FRA determined that improvements in radio technology have improved the clarity of voice communications. However, FRA continues to view with concern the extent to which congestion of dispatcher frequencies disrupts normal dispatching functions, including communication of track warrants and other authorities. Although Federal and carrier rules prohibit acting upon authorities that are not complete, well-disciplined communication is necessary to ensure proper delivery and receipt of movement authorities.

Interference with communications on channels assigned for switching in yards, terminals or intermediate points, whether as a result of improper use of adjacent channels or congestion, is a particular concern. Every year railroad employees die while conducting switching movements, and factors related to communications are often at issue in the ensuing investigations. Good radio discipline by all railroad employees and careful control of technical factors (e.g., coverage overlaps and adjacent channel interference) are essential to safe switching operations.

> *"(5) how advanced communications technologies such as digital radio can be implemented to best enhance the safety of railroad operations...."*

Digital data radio as a part of a central communications platform can serve as a highly competent element of a PTC system. The UP/BN test bed will evaluate this potential further.

Prior to the full implementation of PTC, digital data radio can be used to transmit movement authorities to trains directly from the Computer-Aided Dispatching (CAD) system in a much more secure manner than is possible using voice radio. FRA believes that digital radio will be employed to transmit track warrants on a major railroad within the next year, and FRA will work with that railroad to ensure the success of the project.

"(6) the status of advanced train control systems that are being developed, and the implications of such systems for effective railroad communications....

AAR ATCS specifications are well suited to achieving the safety objectives of positive train control. Independent modeling and validation of the control flow specifications and demonstration of ATCS in one or more test-bed applications are recommended. In addition to supporting PTC, technology such as ATCS will reduce capacity demands on voice frequencies, further improving emergency and other radio traffic flows (see Chapter IV).

"(7) the need for Federal standards to ensure that [ATCS] systems provide for positive train separation and are compatible nationwide ...."

PTC technology can prevent train accidents, including train accidents of the type most likely to result in employee or passenger fatalities. PTC technology can also enhance protection provided to roadway workers performing their duties under specific authorities.

Under applicable executive orders, Federal regulations may be issued only when they are required by law or where it is determined that the benefits achieved outweigh the costs. As illustrated by the data presented in Chapter V, the safety benefits of PTC are substantial, but the costs of applying current technology to all rail lines are far greater. As further discussed below, a number of options exist to hasten the implementation of PTC.

Requiring that PTC be implemented *universally* across the national system at the present time could result in a misallocation of national resources. There is no guarantee that the overall safety of the American people would benefit from such a requirement, since one likely outcome would be diversion of large quantities of freight to other means of transportation, with adverse safety impacts for the transportation system as a whole. Another likely outcome would be diminished railroad investment in track and rolling stock, increasing the risk of train accidents from other causes.

Application of PTC to freight railroads will require determining which categories of operations have risk characteristics that warrant early PTC implementation.[39] Modification of existing signal and train control regulations to require PTC implementation on those lines will then be appropriate. To the extent the business benefits of PTC and related technology become more evident or implementation costs fall, gradual extension to other segments of the freight railroad industry might be warranted.

PTC is clearly necessary in the context of high speed rail, as illustrated by Amtrak's modifications to an existing ATC system for high speed operations on the Northeast Corridor. Expansion of high speed rail to other mixed service corridors will require making PTC more affordable. This, in turn, will require that the PTC system be fully interoperable

[39]The President's Budget for FY 1995 requests funding for this purpose ("corridor risk analysis model").

with PTC systems adopted by freight railroads. Full interoperability will ensure the highest level of safety, since all movements over lines used for high speed service will be equipped to respond to the PTC system.

REQUIREMENTS FOR COMMUNICATIONS AND TRAIN CONTROL SYSTEMS

One major goal of this report is to identify the particular communications and ATCS technologies best suited to fulfill particular operating safety requirements. These requirements include:

Requirement No. 1:	**Communicate train movement authorities from dispatcher to train.**
Risk:	Introduction of inaccuracies.
Redundancy:	Total failure of a delivery system does not create immediate hazard due to limitations contained in the operating rules, but poor functioning of a system may result in a garbled message. The failsafe condition is assurance that incomplete or garbled messages are not acted upon. Only selections 1 and 2 meet this requirement with a high degree of confidence.
Selection:	1. Traffic control system with CAD or PTC. 2. Digital data with CAD. 3. Voice radio.
Requirement No. 2:	**Enforce train movement authorities and operating restrictions.**
Risk(s):	Collision, overspeed derailment, impact with roadway workers or their equipment.
Redundancy:	This requirement is itself a redundant feature. Should PTC fail, operating rules should provide appropriate restrictions (e.g., limit train speeds).
Selection:	PTC technology.

Requirement No. 3: **Communicate emergency warnings (train to dispatcher and reverse).**

Risk: Known hazards will not be communicated in time to prevent harm.

Redundancy: Requirement is intermittent and relatively rare. A redundant means of communicating would be desirable should the primary means fail.

Selection:

1. Voice radio or cellular telephone (preferred due to flexibility of medium).
2. Digital data radio, PTC technology (where pertinent).

Requirement No. 4: **Receive wayside detector readings.**

Risk: Wayside detector warning will be missed or disregarded, resulting in train accident.

Redundancy: None is currently provided in most systems, but at least one level of redundancy is desirable.

Selection: More information is required; however, digital data radio with continuous PTC enforcement appears desirable. Current warning systems will continue to serve valuable purposes, however, without those enhancements.

Requirement No. 5: **Communicate between locomotive engineer and ground person to control switching.**

Risk: Incomplete or garbled transmission or failure to maintain continuous communication may result in serious personal injury or death.

Redundancy: Hand signals and lanterns are no longer viable alternatives to radio for many switching moves, particularly given reductions in crew size and increases in car lengths and heights that restrict vision of crew members on the ground. Federal radio rules and carrier operating rules require immediate cessation of switching move if radio contact is lost. Where switching is required, back-up portable radio (or duplicative circuitry) may be warranted; or operating rules should place limits on switching conducted.

Selection: Voice radio.

Requirement No. 6: **Emergency requests (call for help following crossing accident, train accident, personal injury to crew member or in the event of release of hazardous material through valves or fittings).**

Risk: Inability to summon aid.

Redundancy: Need is intermittent and infrequent, but urgent. A second radio on another locomotive in the consist should provide adequate redundancy. A cellular phone within its coverage area should also be adequate.

Selection:
1. Voice radio or cellular telephone.
2. Data radio terminal with keypad or other means of flexible communication.

Signal and train control systems address additional requirements through vital circuits. For instance, signal systems automatically perform the following functions and display appropriate signal indications to trains --

- Detect and communicate track occupancy, spacing trains;
- Monitor switch position;
- Verify route integrity;
- Indicate wayside detector status; and
- Assist in detecting broken rails.[40]

Properly configured and augmented, central communication-based PTC is also capable of performing these functions or their equivalent.

The discussion above illustrates the fact that the safety of railroad operations currently depends upon a mix of communication and train control capabilities. Even under the optimum case in which all requirements stated above are met with the desired level of redundancy, more than a single type of technology will likely be necessary.

[40] It is estimated that roughly half of all broken rails in signal territory may be detected through the signal system.

VOICE RADIO COMMUNICATIONS

The major railroads have invested heavily in traditional communications and S&TC technologies. Voice radio systems are widely deployed on all major railroads. All-channel capability is the norm, dead spots along the railroad are far fewer than in prior years, and crew members are provided with portable radios to facilitate switching operations. Radios are more reliable than ever before, and increasingly capable technology permits automatic prioritization of emergency calls.

Yet some railroads continue to permit the misuse of available channels, resulting in excessive congestion and interruptions of safety-related communications. Radio discipline remains poor on many railroad divisions, increasing the likelihood that misspoken or misunderstood directives will lead to an accident. Further, while generally acting in the interest of safety by investing in communications technology, railroads continue to deny that voice radio communications are important for safety. Instances continue to occur where trains are dispatched without operative locomotive radios (at least in the lead unit). Though generally small, gaps remain in the application of state-of-the-art voice radio technology.

Federal radio standards and procedures have stood unreviewed for many years, and railroad officers contend that they are inflexible, leading to disrespect and poor compliance. Although the basis of widespread noncompliance with sound radio procedures (including carrier rules) is subject to dispute, Federal safety standards should not be an impediment to sound practice; and their review is overdue.

Future directions in Federal regulatory policy should be guided by a clear understanding of functional requirements, levels of risk, and levels of redundancy of existing and planned communications systems. Regulatory activity should be directed at closing gaps and improving the performance of existing communication systems, while avoiding unnecessary burdens. For instance, FRA should propose that railroads be required to develop communications plans that address safety communication needs and implement them. Technology must not be required simply because it is available, but only when it is needed. Many smaller railroads may be able to meet their communication needs using portable low-power radios and cellular telephones. Major railroads may require more sophisticated systems, including data radio and appropriate provisions for redundant communications capability on long-distance trains. Through a cooperatively developed rulemaking, a safety minimum can be established for such plans.

Future Actions

As a result of the findings of this study, FRA will--

- ***Revise the Radio Standards and Procedures to make the regulations more flexible and to promote improved compliance.***

  - Work with representatives of labor and management to identify those aspects of the current rules that may discourage compliance because they lack flexibility.

  - Revise the regulations through a public proceeding.

  - Seek commitments from employee representatives and company officers to work for improved compliance with radio rules under revised standards.

  - Monitor compliance and strictly enforce the rules.

- ***Include in the proposed rule requirements that railroads provide suitable communications capabilities between trains and dispatchers, and between locomotive engineers and ground employees, and that back-up systems be established for critical functions.***

  - Propose that railroads develop and implement communication plans that address all safety-relevant functions.

  - Consider use of a wide range of technologies, including commercial options such as cellular telephone.

  - Review the number of layers of safety required for specific functions, considering the importance of the function to safety, the extent of daily reliance on the function, and the cost of the protection.

  - Recognize distinctions among rail passenger and freight operators and different operating environments, regarding the communications technologies that may be acceptable for primary reliance and the depth of safety redundancy warranted.

- ***Propose as a part of that rulemaking that each lead locomotive be equipped with an operative radio or suitable alternate communication equipment.***

- ***Work with a major railroad and its employees to implement transmission of movement authorities by digital data radio, in lieu of voice radio communications.***

  - Ensure that movement authorities are generated by the CAD system and issued directly to the on-board terminal.

  - Review changes in operating rules.

- Determine the most effective and secure means of providing hard copy authorities to crew members without transcription errors. Include an evaluation of on-board printers.

- Determine the feasibility of transferring concept to railroads employing other types of data communication technology.

POSITIVE TRAIN CONTROL

Signal and train control systems continue to serve the railroad industry with a high degree of reliability and enviable failsafe characteristics. Positive train control is the logical extension of those S&TC systems that do not yet provide PTC features. The railroad companies are beginning to recognize the opportunities presented by integration of data radio communications platforms and existing signal systems. Approximately half of the national rail system is not signalized, and this "dark territory" is particularly in need of supplementary safety systems.

Railroads recognize the need to move in the direction of positive train control, but, with limited exceptions, have not considered the necessary investments justified. For the near future at least, safety benefits will have to be accompanied by "business" benefits for PTC investments to make business sense for widespread application to freight lines.

The promise of ATCS has thus far failed to emerge--ironically, not because the railroad companies have clung to old ways, but because the railroads have moved ahead on a variety of fronts, utilizing alternative communication technologies to meet many of the needs ATCS was designed to meet. But the alternative technologies are not necessarily as suitable as a platform for train control functions as the ATCS digital data infrastructure. Thus, ATCS may not be deployed voluntarily on the basis of business requirements. For the immediate future, this means continued heavy reliance on voice radio for many communication functions.

A central communication-based approach to PTC remains the most likely path to safer train operations. In addition, that approach has the greatest chance of returning business benefits that can help pay for a portion of the communication infrastructure needed to support safety applications. Although the application of PTC on all rail lines would not be cost beneficial at the present time based on accident avoidance, PTC is required for high speed rail service and may be warranted on heavily traveled freight lines as well. Implementation of PTC that is interoperable will facilitate more widespread realization of safety and other benefits.

The absence of highly capable positive train control systems is a major factor limiting railroads' ability to serve the public. This study has refocused FRA's attention on the importance of promoting affordable positive train control. Consider:

- Antiquated train control limits system capacity.

  - Limited capacity could foreclose options for intercity and commuter passenger service on existing, heavily used freight lines (or unnecessarily increase capital and operating costs).

  - On some major freight corridors, downsized rail plants are now straining to handle increasing volumes of intermodal freight movements, as trucking companies and international brokers recognize the value of rail as part of the intermodal team. If freight capacity becomes a limiting factor, the ability of the railroad industry to relieve pressure on congested highways and to serve the Nation's environmental goals may be compromised.

- The cost of a highly capable positive train control system is a major element of any proposed high speed passenger rail system. New technologies offer the promise of lower cost. The cost of such a system might also be greatly reduced if part of a larger, interoperable design.

Given these stakes, fragmented decision-making by agencies of the Federal Government, the railroad companies, and rail suppliers is not acceptable. If planning is not coordinated, resulting train control systems may be wholly incompatible; or the cost of effecting interoperability may become too great to bear. Inevitably, this would lead to less effective systems on many of those lines where the need is greatest, since considerations of cost might require that nonequipped trains be allowed to intermingle with equipped trains.

FRA concludes that significant opportunities exist to promote the development of communication-based PTC. FRA also concludes that rail management will increasingly recognize the value of multi-purpose data communications platforms. Even where such platforms are not put in place quickly, railroads and their suppliers will develop innovative means of achieving PTC benefits in ways that offer adequate interoperability. Based on current forecasts for technology and service demands, FRA expects that the advantages of enhanced PTC systems with respect to train and crew management will result eventually in fully developed and integrated central communications systems.

Implementation of central communication-based PTC, the first choice of the freight railroads, will permit realization of safety benefits early in the migration to more capable systems, including reductions in demands on voice radio systems that are suffering from congestion and more secure transmission of movement authorities.

The Federal Government must play a constructive role as an investor, a facilitator and a regulator. Federal investments should be strategic--capable of meeting the broadest feasible range of functional requirements and appropriately linked to other Federal initiatives. The most competent PTC systems (such as Level 40 ATCS) promise increased capacity on existing rail lines and better precision to meet future service needs; and investments that are coordinated in a way that results in maximum impact on all objectives will be most likely to satisfy Federal investment criteria.

FRA should continue to facilitate development by the private sector of PTC technologies. This role should include a strong emphasis on creating partnerships among the AAR, the railroad companies, established rail suppliers, the Federal Government, and defense industry suppliers seeking opportunities for conversion of technology to civilian use under programs administered by the Advanced Research Projects Agency, Department of Defense.

Regulatory action may also be appropriate to provide a level playing field for intramodal competition and to ensure prompt action to implement justified safety measures. In order to determine where investments in PTC may be warranted, it will be necessary to conduct a corridor analysis to examine risk characteristics (numbers of train movements, speed, passenger traffic, hazardous materials traffic). Should one or more categories of line segments stand out as presenting accident experience or future risk such that accident avoidance benefits would be greater than the cost of PTC implementation, rulemaking to require implementation should immediately follow.

Future Actions

In order to advance PTC, FRA will invest strategically, form and nurture partnerships with the industry to promote technical standards development, and aggressively prepare to exercise its regulatory responsibilities where justified by costs and benefits.

FRA will take the following actions:

- With funds requested in the President's Budget for Fiscal Year 1995, initiate development of a risk analysis model to guide determination of priorities (among major freight rail corridors) for application of PTC technology.
    - Determine cost/benefit ratio for application of PTC to priority corridors.
    - Consider factors pertinent to frequency and severity of preventable train accidents and incidents, such as train densities, passenger traffic, hazardous materials flows, etc.
    - Develop strategy for determining and applying trend lines to the analysis.
- Utilize results of risk analysis model and experience gained in review of Amtrak's enhanced ATC system for the Northeast Corridor to develop and issue a regulatory proposal requiring appropriate levels of PTC for applications where PTC is justified (including high speed rail).

Time line:

FY 1995 - Begin risk study.

FY 1996 - Complete risk study.

FY 1997 - Initiate rulemaking.

- Monitor the BN/UP pilot project for positive train separation, provide access to technical assistance available in the Federal Government, document the lessons of the project, and make recommendations to the AAR regarding future demonstrations and system implementation.

    - Working with the U.S. Coast Guard and the participating railroads, use this project to determine feasibility of differential GPS as a train location system on main lines both inside and outside rail terminal areas.

    - Determine cost implications of employing multiple data radio frequencies and communication software packages.

Time line:

FY 1995 - 1996 - Monitor test bed development; work with UP/BN and AAR regarding interoperability, GPS, technology validation.

FY 1997 - Incorporate lessons in proposed rulemaking, if indicated by risk analysis.

- Support Amtrak's enhancement of its automatic train control system for the Northeast Corridor (NEC); issue performance criteria for operations to 150 miles per hour.

    - Propose S&TC/PTC safety requirements for NEC high speed operations to 150 miles per hour, taking into consideration the unique characteristics of that territory.

    - Refine issues for high speed PTC systems for later application in proposed generic high speed standards.

Time line:

FY 1995 - Conduct NEC S&TC/PTC proceeding.

- Work closely with the AAR to ensure that AAR's open architecture approach for universal compatibility remains effective and that standards meet safety needs.

Time line:

FY 1995 - Review report of AAR's tactical development task force. Provide feedback regarding safety competency issues posed by proposed approach.

FY 1996 - Work closely with UP/BN and AAR to incorporate test bed lessons into planning for AAR's positive train separation project.

FRA will also make and promote strategic Federal investments in the development and deployment of PTC and work with other Federal agencies to foster PTC, including the following:

- As proposed in the President's Budget for Fiscal Year 1995, include PTC as a major element in the technology development effort required for operation of high speed rail service over mixed passenger and freight corridors.

  Time line:

  FY 1995 - Initiate a project to assist in the testing and demonstration of PTC technology on a high speed corridor. Select corridor, determine technical approach, and begin system implementation.

  FY 1996 - Complete safety verification of enforcement features.

  FY 1997 - Enforcement features operative, transparent to operator; enhanced PTC working in the background.

  Confirm adequacy of PTC for application to other high speed rail corridors.

  FY 1998 - Implement enhanced PTC if consistent with regulatory findings.

- Work with the Federal Transit Administration to (i) evaluate the role that Federal capital investment in commuter rail service can have in hastening the development and deployment of PTC nationwide and in creating new capacity that would be available for commuter rail service; and (ii) assess relevant aspects of train control technologies applied to rail transit systems.

  Time line:

  FY 1995 - Complete review and determine need for Federal transit investment criteria specific to commuter rail signalization and train control.

  FY 1996 - As indicated, propose any necessary regulations or legislation.

- ■ Work with other DOT agencies and the Advanced Research Projects Administration (ARPA), Department of Defense, to promote integration of defense technology into PTC systems.

    - Work with the AAR, major railroad companies, and rail suppliers to form partnerships with defense suppliers and promote defense conversion in ways that enhance the capability and affordability of interoperable PTC.

- ■ In partnership with the Federal Highway Administration (FHWA), implement the Secretary's Action Plan for highway-rail grade crossing safety by working together to plan for interface between PTC technology and Intelligent Vehicle Highway Systems (IVHS).

  Time line:

  FY 1994 - 1996 - Conduct evaluation in connection with FHWA regarding PTC and the Vehicle Proximity Alerting System to provide grade crossing warning on high speed corridors, including use of the Transportation Test Center to perform evaluations of candidate technologies.

  FY 1997 - Demonstrate IVHS and PTC interface for highway-rail crossing safety in cooperation with selected railroads and trucking companies.

- ■ Work with other Department of Transportation elements to ensure that availability of highly precise, differential GPS navigation contributes to the cost effectiveness of PTC technology.

- ■ Work with the DOT Office of Intermodalism and the Federal Highway Administration (FHWA) to determine the value to intermodal transportation of fully developed PTC technology that could provide increased capacity and service reliability on major freight corridors, where both rail and highway resources are approaching capacity.

Prior experience with widespread application of technology, particularly modern electronics, offers strong evidence that early success supports rapid deployment. FRA believes that this is particularly true with respect to PTC. Central control software for a communication-based system, for instance, may be capable of application to many rail properties, once created. As more and more locomotives are equipped with on-board equipment, the cost of extending PTC to additional territories will fall.

Initial steps may be costly, and technical challenges remain. Railroad companies will insist on technology that is reliable, since low reliability will disrupt service. However, as technical obstacles are overcome and initial investments are made across one or more rail systems, significant momentum will have been achieved. The UP/BN test bed, though by no means an answer to all pertinent questions, augurs well for an era in which theory will be translated into practical application. In addition, FRA will assist in development of enhanced

PTC technology suitable for high speed rail applications. If the signal engineers of the 1920s were able to create practical automatic train control systems, the future of contemporary PTC should be very promising.

FRA believes that private and public sector efforts can be combined to foster deployment of contemporary PTC systems on high-risk rail corridors by the year 2000. ***FRA will make it a high agency priority to accomplish this objective.***

Glossary of Terms and Acronyms

AMERICAN SHORT LINE RAILROAD ASSOCIATION (ASLRA) - An organization of participating railroads that addresses issues of a common interest to short line operators, e.g., legislation, rulemaking, operating problems.

ASSOCIATION OF AMERICAN RAILROADS (AAR) - An organization of participating railroads that addresses issues of a common interest to the railroad industry, e.g., legislation and rulemaking; issuance of recommended practices for motive power and equipment, signal and train control systems, communication systems, and operating rules; and assignment of radio frequencies.

ADVANCED TRAIN CONTROL SYSTEMS (ATCS) - A microprocessor/communications/transponder-based system designed to provide both safety and business functions. Safety area capabilities are: (1) the digital transmission of track occupancy/movement authority to trains and an acknowledgement from the train crew via digital radio communications in lieu of voice communications, (2) provision of positive train separation control functions to preclude the train from exceeding its assigned limits of authority, (3) protection for maintenance-of-way and other workmen on track, (4) enforcement of authorized operating speed limits for trains consistent with civil engineering and other operating constraints, including temporary slow orders. In the business related function area, ATCS enables the transmission of work order activity related to pick-ups set-outs of individual and drafts of cars, locomotive health reporting, and other functions. ATCS is a joint program of the AAR and RAC.

ADVANCED RAILROAD ELECTRONICS SYSTEM (ARES) - An integrated command, control, communications, and information system which applies advanced avionics to the business of railroading. ARES generates efficient traffic plans, conveys them into movement instructions to engine crews and monitors actual train movements to detect deviations from plan. Designed to control rail traffic with a high degree of efficiency, precision, and safety. ARES communications flow through an automatic digital data link. The data link uses the railroad's existing microwave and VHF radio frequencies to communicate information, instructions, and acknowledgements between the control center and a train or other track vehicle. To determine position and speed, ARES uses the Global Positioning System (GPS) being deployed by the Department of Defense. On-board GPS equipment calculates vehicle position and speed, and the digital data link conveys the data to the control center. In addition ARES has the capability to be supported in part or totally by the strategic placement of transponder devices. The capabilities of ARES can be compared to those of ATCS. Developed and demonstrated by the Burlington Northern Railroad.

AUTOMATIC EQUIPMENT IDENTIFICATION (AEI) - A concept that provides the display of an electronic identification tag for rail equipment to be read by trackside scanners as the equipment passes. AEI is designed to provide timely, accurate data entry to railroad computers for use as a management tool and customer service purposes, in the tracking of loaded and empty equipment.

ADVANCED CIVIL SPEED ENFORCEMENT SYSTEM (ACSES) - Program of the National Railroad Passenger Corporation (Amtrak). This system will use a carefully constructed blend of transponder scanning, radio, and microprocessor technology to meet specific needs of Amtrak's multiple-track, high-speed Northeast Corridor. Prototype testing and final specification for procurement of the ACSES system will be completed in 1995. ACSES will supplement the new continuous 9-aspect cab signal and speed control system by enforcing civil speeds at 5 mph increments up to 150 mph and by enforcing a positive stop at interlocking home signals where an overrun stop signal could compromise an adjacent high speed main track. It is being designed with a view toward ultimately equipping the entire Amtrak Northeast Corridor.

AUTOMATIC BLOCK SIGNAL SYSTEM (ABS) - A series of consecutive blocks governed by block signals, cab signals, or both, actuated by a train or engine, or by certain conditions affecting the use of a block, e.g., track circuit, control circuit, switch or derail position.

AUTOMATIC TRAIN STOP (ATS) - * A system supplementing an ABS or TCS system in which locomotives are equipped with a device so arranged that its operation will automatically result in the application of the brakes until the train has been brought to a stop in the event an engineer fails to acknowledge a signal that restricts the movement of the train.

AUTOMATIC TRAIN CONTROL (ATC) - * A system supplementing an ABS or TCS system of which locomotives are equipped with a device so arranged that its operation will automatically result in the following:

(a) A full service application of the brakes which will continue either until the train is brought to a stop, or, under control of the engineman, its speed is reduced to a predetermined rate; or

(b) When operating under a speed restriction, an application of the brakes when the speed of the train exceeds the predetermined rate and which will continue until the speed of the train is reduced to that rate.

AUTOMATIC TRAIN PROTECTION (ATP) - That subsystem within the automatic train control system which maintains safe train operation through a combination of train detection, train separation, and interlockings.

ASPECT - * The appearance of a roadway signal conveying an indication as viewed from the direction of an approaching train; the appearance of a cab signal conveying an indication as viewed by an observer in the cab.

BACKUP - An alternate means of accomplishing a function using software, hardware, circuits or operational procedures separate from those used for the primary method.

BACKUP SYSTEM - A redundant system that performs the principal functions of the primary system with minimum deviation from the performance of the primary system.

BLOCK - A length of track of defined limits.

BLOCK, MANUAL - * A block established manually by signal, timetable or mandatory directive.

BLOCK SIGNAL - * A roadway signal operated either automatically or manually at the entrance to a block.

BLOCK SIGNAL SYSTEM - * A method of governing the movement of trains into or within one or more blocks by block signals or cab signals.

BOOK OF RULES (OR OPERATING RULES) - A set of codified regulations governing the conduct of railroad transportation which defines signal indications, speeds and specific operating requirements.

BLOCK TERRITORY - Trackage equipped with a manual block system, automatic block system or traffic control system.

BLEEDOVER RADIO INTERFERENCE - A condition where the voice communications from an adjacent frequency causes an unscheduled disruption to a voice communication in progress.

CENTRALIZED TRAFFIC CONTROL (CTC) - A traffic control system operated from a central dispatching office.

COMPUTER AIDED DISPATCHING (CAD) - A computer-based dispatching system providing automatic train routing and in some installations, a paperless dispatcher environment. CAD contributes by guarding against the inadvertent conflicts in train movement authorities. CAD systems typically consist of computer hardware and specialized software programs designed for railroad applications. CAD systems may have enhanced existing TCS capabilities through a number of subsystems. Trains can be tracked and recorded automatically, and written movement authorities, where necessary, can be generated, recorded and filed completely within the computer system. These activities provide an added enhancement to train operations safety.

DEAD SPOT - A location where the transmission of radio is not always achieved for reasons of the presence of terrain, tunnels, low areas with heavy foliage, as well as locations with atmospheric or other conditions creating interference.

DIVISION - A defined territory of a railroad under the jurisdiction of a superintendent or manager of operations.

DARK TERRITORY - Trackage that is non-signaled over which the movement of trains are governed by timetable, train orders/track warrants, or operating rules for the movement of trains in other than block signal territory.

MANUAL BLOCK SYSTEM (MBS) - A block or a series of consecutive blocks governed by manually-operated signals or by mandatory directives.

DIRECT TRAIN CONTROL - A method of operation wherein the train dispatcher issues mandatory directives to establish limits of train movement authority in a series of consecutive blocks that may be signaled or non-signaled.

DIFFERENTIAL GPS - An application of the Global Positioning System in which a ground-based radio transmission is utilized to correct or calibrate the position determined by reference to satellite-based transmissions, increasing accuracy of positioning.

DIGITAL DATA RADIO - System for transmission of electronic data via radio.

ELECTRONIC DATA INTERCHANGE (EDI) - The transmission of electronic data regarding rail shipments among rail shippers and carriers.

FLAG PROTECTION - A method of manually protecting trains to avoid collisions during an emergency or unusual operating conditions.

FAIL SAFE DESIGN - A term used to designate a design principle of any system, the objective of which is to eliminate the hazardous effects of a failure by having the failure result in nonhazardous consequences.

GLOBAL POSITIONING SYSTEM (GPS) - A satellite-based radio navigation system deployed and operated by the Department of Defense which, when fully operational, provides highly accurate three-dimensional position, velocity, and time data to users worldwide.

INTEROPERABLE - As applied to signal and train control systems, including PTC, the ability which permits trains equipped with the same or similar systems to operate on all railroads interchangeably and automatically without hindrance, delay or additional on-board equipment.

INTERLOCKING - An arrangement of signals and signal appliances/systems so interconnected that their movements must succeed each other in proper sequence, train movements over all routes being governed by signal indications. Interlockings may be either automatically or manually controlled. Manual interlockings are controlled from an interlocking machine that must be operated for each train movement. Automatic interlockings are designed with inherent powers that function by means of electric/electronic circuits to perform the functions of a manual interlocking.

INTERLINE SERVICE MANAGEMENT (ISM™) - Railroad "industry level" systems development to foster the implementation of business processes and supporting information systems that will allow interchange of goods or passengers between carriers to provide (and support customers) reliable, competitive, seamless service. Due date late 1996.

INTERMODAL SERVICE - Carriage of a vehicle, container or passenger successively by two or more modes of transportation (e.g., ocean-going ship, railroad, air and highway). Involves transportation partnerships among differing transport modes - as between the highway mode, railroads, and transoceanic shipping.

INTERSTATE COMMERCE COMMISSION (ICC) - Independent agency of the United States Government responsible for designated transportation regulatory functions. Predecessor of the FRA with respect to administration and enforcement of the Federal railroad safety laws and regulations.

JOINT OPERATIONS - Railroad operations involving more than one railroad company, as at interlockings or other facilities jointly-owned, maintained or operated.

MAINTENANCE-OF-WAY (MOW) - Having to do with the installation and maintenance of track and related structures to facilitate the operation of trains.

METHOD OF OPERATION - The authority for the movement of trains, e.g. signal indications, timetable and train orders, track warrants, etc.

NATIONAL RAIL SYSTEM - The general system of rail transportation, consisting of interconnected trackage of all rail carriers that provide interline service.

NORTHEAST CORRIDOR (NEC) - That segment of tracks extending between Washington, D.C. and Boston, MA and certain connecting lines.

POSITIVE TRAIN SEPARATION (PTS) - As applied to the next generation of train control systems, e.g., ATCS, the application of technology to control the movement of trains in a manner that precludes the occurrence of collisions. This term has also been employed by the Union Pacific and Burlington Northern Railroads to denote a test program for positive train control on certain of their main lines in the States of Oregon and Washington.

POSITIVE TRAIN CONTROL (PTC) - As applied to the next generation of train control systems, e.g., ATCS, the application of technology in various subsystems that intervene to prevent trains from operating at a speed in excess of the maximum allowed, movement past any point of known obstruction or hazard, and movement beyond the limits authorized.

RADIO FREQUENCY SPECTRUM - The entire range of electromagnetic communications frequencies, including those used by radio, radar and television, administered by the Federal Communications Commission. Several frequencies have been allocated to the railroad industry for the transmission of voice and digital data in connection with railroad operations.

By agreement the AAR serves as the clearing house for assignment of voice radio channels in order to prevent radio interference among the users.

RAIL SAFETY ENFORCEMENT AND REVIEW ACT (RSERA) - Public Law 102-365, enacted September 3, 1992. Section 11 of this legislation set forth the mandate for this report.

ROAD MILES - Route miles of trackage over which a railroad provides service. (Compare number of track miles, e.g., one road mile of double track equals two track miles.)

SIGNAL INSPECTION ACT - Legislation contained in 49 U.S.C. 26 granting the Secretary of Transportation authority to require, among other things, the installation, testing, maintenance and repair of Signal and Train Control Systems.

RULES, STANDARDS, AND INSTRUCTIONS GOVERNING THE INSTALLATION, INSPECTION, MAINTENANCE, AND REPAIR OF SIGNAL AND TRAIN CONTROL SYSTEMS, DEVICES, AND APPLIANCES (RS&I) - Rules and regulations promulgated under the authority of the Signal Inspection Act that governs Signal and Train Control Systems.

SIGNAL INDICATION - The information (authorization or directive) conveyed by the aspect of a signal.

SIGNAL AND TRAIN CONTROL SYSTEM - A generic term used to reference existing types of signal systems, e.g., block signal systems; interlockings; automatic cab signal, trainstop and train control systems; and other protective devices.

TRAIN ORDERS - Mandatory directives governing the movement of trains.

TRACK WARRANT CONTROL - A method of operation wherein the train dispatcher issues mandatory directives (track warrants) to establish limits of train movement authority between fixed points on a segment of track that may be signaled or nonsignaled.

TRAFFIC CONTROL SYSTEM (TCS) - * A block signal system under which train movements are authorized by block signals whose indications supersede the superiority of trains for both opposing and following movements on the same track.

TRANSPONDER - A device encoded with an electronic message which, upon receiving a designated signal from an interrogator, emits a radio signal conveying its message in digital form. As applied with the transponder placed in the gage of the rail or on the wayside and the interrogator placed on a locomotive, this mechanism provides information about the identification, location and operating speed (from elapsed time) of trains in equipped territory.

WORK ORDER REPORTING - A business-related function of ATCS which provides communication between the crew of a train and a central point, by digital data radio, related to pick-up and set-out of rail cars at shipper and consignee locations and handling of cars at yards and terminals en route.

WAYSIDE INTERFACE UNIT (WIU) - An element of an ATCS field system providing the interface with switches, signals, grade crossings and other devices for continuous monitoring and communication of their status to the central control offices, locomotives and other users.

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* Denotes requirements of the Code of Federal Regulations (CFR) at Title 49, Part 236 - RULES, STANDARDS, AND INSTRUCTIONS GOVERNING THE INSTALLATION, INSPECTION, MAINTENANCE, AND REPAIR OF SIGNAL AND TRAIN CONTROL SYSTEMS, DEVICES, AND APPLIANCES (RS&I).

Appendix 1

EXAMPLES FROM FRA'S FILES, ACCIDENTS AVOIDABLE
THROUGH THE POSITIVE TRAIN CONTROL FEATURES OF ATCS

- CIVIL SPEED ENFORCEMENT
- POSITIVE TRAIN SEPARATION CAPABILITY
- DIGITAL DISPLAY AND CONFIRMATION OF OPERATING AUTHORITY

	Accident	Cause	*Reported Damage	Fatalities/ Injuries
(1)	Norfolk Southern, at Sugar Valley, Georgia, on August 8, 1990. Two freight trains collided head-on on single track.	Disregarded a stop signal when moving off a siding beyond the authorized limits, onto a main track and into an oncoming train.	$1.8M	3 fatalities 3 serious 1 minor
(2)	Burlington Northern at Lyons, North Dakota, October 19, 1990. A freight train collided with the rear of the train at rest. The derailing equipment struck another train on the adjacent track.	Failure to operate the train within the speed authorized by signal indication.	$1.3M	1 fatal 0 serious 1 minor
(3)	Atchison, Topeka and Santa Fe, at Corona, California, on November 11, 1990. Two freight trains collided head-on.	Failure to stop short of a signal displaying a stop indication.	$4.0M	4 fatal 2 serious 0 minor
(4)	Amtrak at Boston, Mass., on December 12, 1990. An Amtrak train derailed and struck a standing train.	Failure to reduce speed in time to negotiate a 30 mph curve. Entered curve at 76 mph derailing 3 locomotives and 7 occupied cars.	$12.5M	0 fatal 14serious 439minor
(5)	Norfolk Southern at Wolf Creek Jct. near Kermit, West Va. on April 24, 1991. A freight train derailed 2 locomotives and 9 cars of its train.	Failure to observe speed authorized for the train.	$ .2M	0 fatal 0 serious 0 minor

(6)	Burlington Northern and Chicago Northwestern, at Converse Jct., Wyoming, on June 19, 1991. A BN train collided with the rear of a CNW train.	Failed to operate in accordance with signal indication.	$1.7M	1 fatal 1 serious 1 minor
(7)	Burlington Northern, at Ledger, Montana, on August 30, 1991. Two freight trains collided head-on under track warrant authority.	The crew of the offending train and the dispatcher failed to fully comply with the provisions of the rules governing track warrant authority.	$10.7M	3 fatal 2 serious 3 minor
(8)	Norfolk Southern, at Knox, Indiana, on September 17, 1991. Two freight trains collided head-on.	Failure to stop short of signal displaying a stop indication.	$3.0M	1 fatal 1 serious 0 minor
(9)	Amtrak operating on CSXT, at Palaika, Florida, on December 17, 1991. Passenger train derailed.	Failure to control the speed on a curve in accordance with a permanent restriction on speed.	$1.2M	0 fatal 1 serious 63 minor
(10)	Norfolk Southern at Sadorus, Illinois, April, 25, 1991. A freight train collided with the rear of a train at rest.	While operating at excessive speed, failed to stop at a signal displaying a stop indication.	$ .2M	0 fatal 1 serious 4 minor
(11)	Burlington Northern, at Marshall, Minnesota, on December 28, 1992. BN train collided with 30 cars and two cabooses standing on a siding.	Failure of the prior crew to realign the switch for main track movement.	$1.0M	0 fatal 1 serious 4 minor
(12)	CSXT and Central of Georgia at Talladega, Alabama, on October 3, 1992. A CGA train struck a CSXT train at a railroad crossing at grade.	Failure of a CGA train to stop at an interlocking signal displaying a stop indication. Contributing factor was excessive speed.	$ .2M	0 fatal 0 serious 5 minor

(13) Illinois Central, at Fulton, Kentucky, on March 22, 1992. Two IC freight trains collided head-on.	Failure to comply with speed restriction and misunderstood train movement authority via radio.	$ .3M	1 fatal 0 serious 2 minor
(14) North Indiana Commuter Transportation District (NICD), near Gary, Indiana, on January 18, 1993. A commuter passenger train collided (side raking) another NICD train.	Failure to comply with the limits established by signal indication.	$ .8M	7 fatal 2 serious 93 minor
(15) Atchison Topeka & Santa Fe and Burlington Northern at Fairmount, Oaklahoma, on February 21, 1993. The AT&SF train struck a BN train at a railroad crossing at grade.	Failure to stop short of a signal displaying a stop indication.	$ .8M	1 fatal 1 serious 2 minor
(16) Burlington Northern and Union Pacific at Longview, Washington, on November 11, 1993. A BN train collided head-on with a UP train.	Failure of the BN train to operate in accordance with signal indication.	4.0M	5 fatal 0 serious 0 minor
(17) Illinois Central, at Flora, Mississippi, on February 26, 1994. Two IC trains collided head-on.	Failure to stop at the limit of authority for a meet with the opposing train.	$1.5M	1 fatal 2 serious 1 minor
(18) Burlington Northern, at Norway, Nebraska, on June 8, 1994. A rear-end collision was followed by a raking collision.	Preliminary information suggests the failure of the striking train to operate in accordance with signal indication.	$2.5M	2 fatal 0 serious 2 minor

* REPORTED DAMAGE TO FRA AS SHOWN ABOVE IS NOT INCLUSIVE OF ALL THE COSTS ASSOCIATED WITH THESE ACCIDENTS. RATHER, THE COSTS ARE LIMITED TO REPORTABLE RAILROAD PROPERTY DAMAGE.

Appendix 2

AN EVALUATION OF THE NORTH AMERICAN ADVANCED TRAIN CONTROL SYSTEM

PREPARED BY:

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PREFACE

This report was sponsored by the Federal Railroad Administration, U.S. Department of Transportation, under Interagency Agreement Number DTFR53-93-X-00074. The recommendations contained in this report are those of the authors, and should not be construed as official policy of the U.S. Department of Transportation or the Federal Railroad Administration unless so designated by other official documentation. Likewise, this document does not convey official policy of the U.S. Department of Commerce, the National Telecommunications and Information Administration, or the Institute for Telecommunication Sciences.

Federal Railroad Administration management and administration of this project have been provided by Mr. Gene Cox of the Office of Safety Enforcement.

The authors would like to acknowledge the cooperation of Mr. Howard Moody of the Association of American Railroads and engineers from ARINC Research Corporation in the completion of this project.

CONTENTS

EXECUTIVE SUMMARY

In 1992, Congress passed the Rail Safety Enforcement and Review Act. The Act directs the Secretary of Transportation to conduct a safety inquiry regarding Department of Transportation (DOT) railroad radio standards and procedures. The inquiry is to include assessments of:

- the status of advanced train control systems that are being developed, and the implications of such systems for effective railroad communications.
- the need for minimum Federal standards to ensure that such systems provide for positive train separation and are compatible nationwide.

Within DOT, the Federal Railroad Administration (FRA) is responsible for the assessments listed above.

The Association of American Railroads (AAR) and the Railways Association of Canada (RAC) have proposed a set of specifications for what is known as the North American Advanced Train Control System (ATCS). The ATCS is a communications-based system that transmits command and control information between dispatch centers, locomotives, track maintenance vehicles, and wayside devices. It is intended to lead to more economical, efficient, and safe train movement in North America.

To help assess the potential of the ATCS to provide for positive train separation, speed restriction enforcement, and other safety enhancement functions, FRA entered into an inter-agency agreement with the Institute for Telecommunication Sciences (ITS). ITS is part of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce, and serves as a principal Federal resource for assistance in solving telecommunication problems of other Federal agencies, state and local governments, private corporations and associations, and international organizations.

ITS was tasked to study the ATCS Specifications and evaluate the system development process. This technical evaluation of the ATCS will help FRA complete the assessment required by the Rail Safety Enforcement and Review Act.

ITS has evaluated the ATCS based upon a review of the system's description as contained in the ATCS Specifications and other documents. Additional system information was obtained through discussions with ARINC Research Corporation, the engineering firm hired to develop the Specifications, with AAR and railroad industry representatives, and with railroad equipment manufacturers.

Conclusions

1) The ATCS Specifications have been developed to ensure compatibility and interoperability. The Specifications are written to ensure compatibility between system components produced by different manufacturers. They are written to ensure interoperability between railroads. Such compatibility and interoperability is needed to provide positive train separation throughout the North American rail system.

2) The ATCS Specifications apply sound engineering techniques to ensure the proper delivery of data from source to destination. Data communication systems must rely on automated techniques to ensure that data arrive at the intended destination, that errors are detected and corrected, that data have been protected, and that data arrive within established time constraints. The data communication system must have the ability to detect and recover from faults. In the event of failure, the data communication system must allow a graceful and safe return of control to a secondary system, in this case voice communication between the dispatcher and locomotives or track maintenance vehicles. The ATCS specifications describe a system which will accomplish these tasks well.

3) The ATCS has the components to provide positive train separation. Positive train separation refers to the capability to detect and prevent impending collisions between trains. Within the ATCS, the access of trains and track work crews to any section of track is strictly controlled by authorities issued by a dispatcher. The speed and location of trains and track work crews are continuously monitored. If violation warnings are not heeded by the operator, speed restrictions or the limits of movement authorizations are enforced through automatic brake application.

4) The ATCS Control Flow Specifications need further testing and validation. The ATCS Control Flow Specifications provide functional descriptions of certain aspects of railroad operating logic, and define how hardware and software elements of the system should interact in order to execute railroad operations. For example, one of the ATCS control flows describes the process by which central dispatch would issue a movement authority to a locomotive, and defines the associated messages that would be exchanged between various system processors.

A major revision of the Control Flow Specifications was completed in 1993. The control flows have become increasingly complex as system development has progressed, and ARINC is working on further documentation to aid ATCS software developers.

Because of the complexity of the control flows and because correct control flows are essential to safety, ITS recommends independent modeling and validation of the ATCS control flows under a variety of operating scenarios to ensure that the system functions as intended.

5) A coordinated field test of a full implementation of the ATCS is needed. Various railroads and railroad equipment manufacturers have implemented only portions of the ATCS Specifications, or have conducted only limited tests of ATCS applications and equipment. A coordinated effort is required to field test a full implementation of the ATCS on a section of track with a variety of typical environmental conditions. A more comprehensive field test or pilot demonstration would be required to show that the ATCS can properly function in more severe environments such as the Chicago hub or the Northeast corridor with their more dense numbers of trains, urban conditions, etc.

6) A migration plan and a timetable for implementation of the ATCS is needed. A migration plan provides for an orderly transition from one system to another. The migration plan ensures that safety measures already in place are not removed before all trains that pass through the territory have fully-equipped ATCS locomotives. Older systems and the ATCS will probably have to be operated in parallel while the ATCS becomes fully operational.

The implementation timetable accounts for the acquisition of funding, the installation and testing of ATCS equipment, and training for users of the new system. The timetable should seek to accommodate all railroads to encourage widespread use of the ATCS.

7) A joint project that will have many of the ATCS features, as proposed by two railroads, needs to be evaluated and used to improve the ATCS. A press release on April 28, 1994, by the Union Pacific and Burlington Northern Railroads indicated the start of a joint project between the two railroads to develop the Positive Train Separation system with a pilot test program to be conducted on Union Pacific and Burlington Northern track in the Pacific Northwest. The preliminary descriptions of the joint project provide insight as to the scope of the effort. Many of the ATCS features will be retained with potential new ones added. The field tests and migration experiences will provide much of the knowledge requested in the last two conclusions listed above.

AN EVALUATION OF THE NORTH AMERICAN ADVANCED TRAIN CONTROL SYSTEM

Eldon J. Haakinson, Wayne R. Rust, and Martin M. Garrity[1]

The railroad industry has proposed an advanced system for train control. This report presents an evaluation of the system development process, with particular emphasis on the data communication system that interconnects dispatch centers, locomotives, track maintenance vehicles, and wayside devices. The report describes the proposed train control system, establishes generic requirements for collision avoidance and telecommunication system development, and analyzes the system in light of the generic requirements.

Key words: advanced train control system; collision avoidance; data communication system; positive train separation; radio communication system; system architecture

1. INTRODUCTION

In 1992, Congress passed the Rail Safety Enforcement and Review Act [1]. The Act directs the Secretary of Transportation to conduct a safety inquiry regarding Department of Transportation (DOT) railroad radio standards and procedures. The inquiry is to include assessments of:

- the status of advanced train control systems that are being developed, and the implications of such systems for effective railroad communications.

- the need for minimum Federal standards to ensure that such systems provide for positive train separation and are compatible nationwide.

Within DOT, the Federal Railroad Administration (FRA) administers and enforces the Federal laws and related regulations designed to promote safety on railroads. FRA is responsible for the assessments listed above.

The Association of American Railroads (AAR) and the Railways Association of Canada (RAC) have proposed a set of specifications for what is known as the North American Advanced Train Control System (ATCS) [2]. The ATCS is intended to lead to more economical, efficient, and safe train movement in North America. The specifications have been developed over the last 10 years through an open-forum process involving contracted systems engineers, railroad industry professionals, and suppliers. The specifications define a telecommunication system architecture that accommodates the

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flow of all necessary command and control information and they define performance and interface requirements for the components of the system. They are intended to document the stated requirements of railroad operational and technical authorities and to influence the design of new, compatible equipment without limiting the internal design approaches of individual suppliers.

To help assess the potential of the ATCS to provide for positive train separation, speed restriction enforcement, and other safety enhancement functions, FRA entered into an inter-agency agreement with the Institute for Telecommunication Sciences (ITS). ITS is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce, and serves as a principal Federal resource for assistance in solving telecommunication problems of other Federal agencies, state and local governments, private corporations and associations, and international organizations.

ITS was tasked to study the ATCS specifications and evaluate the system development process, with particular emphasis on the Data Communication System. This technical evaluation of the ATCS will help FRA complete the assessment required by the Rail Safety Enforcement and Review Act. Section 2 provides background material on the ATCS. Section 3 gives general requirements for a collision avoidance system. Section 4 describes the methods used to evaluate telecommunications systems. Section 5 presents the ITS evaluation of the ATCS and Section 6 provides the evaluation conclusions.

2. DESCRIPTION OF THE ADVANCED TRAIN CONTROL SYSTEM

2.1 Purpose and Capabilities of the ATCS

The Advanced Train Control System (ATCS) uses computer-aided techniques to supplement human control in the movement of trains. To accomplish this supplemental role, the ATCS must:

- mimic the current human decision-making steps in the operations of a railroad,
- ensure train movement authorizations are safe, valid, and observed,
- warn railroad personnel of unsafe operations and potential hazards, and
- apply locomotive braking automatically when warranted.

The ATCS imitates the actions of the railroad personnel carrying out railroad operations. As an example, one can compare the steps that occur in originating a train without the ATCS implementation and with the ATCS implementation. In both implementation cases, to originate a train, the dispatcher develops the train route from source to destination, defines the locomotive and car composition, and identifies the crew. The following compares the steps of actions:

- Without the ATCS, the dispatcher uses the voice radio to communicate with the locomotive crew about the train origination. The crew responds with verbal acknowledgements. The dispatcher also passes on information about conditions of the track, locations where track crews would be working, safe train speeds, etc. The locomotive crew copies the information on paper and verbally acknowledges. Finally, the dispatcher provides the authorization for the train movement and the crew acknowledges and proceeds.

- With the ATCS, the dispatcher uses the dispatch data terminal to enter the train origination data into the dispatch center computer. The ATCS checks the information for validity and forwards the information to the on-board locomotive computer. The locomotive crew logs on to the on-board computer through the locomotive terminal to provide crew and locomotive identification, and to confirm the train composition and destination. The locomotive's computer then determines databases required for the planned route and requests them from the dispatch center computer. The dispatch computer supplies the data, including specific track conditions, safe speed limits where track crews are located, and other route-specific information. After the crew has confirmed the train's readiness, the crew enters the message that the train is ready to leave. The dispatcher then requests movement authority from the dispatch computer, which verifies the route is clear of other trains and track crews, that all databases have been received by the locomotive computer, that all restrictions have been received, and that the train is initialized. Track that is not clear is identified for later checks and clearance. The dispatch computer informs the dispatcher of the train's status and the dispatcher then releases the train with its movement authority.

Under the ATCS, all of these steps can be completed without voice communications between the dispatcher and crew. The ATCS ensures that all necessary information is collected and exchanged between the dispatcher and crew. It is also able to provide the information without the ambiguity or misinterpretation that can be associated with voice communications between crew and dispatcher.

The ATCS ensures that actions requested by railroad personnel are safe by checking and verifying the trains' locations and their movement authorizations, by following the track crews' work locations, by comparing locomotive speeds versus safe or restricted conditions, and by validating the proper alignment of switches and other controllable devices, etc. These are steps that would normally be completed by railroad personnel following railroad policy and procedures. The ATCS can perform these steps more reliably and efficiently than humans, thus increasing the likelihood that railroad procedures developed for safety are followed at all times by locomotive crews and track crews.

The ATCS acts to alert and warn the locomotive engineer and dispatcher when unsafe conditions are present. If safe or restricted speed limits are exceeded by the locomotive, the on-board computer warns the engineer to take corrective action. If the computed safe braking distance to the next control point is approaching the safe limits, the engineer is again alerted to begin corrective action. If the dispatcher requests a movement authority of the dispatch computer and the movement is predicted by the dispatch computer to be unsafe, the dispatcher is alerted of the conflict and the authority is withheld. Again, these are all steps that would normally be followed by railroad personnel; the ATCS acts to supplement the actions of personnel.

Finally, the ATCS intervenes to apply braking for those situations where unsafe operations or hazards exist and the railroad personnel either have not or could not have reacted in time to the warnings.

With the ATCS checking, validating, and (when necessary) overriding the actions of humans charged with following the safe operating procedures of the railroad, the ATCS and railroad personnel can combine their responsibilities to provide for safer train movement. Safer train movement can lead to increased railroad efficiency and greater productivity.

2.2 The ATCS Specifications

The ATCS is a set of specifications developed to provide a unified agreement among the railroads of North America on a train movement control system. The specifications define the performance and interface requirements for the ATCS software and hardware. The specifications must be common to all railroads in order to provide the desired interoperability and compatibility between railroads.

ARINC Research Corporation (ARINC), with the cooperation of the railroads, developed a set of common operating procedures that can be converted into sequences of commands and associated responses. An example procedure might be the set of information and commands sent from the dispatcher to the locomotive engineer to advance from one control point to another; the responses might include the acknowledgements the crew provides to the dispatcher as the train moves between control points. Another procedure might be the command and response required to change a track switch and verify its position. Agreement on the sequence of commands and responses is needed among the railroads so that a train can operate under ATCS on track belonging to several railroads. The train's on-board computer must recognize the commands of the dispatch center and issue its own requests in the manner and sequence required by the dispatch center.

Each procedure, after conversion to a sequence of commands and responses, must be converted to software instructions. The specifications of the ATCS define the procedures and their sequence of commands and responses without defining the software code itself. Since the software is internal to a particular train computer, compatibility demands only that the computer properly recognizes certain commands and provides certain responses, without being concerned about the details of the internal computer operations.

ARINC, with the cooperation of the railroads and equipment manufacturers, developed requirements for the hardware to implement the procedures and to communicate the instructions between the dispatcher, locomotive crew, and other railroad personnel. The hardware requirements define the functions to be performed by the ATCS components, the interfaces between the hardware components, and the information that must pass between the components via the interfaces. The design goals and features of the hardware components are left to the ingenuity of the equipment manufacturers. The specifications of the ATCS define the requirements for the hardware such that the equipment of the different manufacturers will be compatible, interoperable, reliable, and functional.

2.3 The ATCS Architecture

The ATCS architecture is composed of five major systems [3]. These include four information processing systems: the Central Dispatch System, the On-Board Locomotive System, the On-Board Work Vehicle System, and the Field System. The fifth major system is the Data Communication System, which interconnects the other four systems. The relationship between the five systems is illustrated in Figure 1.

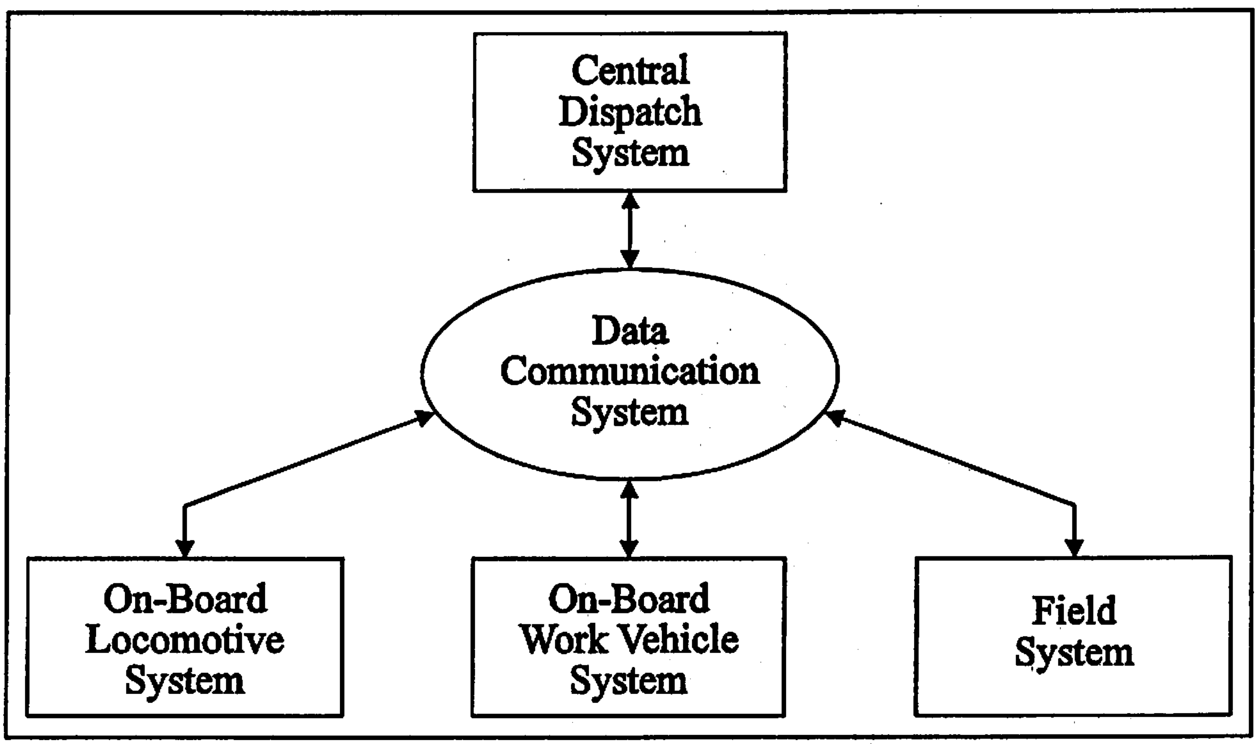

Figure 1. Relationship between the five ATCS subsystems.

These five systems work together to handle requests for information, process data in real time, ensure error-free delivery of data, and handle conflicts and equipment failures. System interconnection is accomplished through a combination of communication nodes and wireline and radio links.

The ATCS Specification 100 on System Architecture explains the functions of the subsystems:

"The function of the dispatch system is to manage the movement of trains throughout the rail network with the objective of guaranteeing safe operations without incurring train delays. The function of the locomotive system is to provide automatic location tracking and reporting, predictive enforcement, and automated transmission of movement authorizations and switch monitoring and control information via the data communication system. The primary function of the work vehicle system is to provide the capability for a track maintenance foreman to communicate with the central dispatch system and other vehicles via the data communication system. The ATCS field system is designed to provide remote monitoring and control of wayside devices." [2]

2.4 The ATCS Levels of Operation

The ATCS is designed for expansion from a basic level of ATCS implementation to a full-capability level. Table 1, also from ATCS Specification 100, provides the capabilities of ATCS at each level, noted as Levels 10, 20, and 30.

The ATCS Specification 100 is again quoted to define the levels:

"Level 30 operation assumes that trains are equipped with an enforcement system, a datalink system, an onboard computer, a location system, and a display. Field devices may or may not be ATCS equipped and/or controlled. The dispatcher uses the central dispatch computer (CDC) which can communicate via the datalink to the onboard ATCS equipment and ATCS equipped field devices.

"Level 20 operation is similar to Level 30 operation except that the train has no enforcement capability, no location system, and less sophisticated onboard processing capability.

"Level 10 operation is similar to Level 20 and 30 operation except that the train has no onboard ATCS equipment, or the ATCS equipment on the train is disabled or turned off. Note that in Level 10 no capability exists for the train to contact field devices directly. Also note that field devices are able to function unaware of the equipped level of the train.

"In Level 10 operation the dispatcher delivers Track Condition Notices (TCNs) and Track Work Protection (TWP) to the engineer or foreman via the voice radio. Where railroads have mechanisms in place to deliver written TCNs and TWPs, a confirmation that the items are on hand should be substituted for voice delivery. It is important, however, that the CDC receive verification that the crew has these items in hand. .....". [2]

Table 1. The ATCS Capabilities for Levels 10 through 30

CAPABILITY/LEVEL	10	20	30
Centralized route and block interlocking	R	R	R
Voice delivery of movement authorizations and operating instructions	R	R*	R*
Data delivery of movement authorizations and operating instructions		R	R
Voice reporting of train location to dispatcher	R	R*	R*
Manual reporting of train location and automatic delivery to central dispatch computer		R	R*
Automatic reporting and delivery of train location to central dispatch computer			R
Speed enforcement			R
Movement authorization limit enforcement			R
Monitor and control field devices by code lines from central dispatch computer	O	O	O
Monitor and control field devices by datalink from central dispatch computer	O	O	O
Monitor and control field devices from locomotive cab		O*	O*
Automatic reporting of ATCS device health		R	R
Automatic reporting of locomotive health		O	O

R - Required capability for this level

R* - Required capability to support fallback to lower operating levels

O - Optional capability

O* - Optional capability for field and central dispatch; required on locomotives

2.5 Additional ATCS Design Information and Background

The ATCS is designed according to an international standard called the Open System Interconnection (OSI) reference model [4]. The OSI model serves as a framework for communication architecture and protocol development. It divides the functions that must be performed by a digital communication system into seven layers, with each layer making use of services provided by the layer beneath it. User applications are at the top of the model, while the lowest level is concerned with the transmission of raw bits over some physical medium. ATCS users include dispatch applications, locomotive applications, work vehicle applications, and field system applications. An application is a computer program that processes instructions to satisfy one or more of the operating procedures.

The ATCS data communication system includes several types of nodes [3]. A computer, called the front end processor, is the entry point for the railroad's host computer and dispatch center to the ATCS. The front end processor is connected to several cluster controllers. The function of the cluster controllers is to route data from the dispatch center to locomotives, work vehicles, and field systems. Cluster controllers are normally connected to several base communications packages. These packages provide radio communication to the mobile communications packages of locomotive systems, work vehicle systems, and field systems configured as mobiles.

The communication nodes perform such functions as: vehicle tracking for data packet addressing; data packet routing; data packet flow control; data packet buffering and queuing; data packet prioritization; event timer control; and communication system failure or alarm detection and reporting. These functions are necessary to ensure that data and information are delivered properly and in a timely manner from data senders to data receivers.

The references [2], [3], and [5] provide more detailed descriptions of the ATCS. The details are not repeated in this report, but aspects of the ATCS which are considered important are dealt with in more depth in the following sections.

One of the purposes of the ATCS is to provide safer train operation. The next section defines the concept of collision avoidance from a system perspective and how the ATCS relates to that definition.

3. REQUIREMENTS FOR COLLISION AVOIDANCE

A collision avoidance system provides the means of detecting and preventing impending collisions between vehicles [6]. Such a system performs the following functions:

- Detection of a second vehicle either approaching the planned path or already in the planned path of a first vehicle.

- Evaluation of the collision hazard.

- Determination of the precise maneuver required to avoid a collision.

- Execution of the maneuver.

Positive train separation is the term used within the railroad industry as a synonym for collision avoidance. The ATCS specifications implement a common set of procedures used by the rail industry to provide safe train movement. Consider the following example illustrating railroad procedures for safe train movement and the role of the ATCS in monitoring and enforcing the procedures:

Each train is required to obtain movement authority to advance into a block of track. Inside a block, a train is allowed to proceed to the control point at the end of the block. The ATCS monitors the location of the ATCS-equipped locomotive and its speed within the block. The ATCS computes the required stopping distance of the train as it approaches the control point. If the ATCS determines the conditions are such that the train needs to reduce its velocity or begin braking to stop ahead of the control point, the ATCS alerts the dispatcher and warns the engineer to take corrective action. If action is not taken, the ATCS can enforce corrective action through automatic brake application. The ATCS protects an ATCS-equipped train from a follow-up accident with a slower moving train in the next block. (A "follow-up accident" occurs when a slowly moving train in overtaken by a faster moving train on the same track.)

For ATCS-equipped locomotives operating on ATCS-equipped track, the ATCS can provide positive train separation.

4. EVALUATION OF A TELECOMMUNICATION SYSTEM

ITS has been tasked to evaluate the ATCS as a telecommunication system. Several evaluation methods are available, and two of them are described below. The method selected for the evaluation of the ATCS was one that fell within funding and time constraints.

One method of evaluating a telecommunication system involves modeling, simulation, and testing. Engineers develop software models of the components of the system, combine the software models to simulate the proposed system configuration, and then exercise the combined models by introducing average and peak traffic conditions. Such simulations help to determine the capacity of the proposed system, when and where congestion of the system occurs, and overall system performance. Modeling and simulation provide insight into design decisions prior to committing to building the system, and allow redesign if the simulation indicates weakness.

After the system design is completed but before it is committed to full field deployment, the system is further evaluated by placing it in a working environment on a limited scale. The environment might be simulated initially using hardware in a laboratory, but eventually the system is fully tested under actual field conditions on a test bed where system performance can be monitored.

This method of system evaluation can be completed either by the system designers or by an independent system evaluator. An independent evaluator has the advantage of a certain level of objectivity. The method is thorough, but costly and time-consuming, and because of the limited funds and time available, ITS was not able to perform this type of evaluation and instead used a second approach.

A second method of evaluating a telecommunication system is to review and rate the engineering decisions made in the development process. By reviewing system documentation and discussing particular concerns with system designers, evaluators can make judgments of the engineering choices and overall system design. A useful tool in this type of evaluation is a matrix that identifies key issues that should be addressed in the system development process. The matrix serves as a checklist to guide the evaluators. This is the method adopted by ITS to evaluate the ATCS, and the matrix used is described below.

4.1 ATCS Evaluation Matrix

The matrix used by ITS to evaluate the ATCS has seven columns corresponding to seven general areas of concern that should be addressed in the system development process. Within each area, several elements critical to successful system development are identified. The matrix is shown in Table 2, and the seven areas of concern are briefly described below. They are explored in more detail in Section 5.

Table 2. ATCS Evaluation Matrix

Architecture	Data Communication	Radio Network	Wireline Network	Test and Validation	Migration	Management
Standards-Based	Error Detection and Error Correction	Redundancy	Redundancy	Data Communication Simulation	Implementation and Replacement Plans	Conflict Resolution
Open System	Timers	Radio Frequency Interference	Capacity	Radio Communication Simulation	Continuous Protection During Migration	Hand-off Between Nodes
Common Air Interface	Flow Control and Congestion Management	Signal Coverage		Field Test - Range of Environments		Protection From Threats
Fail Safe	Routing	Blocking and Capacity				
Upgradable Design	Priority					

Architecture defines the structure of the system and the relationship between system components. Evaluation concerns in this area include the process used to determine user needs, whether the design approach was open or proprietary, and whether the system provides for growth and migration.

Data Communication refers to the control of data as it moves from sender to receiver. Concerns include detection and correction of errors that may be introduced along the transmission path, management of data traffic, and priority schemes to ensure that the most important data arrives first at the receiver.

Radio Network and **Wireline Network** refer to the two portions of the data transmission path. Most of the data for the ATCS will be delivered to or received from mobile units. At some point in the transmission path from sender to receiver, data will be sent by means of radio. The remainder of the path will be over fixed wireline circuits. The radio portion of the path operates under constraints that are not encountered on the wireline path.

Test and Validation refer to the means used to test the system to verify that it meets requirements and provides the desired performance.

Migration refers to how the transition from the old system to the new system will take place and what timetable will govern the process.

Management refers to the different methods that system configuration and security are controlled. Concerns include resolution of address conflicts, administrative control as mobile units move through the system, and protection from attempts to corrupt system integrity.

5. EVALUATION OF THE ADVANCED TRAIN CONTROL SYSTEM

Comparing the development of the ATCS against the evaluation matrix leads to a judgment of the soundness of the system design and whether the system can be expected to work as proposed. All design decisions are not reviewed, and a positive evaluation does not guarantee that the ATCS will perform exactly as intended. If, however, the ATCS development process successfully addresses all the evaluation matrix elements, the system is likely to meet its goal of moving trains safely.

The remainder of this section provides a brief tutorial description of each matrix element, followed by an assessment of how well the ATCS development process has addressed the element.

5.1 Architecture

5.1.1 Standards-Based System Development

System designers, software developers, equipment vendors, and system users require interoperability among the components of large data systems. System designers must incorporate standards in the development process to ensure interoperability and compatibility of the system components. The system developers can use existing industry or national standards; in addition, new standards that are specific to the application can be developed and used by the system designers.

A railroad industry committee acted to develop the ATCS based upon railroad needs, equipment vendor capabilities, and proven data communication techniques [3]. With time, the committee has evolved the specifications based upon knowledge gained from the railroads and manufacturers as the specifications are tested for desired results, required performance, and possible implementation. As a result, the specifications have become a standard, in the usual sense. If all manufacturers, system integrators, and railroads adhere to the specifications, then the resulting train control systems of the railroads will be interoperable and compatible.

Matrix Element Evaluation *The ATCS specifications define performance and interface requirements for the hardware and software components of the system. This use of a standard is necessary to ensure that those system components and operations that affect train safety are defined the same way throughout the entire system, across all railroad systems.*

5.1.2 Open System

The need for dissimilar data systems to communicate with each other has led system designers to establish both physical and protocol standards for linking different data system equipment together. The equipment of different manufacturers must be able to interface to each other physically. This is accomplished by setting hardware standards. Likewise, the information passed between the different manufacturers must be of a format that each piece of equipment understands. These standards for communications between computers and data systems have developed on an international level with the International Standards Organization fostering a reference model for Open Systems Interconnection (OSI) [4]. The OSI model consists of a seven-layer communications architecture with each layer having its own set of protocol or rules for communications. Several advantages of an OSI structure are:

- all vendors have an opportunity to supply equipment to meet the users' needs,
- different equipment from different vendors (or even the same vendor) will be designed for interoperability,

- different data communications design groups can work on specific layers independently of other groups assigned to other layers, and

- as technology changes, the affected layer's protocols can be modified without affecting the other layers.

The ATCS endorses the reference model of OSI. Specifications are written with an open system approach and follow the OSI guidelines.

Matrix Element Evaluation *The use of the OSI model for systems development will benefit the railroads and the vendors. The greatest benefit is that the OSI philosophy allows the incorporation of new technology as it becomes available and is needed by the railroads. As new devices or technologies are developed that assist in positive train separation, the ATCS will have the framework that allows their introduction in the easiest possible way.*

5.1.3 Common Air Interface

Much like the Open System Interconnection model between computer and data systems, the Common Air Interface concept has been developed for the radio portions of communications networks. A Common Air Interface is a standard that ensures that the radio equipment will be interoperable with radio equipment from different manufacturers and compatible with radio systems for different users (railroads). Such an interface standard disallows the use of media access schemes, modulation techniques, or any other radio air interface specifications that are considered proprietary, unless all vendors are allowed to use the proprietary techniques in the design of all radios for the application. In an approach such as the Common Air Interface, new techniques, designs, and solutions are encouraged to counter difficulties in radio communications, but the resulting intellectual properties become available to all competitors and users of the system.

The ATCS specifications indicate the characteristics for digital communications by specifying the radio channel bandwidth, radio channel bit rate, modulation, channel access, and frame formats including codes for error detection and correction [5], [7]. No proprietary measures were indicated in the specifications, allowing for a common air interface.

One possible potential for the growth of the ATCS is to consider the voice and data radio system currently being developed by the Association of Public-Safety Communications Officials, the National Association of State Telecommunications Directors, and the Federal Government [8]. Their standard for digital land mobile radio incorporating both data and voice is known as the APCO-25 Standard. Consideration of the Standard could result in a cost savings for railroads and allow compatibility with other users in the band.

Matrix Element Evaluation *The air interface is defined for the ATCS and allows for compatibility between various vendors' systems and between various railroads. Compatibility of the radio systems will be required to serve rail safety to the maximum possible extent.*

5.1.4 Fail Safe

Fail Safe is defined as a specific quality of a system such that the system continues to function (with reduced performance) after the failure of some component or piece of the system [6]. For example, a traffic light control malfunctions and the light begins to flash red in all directions, indicating traffic control is being returned to the individual drivers of the cars entering the intersection. This system performance change, without a complete system shut-down due to a system failure, is considered to be fail safe. In some of the ATCS documentation, the term fail passive is used, as "that property of a system to recognize that a failure has occurred and transition into a passive state to avoid adverse affects on system operation." [9]

The purpose of our examination is to examine the data communications systems of the ATCS as they relate to collision avoidance. From this perspective we can modify the initial definition to say, a fail safe architecture is one that continues to provide collision avoidance after the failure of some component or piece of the system. In the case of an automated control system, the desired actions usually are:

- identify the failure(s),
- notify the human managers of the problem, and
- defer all decisions to the human manager until the problem is corrected.

The ATCS Specification 200 states that the elements of the ATCS required to ensure safe train movements and track occupancies are considered Vital Elements. Vital Elements of ATCS are those related to the organization, issuance, safe execution, and enforcement of movement authorities. If the failure of a vital element occurs, the system must fail in a safe failure mode, selected to eliminate hazardous consequences.

Matrix Element Evaluation *The ATCS design acknowledges that vital components will fail. As with other control systems developed for fail-safe shut-down operations, the ATCS is designed to shut down safely and to relinquish decision-making responsibilities to the human operators, the dispatcher and locomotive engineers.*

5.1.5 Upgradable Design

A goal of system design today is to avoid locking the system into current technology. Systems need to be able to incorporate new technologies as they become available and are needed by the users. Open, standards-based systems have the best opportunity to expand with new technologies and applications. Designers and manufacturers are more likely to provide technological improvements to systems which have well-defined, non-proprietary interfaces than those which do not.

As discussed above, the ATCS has been developed with upgrading as a potential migration path. One area where expansion is already allowed is that of negotiating between a cluster controller (CC) and a mobile communication package (MCP) on a locomotive or track maintenance vehicle that has come into the controller's area. The negotiation allows the CC and MCP to decide which protocols they both understand and what are the associated parameters. This form of negotiation allows the system to expand, allowing new protocols to be established with newer equipment, but retain the capability to communicate with older equipment supporting older protocols.

Matrix Element Evaluation *A system that allows expansion from its present configuration and operation will serve the interests of railroad safety. New application programs can be developed to further ensure positive train separation, even with tighter spacing between trains. The application programs can utilize newer techniques, developed in other industries, to solve the problems faced by the railroad industry. Techniques such as Kalman Filters [19] and Fuzzy Logic [20] use information from the process they are trying to control to improve the process in a real-time, adaptive manner. The ATCS has the framework to allow the software and hardware to migrate and expand in performance.*

5.2 Data Communications

5.2.1 Error Detection / Error Correction

Transmission errors occur in all data communication systems. While today's technologies and transmission media have dramatically reduced the frequency of errors, errors can never be totally eliminated. A properly designed system must have the ability to detect and handle errors in their transmitted data.

There are two basic strategies for dealing with data transmission errors. The first strategy is to detect errors and request a retransmission of the data packet containing the error. The second strategy is to correct the detected error at the receiver.

An error-detection-only strategy includes, with each data packet transmitted, a code called a cyclic redundancy check (CRC) that allows the receiver to determine the presence of an error in a given block of data. The receiver may then request that the flawed data packet be retransmitted. The process is repeated until the receiver accepts a flawless packet. This method is called automatic repeat request (ARQ), because if an error is detected the receiver automatically requests that the packet be repeated (retransmitted). This strategy has the potential problem of requiring the data system to provide a large number of retransmissions as the result of isolated, single-bit errors.

An error-correction strategy places enough overhead into the data packet to allow the receiver to detect and correct most errors, if they are of the isolated, single-bit variety. The amount of data redundancy, in each data block, needed to detect and correct errors is greater than the amount required for simple error detection; however, the total amount of data passed from sender to receiver may be reduced with an error correction scheme if errors occur often enough to cause frequent retransmissions in a detection-only scheme. Error correction is frequently called forward error correction (FEC) because the receiver corrects the errors. When these two strategies are used together, the technique is called modified ARQ.

The ATCS uses modified ARQ for two reasons. The ATCS system designers examined several received data files that had been transmitted over typical railroad radio channels [7]. The errors that occurred in the data indicated in most cases errors would be present as isolated errors in a data block. An FEC scheme is ideal for correcting isolated errors. The other cases of errors in the data indicated a large number of errors occurred together, in a burst. Error bursts are best dealt with by a retransmission of the data block. FEC corrects isolated errors without requiring large numbers of retransmission. The FEC capability allows the system to recover from small errors without excessively large amounts of overhead. The ATCS uses a type of FEC called Reed-Soloman, after the code's designers. This error correction method uses 25 percent overhead (20 of 80 bits) to identify and correct errors occurring in a group of two or fewer five-bit symbols in error per block. The method was chosen after examining five different FEC correction methods. All these methods were tested against four different channel error files. The Reed-Soloman method of FEC was selected because of its throughput and its relatively high performance on all tests which were conducted.

Matrix Element Evaluation *The decision process used by ARINC and the Component Specification Drafting Committee (CSDC) follows a logical progression. The committee and ARINC determined that the most likely errors within a data packet would be isolated in occurrence and could be corrected by FEC without introducing large amounts of overhead into the system and that a Reed-Soloman code was best for their needs. The decision to use ARQ to recover from bursts of errors within a data packet was retained because it mitigates the need for large amounts of error correcting overhead.*

5.2.2 Timers (Time Outs)

Timers or time outs provide the ability of a system to manage and control the time allotted for different functions. The purpose of these timers might be to control run times for different functions or to measure time periods during which responses are to be received. Timers prevent a system from waiting an inordinate amount of time for the completion of a task, and prevent a system from retaining information for an unacceptable amount of time. Timers are especially important in a system that must integrate components that are produced by different manufacturers. A system cannot successfully function without the use of timers as part of its flow control/congestion management scheme. The ATCS employs timers in many different functional areas. Examples include the following:

- When a train enters the system (starts up), the cluster controller sends a message to its adjacent cluster controllers informing them about the new train. The adjacent cluster controllers modify their individual address tables to reflect the new entry. If that address is not referenced within a set amount of time, the adjacent cluster controller may purge or erase the idle entry from its table. In this case, a timer is used to manage memory and buffer space.

- Carrier sense multiple access (CSMA) is a method used by the ATCS to allow many radios to share the same radio channel or frequency. If a radio wishes to transmit, it first listens to determine if that channel is busy. If it is busy, the radio "backs off", waits a random amount of time, before trying to transmit again. The ATCS uses an initial "back off" window of 10 - 200 ms. The timer assists in flow control and congestion management. The back-off/delay time constants used in the ATCS radio network were taken from those used by other similar radio networks.

Matrix Element Evaluation *The use of timers is essential to minimize the congestion of the system and to allow different brands of equipment to work together. The ATCS employs timers at important junctures. The settings of these timers is based on sound logic and empirical data. Whether or not the time limits selected in the specifications are the best possible will be determined as the result of system simulation, equipment interoperability tests, and actual field experience. The tests and experience will lead to improved implementation of system timers.*

5.2.3 Flow Control / Congestion Management

Flow control refers to techniques employed to ensure that a data sender does not overwhelm a receiver before the receiver has an opportunity to process incoming data [10]. Because of the layered approach of the OSI model and the various system configurations, flow control may take place at many different OSI layers within a data communication system.

There are several different types of flow control. Two of the most common are stop-and-wait and sliding window. Stop and wait directs the sender to wait for an acknowledgment from the receiver before sending the next packet. Sliding window flow control allows the receiver to accept several packets before sending a group acknowledgment.

Congestion management is the ability of the system to protect itself from "congestion collapse". Congestion collapse occurs when system data buffers overflow and data transmission queues become so long that data throughput ceases.

The ATCS employs several different methods of flow control. The data link protocol used, high level data link control (HDLC), has the capability to provide a "receiver not ready" command. The ATCS also uses a sliding window flow control method. This provides greater utilization of the communications channel than the stop-and-wait flow control method.

As defined in Section 5.1.2 on the OSI Model, the system has seven layers for communications. The ATCS layer 3, the network layer, acts as a control point between the transport and the data link layer. If the network layer receives a congestion message from layer 2, it will control the information it receives from layer 4, discarding traffic starting with that having the lowest priority until the congestion is cleared.

Matrix Element Evaluation *Data flow control and congestion management are required aspects of a well-designed data communications system. The ATCS has been designed with a thorough understanding of flow controls and congestion management, and uses proven techniques to manage a potentially catastrophic problem.*

5.2.4 Routing

Routing can be defined as the method by which a data packet or message is directed from node to node through a data communication system [10]. Many different types of routing are available and may be organized into two categories:

- Non-adaptive routing bases routing decisions on a fixed set of rules that do not change with time.

- Adaptive routing bases routing decisions on updated information of traffic loads and system configuration and attempts to use the "best path".

The routing mechanism selected for a particular system depends largely on needs of users. As a rule, adaptive routing is better suited for situations when stations may move, traffic loads vary, or the configuration changes.

Three different types of algorithms are used for adaptive routing. Global algorithms, the first type, use information from the entire system to make routing decisions. This method can suffer from excessively large and cumbersome routing tables. The second type is a local algorithm which allows each individual node to determine routing. The third type of algorithm combines both global and local methods into what is known as distributed routing.

The ATCS uses distributed routing. Each node periodically updates its neighbors about addresses it is able to reach. When there is traffic for that address, the other nodes point the traffic toward the controlling node. In cases where addresses are not known, the global directory is consulted. If this fails, an orderly, expanding search is generated in the attempt to locate the address. The ATCS controls its routing table size by periodically purging unused addresses from the routing tables.

Matrix Element Evaluation *The ATCS uses adaptive distributed routing to transmit data from sender to receiver. As the system is reconfigured due to growth and migration, the system will be able to route the data along the most efficient paths afforded by the new configuration.*

5.2.5 Priority

Priority provides the data sender with a means to designate some messages more important than others, thus expediting their delivery. A priority scheme is extremely important in systems where emergency traffic may be present. It is also an important component of congestion management. High priority traffic is usually allowed to proceed while low priority traffic is discarded during periods of data traffic congestion.

The ATCS uses priority to its fullest advantage. The requirement of four priority levels was derived through many user group meetings. Each message format has an assigned priority level. The priority scheme allows three procedures to be followed:

- Each message format is required to have a preassigned priority thus preventing an application or component from choosing an inappropriate priority for one of its messages.

- The data sender is required to always attempt to send the highest priority messages out of its buffers first.

- Each message is required to be checked for its level of priority before it is delayed or purged during periods of data congestion.

Matrix Element Evaluation *The ATCS priority levels have been developed in a logical manner. A four-level priority scheme was chosen to reflect user needs and operational requirements. Methods for expedited handling of high priority traffic allow the data communication system to be used to its fullest advantage.*

5.3 Radio Network

5.3.1 Redundancy

Redundancy is duplication of elements in a system or installation for the purpose of enhancing the reliability or continuity of operation of the system or installation [6]. Redundancy can be accomplished by the use of identical equipment, equipment diversity, or functional diversity.

Redundancy, as related to radio communications, is defined as the availability of duplicate radio transmission and reception means to support the system in the presence of failures in the primary system [6]. The examination of redundancy is important because it relates to the system's ability to continue to function despite failures.

According to the ATCS design rules, a duplicate ATCS data radio system to provide backup support to the primary ATCS data radio system is not a requirement. In case of failure of the ATCS data radio system, the voice radio system is to provide the fallback operation in the ATCS (see Table 1 which provides the ATCS capabilities for Levels 10 through 30). Table 1 indicates, at Level 30, that speed enforcement and movement authority limit enforcement are still available in the event data radio communications have failed, even though the ATCS must rely on voice delivery of movement authorities and operating instructions, and voice or manual reporting of train location. In this situation, redundancy is accomplished by the use of functional diversity; the independent voice radio communication system is used to replace the data radio communication system.

Both technology and policy of voice radio communication systems, as used by the railroads and other land mobile radio users, are undergoing changes. Technology is moving towards digitizing voice for voice radio communication system applications. Policy changes will modify the equipment characteristics as well as require the systems to be more efficient and support greater user capacity. As the ATCS matures and as the changes to the railroads' voice radio communication system are implemented, the ATCS could rely on the voice radio systems as a redundant system providing digital data communications. If voice is digitized for transmission and reception on a digital voice communication system, then any digital signal may be handled by the voice radio communication system as well.

Matrix Element Evaluation *Redundancy of the ATCS data radio system is not accomplished through duplicate equipment to automatically replace failed equipment. Instead, the ATCS falls back to the voice radio system to provide the movement authority and location information. The railroads' design rule as a response to the failure of the ATCS data radio communication system is not unlike present procedures used when the voice radio system fails. The procedure requires the locomotive engineer to observe safety rules and advance the train to the next location providing telephone service for communications with the dispatcher.*

5.3.2 Radio Frequency Interference

When designing a radio communication system, the designer must consider not only what capabilities the system must have, but also the radio environment in which the system must operate. Radio systems are vulnerable to unwanted disturbances, superposed upon a useful signal, that tend to obscure the desired signal's information content [6]. Disturbances produced by other transmitters within the frequency band of the desired system are generally referred to as interference, while broadband disturbances across a wide range of frequencies whose sources are man-made (such as arc welders), atmospheric, or internal to the radio system itself are referred to as noise. System designers must take steps to protect a radio communication system from interference and noise.

The ATCS development included studies to measure or analyze the interference and noise environments of the ATCS [11]. A measurement study consisted of a comprehensive interference and noise examination of the locomotive's cab. This was done to establish a reference interference and noise environment due to the internal locomotive components. The ATCS components must be designed to accommodate the measured reference levels.

The second significant study was an environmental analysis of the radio communication channel's operating environment [12]. The ATCS must operate in radio-congested cities as well as across vast plains. Interference from other radio services is a major concern in most metropolitan areas. Of the two frequency bands considered, Very High Frequency (VHF) and Ultra High Frequency (UHF), the UHF band presently experiences less radio congestion in metropolitan areas.

Matrix Element Evaluation *ARINC examined the implications of noise and interference on the frequency bands selected for the ATCS. The first examination evaluated the electromagnetic environment of the locomotive and provides guidance on the radio environment to the equipment designers. The second analysis identified the UHF band as the more desirable of the VHF and UHF bands in metropolitan areas.*

5.3.3 Signal Coverage

Signal coverage is the condition whereby a base station and mobile have reliable communication service for a specified percentage of time, typically 90%. The signal coverage area is the area surrounding a base station that meets the conditions for signal coverage. A line that can be drawn around the coverage area, such that the enclosed area meets the signal coverage conditions is called the coverage contour, for example the 90% coverage contour [6]. Communications outside the contour can occur but not with the desired 90 percent reliability.

Several factors influence signal coverage. Terrain, vegetation, and man-made obstacles between transmitter and receiver influence the received signal's amplitude and structure. Radio communication system designers need to know typical conditions for the radio system to plan its design. Noise and interference are other factors that can reduce signal coverage. Typically in rural environments, radio coverage is limited by weak desired signals, whereas in urban environments, coverage is limited by the presence of interference from undesired signals.

There were two different frequency bands under consideration, VHF (160 MHz) and UHF (900 MHz). These frequencies have distinctly different propagation or coverage characteristics. As frequency increases, the propagation loss also increases. Thus to deliver the same power to a radio receiver at UHF as at VHF, the UHF transmitter must have a greater radiated power level compared to the VHF transmitter. For this reason, VHF is preferred over UHF for long distance communications, in rural and mountainous areas.

As frequency increases, atmospheric and man-made noise decreases. The band selection would then favor UHF. A principle consideration in selecting UHF was its performance in cities and the relative uncluttered spectrum as compared to VHF. A study conducted by Battelle provides support to the decision to use UHF. UHF is a weaker choice than VHF in open terrain and through foliage. Battelle points out that by increasing antenna height, increasing transmitted power, or increasing the number of base stations, some of the disadvantages of UHF versus VHF may be reduced. [12]

Signal coverage performance models provide guidance on required spacing and location of base stations along track routes to provide the desired signal coverage [12-14]. In practice, exact base station location or characteristics can be adjusted to fill in areas which have experienced poor coverage.

Matrix Element Evaluation *The railroads presently use assigned spectrum in the VHF band for voice communications. The FCC has made additional spectrum available to the railroads in the UHF band to be used for data communications. Presently, the allocated UHF spectrum has less noise and interference than does the allocated VHF spectrum. The disadvantages of UHF signal coverage compared to those of VHF can be overcome by good base station site selection.*

5.3.4 Blocking and Capacity

Blocking occurs when one user wants to use a radio channel already in use by another user. The second user must wait until the channel is not busy before sending any radio traffic. Severe blocking occurs when more users are waiting with messages to send than can be handled within the specified time limits for message delivery.

Two concerns follow from the issue of blocking. The first concern is whether there is a means to recover from the congested state. This concern was covered under flow control and congestion management. The second concern is whether there is sufficient capacity to handle the amount of traffic that the ATCS might typically be expected to handle. This is particularly important with the ATCS radio system which uses a CSMA scheme (see Section 5.2.2).

Automated Monitoring and Control International (AMCI) has studied the issue of blocking and capacity of the radio channel [16, 17]. The studies evaluated the ATCS channel as specified in Specification 200, analyzing work order reporting for a national, twenty train system with position location. The data used in the studies represented operating radio traffic from the Union Pacific Railroad. The reports conclude, based upon work order reporting, that no problem with congestion exists.

A need for increased capacity may become necessary as the railroads provide more information to be communicated via the ATCS. As with the cellular-phone industry, the railroads may have to add more base stations to handle increasing capacity due to more data traffic between mobiles and base stations. The additional base stations would operate with reduced power characteristics but would increase the density of the stations along the route. Since each base station can handle a certain average number of messages (trains), increasing the number of base stations along a track segment will increase the total number of trains that can be accommodated.

Matrix Element Evaluation *Congestion and blocking of the radio channel are significant concerns. While the ability exists to clear the channel if it becomes blocked, the ideal method is to avoid blocking through sufficient capacity. The studies conducted by AMCI address the capacity concerns. The studies only model work order reporting traffic. The Chicago hub, with its concentration of locomotives, provides an example of a severe communications environment. A more thorough understanding of the data traffic levels, in typical as well as severe communications environments, needs to be developed and modeled to ensure that the system has been properly designed for all potential geographic areas.*

5.4 Wireline Network

The wireline network is defined here to include all equipment of the ATCS other than that directly used for radio communications. Thus the wireline network includes components such as the dispatch computers, front-end processors, cluster controllers, way-side devices, field equipment, and the land line connections between computers, controllers, field equipment, etc.

5.4.1 Redundancy

For a definition of redundancy, see Sec. 5.3.1.

Critical, vital computer systems are designed with redundant modules operating side-by-side, with the ability to immediately detect and alert both other system equipment and system personnel when there has been a failure in either computer. While one side of the redundant computer system awaits repairs, the other carries out its tasks. Thus they have high levels of availability, and low error rates.

Front-end processors and cluster controllers, for example, are not designed with redundant components operating side-by-side. Instead, the connections between front-end processors and cluster controllers are made in a mesh configuration. In other words, there are primary connections between a front-end processor and its cluster controllers. There are also connections from the processors to cluster controllers served primarily by other processors. In the event a processor or controller fails, other equivalent devices can be commanded to service the failed unit's clients until the unit is repaired or replaced. Similar connections are made between cluster controllers and the equipment such as base stations that the controllers serve.

System designers have a tradeoff option between the design of a component that has a very long time between component failures and a design that uses two relatively inferior components in a parallel or redundant operation. To understand the difference between redundant operation and a high mean time between failure (MTBF) design, consider the need to have a light on in the locomotive cab. The designer could have put two light bulbs operating in parallel (on simultaneously) or the designer could have used a single light bulb. Suppose in the case of the two light bulbs, the MTBF is 200 hours for each bulb. The equivalent single bulb would require a MTBF of 1600 hours to provide the same performance.

A report by Draper Laboratory provided the ATCS development team with an analysis of the relative contribution of the various ATCS elements to the overall accident rate under ATCS Level 30 operation. The report identifies those elements required to have redundant (or dual) operation and those required to have high MTBF designs [18]. The ATCS has been developed with those requirements as factors.

Matrix Element Evaluation *An engineering organization modeled and developed the requirements for availability and these requirements were incorporated into the specifications. Vital components, as defined by the railroads, are required to be designed using redundant modules. Other components use multiple connections between like equipments to support redundancy features. Redundancy in the wireline network of the ATCS is required to support safety. In some cases, redundancy is provided functionally, where failure of some components forces the ATCS to fall back to reliance on voice communications, for example.*

5.4.2 Capacity

Capacity refers to the ability of a system or component to handle a certain or predetermined level of traffic. For components such as the dispatch computer, capacity might be described in instructions per second. For wireline connections such as the link between cluster controllers, capacity might be described in bits per second.

The ATCS does not specify requirements for absolute capacity since that would vary with the number of trains being served. Instead, Specification 200 provides requirements for maximum acceptable delay. A specification that mandates a maximum packet delay time ensures that the different priorities of traffic receive appropriate handling. By establishing a delay criteria as opposed to a throughput capacity, the ATCS specifications are more realistic and the system is more able to efficiently handle different degrees of message priorities throughout the network.

Matrix Element Evaluation *By establishing data delay criteria, the ATCS states the requirement for the data communication system. Component manufacturers and system integrators have the freedom to provide the necessary capacity in different ways to satisfy the data delay requirements.*

5.5 Test and Validation

5.5.1 Data Communication Simulation

Simulation is the creation and use of a model that behaves or operates like a given system when provided a set of controlled inputs [6]. Simulation is used in place of a system (under development, for example) to verify expected performance, to test responses to various stressful conditions, and to validate operational sequences. Simulation can be composed of software models, hardware models, or a combination of both. Using simulation techniques, conditions can be changed in a step-wise process to determine when and why a proposed or functioning system breaks down. A simulation can model a proposed modification to the system and can be used to evaluate the modifications using the exact conditions that were applied earlier to stress the system.

Simulation and modeling are required early in the development effort, prior to implementation. Field testing of prototype systems is also required, but field testing rarely allows the testers to repeat conditions exactly or apply extreme situations that the system may eventually encounter. In addition, deficiencies uncovered during simulations are usually corrected with much less expense than those uncovered during field testing.

The need to model data communications has been established for the ATCS. Modeling of data communications accomplishes two tasks. First, it ensures the different communication layers interact as expected and do not develop bottle necks. Second, it allows validation of different vendors' implementation of protocols. Currently, AAR has contracted for a simulation tester to test lower layers of data communications equipment. Recent conversations indicate this will be modified to test all layers.

Control flow specifications provide functional descriptions of certain aspects of railroad operating logic, and define how hardware and software elements of the system should interact in order to execute railroad operations. The ATCS execution of railroad operations is through applications, which are computer programs that are processing instructions to satisfy one or more of the operating procedures. Each time a dispatcher or an application generates a command, control, or information message to be delivered to a locomotive or signal, a series of events occur that are related to the message generation. Control flows are extremely complex because of the logic necessary to translate railroad procedures into events that are to be carried out by the ATCS, and because of the validation that must precede and follow-up the occurrence of each event. For example, one of the ATCS control flows describes the process by which central dispatch would issue a movement authority to a locomotive, and defines the associated messages that would be exchanged between various system processors. Correct control flow is necessary because safety can be affected by improper logic allowing a wrong translation of railroad procedures into events to be performed by the ATCS or by a wrong sequence of events to be followed by the ATCS. As an example, if control flows allow a locomotive to continue on after an unexpected transponder address is read, then those control flows may not be able to detect the potential for a collision.

A major revision of the Control Flow Specifications was completed in 1993. The control flows have become increasingly complex as system development has progressed. ARINC is working on further documentation to aid ATCS software developers.

The control flows are sufficiently important to warrant further study of the development effort. For example, individuals who write control flows should not be asked to validate them. An independent validation of the control flows or an independent simulation of the control flows should be completed. The Draper Laboratory report also noted "the exhaustive technical analysis of the ATCS system logic and the development of engineering tools to control the implementation of the system logic will serve to reduce the risk of this as an accident cause." [18]

Matrix Element Evaluation *The ATCS is a complex system that requires numerous different entities to interoperate in a dynamic situation. Simulation is a method used to assist system developers evaluate whether system components are interoperating as desired. Hardware emulation efforts are currently underway to evaluate vendor products in their compliance with the data communication specifications.*

Because of the complexity of the control flows and because correct control flows are essential to safety, ITS recommends independent modeling and validation of the ATCS control flows under a variety of operating scenarios to ensure that the system functions as intended.

5.5.2 Radio Communication Simulation

Radio communication simulation is similar in purpose to data communication simulation as described above. The radio simulation efforts are somewhat different as the radio environment and communications channel must be modeled. The radio environment simulation involves modeling of radio interference and noise. The communications channel involves modeling of varying signal levels due to the propagation conditions caused by foliage, rugged terrain, tunnels, etc., and the modeling of varying self-interference at the receiver due to multiple reflections of the transmitted signal along the path between transmitter and receiver (i.e., multipath).

Battelle has analyzed the radio environment to compare the VHF band performance with UHF [12]. Both AMCI and Rockwell have laboratory equipment to simulate the radio environment and channel.

Tests have been conducted by both organizations to determine performance of their system components.

It is reported that most of the radio traffic will be in-bound, meaning from the mobile to the base station [17]. Severe radio environments, such as the Chicago hub, exist where many mobiles may be contending for the same base station, interference from other signal sources may be greater than normal, and propagation effects due to the urban environment may be more demanding of the radio system than normal. No known simulations have been conducted for the ATCS to determine the radio system performance in severe radio environments with many mobiles contending for the base station.

Matrix Element Evaluation *Hardware simulators of the radio channel and environment have been developed by equipment manufacturers to test their system components. Analyses of radio communications in the ATCS have been completed to determine radio channel capacity under defined conditions. Simulation studies should be conducted to determine the ATCS radio system performance in severe environments with many mobiles contending for the base station.*

5.5.3 Field Tests - Range of Environments

A field test provides a situation where the proposed system is linked with live or operational equipment that the system will eventually support, while the live equipment operates in the environment that is its domain. In a field test, ultimate control usually resides with the human operators of the live equipment, allowing the operators to respond to and correct any mistakes made by the system under test. Field testing is the next step in test and validation of a proposed system after simulation studies. Laboratory hardware and computer software simulation techniques can never totally replace the environment of the live equipment.

AMCI and Union Pacific have implemented portions of the ATCS on Union Pacific track to control Work Order processing. Canadian National has attempted limited tests of the ATCS on a section of their track. Others have tested functions of the interrogators/transponders under a variety of conditions or have tested limited features of the ATCS on selections of track. Rockwell and Burlington Northern did a considerable amount of testing of the Advanced Railroad Electronic System (ARES) project on the Iron Range section of Burlington Northern track. All of these tests provide confidence builders and valuable information for improving portions of the ATCS. However, no known full-function ATCS testing on an operational field test is planned.

It is human nature to rely on the results of live demonstrations of systems in operation, beyond the simulation stage, before we humans can put faith and trust into a new system. A field test program of a fully-functioning ATCS will need to be initially demonstrated in a non-hostile, less stressful environment. The purpose of field testing is to discover and correct system problems in order to improve the system before a larger implementation begins. A system that has been demonstrated to work in a field test would next be introduced into a more hostile environment. This expanded field test is known as a pilot demonstration and is larger in scope and would probably involve a transportation corridor to demonstrate the ATCS.

On April 29, 1994, the Union Pacific and Burlington Northern Railroads issued press releases outlining their joint project to develop and test the feasibility of electronic train monitoring and control systems under what they call "Positive Train Separation", PTS. The PTS multi-year test project will be conducted on both Union Pacific and Burlington Northern tracks in Washington and Oregon, where the two railroads have connecting and parallel track. The PTS project will share many of the features of the ATCS as Union Pacific has installed ATCS-compliant equipment on much of its track, and the PTS project could have new features based upon knowledge gained by Burlington Northern with its ARES field trials.

Matrix Element Evaluation *Some individual railroads have begun testing different features of the ATCS. A coordinated effort is required to field test a full implementation of the ATCS on a section of track with typical environmental conditions. A more comprehensive field test or pilot demonstration would be required to show that the ATCS can properly function in more severe environments such as the Chicago hub or the Northeast corridor.*

5.6 Migration

5.6.1 Implementation and Replacement Plan for Each Current System (Railroad)

Migration provides for the orderly transition from one system to another. It is a step-by-step plan to phase out one system for another. Businesses rarely can shut down one system and immediately start up another. In many cases the two systems are operated in parallel. Parts of a business may convert to the new system before other parts are able to start their conversion.

The AAR/RAC has recently formed a committee to investigate migration. Discussions on migration were presented at the September 1993 meeting on the ATCS in Baltimore. Firm migration plans are still to be developed.

Migration also includes a timetable for the conversion process. The timetable accounts for the acquisition of funding, the installation and testing of ATCS equipment, and training for users of the new system.

Matrix Element Evaluation *Without a clear migration path and associated timetable, the benefits of positive train separation provided by the ATCS could be greatly delayed. The migration plan and timetable should seek to accommodate all railroads, and to encourage widespread use of the ATCS in the shortest time schedule possible.*

5.6.2 Continuous Protection During Migration

As discussed in the preceding section, systems are rarely implemented overnight to replace existing systems. Each railroad will need to operate its present safety system simultaneously with the ATCS it is implementing. After the ATCS implementation is complete and thoroughly tested, the railroad would phase out and remove its existing control system.

Different railroads may not implement the ATCS elements needed for safety, or they may not implement them on the same time schedule as other railroads that are implementing full ATCS. Because the railroad industry allows equipment of one railroad to be operated on the tracks of another railroad, a safety issue could develop if existing control systems were removed too soon.

The experience gained from the PTS pilot project will provide knowledge on how to proceed with current safety features while implementing the new safety features obtained through the PTS project. Other railroads will be able to learn from the Union Pacific and Burlington Northern experience and knowledge.

Matrix Element Evaluation *The migration plan needs to ensure that safety measures already in place are not removed before all trains that pass through the territory have suitably-equipped ATCS locomotives. Older systems and the ATCS will probably have to be operated in parallel while the ATCS becomes fully operational for all railroads providing track to other rail industry users.*

5.7 Management

5.7.1 Conflict Resolution

Conflict resolution commonly refers to situations where two or more entities claim that they control the same address or that they have the same address. For instance, two different CCs might claim responsibility for the same train. In this situation, both CCs would attempt to have traffic addressed to that train routed through each controller. Or, two trains, incorrectly identified with the same address, conceivably could be provided with the wrong commands. The system logic needs to understand how to handle these situations. Failure to properly deal with conflicts could have serious results.

The approach taken by the ATCS to handle and prevent this sort of problem is multi-leveled. The first level approach is an attempt to prevent such a circumstance. The second level is to design control flows to correct such a problem. The third level is to ensure that authorizations limit movement of trains.

Prevention is the first level and probably the most elaborate process in the ATCS's conflict resolution scheme. The address of each train, and track force vehicle is "hard coded" into the device. Hard code means that the address is non-changeable. Additionally, the reliability specifications demand that the probability of any device transmitting the incorrect address is 10^{-9}.

At the second level, control flows work to prevent such an contention through at least three different processes. First, there is an elaborate "hand-shaking" between CCs before train responsibility is provided to one of the controllers. Hand-shaking is defined as a hardware or software sequence of events requiring mutual consent of conditions prior to the change [6]. The second process involves the message information. All messages which a train sends forward contain the authority under which that train is operating. If the authority reported by the train is different from that recorded by the dispatch computer, the train should stop immediately. The third process consists of the train's on board computer checking with each switch as the switch is approached. In this manner the switch setting and the authority number are verified. Any discrepancies result in the train stopping.

The third level which helps prevent collisions in the event of some conflict between nodes is the issuance and content of movement authorities. Before a safety computer allows a dispatch computer to issue a movement authority, the safety computer records the train address (ID) and the track assigned by the authority. The computer also certifies that there are no previously issued authorities which will conflict.

Matrix Element Evaluation *The ATCS addresses the possibility of conflicts. Conflicts are expected to occur on establishing control between nodes and with improperly transmitted addresses. These conflicts are to be resolved by well-planned control flows. This demonstrates the need for the validation of control flows.*

5.7.2 Hand-off Between Nodes (Cluster Controllers)

In a communications network where some of the stations are mobile, there is a need for the system to hand-off, transfer control of a mobile station from one base station to another, as the mobile station moves. Radio-based systems add to the degree of hand-off difficulty because the signal reception can vary in amplitude as the mobile station moves. As the received signal level from the mobile transmitter varies in amplitude at two adjacent base stations, there is the potential for transferring of the mobile station back and forth between the two base stations unless some procedure prevents this occurrence.

A protocol must be established and tested that allows a smooth transfer from one base station to the other to occur as the mobile station moves. Issues such as signal strength, conflict resolution, addressing, and management responsibility must be addressed and resolved. The consequence of not establishing a proper hand-off procedure can result in unwanted responses, such as freezing trains in place, "losing" control of a train, or generating so much traffic that the system reaches congestion collapse.

Hand-off procedures are described in Specification 200, Figure R-1. In a brief summation, the base station computer/radio, called the base controller package (BCP), reports that it has detected the transmission of a data message from a train's mobile radio station. Then the BCP's cluster controller, CC (A), announces to other CCs that it is receiving train X, and CC (A) checks to see if another CC controls train X. CC (B), currently controlling the train, tells CC (A) that it is controlling train X. The two CCs check signal strength until the train is stronger in CC (A) territory. The CCs jointly control the train until the train is completely in A's territory. At this point CC (A) announces that it is now the controller of train X. The procedures defined in the hand-off specification are typical of other operations to be performed by the ATCS.

Matrix Element Evaluation *The system developers have provided a considerable effort to detail the hand-off procedure between base stations, cluster controllers, etc. The concern remains in how the procedures are to be verified in real-world circumstances.*

5.7.3 Protection from Threats

In a data communications system, a threat is any possible or conceivable intrusion into or against the system which either disrupts operations or causes the system to act in a manner other than its intended functionality. In terms of the railroad control system, a threat could be defined as anything from tampering with a switching device to breaking into the system and generating false messages. The threats may include deliberate intruders (like terrorists) or accidental ones (like careless employees). To properly address the concern of threats the user must conduct a threat analysis, evaluate each threat and then determine which threats need to be mitigated through hardware/software design or through modified procedures.

The ATCS addresses threats through a variety of different methods. A "Security Threat Summary" is contained on page 3-27 of Specification 200. Developers of the specification indicated that their threat analysis showed a very low threat probability, and further investigation is not required.

Matrix Element Evaluation *An ATCS threat survey has been conducted and potential solutions are contained within the specifications. Completeness of the threat analysis in Specification 200 can not be determined from material available to ITS. A literature search did not reveal any additional threat studies. Modeling of system performance and the potential impact of intrusions into the ATCS network could indicate a need for a more detailed threat analysis.*

6. CONCLUSIONS

The Advanced Train Control System is a development project of two railroad associations, the Association of American Railroads and the Railways Association of Canada. The ATCS' purpose is to provide enhanced control of train movement with a common set of operating procedures and system performance requirements across all railroads in North America. The ATCS implements and automates the safe operating procedures, presently practiced by the railroads, to help railroad personnel perform their responsibilities in a safe manner. The system specifications are intended to allow open competition among all vendors, while ensuring compatible and interoperable operation of the system components.

The ATCS, as a set of specifications, have been developed from a well-planned open forum of railroad specialists, system designers, and equipment manufacturers. The ATCS follows established, safe operating procedures to aid railroad personnel in their decision-making and actions in the movement of trains. The ATCS uses techniques that have been well tested by other systems to ensure the validity, accuracy, and timeliness of the data sent from the data source to the data receiver. The ATCS conducts self-tests to determine equipment faults and provides a means to recover from the failures. When the ATCS begins to fail, the system alerts the human operators of the conditions while maintaining as much of the data communications as possible. The system operates in a fail-safe manner, in the event the ATCS suffers a complete failure, operators and other components of the system are notified and the decision-making control is yielded to human operators. Finally, the ATCS will allow for expansion of capabilities as new technology or new operating techniques develop in the years to come.

A collision avoidance system provides the means of detecting and preventing impending collisions between vehicles. The ATCS has the ability to provide collision avoidance or positive train separation between ATCS-equipped trains operating on ATCS-equipped track. The significant factor in the statement is "ATCS-equipped", which can mean anything from a very limited implementation of the ATCS to a full implementation. However, anything less than full implementation of the safety features provided by the ATCS may not result in positive train separation.

Additional ATCS development effort is required, or at least desirable, in the following areas:

- The ATCS specifications implement safe railroad operating procedures through computer and communication hardware and software to assist railroad personnel in following the procedures. Those ATCS specifications which define all the steps required to carry out the procedures are called control flows. Because of the complexity of the control flows and because correct control flows are essential to safety, ITS recommends independent modeling and validation of the ATCS control flows under a variety of operating scenarios to ensure that the system functions as intended.

- Various railroads and railroad equipment manufacturers have implemented portions of the ATCS or have conducted limited tests of the ATCS system components. A coordinated effort is required to field test a full implementation of the ATCS safety features on a section of track with typical environmental conditions. The results of the testing could be used to further improve the control flows and system specifications. A more comprehensive test should follow in a more severe environment, such as the Northeast corridor or the Chicago hub. A pilot demonstration in the severe environment will build confidence in the system capabilities as well as provide information to further improve the system specifications.

- A migration plan and a timetable for full ATCS implementation is needed. The migration plan will allow for an orderly transition from present control systems to the ATCS. It is important that presently available safety features are not disabled while the ATCS is installed. The present ATCS implementation plan allows railroads to adopt any level of the ATCS they desire. As noted in the ATCS specification documentation, the ATCS will be at the lowest capability of either the equipment or track at any instant. For example, ATCS-equipped trains on non-ATCS equipped track will not provide ATCS safety; neither will non-ATCS equipped trains on ATCS-equipped track. The implementation timetable accounts for the acquisition of funding, the installation and testing of the ATCS equipment, and training for users of the new system. The timetable should seek to accommodate all railroads to encourage widespread use of the ATCS at its fullest safety capability level.

A press release on April 28, 1994, by the Union Pacific and Burlington Northern Railroads indicated the start of a joint project between the two railroads to develop the Positive Train Separation system with a pilot test program to be conducted on Union Pacific and Burlington Northern track in the Pacific Northwest. The preliminary descriptions of the joint project provide insight as to the scope of the effort. Many of the ATCS features will be retained with potential new ones added. The field tests and migration experiences will provide much of the knowledge requested in the last two recommendations listed above.

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Appendix 3

Background Note: PTC Criteria and Technological Alternatives

Chapter IV of this report describes the history of automatic train control (ATC) systems and similar safety systems (ATS, ACS) in the United States. In general, the most active phase of ATC installation coincided with high frequencies of intercity rail passenger service. A variety of ATC systems continue to be employed in the United States and internationally.

The purpose of ATC is to stop the train or reduce its speed to the prescribed rate if the crew member fails to acknowledge and/or obey the more restrictive indication within the prescribed time. These and similar systems have long been recognized as necessary to assure safe operations of trains at high speeds. Although this report uses PTC to describe a range of technology that includes signal-based ATC and other systems, contemporary ATC systems remain among the most capable alternatives to promote safety.

From a regulatory standpoint, requirements for train control in the United States are presently based exclusively on speed. The speed provisions contained in 49 CFR § 236.0 (which require ATC, ATS or cab signals above 79 miles per hour) have remained unchanged since being issued in 1947. Different speeds, both higher and lower, were suggested at the time the order was being considered. During the interim years there have been recommendations to both raise and lower the speeds. As this report was being finalized, FRA received a petition for rulemaking from a rail labor organization that would require the latter.

Train density has been suggested as an alternative criterion for deployment of PTC systems. In fact, the number and temporal spacing of train movements is employed as an evaluation criterion by FRA when railroads seek to discontinue signal systems of all kinds. Factors that may be pertinent to PTC requirements include number and kinds of trains in a specific time frame, as well as speed. Although density, as such, is not currently a regulatory criterion for deployment of ATC or other positive train control technology, it is definitely a practical consideration with respect to the cost effectiveness of more capable train control systems. Recently, for instance, the Florida East Coast Railway installed a new ATC system on its heavily used main line in Florida.

The signal and train control system characteristics required in Europe for speeds between 100 and 125 mph are broadly similar to the FRA requirement for speeds of 80 mph and over. The principal difference is that in the U.S., all trains operating on a line equipped with cab signals and/or ATC are required to meet the minimum requirements. In Europe, only high speed trains are required to meet the minimum requirements. This distinction is without meaning, of course, on those lines dedicated to very high speed passenger operation.

New train control systems in Europe, Japan and North America make extensive use of microprocessors. New applications for high speeds invariably provide for all or most of the features of positive train control. However, technical approaches differ.

On the French TGV Atlantique Line, the train operator controls the train, relying on input received from the cab signal system. Information for the cab signal system can be received from up to 18 ac audio-frequency coded track circuits. Information from the cab signal system includes the speed limit of the current block and the speed required by the end of the following block. The TGV has an automatic braking system that stops the train when the operator exceeds the speed limit.

In Germany, the ICE train utilizes computers for vital safety-critical information and control elements of the automated control system. Three operational methods are available: (1) fully automated speed control; (2) manual selection of speeds, allowing the speed control to meet the preselected speed; and (3) full manual operation, utilizing control system information on the console for guidance. Communication between the train and right of way is provided by inductive loops in the gage of the track (a communication method also employed in Austria and Spain).

European planners are working toward a network of high speed railroads that may eventually utilize a common ATC system. The extent to which lower speed lines used for mixed passenger and freight traffic might be affected by this development is not presently known.