CONFERENCE PROCEEDINGS 2

Railroad Freight Transportation Research Needs

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Railroad Freight Transportation Research Needs

Proceedings of a Conference
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Preface

More than 18 years has passed since the Transportation Research Board (TRB) undertook the first comprehensive examination of railroad research needs under the joint sponsorship of the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA). The 1975 conference report helped guide railroad research for more than a decade.

In 1992 AAR and FRA asked TRB to organize a new assessment of railroad freight transportation research requirements and conduct a national conference to help guide railroad research into the 21st century. The primary objective of this Conference on Railroad Freight Transportation Research Needs was to identify research needs, opportunities, and priorities—for both the public and private sectors—during the next 10 to 15 years. The primary focus was research needs related to the nation's freight rail network. However, passenger rail issues were included insofar as they involved common use with freight rail service or were applicable to both freight and passenger rail service.

Many factors have changed since the previous TRB assessment of railroad research needs. Congressional action in 1976 and 1980 ended much of the economic regulation under which the railroad industry had operated for almost a century. Deregulation created a new, more competitive environment in which railroads have powerful incentives to increase efficiency and trim costs. Moreover, deregulation reduced federal involvement in railroad operations and related research, shifting responsibilities for research and its funding more heavily onto the private sector. In sum, the passage of time since the last assessment of railroad research needs combined with changes in the industry and in the arrangements for conducting research made a strong case for a new assessment of railroad research needs.

FRA and AAR are the major sponsors of rail research today, although individual railroads, and to a lesser extent the railroad supply industry, also conduct research. FRA's research budget reflects its exclusively safety-related mission since deregulation. Its current research program is focused on two areas related to safety—equipment and track.

AAR conducts research on behalf of its members, the major (i.e., Class I) railroads. In 1992 its Research and Test Department engaged in a strategic planning process with railroad industry leaders from which emerged a consensus to refocus AAR's research program on improving industry competitiveness through better railroad service quality and efficiency.

A primary objective of AAR in cosponsoring the Conference on Railroad Freight Transportation Research needs was to update its current research plan. The Research and Test Department of AAR viewed this conference as the second of three steps to construct a new 1995–1999 research plan for AAR. The first step was a March 1993 conference that provided an overview of transport market trends and key opportunities for technology innovation in the railroad industry; results of that conference are summarized in this conference proceedings. The final step will be the incorporation of the recommendations of both conferences and the advice of AAR member committees into a 5-year research plan.

FRA's objective in cosponsoring the Conference on Railroad Freight Transportation Research Needs was to obtain input for its long-range research program. Specifically, FRA looked to the conference to help define needed areas of research, set priorities, and identify opportunities for potential cooperative research between FRA and the railroad industry to achieve an integrated research program that would maximize the benefits to industry, labor, and government. These inputs would be integrated with FRA's other research needs dealing with safety issues.

Approximately 130 participants attended the 2½-day conference July 12–14, 1993, in Bethesda, Maryland. Conferees composed a broad but balanced group of railroad officials, suppliers, shippers, government officials, academics, and other transportation researchers and consultants; members of the railroad trade press also attended. A follow-up meeting was held with representatives of railway labor organizations to obtain their suggestions and recommendations on research priorities. (Representatives of the following unions attended this meeting: Railway Labor Executives' Association, Brotherhood of Locomotive Engineers, Brotherhood of Maintenance of Way Employes, American Train Dispatchers Association, Brotherhood of Railroad Signalmen, Transportation Communications Union, and Transport Workers Union.) Subsequently, several of these labor representatives submitted written suggestions and recommendations, which are summarized in the Responses from Labor Representatives section of this conference proceedings. (Written comments were received from representatives of the Brotherhood of Locomotive Engineers, Brotherhood of Maintenance of Way Employes, and American Train Dispatchers Association.)

Four major recurring themes emerged during this conference: customer focus, appropriate use of information, integration among train system components and between technology and people, and the need for cooperation at many different levels—public-private, industry-suppliers, management-labor, and domestic-international.

Guided by these themes, conference participants focused on research needs in four major categories: infrastructure, including track, vehicles, and track-train dynamics; command, control, communication, and information systems; service management; and energy and environment. Safety was identified as a critical topic and considered as an element of each major category. Other cross-cutting issues, such as future market requirements, productivity and cost, human factors, and advanced technologies were also discussed, as appropriate, under each research category. Research needs were considered within the broader framework of a future vision of the railroad industry. Future trends in transportation and logistics were examined from the viewpoints of the railroad industry, the research community, and shippers to help establish this future vision and provide the basis for identification of needed research.

Commissioned papers in each research category and invited presentations on future trends in transportation and logistics provided points of departure for discussion at the conference. Conferees were organized into five discussion groups and instructed to identify key issues and areas for research under each category. Research priorities were identified within each subject area, but no attempt was made to determine priorities across subject areas.

The conference resulted in a set of significant research areas that participants viewed as critical to moving the industry forward. These research areas are described in this volume and represent a first step in defining a research program and specific research project task descriptions. Additional effort is required by the industry, AAR, and FRA to formulate and initiate more specific research plans and programs. As the process progresses, it is intended that the recommendations provided through this conference will be of significant assistance to the industry, AAR, and FRA as they define and set priorities for the direction of railroad research well into the next decade.

ACKNOWLEDGMENTS

The success of this conference resulted from the valuable contributions of many individuals who participated in a variety of functions, including the steering committee, keynote speakers, paper authors, and participants in the discussion groups. The discussion groups fulfilled the purpose of the conference by identifying priority areas for future research. Those who served as conference discussion group and subgroup leaders particularly deserve recognition: Roy A. Allen, AAR; Julie Hertenstein, Northeastern University; John M. Samuels, Consolidated Rail Corporation (Conrail); Ralph von dem Hagen, Conrail; Henry B. Wyche, Jr., Norfolk Southern Corporation; E. Thomas Harley, LTK Engineering Services; Nigel Peters, Voest-Alpine Nortrak Ltd.; Thomas Sheridan, Massachusetts Institute of Technology; Robert E. Gallamore, Union Pacific Railroad; William C. Lyman, Lyman Transportation and Logistics; Steven D. Cavanaugh, CP Rail System/Soo Line Railroad Company; and William J. Harris III, Norfolk Southern Corporation. These individuals not only provided leadership in the discussion groups but also made substantive contributions through summaries of the group discussions, which were presented at the closing conference session and appear in this proceedings.

Contents

ENERGY AND ENVIRONMENT

RESPONSES FROM LABOR REPRESENTATIVES

Summary of the Association of American Railroads Future Search Technology Conference

Roy A. Allen, *Association of American Railroads*

Railroads have only just started out on the quality journey, and achieving customer satisfaction will soon become a way of life. This new business attitude will be a driving factor in the railroads' future and will have a direct influence on technological developments.

The AAR Research and Test (R&T) Department is developing a new 5-year plan for its research activities. To begin this process, in March 1993, 71 invited participants attended a conference, Railroads in the 21st Century: Opportunities for Technological Innovation. A relatively new technique called future search conferencing was used at the meeting.

The future search technique is a carefully planned, structured workshop process. It takes advantage of highly participative group brainstorming to build cooperative, mutually supportive goals set by delegates from diverse interest groups. Each stakeholder group soon recognizes that its objectives will be best met by agreeing to a common vision of the future for the industry and working with peer groups to achieve it. Once the sense of common ground is achieved, new concepts, ideas, and the means to achieve the best of them flow. Group presentations and analysis of the key concepts promote enthusiastic support for plans and assignments that will help realize the groups' collective view of a desirable future.

Stakeholder groups at this conference consisted of customers (representing coal, grain, chemical, intermodal, and port authorities), railroads (strategic planning, operations, mechanical, engineering, and research functions), suppliers (of locomotives, cars, track equipment), academia, technical consultants, and AAR staff.

Participants began by examining the past and the present, and, using those lessons, learned to help generate a collective vision of the future of rail technology.

Customer satisfaction will be the driving force leading to the formation of multimodal, global, integrated transportation systems that provide seamless service. Scheduled, and sometimes faster, train service will be required, as will vastly improved service reliability.

Information technology and command, control, and communication technology will play major roles in providing customers, operating groups, and executive departments with correct and timely information from which effective planning, command, and control decisions can be made and executed to ensure that customer requirements are met. A number of specific recommendations were made to ensure that this goal is reached.

Increased emphasis on preventative maintenance for both track and rolling stock will be necessary to improve service reliability. Improved monitoring systems and techniques to predict maintenance requirements are needed. It was also considered desirable to build a "fit and forget" track structure that requires significantly less maintenance. The track structure and the trains that run on it must be designed with a view to optimizing performance of the whole system. Performance specifications are considered important in this system's engineering context, with a recognition of the need for performance standards to be broad enough to encourage innovation and accommodate new technologies.

Environmental issues played a major role at the conference. The need for new energy sources and power system technologies was highlighted for more efficient and cleaner systems to preserve the inherent environmental advantages of rail transportation over competitive modes.

Overall, considerable optimism was expressed for the future of rail transportation and the role that technology will play in that future. However, frustration at the relatively slow pace of technological change in the industry was expressed by many. Improved life-cycle costing techniques and better appreciation of life-cycle costing was seen by many as an essential ingredient for the acceleration of technological change.

The future search conference was the first of a three-step process to develop a new 5-year research plan for the Association of American Railroads (AAR). From AAR's perspective, the current conference, the Transportation Research Board Conference on Railroad Freight Transportation Research Needs, serves as the second step. The two conferences will provide more detailed input than is usually received in the research planning process. With the challenges that the industry faces, the research community must take full advantage of its scarce resources. Research programs need to be coordinated and be fully responsive to the needs of the industry. These conferences will play a major role in achieving that goal.

After this conference, AAR will consolidate the suggested approaches and seek further advice and counsel from its member railroads and the rest of the railroad community.

Major conclusions from the future search conference are summarized here. The opportunities for technological innovation drawn from that conference should provide important input, but certainly not the only input, to assist participants at this Conference on Railroad Freight Transportation Research Needs in achieving the goal of identifying railroad freight transportation research needs, opportunities, and priorities, for both the private and public sectors, during the next 10 to 15 years.

Lessons from the Past

The first half-day of the AAR conference was designed to determine what lessons could be learned from the past in order to better shape the future. Three aspects of the past were examined: participants' personal and professional lives, world affairs during the past 3 decades, and the history of the railroad industry.

To some extent, the three topics were linked in the minds of the participants. For instance, on the personal level, the primary theme of the discussions was survivability. The individuals, the majority of whom were in the 30- to 50-year age bracket, survived world upheavals, with the Vietnam War prominent in many minds; personal and family crises and tragedies; and major downsizing and restructuring of the railroad industry. There was a feeling that survivors tend to have a good outlook on the future. Because of their past experiences, survivors are more comfortable with the change, growth, and risk that is inevitable as the railroad industry moves into the 20th century.

In examining the industry's past, all attendees participated in an exercise to list the major events that occurred before 1973, in the 10 years from 1973 to 1983, and from 1983 to the present. One group of participants collated this list, which is presented in the appendix to this paper.

These events were summarized by another group, which titled the pre-1973 phase as Power Brokers to Broke, as railroads moved from being the primary mode of transportation in the 19th century to fighting for survival by 1973. Technology played a major role in the glory years but, despite such advances as continuous welded rail and higher capacity freight cars, could not prevent the decline in market share or financial problems. The group noted that part of the railroads' decline could be attributed to failure to perceive customer needs and that the period ended with railroads having an inward focus.

The next phase (1973–1983) saw some major restructuring [e.g., the National Railroad Passenger Corporation (Amtrak) and Consolidated Rail Corporation (Conrail)] and deregulation through the Staggers Rail Act. The industry began to do more research, particularly through cooperative industry programs, to examine specific problem areas, such as tank car safety and track-train dynamics. Modal competitive pressure continued to increase, however, and the industry was just beginning to face up to its excessively costly labor and the need for major improvements in productivity.

The same group of conference participants labeled the last 10-year period as Reinventing Our Technology, highlighted by the improved productivity as fewer employees, locomotives, and cars accomplished more ton-miles of rail traffic movement. The decade was focused on safety, energy, and the environment and, in the past few years, on technologies involving enhanced information exchange, such as Automatic Equipment Identification (AEI) and Interline Service Management (ISM). The major reinvention, however, came with the emphasis on quality and responsiveness to customer needs.

How should this view of the past affect future thinking? The consensus was that there must be a continuing emphasis placed on working with railroad customers and working toward growth through quality. Partnerships with other transportation modes will expand and railroads will leverage advantages in energy and environmental considerations to promote traffic growth. New technologies must be pursued to maintain and improve this environmental advantage.

Technology must continue to help make productivity and safety improvements. Emphasis was placed on the requirement to balance technology needs with railroad operating plans, philosophies, and strategic business objectives.

Lessons from the Present

The second day of the conference began with a brainstorming exercise to determine which areas are of most concern to the industry at the present time. The group identified nine distinct, major trends influencing the present and future of the industry:

- Focus on customers,
- Customer satisfaction,
- Reliability,
- Infrastructure performance,
- Improved system engineering—trains and rolling stock,
- Highway congestion,
- Fuel conservation,
- Organized (computerized) information, and
- Technology.

Participants then met in groups organized on the basis of their stakeholder affiliations to assess the industry's capabilities as they relate to the present and the future of the industry. Each group was charged with examining three of these trends to determine opportunities for technological innovation. The groups' deliberations are discussed in the following sections.

Focus on Customers and Customer Satisfaction

These two categories of trends are so closely related that it is appropriate to discuss them as one. It is interesting, but perhaps not surprising, to note that the stakeholder group of customers was far more critical of the current status of customer focus than most of the other groups. The customers believed that railroads still have a largely internal focus. They believed that railroads do not properly recognize their competition and that they measure performance by internal railroad standards.

One of the two groups of railroad suppliers also noted that railroads still have an internal focus, but the other industry groups were not as critical of the present situation. All other groups recognized the need for improvement, but noted that railroads are building an awareness of and focus on the customer, including moves toward scheduled train service, customer surveys, more tailored services and equipment, and the presence of railroad representatives in customer offices.

The customers and the rail industry groups were in good accord with what needs to happen in the future. Railroads must adopt an external focus and recognize customers' needs. More partnerships with customers are required. Railroads need to better understand customers' markets and the role of transportation in those markets. Railroad performance needs to be measured by customers' standards, and there was universal appreciation of the need for a seamless transportation system with the customer having only one point of contact. Technology components of this future trend will include improved service reliability, more custom trains designed in cooperation with the customer, and a closer working relationship between railroads and suppliers.

Reliability

Three groups chose to study reliability. One major problem seen by customers is that dock-to-dock times are highly variable. This group regarded consistency of service as the primary goal for the future to ensure that promised delivery times are always achieved.

Other groups agreed that reliability must be improved, with failure-based maintenance being identified as a major cause of unreliability. There is relatively little preventative maintenance being performed. Systems need to be installed, both on-board and wayside, to constantly monitor conditions to enable maintenance management programs to be installed. It was also suggested that equipment needs to be specifically designed and purchased for reliability if major improvements are to be achieved.

Terminal operations were also cited as a reason for unreliability. A need for better terminal designs and advanced terminal operations and controls was recognized. The concept of reliability also extended to information processing, with recognition of the need for improved accuracy of data and information exchange and for a common communications platform, such as ISM.

Infrastructure Performance

Five groups examined trends in infrastructure performance. The dominant theme was that the rationalization of the rail network has increased density and led to reduced opportunities for maintenance without interrupting service. Consequently, many of the predictions for the future were concentrated on ways to reduce maintenance frequency, including more robust track design (one group dubbed this "fit and forget" track), improved inspection and failure prediction techniques, and quicker, more automated track maintenance techniques and equipment. Techniques for extending the lives of bridges and for predicting those lives are required. Participants observed that current track maintenance practices tend to treat the symptoms of the failure and that far more attention must be paid to addressing the underlying causes of problems.

Track standards were another major theme. Concern was expressed that both regulatory and design standards are based on historical data and experience. It was also recognized that standards are often inconsistent and are not well coordinated with the requirements and limitations of rolling stock. Solutions for the future were based largely on the concept of developing performance standards, as opposed to design standards, with current and future rolling stock and business requirements in mind.

One other major theme was the perceived lack of life-cycle costing practices in the design of the track structure and in purchasing and maintenance decisions. More life-cycle costing tools are required.

Improved System Engineering—Trains and Rolling Stock

One of the biggest problems identified by the four groups that examined this issue is that, for the most part, current rolling stock designs are evolutionary and bound by the interchange rules. Freight cars are designed as a series of specific subsystems, and, as a result, changes have been largely incremental. Participants agreed that vehicles must be designed to meaningful performance-based standards and should be designed as total systems instead of as a collection of components. Participants recognized that locomotive design is much more system oriented and that the next logical step is to design the whole train as a system. The High Productivity Integral Train (HPIT) program is a step in that direction, as are a number of other integral train designs.

Participants noted that innovation is often driven by technology, whereas it would be more appropriate for new designs to be market-driven, double-stack container cars being a good example. Equipment can also be subject to human failure; it should be designed for flawless operation.

Other observations included the need for an improved approval process for new car designs, more use of analytical techniques in vehicle design, better life-cycle costing to allow for purchasing for quality and reliability, and increased use of concurrent engineering techniques.

Highway Congestion

Both groups that considered this subject recognized that highway congestion is increasing, particularly in urban areas, and that the highway infrastructure is deteriorating, yet pressure for larger and heavier trucks is mounting. More rail transportation is an obvious solution, but one drawback is that the public does not understand the value of rail transport. Both groups recommended a more proactive position in public policy with attempts to improve the image of railroads through public relations and through the press. More involvement in commuter rail, both on and off existing railroad property, will help to reduce highway congestion and improve the image of railroads. Continued progress in the elimination of railroad-highway crossings was also identified as an important element.

Several technological innovations were suggested for helping move highway traffic to rail. These included developing intermodal systems that are cost- and time-effective for the short hauls, increasing rail line capacity, improving access to ports and intermodal facilities, reducing railroad air emissions, and developing higher speed services.

Fuel Conservation

There are a few ongoing developments in locomotive power, but the standard is head-end power based on direct current traction motor diesel-electric locomotives. This has been the standard for many years, although significant incremental changes have been made.

The group examining this issue foresaw several major changes having a dramatic effect on fuel conservation and environmental pollution. In the immediate future, they expect alternating current (AC) traction motors and natural gas fuel to be commonplace. Distributed power applications will be the norm, with greater use of power and improved horsepower matching to adhesion. Locomotive health monitoring technology is largely available now and will be used increasingly in the future.

In the more distant future, other technologies should be closely monitored. These technologies include fuel cells and methods to recover braking energy.

Organized (Computerized) Information

The three groups that examined this topic all agreed that, although the industry was beginning to make the required changes, including the reengineering of some business processes, such as ISM, change is slow. Existing technologies from other industries should be used more extensively. Railroads develop systems or specifications for their own individual properties, whereas they should do more pooling of expertise and resources to develop common systems and standards.

For the future, the groups made a host of specific recommendations, including the following:

- Improve shipment-based tracking systems;
- Reengineer all business processes (car hire, etc.);
- Develop customer-based specifications;
- Develop systems to predict performance instead of monitoring failures;
- Normalize data in communications networks to reduce redundancy;
- Create and enforce data quality standards;
- Use expert systems more;
- Establish industry architectures for locomotive and train diagnostics, messages, and communications, including newer communications technology; and
- Integrate geographic information systems technology.

Technology

One group tackled this broad subject and concluded that acceptance and implementation of new technology in the railroad industry are slow. Software and data systems technology are underappreciated. Design specifications and standards are typically based on current technology at best and on outdated technology in many cases. The group observed that there are relatively few suppliers to the industry and little sharing of technology exists.

A number of technical successes have been implemented rapidly, including continuous welded rail, improved rail steel, double-stack and articulated freight cars, rail grinding and lubrication, and better track performance. However, many technology gaps remain. Time constraints prevented development of a full list, but a few needed developments in technology that were identified included signalling system improvements, alternatives to wood ties, planning and controls for operations and service, and electronic data interchange (EDI).

Some general areas of technology improvement were identified for the future, including increased use of artificial intelligence, automation, and robotics. Increased efforts were recommended to transfer technology from other industries (aviation, shipping, and manufacturing were mentioned), including the use of pilot projects or demonstrations. Performance specifications allowing for future technology, thus requiring expandability and flexibility, were suggested.

"Prouds and Sorries"

In this session, each stakeholder group was asked to identify the three events or trends of which it was most proud and the three for which it was most sorry. This exercise produced a long list. However, it is interesting to note that the top three "prouds" and the top three "sorries" of all the groups aggregated had similar themes. These three topics are probably of the most importance to the attendees.

The first topic was quality and customer focus. Groups that listed this topic at the top of their "prouds" list were pleased that railroads had begun the quality journey and were starting to develop an improved customer focus. Those that listed this topic at the top of the "sorries" list were frustrated that progress in this area is not quick enough and that a strong internal focus still exists.

The second topic was technological innovation. Some of the groups were proud that unit-train technology had brought about significant economies of scale and that double-stack trains had played a major role in capturing intermodal business. This view was balanced by four groups that expressed frustration that the rate of acceptance of new technologies is painfully slow.

The third topic is profitability and market share. The same groups that lauded unit-train economics of scale and intermodal growth were balanced by those bemoaning low railroad profits and low overall market share.

FUTURE

Having discussed the past and the present to identify some opportunities for the future, conference attendees met in groups of representatives from various stakeholders to develop and act out short scenario themes of what the industry would look like in the year 2013. In addition to providing entertainment, the short skits identified 12 major themes for the perceived future of the industry:

- Accurate, timely information systems;
- Multimodal, global, integrated transportation services and products;
- Improved safety and reliability;
- Sophisticated command and control systems;
- Customized equipment and materials design and use;
- Automation of equipment;
- High-performance infrastructure;
- Beneficial impact on people and the environment;
- Advanced power systems and new energy sources;
- Improved train performance with integration of rolling stock and track systems;
- Greater emphasis on moving people by trains; and
- Human resource programs, particularly for retraining and cross-training.

The third day of the conference was devoted to further examination of most of these themes, including development of a problem definition and a statement of the impact on the railroad industry. Where appropriate, an action plan was developed to begin the work of achieving these goals. Eight groups were formed; a brief overview of each group's deliberations follows.

Infrastructure

Problem Definition

Railroad professionals need to design, develop, and implement a transparent infrastructure that is a defect free, low maintenance system for long-life track. Ergonomically friendly tools and self-diagnostic equipment with automatic defect free signal systems must be developed. A long-range life-cycle cost-effective system must be environmentally friendly.

Impact on Railroad Industry

Railroad professionals must change their view of how track is purchased, installed, and maintained. This track infrastructure system will facilitate and enhance train operations and be integrated with improvements in rolling stock. The system will incorporate systematic training with automatic built-in safety tools and procedures.

The implementation of this goal will produce the desired operationally transparent infrastructure to help permit seamless, customer-responsive transportation.

Action Plan

The group determined that the primary goals should be to design, develop, and implement a transparent turnout system and transparent rail. These were the two goals with the most opportunities for advancement to "fit and forget" track structures. To achieve these goals, a series of action steps was identified that included evaluation of optimum geometry and material characteristics and development and implementation of cost models.

Rolling Stock and Materials Design

Problem Definition

Railroad professionals need to design and build equipment for the railroads and private car owners that meets the needs of the customer and enhances the customer's competitive position.

Impact on Railroad Industry

The customer's competitive position will be enhanced, totally satisfying needs while achieving the lowest overall system transportation cost (use, maintenance, first cost, fuel efficiency, track and infrastructure damage) and reducing the impact on the environment.

Action Plan

Achievement of the goal is envisioned as a four-stage process. The first would be determination of the needs of the customers, which would include formation of joint shipper-railroad-supplier teams. The second stage would require development of relevant and accurate performance standards that would ensure safe operation, not impede innovation, and promote streamlined certification procedures and processes. The performance standards must include the ability to monitor equipment condition to allow intervention before catastrophic failure. Monitoring could include use of on-board devices in combination with wayside or shop equipment and software embodying algorithms that predict failure of components. The third stage would include further development of analytical tools to determine the lowest overall system cost over the life of the equipment and assessment of nondollar quantifiable and qualitative impacts. The fourth stage would involve development of a system to track components on cars, such as wheels, bearings, side bearings, brake equipment, and the like, in order to monitor their maintenance history.

Improved Trains

Problem Definition

The industry needs to develop a strategy to integrate and implement improved technology and materials in trains to maximize customer and railroad economic performance.

Impact on Railroad Industry

A customer-focused process should be developed to rapidly respond to market requirements and opportunities for improving and designing trains (locomotives and cars) and their associated systems (electric brakes, trucks, etc.) with consideration of the track. (Market is defined here as including economic, safety, customer, and environmental considerations.)

Action Plan

A multistep process was suggested to achieve the goal, beginning with determining customer needs. Next steps are to determine a finance and risk-sharing plan (including effective life-cycle cost models) and eliminate barriers, which includes developing strategies to minimize liabilities.

Other steps recommended include developing a systems integration plan (trainline data standard, interfaces for condition monitoring) and a plan to optimize the train and system dynamics through development of performance specifications. Finally, it will be necessary to develop a general implementation strategy, one that includes a rapid approval process.

Commuter Rail

Problem Definition

The industry needs to expand existing commuter service and develop new starts to decrease reliance on automobiles and the highway congestion and pollution that results from that reliance. Railroads must compete with automobile alternatives in cost, speed, reliability, convenience, comfort, and security.

Impact on Railroad Industry

The impact on the railroad industry involves the following:

- Opportunity to share costs;
- Liability issues;
- Integration of freight and commuter operations;
- Dealing with public agencies, municipalities, and regulations;
- Additional staff; and
- Customer service (recognizing that people are not a commodity).

Action Plan

A rail passenger research conference should be convened to develop a research agenda for the passenger rail industry. A plan was also suggested for increasing government support for long-term commuter rail capital and operating subsidies at federal, state, and local levels of government.

Command and Control and Information Systems

Problem Definition

Customers and carriers do not possess or effectively share the information needed to plan and execute reliable seamless service.

Impact on Railroad Industry

Provide the customer, operating groups, and executive departments correct and timely information from which effective planning, command, and control decisions can be made and executed to ensure that customer requirements are being met. This will satisfy customer requirements by making systems more effective and efficient, which will result in regained market share.

Action Plan

After considerable discussion, it was decided that the group could not develop a cohesive action plan on its own without close cooperation with activities already under way. Thus it was proposed to form a task force (or incorporate into an existing task force) to define an institutional and conceptual framework and a program to achieve the long-term goal.

Integrated Transport Systems

Problem Definition

How to create a global, integrated, multimodal distribution system in which a customer contacts one person or identity that takes responsibility from origin to destination for a given movement.

Impact on Railroad Industry

The impact on the railroad industry involves the following:

- Larger market shares,
- Identification of legal issues,
- Financial requirements (e.g., lease or buy),
- Relations between labor and management,
- Lower total costs,
- Cooperation with current and future competitors,
- Bridging international boundaries,
- Command and control of equipment, and
- Risk and liability issues.

Action Plan

It was suggested that AAR conduct a study to benchmark other global, multimodal transportation company processes, such as in the airline industry and Federal Express. The major responsibility lies with railroads to develop corporate strategies for the future.

Energy Sources and Power Systems

Problem Definition

Transportation systems that are powered by safe, reliable, more efficient, cleaner sources and that have lower life-cycle costs are needed.

Impact on Railroad Industry

In the evaluation of the impact on the railroad industry, the following topics were discussed: global competitiveness, better environmental citizenship, increased autonomy (operationally), and improved service reliability.

Action Plan

The group recommended evaluating an array of potential power sources, including electrical, solar and wind, fuel cells, flywheels, natural gas, hydrogen, linear induction, coal, and other alternatives. The plan included developing a program and funding for research and potential demonstration projects and implementation. It was recognized that external funding sources would be needed to advance many of the technologies.

People and the Environment

Problem Definition

The short- and long-term adverse impacts of railroad operations on people and the environment need to be assessed and reduced. "People" includes all persons in contact with or affected by railroad operations—employees, customers, and the public.

Impact on Railroad Industry

Railroads need to differentiate between (a) routine air emissions, wastewater discharges, and the generation and disposal of solid and hazardous wastes and (b) occasional, or nonroutine, release to the environment of hazardous materials and oil as a result of spills and derailments. Both routine emissions and discharges and occasional releases have the potential for adverse impacts on people and the environment.

Action Plan

The group determined a need to ensure that new equipment and operations are reviewed for short- and long-term environmental and safety impacts to prevent further problems. It was noted that most current activity is associated with fixing or correcting current problems. A research and development review process is needed to identify potential human and environmental impacts of proposed equipment and operational changes.

SUMMARY

The dominant theme of the conference was clearly the rapid movement toward much improved customer focus and the need to continuously satisfy customers' needs. Participants were convinced that railroads had only just started out on the quality journey and that achieving customer satisfaction will become a way of life. This new business attitude will be a major driving factor in the railroads' future and will manifest itself in many ways. These manifestations will include the following:

- Formation of multimodal, global, integrated transportation systems to provide seamless service to customers;
- Scheduled train services and vastly improved service reliability;
- Faster trains in some cases; and
- More joint customer-railroad-supplier teams to ensure that customer expectations are met or exceeded.

Information technology will play a major role in providing the seamless service that customers need. Although the industry is beginning to make the required moves, including reengineering some business practices by methods such as ISM, change is slow and there is much to be done. A number of specific recommendations were made, including enforcement of data quality standards, improved shipment-based tracking systems, and development of systems to predict performance instead of monitoring failures.

It was recognized that command, control, and communication technology is closely linked to the information technology requirements. In that regard, systems are needed to provide the customer, operating groups, and executive departments correct and timely information from which effective planning, command, and control decisions can be made and executed to ensure that customer requirements are being met.

More preventative maintenance activities and procedures will become common if railroads are to achieve the service reliability performance that customers will demand. This theme was present in both track and rolling stock discussions and provides for major technological opportunities in continuous monitoring of track and equipment. This monitoring should not be to merely detect failures but should become part of overall systems to determine optimum maintenance practices and schedules to prevent failures. The use of expert systems was a recurring theme in these discussions. Concern about bridge life and recurring maintenance on other parts of the infrastructure resulted in the determination that the track structure must be designed to last longer. This concept was named "fit and forget" track structure.

System engineering practices were regarded as an essential part of the future of railroad technology. Freight cars need to be designed as systems instead of as a collection of separate components. Trains need to be designed as systems to achieve optimum locomotive and freight car performance. The whole track and train system needs a better systems engineering approach, with each being designed with an appreciation of the need to optimize the whole system. More moves toward performance standards were predicted, particularly performance standards broad enough to encourage innovation and accommodate new technologies. Those performance standards should be driven not necessarily by technology but by the market and by customer needs.

Environmental issues also played a dominant role in the conference. Although it was recognized that rail transportation has inherent environmental advantages over its main competition, there was a strong feeling that the industry needs to be more proactive in exploiting this advantage. Railroads need to better identify potential human and environmental impacts of proposed equipment and operational changes. They need transportation systems that are powered by safe, reliable, more efficient, cleaner sources with lower life-cycle costs. A number of technologies were listed as being worthy of consideration, including electrical, solar and wind, fuel cells, flywheels, natural gas, hydrogen, linear induction, and coal.

Partly because of environmental concerns caused by extreme urban congestion, increased participation by freight railroads in commuter rail operations is anticipated.

Overall, considerable optimism was expressed for the future of rail transportation and the role that technology will play. There was a strong recommendation to ensure that advanced technologies, such as new materials, robotics, automation, expert systems, and others developed in nonrail industries, were monitored and adapted as appropriate to provide implementable products.

Despite this optimism, a certain amount of frustration was expressed at the relatively slow pace of technological change in the railroad industry. Improved life-cycle costing techniques and a better appreciation of life-cycle costing were seen by many as essential ingredients for the acceleration of technological change. These improved costing techniques are needed by researchers, manufacturers, and railroads to better determine the true value of different technologies.

Appendix: Major Events in the History of Railroading

1830–1973

Regulation and Government

Regulation as a result of monopoly excesses (robber barons)
Track safety standards
Mergers, culminating in Penn Central merger
Overbuilding of the system
Government control during World War I
Northeast Rail Crisis (3R Act)
Amtrak
New York City Hudson River Sloop Association Suit Croton/Harmon
Formation of U.S. Department of Transportation, Federal Railroad Administration (FRA), United States Railway Association

Technology

Coal to diesel
Locomotive tractive effort increased greatly from 1900 through 1920
Woodard's super power locomotive concept
Air brakes, steel cars, automatic couplers
Heat-treated rail, welded rail
Increased size weights, Big John Hoppers
Beginning of intermodalism
Computers

Research

Primarily asset based
Wheel/rail contact theory

Customers

Internationalization of markets (iron and steel)
Declining market share
Lost segments of traffic (railway express, passenger, high-value freight)

Environment of Transportation

Military management of railroads during World War I (physical and fiscal exhaustion)
Heavy industry dominant in economy
Oil crisis, rising costs of fuel, alternative fuels

Construction of Network

Standardization, Pennsylvania Railroad first member of ASTM (American Society for Testing and Materials)
Standard gage, standard coupler
Railroads first major user of steel
Industrial revolution aided by railroad construction

Expansion of country due in part to railroad construction
Maturity and maintenance as result of exploration, innovation, and expansion

Management

Adversary relationship with labor, shippers, government, and public (which contributed to decline) caused by institutionalization of management attitude and culture

Operations

Unit trains
Intermodalism

Financial

Strong road/weak road
Periodic waves of bankruptcies
Penn Central collapse

Competition

Rise of alternative modes
Interstate highway system

Environment

"Explosive" derailments involving jumbo tank cars

Labor

Strong unions
Firemen eliminated (but slowly)
Failure of American Railway Union, rise of craft unions

1973–1983

Regulation and Government

Slurry pipeline alternative rejected
Deregulation
Resolution of Northeast Rail Crisis (Amtrak, 3R, 4R, Northeast Rail Service Assistance and Staggers Acts, better abandonment procedures)
Megamergers
Incentive per diem
Loss of political clout due to loss of passenger business and declining employment
Ronald Reagan elected President of the United States
National Institute of Occupational Safety and Health work practices guide

Technology

Automatic car identification
Data processing automated, mature applications

Continued implementation of continuous welded rail
Point-to-train radio
Mid-train power
Advanced passenger train (British Rail), turbo train (United Aircraft Corporation), light-rapid-comfortable (Bombadier)
Train II
10-pack articulated cars, first double-stack cars

Passenger

Survival of Amtrak
Commuter rail funded by government agencies

Customers

Continued decline of market share
Western low-sulphur coal
Rail primarily a freight carrier
Rise of "new wave" logistics
Containerization, growth in intermodal and automobile traffic
Beginning of domestic containerization

Environment of Transportation

Arab oil embargo
Grain embargo
Depression in supply industry
Rise of Pacific Rim trade

Management

Recognition of inefficiencies
Boom and bust cycle in car construction
Holding companies and divesting nonrail components
Reduction of car fleet
First attempts at quality

Operations

Rise of intermodalism
Growth of 100-ton cars
Track structure overloaded

Financial

Modest positive reaction to deregulation

Competition

Trucking deregulation
Trucking technology
Advanced truckload firm

Research

Revitalization of rail research
Bill Harris at AAR R&T
Freight Car Utilization Program
Transportation Test Center
HPIT
Electrification studies
Track-train dynamics
Reduction in railroad staff and reliance on AAR and suppliers
AAR affiliates program

1983–1993

Regulation and Government

Megamergers
Short-line sales
Cabooseless operation
Power and budget given to FRA
Conrail privatized
National Transportation Act in Canada
U.S. Department of Defense and National Aeronautics and Space Administration spinoffs

Technology

Tangent track lubrication
Harder rail
Improvements in supply industry
AC locomotives
Heavy Axle Load–Facility for Accelerated Service Testing (HAL-FAST) testing
AEI
Spread of car scheduling
End of train devices
Better car tracing
Centralized car management systems (reload project)
Solid state centralized traffic control

Research

Interline Service Settlement and Rate EDI Network (error-free rate project)
ISM
Advanced train control systems
HAL-FAST operations
FRA and Occupational Safety and Health Administration (OSHA) standards review
On-board heat detection

Passenger

Commuter rail returns

Customer

Double-stack explosion
Continued loss of market share to truckers
High-quality service demanded

Environment of Transportation

North American Free Trade Agreement
EPA standards (Clean Air Act, Clean Water Act)
California diesel emissions standards
Recognition of infrastructure problem
FRA, OSHA
Reorganization of supply industry
Public concern about hazardous materials

Management

Downsizing
Short lines and regional railroads
Rationalization
High-speed intermodal
Productivity improvements
Evident returns to better management
Focus on quality and customers
Reorganization, new ways of doing business

Operations

Multipurpose double-stack service
Traffic shifted by trucking companies to rail
Better use of equipment

Labor

Crew consist and work rules improved

FUTURE TRENDS AND VISIONS IN TRANSPORTATION AND LOGISTICS

Railroad Chief Executive Officer's View

James A. Hagen, *Consolidated Rail Corporation*

Recently I saw a bumper sticker that read "Railroaders don't die . . . they just lose track." Well, I thought, that is something to look forward to. Then as I moved from the personal level and thought about the play on words a little more, I thought that "railroads" could be substituted for "railroaders." An examination of the past 3 decades reveals that the railroad industry, if nothing else, has been a survivor, and, in a literal sense, it certainly has lost track—26 percent of it went away during the 1980s.

What does that have to do with technology and what railroads ought to be investigating for the future? When I saw that bumper sticker, it did not take any great leap to reflect on the combination of factors that have shaped the recent history of railroads and brought them to where they are today: a survivor, a lean competitor, and a shadow of the former self in the physical dimension. All of the factors that have contributed to defining what the industry is today may be grouped under one heading: competitive necessity. Technology, born of that necessity, is what has gotten railroads in the game today, and it will be technology, born of competitive necessity, that will determine how well railroads compete in the future.

My railroad career, which began on the Missouri Pacific in 1958, has coincided with the development and expansion of one of the most significant public works projects in the history of the world and a significant factor in the erosion of railroad traffic during the past several decades—the U.S. Interstate highway system. That system has created competitive necessity for railroads, and competitive necessity has been the principal driver of technological development in the railroad industry.

The single thought I want to leave with participants at this Conference on Railroad Freight Transportation Research Needs is that with all the change that has occurred and with all the change that will occur in the future, the one thing that will not change is that competitive necessity will remain the principal driver of where technology dollars are invested. I can think of no better focus for research and development, no better way to keep scarce resources focused on what it takes to keep and attract new customers.

I would like to help define the competitive necessities that are driving technology decisions today and for the years ahead. They fall into two broad categories.

First is technology driven by the need for improvements in efficiency and productivity. This is based on the need to continuously get more from the substantial investment in physical assets. Productivity improvement is not new territory; it has been the principal driver of the success of railroads during the past 10 years. It has enabled them to reduce costs and remain competitive. The need for technologies that improve productivity will not lessen in the future. It will continue to be driven by competition and public policy.

The second major competitive necessity that defines the technology priorities of railroads is external. It is driven by customers' continuously changing expectations, which are based on the increasing demands placed on them by their customers. This challenge is a relatively new phenomenon. It is driven by increasing global competition, and its effects may be summed up in two words: time compression. This encompasses the responsiveness of railroads to specific customer needs; their ability to provide timely accurate information about that service; and their ability to make timely decisions to bring new service products to the market quickly.

Customers want all of these things faster, and they want them without the complexity that has typically hobbled their relationships with railroads in the past. Managing time compression is as much a people and cultural challenge to the railroad business as it is a technology challenge, and it is one that plays a growing role in railroads' success in the marketplace.

Let us start with productivity. The need here is still based on a simple premise: railroads own and maintain their plants; trucks just pay when they use theirs. Consequently, many of the technology needs of railroads have been driven by the need to have a first-class track structure, to get the necessary economies of scale, and to be able to build and maintain the physical plant at the lowest possible cost—all critical to their competitiveness. Consider the advanced signaling systems that have enabled effective operation over single- and double-track railroads. Consider the role of computers in dramatically improving the use of locomotives and freight cars.

At Consolidated Rail Corporation (Conrail), if locomotive use levels had remained at 1980 levels, an additional 800 locomotives would be necessary today—at a cost of \$1 million to \$2 million each. Given that cost, the importance of full use and its effect on the cost structure are apparent. The same holds true with freight cars. In just the past several years, the equivalent of 40,000 additional open-top hopper cars has been created by improving the loading and unloading of these cars. Considering what it costs to build a mile of new railroad, the importance of technologies that permit high-density operations over single-track railroads is clear.

If you think the Interstate system is yesterday's news and that railroads have already accounted for the competitive advantage of truckers, you are wrong. A public policy issue quickly coming to the forefront is the National Highway System. According to the authorization in the Intermodal Surface Transportation Efficiency Act of 1991, this system will be a highway system approximately 155,000 mi long, presumably built to Interstate standards, which will include the existing 42,000-mi Interstate system, 17,000-mi Strahnet defense system, and 5,000 mi of commercial corridors identified by the U.S. Congress. The system will generally be an upgrading of existing principal arterial highways.

This is a crossroads issue for the railroad industry. Tripling the existing Interstate system at public expense obviously has significant productivity implications for truckers. This creates competitive necessity. It also emphasizes the importance of continuing to focus on technologies that will allow railroads to get more from their track and equipment at the lowest possible cost.

One of the latest developments, alternating current traction locomotives, is an example of a technology that can help railroads operate with fewer units and at a lower maintenance cost.

Another example is that, in many cases, rail "fatigues" before it wears out, as a result of cracks or Sperry car defects. Railroads have to find the technologies, the science, that can be used to identify the cause of these types of defects. What causes these cracks? What is it in the science that does not permit the rail to be worn out? It is not sufficient to just run Sperry cars. The causes must be found, and the environment that keeps railroads from maximizing their use of this costly asset must be eliminated.

One competitive necessity is productivity improvement, which is an internal necessity. It is driven by railroads' competition and by an ever-challenging public policy environment, and it is focused on cost structure, for which the record of improvement is good.

However, that is no longer sufficient. The industry is not going to make it on cost reduction alone. Railroads cannot continue to succeed just by getting smaller—by "losing track," if you will. The number of miles of track was reduced by 26 percent through the 1980s. Current employment in the industry is less than half what it was in 1980. However, during that period, railroads still lost market share to trucks, as the railroad industry remains one struggling to earn its cost of capital. Without more attention to the revenue side, without the ability to provide a product superior to what the trucks can offer, and the ability to bring it to the market quickly, railroads will be a thing of the past before long.

That is competitive necessity. It is driven by customers' ever-changing, increasingly demanding expectations, and that is what I have called the challenge of time compression.

I think all in the railroad industry are beginning to recognize the market forces at work now that are making this need to manage time compression pretty compelling.

Regional and global competition is increasing and will continue to increase. No longer will any one country have a corner on anything. As a result, marketing and sourcing patterns are changing and will continue to change. Artificial trade barriers are falling. The United States–Canada free trade agreement already is stimulating cross-border investment and changing traffic flows in both countries. New manufacturing growth in the Pacific is moving to Southeast Asia from North Asia, creating new options for reaching North American markets.

The point is this: as world trade increases, change will accelerate, and options will proliferate. That is a new reality with as much meaning to railroads as to their customers. Railroads must be able to be as responsive to new needs in the market as their customers must be.

Railroad customers are confronted with a widening array of choices about which modes to use to access which markets. They are looking to railroads to help fashion the answers to logistics problems of growing complexity. Clearly, this has compelled railroads to develop a new sense of their role in the marketplace—what services they ought to provide, and how to provide them effectively. If railroads are to be a player, they must listen to their customers, help them anticipate their needs in the market, and respond quickly with the services and equipment to meet those needs.

Railroads are learning that time must be considered as a resource as precious in their competitive environment as the creativity of their employees or their investment capital. Time has value. The ability to innovate is useless without a sense of urgency and a coordinated approach to bringing those ideas to the marketplace.

Making decisions about product development and new equipment designs on a shorter cycle means that railroads can be in the market ahead of the competition. It means that they can be more flexible to changes and move to take advantage of opportunities before they disappear. It is the only way they can expect to be successful and to increase their revenue base. It is the only way to satisfy customers under the pressure of global competition.

More demanding customer requirements mean that change cannot occur slowly, one railroad at a time, but that consistent levels of quality and technology must be pursued and maintained across the entire industry.

The opportunity will not be realized if just a few railroads embrace quality improvement, or if new technologies are applied inconsistently. Railroads have always recognized their interdependence, but always with a high degree of independence. It has always been recognized that railroads' collective performance could be only as strong as the weakest link. That was always a convenient excuse for underperformance. It was always "the other guy" who had the problem. Pointing the finger at the other guy will not achieve success in this competitive world. The seamlessness that railroad professionals have all talked about so much means that they must help one another succeed.

The management of time compression has provided new opportunities for transportation companies to work cooperatively. Many railroads are beginning to focus on the same issues in similar ways and in many cases are working on these issues in partnership with others or as an industry. Automatic equipment identification is a good example of an industry initiative based on the need to improve the management of time—to speed the flow of good information—out of market necessity.

More must be done, however, if railroads are to overcome barriers that traditionally have kept them a collection of separate islands handing off freight to one another. The concept of seamless service needs to be taken more seriously, in both physical operations and information flow. Railroads must apply the information technology that will enable them to make the traditional barriers between railroads smooth and invisible to the customer who wants single-system service no matter how many railroads are involved. Railroads need to take the historic complexity of dealing with multiple railroads and create simplicity for the customer.

When the customer calls, it is not good enough to say, "Oh, that's not my problem; the shipment is moving on the Union Pacific now." If the railroad has touched the shipment, then it has to be able to answer to the customer on the first phone call, no matter where the shipment is in the pipeline.

This simplicity is expanding throughout the industry as information systems alliances are created. The industry's Rate Electronic Data Interchange (EDI) Network and Interline Settlement System are well into development and are scheduled for implementation in 1994. Railroads are creating simplified pricing, single-source information on shipment status and more accurate and efficient back office functions in billing and claims.

Following are two examples that demonstrate how dependent railroads are on each other, both for providing successful new services and for backing those services up with free-flowing information.

To provide guaranteed interline rail service for Ford Motor Company, all of the carriers involved need to be aware of where Ford's cars are at any point in time. As a result, Conrail and several of its rail partners had to work together to transform a system that transmitted car status and waybill information only one step ahead of the car into a system that broadcast that information to all of the carriers involved at the time cars leave their origin. This way, the destination carrier responsible for delivering the cars can track their progress.

In another example, several rail carriers have begun working with J.B. Hunt to move Hunt trailers in rail intermodal service, with Hunt drivers handling local pickup and delivery. Before Conrail or Santa Fe or any other carrier could move the first of Hunt's trailers, they needed to develop the ability to communicate with Hunt—via EDI—in the electronic language of the trucking industry, a language railroads had never used before. Without that capability, there could be no business. Railroads have achieved that capability to meet Hunt's needs.

Achieving true seamlessness requires more than information technology; it involves physical assets as well. Equipment designs need to meet customers' logistical requirements. That may mean automated loading and unloading, improved ride quality, or other features that provide damage-free delivery.

Furthermore, if the physical plant is not in top-notch shape, railroads cannot provide the reliable service customers expect. Another term that goes with seamless service is "transparent" physical plant. It must be there. It must work every time. It must never get in the way of the ability to provide transportation. The railroads of the future will learn how to apply science to achieve a more productively maintained, transparent physical plant.

Let us now turn from technology to people. In the competitive world described here—in this era of time compression where railroads must stay on top of customer expectations and be able to respond quickly—the only way to bring the right technology to the right place at the right time is to have all the people in the railroads working together toward that goal.

That is why emphasis on total quality and continuous improvement is so important. Most railroads have developed some form of total quality initiative. Conrail's is called Continuous Quality Improvement. The goal is to replace the traditional top-down, hierarchical style of management with one based on the participation of knowledgeable employees close to the customer. This is key to creating railroads that can respond rapidly to customer needs.

Railroads need to be serious about total quality. Only those organizations that not only talk about it, but practice it, will make it in this world where quality and value are all that count in a product. It no longer matters where the product comes from. The practice of continuous improvement cannot be limited to the Chief Executive Officer or the Vice President of Marketing; it must have the participation of everyone, for that is where the real power to make a difference for customers lies.

In summary, I am optimistic about the future of railroads. I believe that railroads now have greater opportunity to improve quality and to apply technology to improve the product than does the trucking industry. However, they are not there yet. It is up to railroad professionals to move change forward. The changing needs of customers must constantly be anticipated and met. Customers must remain the focus. If technology does not meet the test of competitive necessity, if it does not get at those root causes that will help railroads improve productivity, improve use of their assets, or help them meet real needs in the market, they cannot afford it.

If railroads change, if they make a commitment to quality, if they listen to their customers, and if they rely on the participation of their employees, I believe they opt for something new and invigorating for the industry: satisfied customers and revenue growth.

Research Community's View

Dean Wise, *Mercer Management Consulting*
Bernard J. La Londe, *Ohio State University*

The purpose of this paper is to highlight several important internal and external trends that will affect the future position of railroads and to identify research issues that must be addressed to develop additional, ongoing insights on rail industry initiatives, customer requirements, and the outlook for rail industry market share and financial performance.

Two perspectives are presented: Rail Vision 2000 and Seven Propositions about Transportation and Logistics Change. Rail Vision 2000, an analysis conducted by Mercer Management Consulting for the Association of American Railroads (AAR), examines how changes in railroads' cost and service position could affect shippers' total logistics costs. Seven Propositions about Transportation and Logistics Change uses findings from a recent Ohio State University (OSU) survey to identify several logistics relationships with the customers of railroads.

Rail Vision 2000

The purpose of Rail Vision 2000 was to develop a realistic vision for the U.S. rail freight industry that reflects emerging and potential innovations in technology and management practices, the influence of these innovations on the railroads' "product" (transportation service), and the ways in which the enhanced product would benefit existing rail customers and potential new rail customers. AAR was interested in comparing the shipper benefits from Rail Vision 2000 to the potential shipper benefits from longer combination vehicles (LCVs)—primarily twin 48-ft and triple 28-ft trailer combinations—if they were allowed nationwide.

To develop Rail Vision 2000, Mercer needed to answer four questions:

- What are the key innovations emerging, spreading, or envisioned in the rail industry?
- How will the innovations change the rail "product"?
- How will shippers respond to the new product and how will they benefit?
- How do the benefits compare with benefits from LCVs?

Analyzing these questions involved a variety of techniques, starting with qualitative reviews to identify and categorize a wide range of industry initiatives, then translating them into quantitative impacts using several cost models, a market share model, and the AAR's mode volume data base.

Data from 1990 were used as a base to show how 1990 rail costs, market share, and shipper logistics costs would have changed if the emerging innovations could have been realized in 1990. This approach focuses on and isolates the impact of innovations driven by the railroad industry and their motor carrier competitors, without the complications of cost inflation, overall economic growth, and changes in traffic mix. In this way, the approach reflects what railroads could reasonably accomplish on their own before consideration of the impact of external forces, many of which railroads cannot control.

Key Initiatives and Their Impact on Railroad Productivity

More than 25 key initiatives were identified that will have a significant impact on the railroad industry's productivity and service in the 1990s. These initiatives were grouped into six major categories and quantified in terms of their impact on 1990 costs. The results, shown in Figure 1, indicate total savings of nearly $5.5 billion, or approximately 20 percent of total 1990 costs. The six categories are discussed in the following paragraphs.

- *Door-to-door service management.* Savings of $1.4 billion will result from industry-wide service management (both single line and interline), more sophisticated equipment management systems supported by automated equipment identification (AEI), and the evolution of advanced train control systems (ATCS). As a result, the industry will save 7 percent in fuel costs, achieve 15 percent better use of equipment, achieve 6 percent better use of locomotives, and improve train crew productivity by reducing overtime and arbitrary payments.
- *Track of the future.* Savings of $0.5 billion will result from wider use of concrete ties, widespread rail grinding, improved locomotive and car technologies that will reduce track wear, and better maintenance-of-way (MOW) scheduling.
- *Locomotive of the future.* Savings of $2.2 billion will result from use of larger horsepower units, expansion of alternating current (AC) traction, use of liquefied natural gas fuel (which is 30 percent cheaper than diesel), and use of in-cab electronics to monitor locomotive health.
- *Carload system of the future.* Savings of $0.2 billion will result from use of larger bulk cars, steerable trucks, widespread flange lubrication to reduce wheel wear, and electronic braking systems.

Major Element	Key Initiatives	Savings vs. 1990 *($MM)*
Door-to-Door Service Management	Interline service management (ISM), equipment management, AEI, work order automation	$1,390
Track of the Future	Concrete ties, rail grinding, loco/car technologies, MOW scheduling	498
Locomotive of the Future	4,000-5,000 HP superunits, AC traction, LNG fuel, train crew consist, in-cab electronics (ICE)	2,165
Carload System of the Future	Larger bulk cars, steerable trucks, flange lubrication, electronic braking systems	160
Intermodal System of the Future	Double-stack, RoadRailer, equipment management, drayage management	488
Customer Relations and Administration	Centralized rating and billing, Rate EDI Network (REN), G&A process reengineering	782
	Total Savings	$5,483 20.3%

FIGURE 1 Key initiatives of Rail Vision 2000.

- *Intermodal system of the future.* Savings of $0.5 billion will result from further expansion of the double-stack network and RoadRailer; better management of trailers, containers, and chassis; and better coordination to improve the interface with drayage companies and reduce terminal land requirements.
- *Customer relations and administration.* Savings of $0.8 billion will result from continued centralization of rating and billing activities, introduction of the Rate Electronic Data Interchange (EDI) Network, and reengineering and automation of general and administrative processes.

Impact on Other Shipper Logistics Costs (Existing Rail Users)

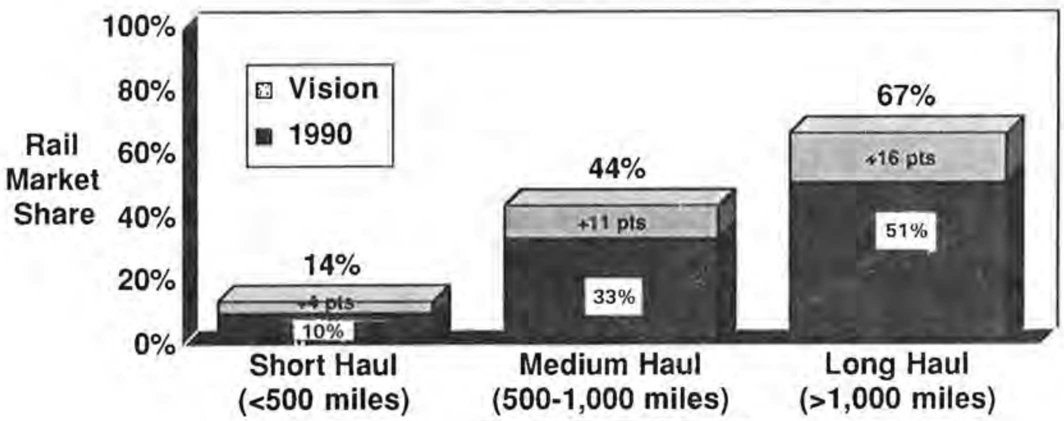
The Rail Vision 2000 initiatives will not only improve the productivity and costs of railroads, but will also improve service in several ways. With faster, more reliable transit times, improved billing accuracy, increased use of EDI, and better multimodal coordination, the railroads will generate other savings for shippers in inventory, record keeping, private railcar fleets, and the nonrail portion of intermodal (local drayage costs and third party fees). These improvements in product quality translate into an additional $2.3 billion in savings to existing (1990) rail users, as shown in Figure 2.

Impact on Rail Market Share and Volume

Improvements in the cost and service position of railroads will also attract new business. Assuming that half of the productivity savings of railroads are passed to shippers and that the speed, reliability, and administrative ease of service are improved, railroads could increase volume by more than 30 percent through market share gains. For example, as shown in Figure 3, the increase in share of medium hauls from 33 to 44 percent represents a 33 percent increase in volume. Overall market share (all mileages) would increase from 40 to 53 percent, a 32.5 percent increase in volume. About two-thirds of the increase would be intermodal; one-third would be carload. The increases would occur at all lengths of haul, as shown in Figure 3.

Service Element	Vision Assumptions	Savings for Current Shippers *($MM 1990)*
Door-to-Door Transit Time	One day off intermodal and non-unit train carload moves	$828 inventory
Door-to-Door Reliability	Intermodal from 80% to 95% Carload from 60% to 90%	792 inventory
Billing Accuracy	Intermodal from 90% to 95% Carload from 85% to 95%	150 clerical
Shipper Ordering Costs	Reduced from $25/CL to $20/CL	91 clerical
Private Equipment	Larger bulk cars, better utilization	220 equipment
Intermodal Drayage/Third Parties	Improved service management and automation	225 purchased services
	Total Savings	$2,306

FIGURE 2 Service improvements and logistics cost reductions expected from Rail Vision 2000 initiatives (CL = carload).



Total New Ton-Miles (B)	
Intermodal	60.4
Carload	40.4
Total	100.8

FIGURE 3 Increased market share expected from improvements in cost and service position of railroads (rail market share of 1990 intercity nonbulk rail and rail competitive truck ton-miles).

Summary of Benefits to Shippers

The benefits to railroads and to existing and new rail users if Rail Vision 2000 is achieved are shown in Figure 4. The railroad and shipper cost savings for existing rail traffic would be nearly $8 billion, and nearly half of the savings realized by current shippers would come from "cost of quality" improvements (inventory, clerical, etc.). New rail traffic that converts from truck would actually pay a penalty for these cost of quality items, but these penalties would be more than offset by savings in direct transportation expense, netting to a total savings of $2.3 billion.

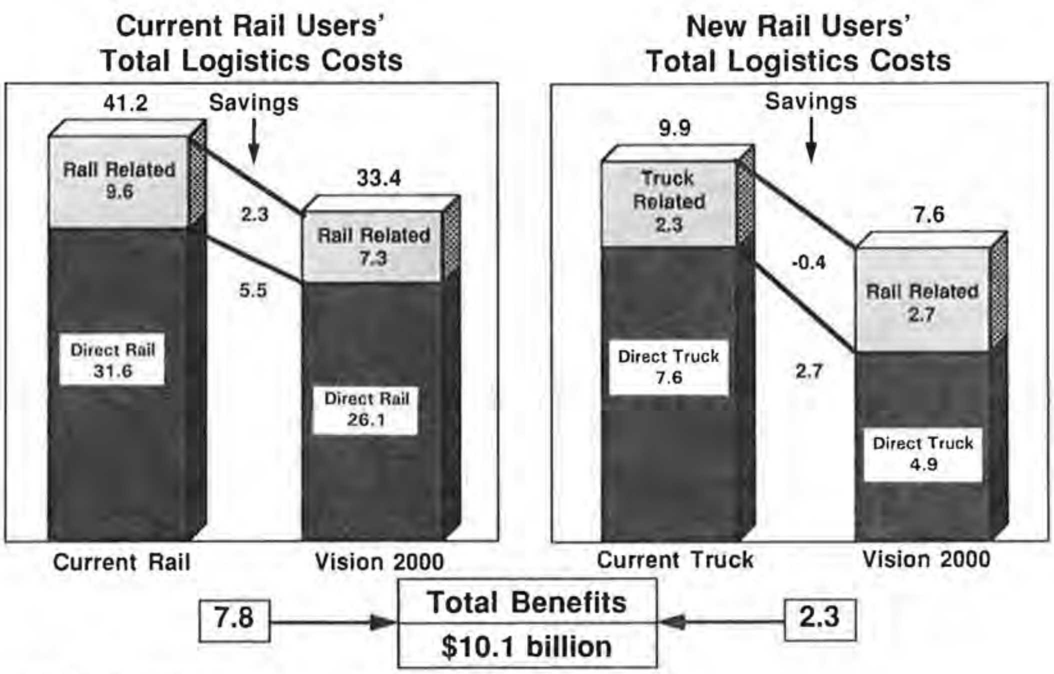


FIGURE 4 Value of benefits [1990 $ (billions)].

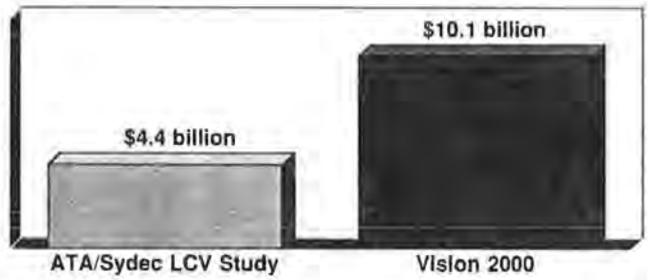


FIGURE 5 Estimated benefits of Rail Vision 2000 compared with estimated benefits from LCVs (*1*).

The combined value of shipper and rail benefits is $10.1 billion, which exceeds the American Trucking Associations' (ATA) estimated shipper benefits for LCVs, as shown in Figure 5.

In conclusion, the railroad industry appears to have a lot of upside potential for productivity, growth, and enhanced customer benefit in the 1990s. Achieving all the elements of Rail Vision 2000 will be challenging, but all of the initiatives are in various stages of implementation today. Other innovations will certainly emerge before the end of the decade; these innovations will include new applications of telecommunications technology, artificial intelligence, and the Iron Highway intermodal technology, which is expected to be in commercial service in 1994. Perhaps the greatest challenge will be for railroads to implement these changes consistently and thoroughly across the entire rail system so the benefits may be realized uniformly by the railroads, their customers, and the public.

Seven Propositions about Transportation and Logistics Change

The seven propositions discussed in the following paragraphs are based on findings from the OSU annual Career Patterns in Logistics survey, conducted in late summer 1992. The survey respondents were the chief logistics executives of 197 U.S. companies, most of them Fortune 1000 companies. All are members of the Council of Logistics Management. This group of companies should be viewed as a "leading edge" sample; chemicals, food products, and consumer products are the largest industry segments represented.

- *Relationships in the logistics channel will shift from a transactional to a contractual basis.* Shippers expect their percentage of inbound freight moved under contract rates to increase from approximately 52 percent in 1990 to about 70 percent in the late 1990s (Figure 6). The growth of contracts parallels the growth of deeper relationships between carriers and shippers

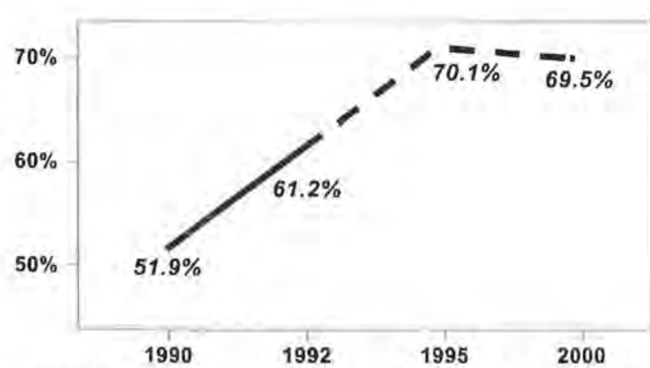


FIGURE 6 Percentage of total inbound freight shipped under contract rates (source: OSU Career Patterns in Logistics survey, 1992).

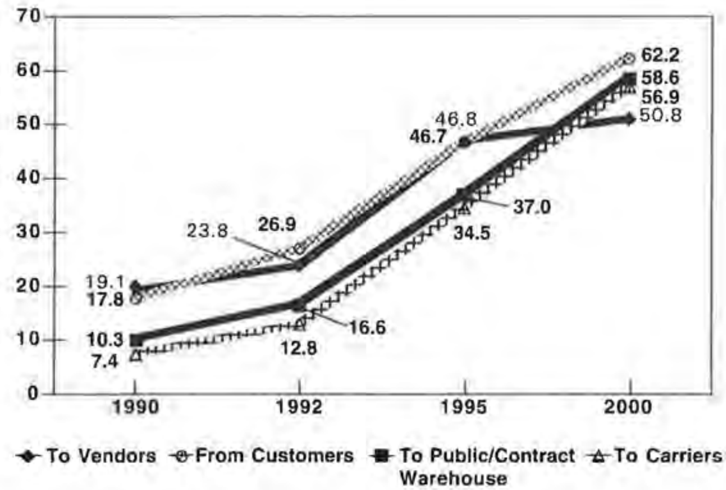


FIGURE 7 EDI patterns and profiles (source: OSU Career Patterns in Logistics survey, 1992).

seeking to identify and execute "win-win" solutions to reduce total logistics costs for both parties. Railroads will increasingly need to develop contract terms that cover a wide range of service, equipment, and administrative features, as well as price.

• *Efficient and effective communications within the logistics channel will be an important driver for positive change in the buyer–seller–third party triad.* Shippers expect EDI use to increase dramatically during the 1990s (Figure 7). Expansion of EDI will reduce clerical requirements for both carriers and shippers, improve accuracy of orders and bills, and lead to better short-term forecasting of shipment and equipment requirements. In several ways, railroads are leading the way in this area and must continue to take advantage of their significant information systems resources.

• *"Technology matching" will be a key element of the buyer–seller–third party productivity mix.* As an example, warehouse automation will increase dramatically during the 1990s (Figure 8). Warehouse automation is one of the developments that will allow true seamlessness in service—not only for door-to-door transportation, but for the whole sequence of activities in a complex distribution pipeline from raw material to consumer—involving several carriers, modes, and inventory points. With greater information about what is in the pipeline, carriers and third parties will have more opportunity to provide more responsive, and more efficient, services.

• *The ability to support "global reach" will be an increasingly important element of third party value added in the 1990s.* Shippers are globalizing both their material sourcing and finished product markets (Figure 9). Logistics providers who can respond to both the broader

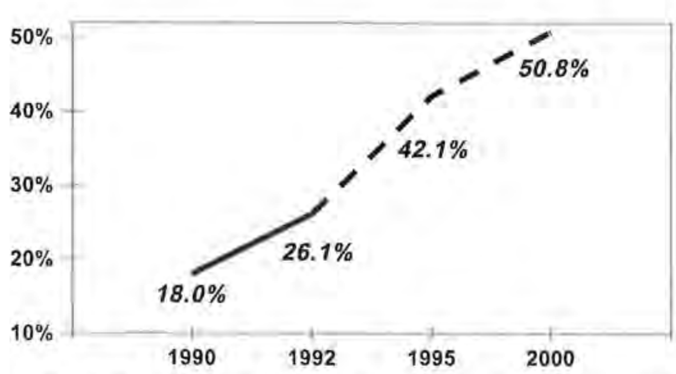


FIGURE 8 Current and projected levels of warehouse automation (source: OSU Career Patterns in Logistics survey, 1992).

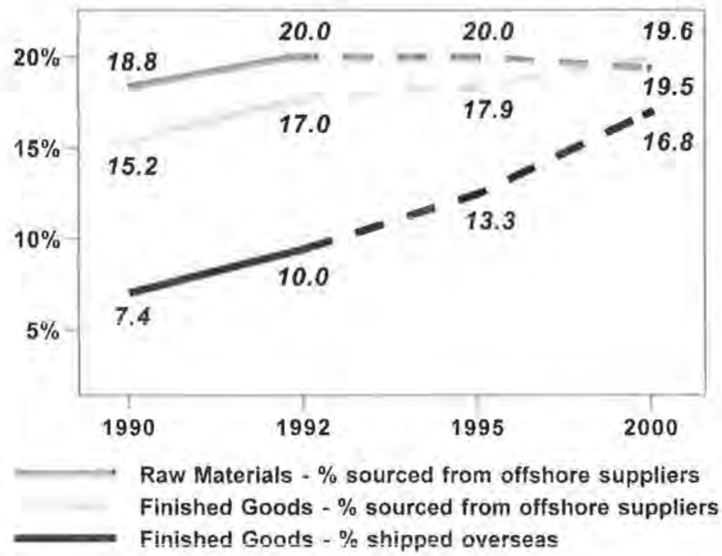


FIGURE 9 Import and export patterns and profiles (source: OSU Career Patterns in Logistics survey, 1992).

reach (within North America and across continents) and the pace of change as patterns shift will be valuable partners for manufacturers, distributors, and retailers. Although many North American railroads may not formally extend their reach overseas, they can be sensitive to the globalization trends and respond proactively to the shifts in patterns, instead of just reacting.

- *Quality, or "do it right the first time," will be the performance norm in the 1990s.* The percent of orders without errors is expected to increase from mid-90 percent to more than 98 percent by the end of the decade (Figure 10). Shippers expectations are increasing—last year's level of satisfactory performance will not be adequate in future years—and carriers that are not striving for perfection in their own quality management efforts will not be viewed favorably as performance standards continue to tighten.
- *Improved asset productivity will be a central driver for individual and joint management action in the 1990s.* Inventory turns are expected to increase from 6 to 8 per year to 9 to 10 per year by the end of the decade (Figure 11). The railroads can support this trend if they can achieve significant improvements in transit time consistency through interline service management, AEI, and ATCS. The more consistent the transportation delivery time, the smaller the

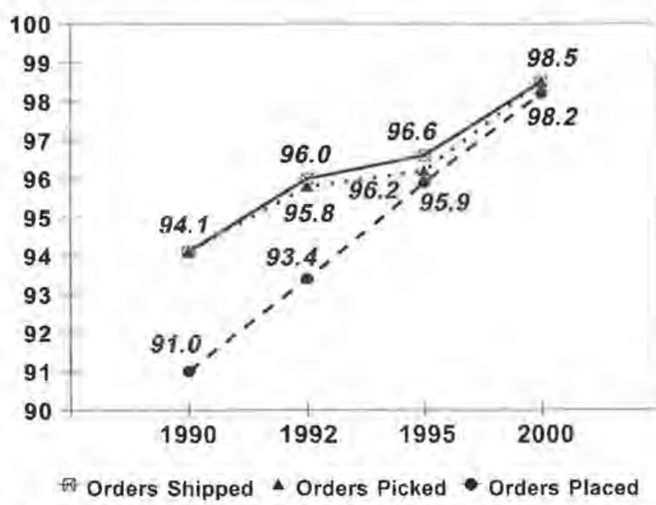


FIGURE 10 Percentage of orders without errors (source: Warehouse Education and Research Council/OSU study, 1993).

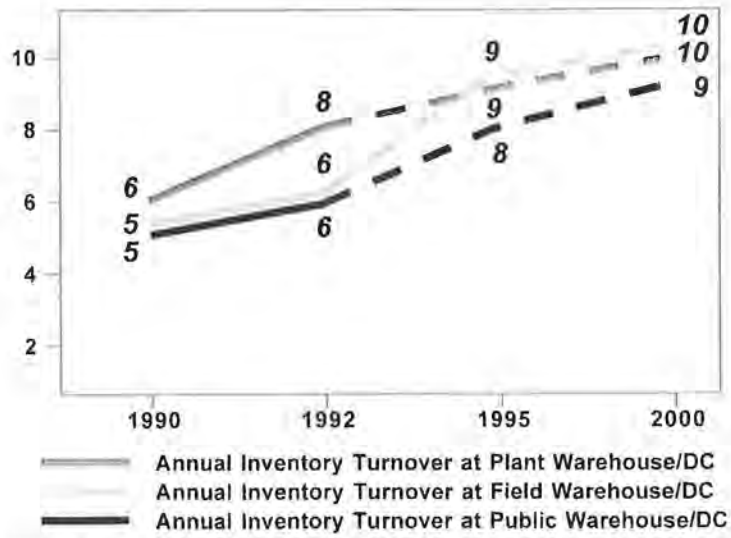


FIGURE 11 Annual inventory turnover patterns and profiles (source: OSU Career Patterns in Logistics survey, 1992).

inventory safety stock shippers need to ensure product availability and the less capital they need to tie up in inventories.

- *Improved competitiveness will be the name of the game for the 1990s.* As Joseph Schumpeter said, "Profit is the payment you get when you take advantage of change." Railroads must be prepared for some dramatic changes in the way shippers do business. If they can respond to their customers with better cost and service offerings that meet the changing requirements, they will prosper in the 1990s.

Research Questions and Requirements

Questions

On the basis of the Rail Vision 2000 analysis and the trends highlighted in the Ohio State survey, the following research questions have been identified:

- What are shippers' future requirements by industry sector?
- How will rail innovations change the rail cost and service profile?
- How will modal competitors' cost and service profiles change?
- How will shippers respond to these changes by industry sector?
- How will rail network economics and service change with increased volume?

Requirements

The research questions are challenging and not easily answered by the rail industry or any one railroad. Full exploration of these issues will require a number of analytical tools, data bases, and ongoing research efforts, including the following:

- Accurate modal volume and share data by lane, commodity, and equipment type;
- Price and service elasticity estimates by lane, commodity, and equipment type;
- Analytical tools to measure (a) total logistics costs and (b) links among physical change, service, cost, and capacity (activity-based costing);

- Real-time best practice data bases for (a) shipper logistics innovations, (b) rail industry innovations, and (c) truck and barge industry innovations.

These research efforts are in various stages of development today. Some are already in place and available (e.g., commercially available modal data bases). Others are being implemented by individual companies (e.g., total logistics cost models). Still others require either ad hoc confidential efforts (e.g., lane- or market-specific elasticity studies) or broad industry-wide participation (e.g., best practice data bases). All should be pursued vigorously—better knowledge about customers, markets, competitors, and high leverage innovations can help the rail industry achieve substantial gains in the 1990s.

Reference

1. SYDEC, Inc. and Jack Faucett Associates. *Productivity and Consumer Benefits of Longer Combination Vehicles*. Trucking Research Institute, ATA Foundation, American Trucking Associations, Alexandria, Va., 1990.

Shipper's View

James E. Zamjahn, *General Motors Corporation*

The stated objective of this Conference on Railroad Freight Transportation Research Needs is to set priorities for research needs for the next 10 to 15 years. The underlying implication of this objective is to identify things that should be changed. Change is a curious thing: who resists change? Few will admit to defending the status quo, and many will claim to favor change. General Motors is finally serious about change. Change was brought about not by a 10-point market share loss, but by a management shake-up. Results are now being seen.

Three things are needed to effect change: identification of what should change, a plan to change (internal to an organization), and the resolve and skill to make the change. The focus here is what should change. Here is an example of what I am leading up to: the average distance a vehicle is shipped is 1,000 mi. The average transit time is 10 days, which equals 100 mi a day. Assuming 24-hr days are available for shipments to move, General Motors Corporation (GM) is delivering vehicles to dealers at 4 mi an hour—walking speed.

Here is another example: in 1980, a shipment from Michigan to California averaged 10 days transit time with a 10 percent chance of transportation damage. In 1993, a similar shipment from Michigan to California averaged 9.5 days transit time, but with a less than 1 percent chance of transportation damage. During this time, the quality of service was improved significantly, but little improvement in transit time occurred.

Link Among Quality, Cost, and Time

GM used to equate high quality products with high cost and low quality products with low cost. Then the Japanese came to the United States with low-cost, high-quality products and took our market share. GM had to learn a new formula; it has, and has virtually closed the quality gap with Japan. If the 1980s was the decade of quality, then the 1990s is the decade of time. GM needs to rethink formulas about time, such as fast (e.g., a Concorde) is expensive, and slow (e.g., a barge) is cheap; or trucks are fast, but cost per ton-mile is high, and railroads are slow, but cost per ton-mile is low. The Japanese changed the rules of manufacturing when they examined the economic run quantity formula (used by GM to determine the exact number to be produced) and worked on reducing the setup time to zero. GM needs to change the rules of transportation so that fast transit time can equal low cost.

Transit Time

Transit time is the total elapsed time from when a product is ready for shipment until it is delivered to its intended customer. Transit time has two major components: speed (the velocity that a conveyance moves when in motion) and idle time (the period when a shipment is not in motion).

All of the major research topics being addressed at this conference can affect transit time in some way. Improvements to infrastructure primarily affect speed and can reduce transit times. Improvements to command, control, and communication systems and to service management can also result in reduced transit times. Energy consumption and the environment can be positively influenced by a lean, low-transit-time rail transportation system, just as lean manufacturing results in lower resource requirements in the automobile business.

Transit time is a topic worthy of further discussion. Transit time is reviewed at the highest levels of GM management. Someday GM will have the manufacturing and order management capability to produce a "3-day car." We do not want to wait 10 days for delivery.

In closing, GM does not believe that transit time is the responsibility of the railroads only, but recognizes that its own business practices need to be changed as well. GM and the railroads must jointly identify those factors that need to be changed.

Discussion Group Summary: Future Trends and Visions

Participants at the Conference on Railroad Freight Transportation Research Needs identified the following as characteristics of the railroad of the future:

- Seamless service,
- Customer driven,
- Transparent physical plant,
- Competitive necessities faced,
- Commitment to time compression,
- Global competition understood,
- Quality improvement embraced, and
- Focus on safety.

Vision for Railroad Research

Research is a foundation for the railroad of tomorrow—dedicated to creating breakthroughs in safety, profitability, and growth as part of a global distribution network.

Research must be comprehensive, encompassing people, economics, hardware, software, and processes. Achieving its potential requires basic and results-oriented research. Railroads, suppliers, labor organizations, customers, universities, and governments must join together to support this effort adequately.

Effective railroad research will provide increased industry vitality; safer, more fulfilling work for employees; reliable, timely, cost-effective service for customers; and environmentally sound safe transportation of people and goods.

Major Themes Driving Research Needs

The following are the major themes that should drive railroad transportation research needs for the next 10 to 15 years.

Improved Short Line Relationships

- Improve relations between Class I and short line railroads,
- Assess future condition of short line railroad physical plant, and
- Strengthen relations with states and labor.

Improved Vehicle and Track Performance

- Accelerate incremental change to provide innovation;
- Create a fault-free railway transportation operating system for freight and passengers (e.g., infrastructure, rolling stock);
- Develop distributed power alternatives;
- Provide systematic technology transfer;
- Develop economic, reliable rolling stock with zero failures;
- Develop low-cost, short-life capital equipment;
- Conduct research to develop technology to support rapid growth;
- Conduct research to develop ways to reduce false train stops by 50 percent; and
- Eliminate slack action damage.

Development, Improvement, and Integration of Information and Control Systems

- Implement advanced train control systems—the electronic railroad,
- Develop intelligent railway transportation systems,
- Maintain electronic data interchange to support throughput,
- Develop expert systems for infrastructure and rolling stock, and
- Develop division support systems for operations management.

Improved Safety

- Research and develop ways to reduce train derailments by 50 percent,
- Eliminate accidents at highway rail crossings,
- Improve the safety of hazardous materials transportation, and
- Eliminate job-related worker injuries.

Understanding and Development of New Markets

- Develop and promote the entire concept of seamless transportation;
- Offer acknowledged environmentally friendly services;
- Communicate benefits of rail transportation;
- Create a unique trinational system from the customer point of view;
- Develop effective short-haul services (bulk, heavy manufactured, and intermodal);
- Investigate ways to reduce shippers logistics costs;
- Increase volume of bulk commodities, which form traffic base;
- Bring back the value added of transportation to the railroad (more retail, less wholesale);
- Count trucking companies as customers instead of competitors;
- Strive to be more market oriented and more market connected and earn higher returns as a result;
- Review continually the defense need for rail transport, and conduct research as warranted;
- Make recyclables an attractive market;
- Research how to extract more value added (including antitrust);

- Research innovative contracting practices and customer needs;
- Understand cost variability with severe induced fixed cost;
- Develop measures of revenue sensitivity to time variance;
- Compete successfully for the less-than-500-mi merchandise market;
- Develop total logistics capability;
- Define what it takes to compete profitably in 2003; and
- Provide seamless single-point contact.

Focus on Customers

- Reengineer management structure to streamline decision process,
- Change culture to become sensitive to customer, and
- Develop seamless operating-marketing interface.

Capital Formation Issues

- Use profit center accounting.

Real Estate Opportunities

- Conserve real property and use land intensively, and
- Establish real property needs for the future (and bank that land).

Passenger Transportation as a Business

- Improve efficiency of commuter trains,
- Conduct sensible research on integrating passenger services, and
- Look at passenger traffic as a new market.

Managing Research and Development

- Develop supplier railroad technology,
- Perform a competent benefit-cost analysis for each research project at an appropriate point after completion,
- Identify source of research dollars,
- Identify research projects in which the public interest is such as to justify public support,
- Increase research expenditures,
- Conduct research on methods to reduce transit time, and
- Conduct research to promote reliance on performance (instead of design) specifications.

Global Focus

- Globalize railroad technology,
- Invest substantially in foreign railroads,
- Exploit railroads' generally attractive clearances in pursuing unit-load transport as part of the vision for the future,
- Conduct research on processes through which railroad innovations develop and are diffused,
- Leverage research as a national strategic advantage, and
- Internationalize and leverage research.

Human Resource Development

- Develop a constructive labor organization environment,
- Achieve employee buy-in to technology,
- Continue to improve labor productivity,
- Develop human factors research program,
- Accommodate, manage, and profit from diversity in the workplace,
- Eliminate department boundaries,
- Learn to manage employment growth,
- Create a work paradigm that allows employees the opportunity to contribute when they are on duty,
- Provide decision aids for operations personnel,
- Provide employee training and retraining, and
- Conduct rail employee surveys.

Service Improvement

- Explore passenger train service for containers,
- Handle nonbulk merchandise traffic like intermodal traffic,
- Explore new intermodal combinations (e.g., air-rail shipments),
- Duplicate the Florida East Coast Railway service,
- Recognize container transport as the emerging mode,
- Conduct research to determine ways to best penetrate the truck market,
- Reduce capital cost and time in container terminals,
- Reduce nontransit time by 50 percent,
- Improve shipment tracking and tracing,
- Investigate methods of improving equipment use,
- Determine ways to expand terminal and line haul capacity at minimal cost, and
- Determine ways to overcome intermodal interchange barriers.

Shaping Public Policy

- Reconsider and revamp industry-government relationship for partnership in research, including adoption of new technology, creation of level playing field, and passage of legislation favorable to railroads;
- Conduct joint railroad-government research;
- Develop methods for participating in transportation planning processes with metropolitan planning organizations;
- Determine changes required in current legislation and regulation to enhance rail transport; and
- Assess impact of legislation on future transportation of coal.

Environment

- Develop environmental-related business opportunities,
- Increase environmental awareness,
- Undertake risk analysis of transportation and cleanup of environmentally unsafe materials, and
- Become involved in regulatory process as it pertains to the environment.

INFRASTRUCTURE

Cost of Quality: A Powerful Management Tool for Infrastructure Research

William C. Thompson, *Union Pacific Railroad Company*

An introduction to infrastructure research is presented in this paper. The railroad infrastructure includes the track, structure, and signal systems. An approach to improve the focus of research, enhancing the development of a high-quality railroad system, is presented. To that end, it is recommended that all railroads develop and deploy a total infrastructure quality-costs system. A similar approach successfully worked for the Union Pacific Railroad Company during the past 5 years and has contributed to the railroad's ability to maintain the lowest operating ratio among North American railroads. For the railroad industry, improvements are needed in the measures of effectiveness, predictability, and maintenance requirements of track, structure, and signal systems.

For the North American railroad industry to collectively meet the future needs of its customers, it must provide track, structure, and signal systems that are reliable, measurable and predictable, and maintainable.

The performance of the railroad infrastructure is controlled by many factors associated with rolling stock and the operating environment. Higher axle loads, for example, result in higher static and dynamic loads, creating more rapid deterioration of the components. Greater electrical resistance at the wheel-rail interface may cause signal systems to malfunction. Railroad professionals must understand which components are most sensitive to changes in these factors. The conditions vary over time, tonnage, from location to location on a given railroad, and between railroads. For Union Pacific, the transportation of coal has had a significant impact on the way the railroad thinks about the business and has resulted in changes to its operations. The materials that are installed and maintained must be of the highest possible quality to survive with this heavy unit train operation.

Requirement for Reliable Infrastructure

The customers' basic transportation needs are low-cost, highly reliable, new, and high value-added services. A new service is double-stack, which did not exist 15 years ago and has become an important part of the freight railroad business. Customers are demanding new technologies, and fixed facilities must rapidly be designed and constructed to support these changing customer requirements.

Union Pacific's rapid business growth has required continued capacity expansion. New construction technology, such as the track construction machine, allowed the railroad to respond quickly and build additional track at a reasonable cost. The railroad is continuing to search for new ways to improve capacity without the need for additional facilities.

The industry must improve physical plant quality to support these growing customer needs. At Union Pacific, the inability to meet customer needs is defined as an external failure, one of four categories in the railroad's quality-cost system. Using a similar approach, the industry could develop an understanding of its total freight railroad industry infrastructure quality costs. The quality-cost information could be used to pinpoint research efforts and dollars on the track, structures, and signal systems.

Development of Infrastructure Quality Costs

In 1987, Union Pacific began an effort to improve its business processes through a total quality management system (TQMS), a key component of which was the cost of quality program (*1*). Union Pacific quickly deployed and strengthened the successful application of TQMS and the use of quality costs as a key measure of performance. A similar approach could be used to describe the quality and performance of the entire railroad infrastructure.

Union Pacific has saved almost $2 billion since the cost of quality program was started in 1987. The program has been used as an effective management tool to enhance performance throughout the entire company. The process has enabled Union Pacific to

- Establish a cost of quality reduction objective,
- Cascade the objectives (top down) through the entire organization,
- Review and interpret trends, and
- Correlate the cost of quality with customer satisfaction.

The cost of quality program is an estimate of critical costs, not a new accounting system. The program's significant benefit is its monthly reporting system, which provides more up-to-date information than do comparable corporate financial statements. Corporate financial statements developed 30 days after the quarter contain some information that is more than 100 days old.

Union Pacific has learned that the cost of quality program

- Focuses attention on problems,
- Ranks problems to be solved in priority order,
- Supports justification of quality investments, and
- Measures effectiveness.

On the other hand, cost of quality numbers do not

- Solve quality problems,
- Recommend research,
- Suggest special actions,
- Clearly reflect improvements in the budget, or
- Clearly match effort and accomplishment.

Estimating the infrastructure cost of quality would require all U.S. Class 1 Railroads to communicate and share information through the Association of American Railroads (AAR). The savings from a cost of quality approach may take several years to develop.

Figure 1, which summarizes Union Pacific's cost of quality annual savings, shows the financial impact as a percent of revenue (*2*). Using this model and focusing only on the track, structure, and signal systems, a $300 million savings should be possible for the entire industry. If the North American rail industry adopted a total cost of quality approach similar to Union

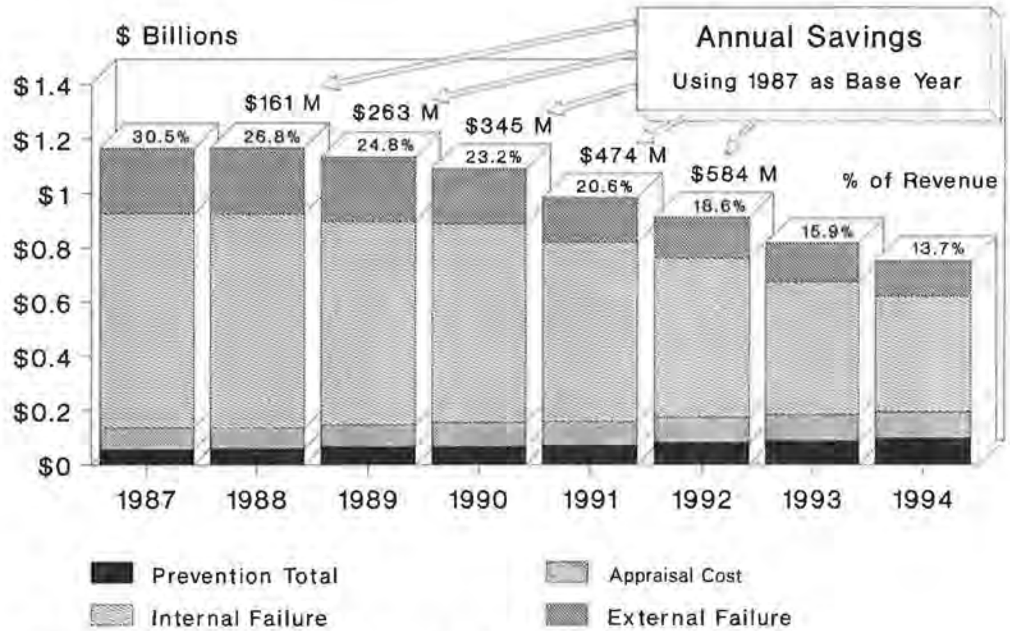


FIGURE 1 Cost of quality annual savings for Union Pacific Railroad.

Pacific's process, a savings of $3 billion to $5 billion would be possible during the next 5 to 10 years. Either approach would require the industry's top management to be dedicated to the process.

Total infrastructure quality costs are the sum of four key cost of quality measures: external failure costs (bad), internal failure costs (bad), appraisal costs (good), and prevention costs (good). These measures are described in the following paragraphs.

External failure costs measure the railroad's inability to meet customer requirements and the eventual lost business.

Internal failure costs are measures of problems that cause significant waste. These problems include broken rail, delays, some derailments, safety issues, environmental problems and the associated clean-up effort, unscheduled repair costs, fines, bridge failures, signal system failures, and so forth.

Appraisal costs include all track, bridge, and signal inspections, many of which are visual. Geometry car, rail profile, and ultrasonic rail inspection are part of the appraisal costs. Support of inspections made by qualified Federal Railroad Administration (FRA) or state inspectors are appraisal costs. Union Pacific wants FRA inspectors to pass on to Union Pacific employees what they consider important and to help them reduce the potential for accidents. Operation of the AAR Track Loading Vehicle (TLV) and the FRA Gage Restraint Measurement System are appraisal costs. Railroads worldwide use various appraisal techniques to evaluate facility conditions.

Prevention costs improve long-term safety and operational performance. Research is a critical prevention cost that reduces system failures and thus improves service. Training at all levels is considered a prevention cost, as are quality- and safety-improvement programs.

One prevention activity at Union Pacific, for example, is the development of improved turnouts. One test turnout near Odessa, Nebraska, uses concrete ties, elastic fasteners, and head-hardened rail. Costs over normal capital costs for this evaluation project are prevention costs. Maintenance cost data from this test is critical information that helps railroad professionals better understand and improve the performance of trackwork. Due to the line's heavy tonnage, failures occur fast, and the new technology's potential benefits can be evaluated quickly (*3*).

Early in the quality-cost process, Union Pacific observed that failure costs were many times greater than prevention plus appraisal costs. The railroad learned to leverage against appraisal and prevention costs to reduce failures. This continuing effort contributes to Union Pacific's low operating ratios.

To better understand the specific needs of freight railroad infrastructure research, AAR and FRA must develop an accurate estimate of the total rail industry's infrastructure quality costs. With this information, industry leaders can plan infrastructure research programs. This approach would indicate areas in which the industry (a) has been on the mark with past research, (b) needs to improve technology transfer to railroads, as in the case where research has shown benefits, but has not been implemented, and (c) needs research.

Requirement for Measurable Infrastructure

The industry must accurately and quantitatively assess the ability of infrastructure components to perform their intended functions and the influence of these components on maintenance requirements. Some necessary measurement systems already exist and are used to varying degrees of success, but other measurement systems need to be developed. In other cases, a single system may provide many of the required measurements. A listing of major track, structure, and signal system components to be measured is presented in the appendix to this paper.

Measurement Issues

Infrastructure components and their condition affect railroad safety and the ability to provide good customer service. AAR should develop measurement systems to determine the condition of high-cost components. Total-system reliability is a function of component reliability. Technology must measure the greatest number of the sensitive component conditions.

Critical areas include the following:

- Impact of each component on the customers' needs,
- Interactions between components,
- Accuracy of the measurement system, and
- Impact that cluster or repeatable defects have on reliability.

Among the questions to be answered are the following:

- In the event of one component's failure, can the load be transferred, and for how long will adjacent components carry the load?
- Can the fatigue that results in a reduction in reliability of the component be modeled?
- If visual inspection is the standard, what improvements in training and technology will optimize the inspection process?

Requirement for Predictable Infrastructure

Developing a predictable infrastructure is part of prevention costs. Important issues for the freight industry are discussed in the following paragraphs.

Influence of Heavy Axle Loads

The influence of heavy axle loads on the infrastructure must be precisely understood. The Heavy Axle Load Program under way at AAR, and partially funded by FRA, has provided excellent feedback to the industry, supporting decisions regarding heavy axle loads. One area requiring more data is track tonnage history; these data are necessary to aid fatigue analysis, especially on structures.

Influence and Interactions Between Vehicle and Track

The influence and interactions between the vehicle and track systems must be understood. The AAR Vehicle Track Systems Program is a key to understanding this interaction. A change in the freight, the car body, suspension system, and wheels will change the load on the rails, ties, and ballast. Changes in the track will likewise affect cars and freight. Union Pacific trackwork manufacturers are being asked to purchase the AAR-NUCARS (New and Untried Car Analytic Regime Simulation) model to help analyze the trackwork. Union Pacific wants its premium trackwork to be checked with the NUCARS model to accurately estimate lateral and vertical accelerations. This will improve performance and reduce trackwork life-cycle cost.

Through investigation of wheel-impact issues, Union Pacific found wheels creating 140,000-lb, static plus dynamic loads. During normal inspection, a wheel causing this load was not considered condemnable by AAR. This defect, probably due to an out-of-round wheel, imparts significantly greater energy into the track than some defects that are AAR-condemnable. Information provided during the Fifth International Heavy-Haul Railway Conference suggests that high-impact loads may have a greater impact on some steel bridges than previously thought (4). The basic need is to decrease the dynamic load on the entire structure.

Predictive Maintenance Models

Predictive infrastructure maintenance models must be developed and implemented. Questions to be answered include the following:

- How long will the component last?
- How fast is the component deteriorating?
- What impact will fatigue have on the life of the component?
- When should the particular component be maintained, treated, or replaced?
- What is the influence of heavy axle loads?
- How should maintenance or replacement of the component be prioritized?
- Should the component be redesigned?
- Are performance standards appropriate?

For example, it appears that the standard railbound manganese frogs will last 25 percent as long as the best movable-point frog in the same load environment. It also appears that concrete ties may help reduce the life-cycle cost of turnouts. Because of service issues associated with limiting speed through the trackwork, Union Pacific developed No. 30 turnouts. The No. 30 turnouts will allow operation through the divergent route at 60 mph, 20 mph faster than existing turnouts allow, and thus provide better service and boost track capacity.

Improved Analysis

Improved analysis techniques for evaluation of the components' performance must be used. Improved analysis techniques include mean time between failures predictions, finite element analysis, and multiple environment overstress testing (MEOST). Union Pacific successfully used MEOST in the development of its new ballast car fleet. AAR should develop expertise in these areas and transfer this technology to the railroad industry.

Requirement for Maintainable Infrastructure

The industry must develop a more maintainable infrastructure. Similar life-cycle models could apply to track, signals, or structures. Long- and short-range plans are developed as an annual program to establish when and where track material replacement is to occur. The program is then executed, with material being ordered, manufactured, built, and eventually installed. This is a moderately expensive portion of the life-cycle cost of the trackwork. During operations, there are the usual minor start-up troubles, as a program of low-risk usage that requires minimal maintenance is introduced. Performance results during low-risk usage, especially for new technology components of which only a few may be in place, can be quickly fed back to material design and reduce risk of failure. This low-risk usage is followed by medium-risk usage, with wear or fatigue becoming issues. Measurement and testing are critical at this stage. Results are then fed back to the long-term, 5-year plan for major renewals. At the end of the life-cycle, high-risk usage, which results in slow orders, should be avoided as much as possible.

Infrastructure maintenance goals include the following:

- Avoid over-maintenance, which is expensive;
- Avoid under-maintenance, which results in high risk; and
- Improve the quality of the total maintenance function.

In many areas, heavy-haul railroads operate quite efficiently; however, on certain heavy-haul lines in other countries, a tendency to over-maintain has been observed. Railroad professionals in those other countries, seeking ways to reduce the costs of over-maintenance, have begun to observe the maintenance practices of North American railroads.

Short-term maintenance needs include the following:

- Improve the prediction of service and material life;
- Improve defect-location information;
- Improve inspection skills, techniques, tools, equipment, and information;
- Improve maintenance skills, techniques, tools, equipment, and information;
- Improve inspectors' and maintenance workers' feedback and involvement in decisions;
- Improve control of maximum defect size, defect growth, and defect distribution, particularly in metal components; and
- Determine the optimum maintenance and replacement strategy.

Changes in the feedback system can result in performance improvements, as Union Pacific learned in a study of maintenance practices. Project Cheyenne is Union Pacific's name for a Management Effectiveness and Employee Empowerment System, developed and deployed with the help of General Systems Company. Through this employee-involvement project, the railroad is able to use ideas from the best employees, especially those closest to the work, and create teams to help improve the maintenance function's performance. A product of one team was improved training for track-buckling preventive maintenance.

Long-term maintenance strategies include the following:

- Understand and optimize the entire operating environment. Tradeoffs are the rule: if a change is made in one area, it will without question affect another area.
- Minimize variability in the infrastructure. Better information on conditions, materials, manufacturing processes, and the load environment will contribute to reduced system variability.
- Develop self-diagnostics for track, signals, and structures. Much work still needs to be done in this area. Union Pacific experimented with real-time performance monitors on tampers, which allowed machine operators to report reasons for specific delays and create a production record. In addition, the operators prefer this to a written or verbal report. Another important need is in the prediction of track buckles, which are truly a worldwide problem.
- Improve safety, ergonomics, and work conditions for maintenance employees. Significant effort is being made at Union Pacific to help improve these conditions for all employees. One

example is the development of a wheel-throw switch stand that reduces the load on the operator's back when the switch is thrown. Although this stand is not the solution to all back-injury problems, it appears to be a reasonable alternative on some turnouts.

• Minimize the environmental impact of the infrastructure. Recycling is a concept with which most railroad maintenance people are familiar. Collection technology to pick up grease, lubricants, and the like along the right-of-way is new and needs to be expanded.

• Develop independent maintenance practices. Devices are needed to help maintenance personnel find the exact location of a defect. For example, the geometry car could download data to a small hand-held geo-positioning system to advise those responsible for making the repair where that defect is located. A track crew would direct maintenance efforts to the precise location.

Another major issue is coordination between the inspection and maintenance functions. Information flow is critical, and once an inspector or inspection device finds a severe defect, this information must immediately go to the maintenance personnel for correction. In the case of wheel defects, Union Pacific provides its car department a picture of the car that shows the exact wheel that is defective.

• Develop performance measurements. The TLV was developed to help provide performance measurements for the track and equipment. This is an excellent device, and its use needs to be expanded. Opportunities exist for using this vehicle to measure track performance, including predicting the performance of a variety of components simultaneously.

• Consider the impact of the Federal Employers' Liability Act and the Research and Development Tax Credit on research.

• Keep an open mind to the many ideas that are being developed in railroads around the world.

Conclusion

The railroad industry can improve performance through the use of research in many areas. A cost of quality strategy will improve the focus of the railroad industry's infrastructure research. Several hundred million dollars in potential savings is possible. As a result of these improvements, the industry as a whole will be able to provide better customer service. This approach will support many of the quality improvement programs already under way within each railroad.

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Appendix: Components to be Measured

Railroads must accurately access the ability of these components to perform their intended function and determine their influence on maintenance requirements. These measurements are part of appraisal cost in the cost of quality system.

Track 1: Rail Condition

- Rail profile,
- Internal soundness,
- Weld soundness,
- Rail straightness, and
- Rail stress.

A variety of techniques has been used to determine rail and weld soundness. Global differences exist in these processes. In North America, ultrasonic inspection of the rail is typically performed using two-person test vehicles. In China, four-person crews use walk-behind units, and more than 2,000 employees are assigned to operate this equipment systemwide. Several years ago, British Rail used a 12-person crew and scope and crystals.

Track 2: Fastener Condition

- Spikes,
- Anchors,
- Elastic fasteners,
- Bolts, and
- Shoulders.

Track 3: Rail Seat Condition

- Plates,
- Pads,
- Shoulders, and
- Insulators.

Track 4: Tie Condition

- Abrasion,
- Gage-holding capability,
- Vertical support,
- Lateral support, and
- Longitudinal support.

Gage-holding ability, vertical support, lateral support, longitudinal support, fatigue, and crushing are all indicators of fastener, rail seat, and tie condition.

Track 5: Ballast, Subballast, and Subgrade Conditions

- Vertical support,
- Lateral support,

- Longitudinal support,
- Drainage,
- Profile, and
- Design.

The substructure components influence track support, resistance to track buckling, and resistance to rail creep.

Track 6: Geometry

- Standard track,
- Curved track,
- Spiral track,
- Special trackwork,
- Superelevation,
- Lateral load, and
- Vertical load.

Track geometry exceptions can usually be corrected through the use of tampers to surface and line the problem area. Geometry degradation can also be caused by several components of the track structure acting together. Geometry problems on straight track vary from those on spiral track, curved track, and special trackwork. Superelevation is required on certain sections of curved track to ensure proper loading and a balanced operation. The geometry through turnouts will greatly affect the lateral and vertical loads that the cars experience, particularly through the divergent route.

Track 7: Special Trackwork Conditions (Turnouts and Road Crossings)

- Wear limits,
- Fasteners,
- Nuts and bolts,
- Lateral load,
- Vertical load, and
- Internal integrity.

Structures 1: Steel, Concrete, Wood, and Composite Bridges

- Abutments, piers, and bents,
- Channel conditions,
- Superstructure,
- Stringers,
- Ties,
- Caps,
- Hangers,
- Ballast,
- Through plate girders,
- Deck plate girders,
- Support conditions, and
- Piling.

Structures 2: Tunnels

- Floor conditions,
- Lining conditions,
- Clearance, and
- Drainage.

Railroads that operate through mountains tend to have a variety of tunnels to deal with. The condition of the floor and substructure is significant when determining the overall condition of the tunnel. A thorough tunnel inspection provides information on the lining, drainage, and clearance in the tunnel.

Structures 3: Culverts

- Overall condition,
- Entrance and exit, and
- Settlement.

Signal 1: Vital Circuits

- Relays,
- Electronics,
- Cables,
- Programmable controllers,
- Contacts,
- Input-output cards,
- Light bulbs,
- Cab signals,
- Detectors,
- Software,
- Insulated joints, and
- Buss.

Signal 2: Communication System

- Switches,
- Base stations,
- Circuits,
- Fiber optics,
- Pole line,
- Interfaces,
- Software, and
- Radio frequency/data radio.

The ability to move information from the dispatch center to the vital circuits is critical.

Signal 3: Dispatch Center

- Terminals,
- Computer,

- Ethernet,
- Code system,
- Modems,
- Power supply,
- Software,
- Switches and servers, and
- Interfaces.

In order for the dispatcher to communicate with the trains and to handle the necessary moves, the terminals, computer, and radio systems must work extremely well. An ethernet system is used in the Union Pacific dispatch center to move information from the computers to the dispatchers. As development continues, the software required to operate these systems has become a more important part of the overall signal system reliability.

Industry Goal

Develop a measurement system to determine the condition and reliability of each of the subcomponents. The total system reliability is a product of the reliability of each subcomponent.

Equipment Infrastructure Needs for Customer Satisfaction and Operational Improvement

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To discuss the subject of the future needs of equipment infrastructure, one must have an understanding of three things: the identity of tomorrow's customers, their requirements, and how the overall rail environment will look in the next century. Although the understanding of these three items requires a certain amount of clairvoyance, the author believes that sufficient focus on these issues can be obtained to at least provide some general assumptions about the future equipment needs of the rail industry.

In articles in the *Journal of Commerce*, Rip Watson indicated who the customers will be and discussed the diversity of their requirements. On May 26, 1993, he discussed the bulk commodity customer (*1*): "As shippers demand more efficient service, and management as well as investors demand better return on investment, railroads and suppliers have been stretched to redesign coal and grain equipment to loads as large as 120 tons a car."

The next day he discussed the intermodal market (*2*): "The contrast between rapid growth in intermodal rail traffic and lack of growth in the fleet of trailers and containers that carry it is prompting fears of a record equipment shortage during the normal peak period this autumn."

On one hand, bulk commodity customers will remain with railroads and will require increasing capacity and reliability at decreasing rates. On the other hand, new customers should enter the market. Their requirements may be such that purchases of equipment may not be limited to what one now visualizes when someone uses the term "freight car." These two expectations are presented to underscore the wide range of customers that the rail industry must learn to serve if it intends to survive in the 21st century.

From the customer's viewpoint, everyone in the railroad industry should be familiar by now with the just-in-time concept. With inventory control at such a high visibility level, this may also implicitly mean "just the right amount." For example, United Parcel Service and its competitors have developed a significant market by providing quality shipping of single, small items. Although it is doubtful that the Railway Express Agency will reappear any time in the near future, the impact of the just-in-time/just-the-right-amount philosophy on new equipment designs will be significant.

The rail industry must provide the diverse services that Watson wrote about if it intends to be a growth industry. It must continue to serve bulk customers with increasing efficiency. It must develop new and faster ways to provide intermodal service, and it must learn how to cost-effectively serve the small-volume owner-operated businesses that have been driven away from the rail transportation market. All of these things must occur in a transportation environment in which revenue per unit volume will be steadily declining because of competitive pressure.

Before specifics in the equipment infrastructure are covered, some basic generalities concerning the rail environment in the next few decades will be discussed. This environment will undoubtedly include passenger traffic. Although it is romantic to talk about high-speed passenger trains, a more realistic view comes from an examination of the goals of high-speed passenger transportation. The author believes that there are two goals: reduce the overall transit time and retain a cost structure that provides a competitive advantage for the rail mode.

From the rail passenger's viewpoint, there is much room for improvement. Reduction of transit time by rail could be achieved in much of North America with a horse-drawn railcart, since service is presently nonexistent in many areas. As much as the magnetic levitation proponents want to see their dreams become reality, the most likely interim step will be to expand passenger service over existing lines. Equipment for this expanded service will be constructed using current designs similar to the equipment that is now running at speeds of up to 125 mph. If rail passenger traffic is to be revived in the United States, it will happen in this fashion because of the unbearable costs of a more advanced, untried technology. The current search of the National Railroad Passenger Corporation (Amtrak) for a train similar to the Swedish X2000 that has been on tour in the United States underscores the validity of this hypothesis.

Why is this point important to the overall future of freight equipment? Simply put, the freight equipment will be sharing track of similar design as the passenger equipment. Because passenger transportation is, by its nature, a just-in-time delivery system, the freight equipment operating in the same environment must be reliable in order to minimize delays. It must also provide reduced dynamic loads to avoid rapid or catastrophic track degradation in conjunction with passenger traffic. For these reasons, an understanding of future freight equipment cannot be developed without consideration of the total rail environment.

Even if passenger traffic does not affect freight transport, one should realize that the goals of rail transportation, whether freight or passenger, are essentially the same. What do freight customers want? They want to reduce the overall transit time while retaining a cost structure that allows them to maintain a cost competitive advantage. This is exactly what passengers want. Thus, there is no real difference between passengers and freight customers. With this understanding, the specifics of freight vehicles in the 21st century may now be explored.

To place this analysis in proper perspective, the long-term needs of rail customers should be viewed as practically unforeseeable, which will force the rail industry to focus on the methods used to design and implement new equipment. A rapid response will be required from not only the equipment design team but from individual railroads to quickly place new, innovative equipment designs in service to meet the needs of new customers.

The existing record of railroads is not good. An arguably worst case in point is that of Roadrailer. This technology languished for many years because no market existed and because railroad operating personnel did not accept it. Only today, with the advent of Triple Crown Services, is a profitable interchange market beginning to develop for this equipment. Future equipment design and implementation cannot take as long or the rail industry will be bypassed by its trucking competition.

Availability and reliability are two factors that will have a great impact on the future design of equipment. For freight transport, equipment makes an average of two trips per month. Indeed, the average rail haul is measured not in hours, but in days and, unfortunately, sometimes in weeks. This time often depends on equipment reliability. Future equipment must be designed to have almost no downtime. It must also be designed to provide quick turnaround. Car cleaning and other preparations must be considered during the design phase. In some cases, use may be improved by providing sufficient flexibility to allow backhauling of a different commodity. These are extremely difficult requirements, but they cannot be dismissed simply because of their difficulty.

Train size and makeup will significantly affect the future. Equipment designs will be influenced by the type of trains that are used. According to conventional wisdom, a train as long as is physically possible should be run to take advantage of the reduced crew costs. The trucking industry makes a living hauling 60-ton loads. The railroad industry must learn to provide the same type of service to its customers. This means shorter, perhaps customer-dedicated, trains with car designs specifically tailored to the customer's product. Impossible, you say? The railroad industry has learned to do this with bulk commodities such as coal and grain; it must now learn how to expand this idea to other commodities.

Attention must be paid to sizing new equipment properly. The more flexible the car, the better. Development of a variable-sized car should be considered. This does not mean an expandable car. One example is an articulated car design that would allow for rapid change in the number of platforms.

In the area of truck design, a whole world of development awaits. Almost the entire North American rail fleet rides on a truck design that is well over 100 years old. Its forte is its ability to negotiate bad track with little maintenance. Although some track fitting this description still exists, for the most part the three-piece truck is not needed for this purpose today. Instead, the rail industry is moving toward an excellent track structure over which high-speed trains operate.

Most three-piece trucks in service today do not receive sufficient maintenance to operate in this environment. Traditionally, they have been maintained on a time basis. As the demands for improved equipment use increase, this time-based maintenance philosophy will not keep pace with equipment use requirements. For such equipment, maintenance must be done on a mileage basis.

Often, no visible signs of truck maintenance deficiency are apparent. Insufficiently maintained trucks are found only after costly lading damage or derailment. Temporary solutions, such as elastomeric dampers, have been applied to allow for operation at higher speeds. These devices trade good curving performance for high speeds. It is unclear whether the overall maintenance costs of these devices will be affordable in the long term. In any event, it should be readily apparent that the North American rail environment needs an entirely new truck design.

Ride quality will, without a doubt, be a major driving force for customer satisfaction in the next century and must be the central focus of the truck design effort. Some sacrifice in performance in the area of track geometry deviation negotiation may be necessary. The new truck must provide improved vertical ride quality and effective lateral control for high-speed operation.

The braking system for this new truck likewise needs to be of radical design. The present pneumatic control system has several disadvantages. Signal propagation time is too long and erratic for the length of typical North American trains, causing unpredictable, uneven braking and consequent excessive longitudinal accelerations and mechanical problems. The air supply for both power and control comes from the same damp, dirty source. This causes reliability problems with the control valves, particularly during rapidly changing ambient weather conditions. A better solution would be to separate the control air supply from the braking power air supply. This solution would ameliorate some of the reliability problems with the control equipment, but would not affect the signal propagation times.

The best solution would be use of an electrical signal for control. This solution would open the door for a feedback path to the controller to ensure that the commanded operation has actually occurred. This signal path may also be used for passing other important messages along the trainline. These messages might include truck performance information, such as roller bearing temperature and alarms, wheel slip/slide warnings, control of remote or distributed power units, and automatic cutout and reporting of defective braking components.

Scheduled maintenance should be addressed when future equipment design is discussed. Consideration should be given to a universal truck-mounting scheme with all braking components installed entirely on the truck itself. This would allow a unit exchange of a truck under any type of equipment without requiring connection of more than the power braking air and the control signal and without adjustment of brake rigging and side bearings, which would be done with the truck removed from the vehicle in a dedicated truck repair shop. Scheduled maintenance could then be performed rapidly.

In addition, a slackless coupling that works as quickly and as easily as the existing interlocking coupler system is needed. Such a coupling system should incorporate the power braking air supply and the electric control buss. This coupling would provide benefits for maintenance as well as longitudinal ride quality, isolation of single platforms of articulated cars on line of road if necessary, and the car-sizing requirements previously mentioned.

Unscheduled maintenance must be kept to a minimum. If regular maintenance can be performed quickly and reliably with a unit exchange philosophy, train delays due to mechanical failure should seldom occur.

Thus far, the issues of track and equipment have been discussed separately. The reader should not be deluded into believing that these two items can each be addressed in a vacuum. Before one can begin discussion of the design needs of either track or vehicles, one must consider the effects of the vehicle and track system as a whole. Although some industry efforts recognize this need today, as evidenced by the Vehicle/Track Systems program of the Association of American Railroads (AAR), few practical tools exist that allow the entire system to be considered at one time during design efforts.

Two examples of this problem follow. The first is the experience that Amtrak had with its initial installation of concrete ties on the Northeast Corridor. The wooden crosstie is forgiving of high dynamic track loads. The concrete tie is not. Its extra weight and stiffness create a barrier where more of these dynamic loads are concentrated instead of being dissipated in the ballast, subgrade, and wooden tie. Not only does the concrete tie suffer, the added stiffness increases the magnitude of the vertical vibrations on such track, which can in turn affect sensitive lading.

The second experience was the inception of the use of chocks instead of chains for restraining automobiles. The chains effectively short circuited the automobiles' suspension. This meant that the automobiles experienced essentially the same vibration as the railcar. With the use of chocks, the automobile suspension became a part of the equation. Much to the chagrin of shippers and receivers alike, more than one case of destructive resonance has been found.

To circumvent this problem, analytical tools need to be developed that will incorporate all parts of the rail environment from the subgrade up to and including the lading characteristics. This will allow an easy method to evaluate new designs of track, vehicles, and lading containment methods during the design phase. Items that should not be ignored in the development of these new tools include wheel and rail profile interaction, angle of attack, and dynamic wheel impacts.

Reduction of the dynamic track loading needs to be a joint goal of both the equipment and track designers. This was successfully accomplished by British Rail in the design of its IC225 intercity equipment. The benefits in this area are difficult to quantify but are empirically obvious. Irregular track leads to higher dynamic forces in the equipment and lading. Not only must the designers of the rail equipment take this into account, but the designers of sensitive lading must do likewise. If a poor vehicle suspension system contributes to the degradation of the track, a high maintenance infrastructure results.

If the author could wave a magic wand and instantaneously develop the perfect rail vehicle, it would have the following characteristics:

- The car body would be considered much like the 40-ft oceangoing container is considered in today's intermodal service. Instead of being placed on a chassis, it would be placed on a universal rail wheel truck. This would not be done as a matter of course as is done with the container, but would be used to provide rapid maintenance, similar to a pit stop at a Formula 1 automobile race.
- The intercar connector would be slackless and be able to be disconnected quickly and without tools. It would incorporate automatically all trainlined functions, both air and electric, during operation.
- Each truck would have its own electrically controlled braking system that would include an antilock, wheel slip/slide detector to prevent wheel damage and reduce wheel maintenance. The truck would require a connection to the power braking air and a connection to the electric trainline data buss.
- Maximum dynamic wheel forces would remain at levels below those presently encountered with existing 100-ton equipment. New 125-ton designs would be included.
- The design of this new vehicle system would have only one requirement from today's freight equipment—the track gage would remain at 56½ in.

Although some of these ideas may never become reality, the following steps must be taken to ensure that future rail equipment meets or exceeds the requirements of the railroad industry and its customers, thus ensuring the survivability of the rail industry:

- A new slackless connector to provide all trainlined functions, including the power braking air and the electrical signal buss, must be designed.
- Hardware and communications protocol for the signal buss must be designed. One essential item will be to develop a scheme for each buss resident to automatically determine its position on the buss and thus its position in the train.
- A high-speed, low-maintenance truck with smooth ride quality from the standpoint of both the track and the lading must be designed. It should be completely maintainable when removed from the rail vehicle.
- A new truck-mounted, electrically controlled, antilock braking system must be designed. This system should be capable of dissipating the braking powers of the heaviest cars within the limitations of the materials.

At the recent AAR Future Search Conference discussed by Roy Allen elsewhere in this conference proceedings, the rolling stock working group suggested the following actions:

- Joint teams of customers, railroads, and car builders should be formed for the timely development of new equipment.
- The AAR mechanical committees should develop relevant and accurate performance standards to ensure safe, reliable interchange operations of new equipment without impeding rapid innovations.
- In conjunction with the development of the total system design analytical tools mentioned earlier in this paper, life-cycle cost tools should be developed to achieve the lowest overall costs for new equipment designs. This tool should not ignore the nondollar quantifiable and qualitative impacts.

As was stated previously, if the railroad industry does not rapidly develop methods to provide customers with the service and equipment that they require, the competition will. With the energy efficiency that the rail industry can provide, there is every reason to prevent it from joining the ranks of other dead or declining industries.

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Discussion Group Summary: Infrastructure

Conference participants assigned to discuss infrastructure were charged with investigating all aspects of the track and associated structures and the rolling stock. For the purpose of the conference structure, the definition of "infrastructure" was broadened to include vehicles and track-train dynamics in addition to track and fixed plant. The group was divided into three subgroups to examine (a) track and fixed plant, (b) vehicles, and (c) track-train dynamics.

The group defined its mission as follows: Identify and rank in priority order research needs and opportunities for the track-train system to (a) meet customer needs and expand customer markets, (b) improve efficiency and productivity and achieve lowest overall life-cycle cost and (c) improve safety.

To achieve this mission, the group alternately met as the three subgroups and then as the complete group to first define the major issues affecting technology in the track-train system and to then determine research needs and opportunities to address those issues. The early phases of the group discussions produced a wide variety of issues. However, as the meeting progressed, the discussions became more focused and concentrated on determining the most critical research needs to address the most important issues. Ten such research areas were identified.

Issues

The issues affecting the group's deliberations were discussed in each of the three subgroups.

Track and Fixed Plant

The track and fixed plant subgroup recognized that reliability of the track structure is more critical than ever before, particularly as line capacity problems emerge, and that there is little redundancy of track and equipment. Additionally, it recognized that all components of the existing track structure, bridges, and signal system may not be completely adequate for future increases in car weights (above 263,000 lb) and speeds (above 70 mph). There is also a pressing need for improved maintenance scheduling and coordination of maintenance activities with train operations.

There was considerable discussion regarding implementation of technology. Some of the larger railroads are better at incorporating new technology than the smaller ones, but overall the results are less than desirable. The main issue surrounding implementation was the recognition that economic analyses should be refined to help better determine the costs and benefits of technological change and implementation of research findings. Improved economic tools would also help to better determine where the biggest gains can be made from research and development.

The following more detailed issues were also discussed:

- Prediction of degradation rates needs to be improved for objective decisions on replacement or repair that take costs and benefits into account. Some are hard to quantify. For example, determining the benefit of borate treatment of ties can be rather subjective on the basis of perceptions of environmental rulings that may come in the future.
- Extension of service life of components such as frogs needs examination. The use of new materials should be encouraged. There are limits to the loads that current materials can withstand.
- New track designs such as slab track should be revisited to determine if maintenance costs can be reduced. The track design goes back further than the design of three-piece trucks. However, the consequences of committing to new designs must be fully understood before they are installed. The "fit and forget" track, structure, or signal system may be an unattainable goal.
- Track time compression is a problem. Coal train contracts and other services demand on-time delivery, and thus the length of time the track is available for maintenance is decreasing.
- There is a need to educate and train railroad engineers to take better advantage of new and current technology.
- Employee motivation must be added to the equation for reliability. All of the technology in the world will not make much difference if it is not implemented properly.
- Maintenance and replacement strategies need to be optimized. For example, should bridges or components be replaced? Should entire sections of rail or just the ones that are currently bad be pulled up? Rail grinding restores profile and surface, which allows accurate ultrasonic testing, but there are conflicting theories about the best practice.
- Bridge integrity remains a concern, even though many bridges were overdesigned. Class I and Class II railroads take care of their bridges with frequent inspections and repairs, and they maintain good records. Can the small railroads afford to keep such records?
- Are there better or enhanced bridge inspection methods? Can new materials be used in bridge designs?
- Is sufficient attention being given to natural disaster survival? Are there problems with seismic qualification of bridges? Is it possible that states may require bridges to be more robust? Is there a role for retrofitting seismic isolation bearings?
- How will changes in the signal system affect the rest of the system? Advanced train control systems (ATCS) may be the way of the future, but many railroads will continue to rely on more conventional signal systems for some time.
- How will equipment currently in use perform under high-speed conditions? Higher speeds are coming to freight railroads. Demand for shorter delivery times will continue to increase.
- Reports from track geometry cars can be used to accurately describe track defects, but a better method to determine the exact location of the defects is required.

Vehicles

The subgroup that examined vehicles developed issues that were grouped into five major categories. The first involved the railroad customers in determining customer needs and areas where research and innovation would be beneficial. The ongoing Future Distribution Systems program, to develop new concepts for transporting finished automobiles from dock or factory to dealer, was regarded as a good model for cooperative efforts involving customers, railroads, and suppliers. Other topics of discussion included the following:

- For automobiles, a totally damage-free loading and transport system is required;
- For trailers and containers, the ability to carry conventional highway trailers by means of circus-loading techniques or alternative lifting arrangements and stackable containers with high inside volume were the major issues;
- For paper, a new concept is needed to replace cushioned box cars with plug doors;
- Requirements for bulk commodities need definition for both liquids and dry goods, and bottom dump and rotary dump cars and the type of weather protection required need to be addressed;
- Transportation of steel products is an issue; and
- For automobile parts, a new concept is needed to replace high-cube box cars.

The second group of issues concerned trains:

- Distributed power using lading weight for adhesion,
- Increased capabilities of alternating current drive,
- Dedicated trains that bypass yards,
- Equipment designed to meet customer needs,
- Establishment of cost-effective programmed maintenance, and
- Faster design and test procedures to bring new cars on-line.

A number of truck and suspension issues surfaced, including the following:

- Improved vertical and lateral ride quality leading to reduced lading damage,
- Track and car structure benefits,
- Reduced fuel consumption,
- Reduced flange and rail wear,
- Increased availability and reliability,
- Reduced weight (including unsprung weight),
- Maximized benefits of life-cycle cost, and
- Benefits to be shared by car owner, customer, and carrier.

Brake systems also received some considerable discussion. The major issues were as follows:

- Elimination of brake rigging problems,
- Quicker, more uniform response,
- Graduated release,
- Brake force proportional to load,
- Higher deceleration rates,
- Alternative energy dissipation means, and
- Improved hand brake and parking brake systems.

The fifth group of issues concerned coupler and draft systems; specific issues included the following:

- Improved longitudinal ride quality leading to reduced lading damage,
- Elimination or minimization of free slack,
- Automatic coupling and air connection,
- Improved gathering range,
- Improved solid drawbar arrangements, and
- Improved articulated connections.

Another major concern of the group was that an increasing portion of the car fleet is not owned by an operating entity. Thus many of the benefits of lower life-cycle costs do not accrue to the owner. A way must be found to equitably share the benefits.

Track-Train Dynamics

The subgroup assigned to discuss track-train dynamics examined the issues concerning the interaction of the vehicles and trains with the track structure. The issues were grouped together into five major areas.

The first issue concerned the need to optimize the vehicle-track system to maximize cost-effectiveness, safety, and reliability of the whole system. This should result in improved ride quality and reduced dynamic loads, energy consumption, system degradation, and hence maintenance requirements. This issue raised a number of related issues, including a need to improve fundamental understanding of vehicle dynamics and vehicle and track interaction, improve modeling and predictive techniques to assess overall system performance, and perform accurate life-cycle costing.

Despite recognition of the benefits of system optimization, the group noted two significant obstacles. The first is that mechanical standards come under the purview of the Association of American Railroads (AAR) Mechanical Division, whereas track standards are set by the Federal Railroad Administration (FRA) and by engineering departments of individual railroads. A suggestion was made that the answer might be in revisiting the institutional framework that leads to the problem in the first place.

The second institutional obstacle concerns how to fairly compensate an equipment owner (which could be a railroad) for investing in premium equipment, which is freely interchanged to all roads to enjoy the benefits. In many cases, the research has been done, the design engineering has been done, and the suppliers are anxious to provide such equipment. However, the rewards go unrealized because it is not in the microeconomic best interest of individual railroads to purchase this equipment. A method is needed to make those company microeconomics coincide with the macroeconomics of the whole industry. If such a methodology were to be found and accepted, not only would past research and existing designs be quickly implemented, but the incentives for new research and design engineering also would be greatly enhanced.

A second issue, closely related to the first, is the need to develop meaningful and effective specifications that will lead to vehicle-track system optimization and, in time, perhaps to the removal of the obstacles discussed previously. This will require effective examination and monitoring of vehicle and track standards to ensure their mutual compatibility. The group was unanimous in its determination of the need for performance standards instead of the present design standard specifications. Work remains to be done to properly determine the appropriate performance criteria to write specifications that will allow, and thus encourage, innovation and improvements, particularly to allow design innovation by the railroad suppliers. It was noted, however, that a number of potential institutional barriers exist, including the present design specifications and the lack of techniques and appreciation for life-cycle costing, which leads to the use of first-cost as the determinant.

A major problem, however, is developing performance specifications that adequately identify and address all of the necessary aspects of performance in such a way that they can be fairly tested before acceptance. Really good performance standards take time to develop.

Fault modeling and prediction was another major issue, with real-time monitoring of performance safety measures, both on-board the train and at wayside, being a key requirement. Real-time analysis and presentation of those data were also deemed to be vitally important, particularly the need to present the data in a format that is easy to read and comprehend.

Longitudinal train performance, including train makeup, train handling, and buff and draft forces, remains an issue, although arguably diminishing in importance after many years of research and gradual adoption of new technologies and improved operating practices. Improvements can still be achieved in the areas of safety, energy consumption, and ride quality.

The last issue identified by the subgroup concerned environmental impacts of the vehicle-track interface. Many rail systems (e.g., in Japan and in U.S. urban transit systems) pay close attention to reducing noise levels, including noise generated at the wheel-rail interface. Although it is not a big issue for U.S. freight railroads at the present time, the group believed that it was likely to become more important in the future. It was also recognized that vehicle-track system optimization will reduce train resistance and thus have a beneficial effect on locomotive emissions. The use of lubricants in general, and at the wheel-rail interface in particular, was also deemed to be an ongoing issue, although it was recognized that lubricants used today do not present an environmental hazard.

Research Needs and Opportunities

Using the issues described previously as a starting point, the three subgroups developed a list of research priorities. There was some overlap among the three subgroups, and subsequent deliberations by the whole group resulted in 10 research areas being identified as high priority. Many of these research areas are new initiatives, or significant extensions of existing programs, deemed to be necessary for the future growth and well-being of the industry. There was an underlying assumption that current research projects would be continued to fruition.

Two of the research areas were deemed to be of the highest priority and will, to varying degrees, be "drivers" for many of the other research topics identified (i.e., other research topics will to some extent use the output from these two top priority areas). One of these top priority projects—customer focused train systems—has a definite external focus. The other—vehicle-track system performance models—has a more internal focus. These two research topics are described in more detail; the remaining eight are described briefly.

Vehicle-Track System Performance and Cost Model

The objective of the vehicle-track system performance and cost model development is to refine, expand, and integrate existing vehicle-track models to (a) accurately predict the overall vehicle-track system performance, (b) explain and predict the behavior of each system component, and (c) perform life-cycle cost analyses of the vehicle-track system and its components.

The major uses of the model, or a series of well-integrated models, will be to accurately assess the performance of the whole vehicle-track system due to change(s) in any of the components of that system and to carry out realistic assessments of life-cycle costs of the system and its components. The model(s) should be able to provide the following:

- Estimates of track damage, wear, and fatigue;
- Estimates of vehicle performance, including shock environment, ride quality, and the like;
- Assessment of lading damage;
- Estimates of noise and ground vibration;
- A good understanding of the interaction of different track and vehicle components; and
- Meaningful sensitivity analyses and estimates of the effects of vehicle-track component variability.

These outputs will be used to improve maintenance and replacement strategies for both track and rolling stock, to better allow for preventive maintenance practices, and to supply input to the development of performance standards for the track, vehicle, and the entire vehicle-track system.

The industry is already well on its way to achieving the objectives just described. A large number of vehicle-track models already exist, to examine both dynamic activity and longer term degradation. However, these models are often developed in isolation. This research project would provide a framework and a plan to focus these models, and develop new models if necessary, to integrate them into one model or a series of models required to examine the broad system issues. This will require an improved understanding of the fundamentals of system dynamics, including the effect of vehicle loads on track performance, the effect of track imperfections on vehicle performance, flange climb mechanics, wheel-rail contact mechanics, and the effects of friction and nonlinearities. For the degradation modeling, improved degradation and failure models are required. These may be developed using existing data on failure modes and degradation rates, although more data may be required in some instances. Proper validation of the models is, of course, essential.

Customer-Focused Train Systems

The objective of customer-focused train systems research is to determine customer needs and market opportunities and to dramatically shorten the time to implement defined train systems.

The output from this research area would include (a) determination of customer needs and market opportunities to ensure that new vehicle and train designs are market driven, (b) definition and refinement of the processes that lead to the introduction of new train systems, (c) design and planning tools to expedite the process, and (d) identification and, where possible, elimination of technical and institutional barriers to innovation and implementation.

As with many other industries, there is a tendency for railroad equipment innovation to be more technology driven than market driven. This research project, which is partly a study of the process of implementing innovations, will help ensure that equipment and train designs are focused on customer needs and market opportunities for the entire industry.

Major elements in the task of process definition were determined as (a) identify customers, (b) identify markets and prioritize, (c) identify equipment needs and performance goals and (d) identify ways to achieve faster introduction cycles by accelerating all stages of the process, such as design, construction, evaluation, approval, implementation and service monitoring.

The group anticipated that some of the major features of the train systems resulting from this process would include the following:

- Special, nonconventional trains designed for customer needs;
- Designs for maintainability, scheduled maintenance, and minimized life-cycle costs;
- Performance-based car and track usage rates to encourage improved performance; and
- Optimized or distributed motive power.

One of the major requirements for achievement of the objectives is to define a process whereby the technologists (researchers, suppliers) can get closer to the railroads' customers and develop a far better understanding of market opportunities for the railroads. This includes improved knowledge of market size and location, identification of corridors, identification of loads and trailers or containers for profitable handling, and identification of rolling stock and handling requirements to develop useful and realistic performance specifications.

A number of technology tools are also required, including more user-friendly vehicle dynamics and vehicle-track interaction models, improved life-cycle costing methods to help railroads move away from purchasing on a first-cost basis, and acceleration of the equipment approval cycle, including testing and industry committee review.

Vehicle-Track System Performance Standards

The objective of vehicle-track system performance standards research is to develop performance standards that (a) optimize the vehicle-track system, (b) replace current design standards where appropriate, (c) promote innovation and improvements, and (d) ensure compatibility of operations between main and secondary lines.

The output from this work will be performance standards. In many cases, they will replace or revise design specifications that are prevalent in existing mechanical and track standards.

The output will also include standards for secondary and short lines to ensure that vehicles that are designed for the optimized main line system can operate safely on secondary lines.

There is a rapidly growing awareness of the need for and advantages of performance standards that provide the user (designer) with guidelines on how the product should perform without detailing what it should look like. Although many new performance standards can be written now with relatively little research, others will require considerable research and development. The vehicle-track systems performance model will be a key to the development of performance standards.

Vehicle Suspension Systems

The objective of vehicle suspension systems research is to develop improved trucks and suspension systems to

- Improve vertical and lateral ride quality to benefit track, car structure, and lading;
- Reduce fuel consumption, flange and rail wear, and track deterioration;
- Increase reliability and decrease maintenance requirements; and,
- Provide for a cost-effective system in the areas of price, operation, maintenance, net weight reduction, and life-cycle cost.

The output from the broad thrust of the topic is to develop suspension systems that meet the objective. The research requirements are to provide analytical tools, evaluation and test tools and methodologies, methods to determine net benefits, and communication of system requirements to stimulate the development of improved suspensions.

Providing analytical tools for this objective also fits well with the requirements for the vehicle-track system performance model. Understanding the benefits of improved suspension systems and the life-cycle costs is key.

Train Braking, Control, and Monitoring Systems

The objective of train braking, control, and monitoring systems research is to develop and integrate on-board and wayside detection systems to continuously monitor and optimize the track-train system performance and allow for real-time fault detection and control of the brake function while achieving quicker, more uniform braking systems.

The output will be an advanced train braking and fault monitoring system or systems. The new train system will have a number of subsystem improvements, including the following:

- Continuous monitoring of train and rolling stock safety parameters;
- Improved fault-detection techniques;
- Selection of standard control protocols, including power sources, common connections, and a transmission carrier;
- Minimized longitudinal intercar forces (needed because of brakes that respond faster than those used previously);
- Brake force proportional to load;
- Higher retardation rates;
- Graduated release;
- Alternative energy dissipation means (possibly); and
- Separation of control function from power function.

The ATCS communication platform is being adopted by most, if not all, railroads, and there is a growing recognition of the advantages of faster acting braking systems, a technology that will require a communication system along the train. Movement toward such a train length communication package will allow railroads to include fault detection and sensor technology.

Such sensing systems could include detection of failing bearings, wheel defects, excessive vehicle vibration, abnormal drawbar forces, proximity to derailment, and virtually any other measurable parameter on the rolling stock.

Intercar Body Connecting Systems

The objective of intercar body connecting systems development is to provide systems that improve safety, minimize maintenance requirements, and improve ride quality.

The output will be connecting systems that will

- Eliminate or minimize free slack,
- Provide fully automatic coupling of individual cars and of all necessary connections,
- Improve gathering range of couplers, and
- Improve articulated connectors and drawbar systems.

As with the suspension systems, the primary role of researchers is to provide analytical tools, evaluation and test tools and methodologies, methods to determine net benefits, and communication of requirements to stimulate the development of improved connecting systems.

Track Materials

The objective of track materials research is to identify and develop new materials or identify properties of existing materials to improve track material performance and develop appropriate evaluation techniques.

The output from this effort will be longer lasting, cost-effective track components incorporating new materials as appropriate.

This research topic will be greatly enhanced by the development of the vehicle-track system performance model or models, which will relate performance of the substructure, ties, fasteners, rail, and special trackwork to measurable properties.

Optimized Track Maintenance

The objective of optimized track maintenance research is to develop optimum maintenance strategies for track, bridges, and signals that achieve the cost-effective balance among track condition, cost-effectiveness, and available track time.

The output from this project will include predictive track maintenance models and improved systems for collecting data and analyzing duration and costs of different track maintenance activities.

The limited time available to carry out track maintenance and increasing demands for service reliability are placing large burdens on railroad engineering departments to develop quick but effective maintenance practices.

Evaluation of Track on Basis of Vehicle Performance

The objective of the evaluation of track on the basis of vehicle performance is to develop a real-time system or systems for analysis of track condition on the basis of vehicle performance.

An advanced, new generation track geometry car, with associated hardware and software, will be able to collect appropriate track condition data and analyze the performance of a range of vehicles over that track. This will ensure that track maintenance needs are based on the performance of the vehicles that operate over that track. Required operational constraints and precise location of track maintenance needs will be immediately identified by this system.

Existing track geometry cars produce exception reports based on predefined geometry criteria that do not always relate to vehicle performance. The concept in this research area would entail collecting track geometry (perhaps similar to existing track geometry cars) and feeding that as input to a computer that would analyze the expected performance of a wide variety of freight cars over that track geometry. The user could define the types of car that operate on that track and determine track locations requiring maintenance to achieve safe, optimum vehicle performance. This scheme would also allow for development of a performance data base that would allow for analysis of trends leading to the development of predictive maintenance techniques.

Consideration of Human Resources

The objective of human resources research is to develop improved safety performance, ergonomics, working conditions, and performance for all employees involved in work in the track-train system.

Better communication is key to improved performance and better understanding and appreciation of human resource issues. Training at all levels is required to identify potential problems, to produce a more motivated work force, and to improve work techniques, including the development of ergonomically correct tools and work methods.

This issue was raised by the track subgroup, but participants agreed that it is an appropriate research topic for all employees in the track-train system.

SUMMARY

The infrastructure group discussed several general issues, which affected its selection of critical research areas (e.g., the need for optimizing the performance of vehicles and track). Railroads own their infrastructure and thus have a significant potential advantage over their competitors. Railroads pay a high price for owning that infrastructure, however, and opportunities to more economically optimize track and equipment standards need to be realized. A number of such opportunities were discussed at this conference. However, the institutional framework presents difficulties in full realization of the benefits of system optimization. The framework referred to is that by which mechanical standards are administered by a single body, the AAR Mechanical Division, whereas track standards are set by FRA and by the engineering departments of individual railroads.

The issues of customer service and service reliability also figured prominently in the group's discussions. There was general recognition that hardware research in the past has been driven largely by improving safety and by the internal focus of improving efficiency and productivity. The external focus (customer service and satisfaction) will be a major factor in the future.

One major problem in achieving customer satisfaction is in accurately identifying customer needs and requirements. Technologists, particularly researchers and suppliers, do not usually interact directly with railroads' customers, the shippers, and thus have a limited understanding of market opportunities and needs of railroads. Improved communication is required. It was recognized that the AAR Customer Service Management Committee is working to achieve the goal of developing and communicating customer requirements.

Achieving improved customer satisfaction, safety, and efficiency requires innovation in the products that suppliers offer to railroads. A major barrier to innovation may be design standards and specifications that limit design creativity. Performance standards are seen as having the potential to promote innovation and improvements. Such standards would define performance and safety targets with only a minimum amount of dimensional specificity. However, performance standards must adequately address all of the necessary aspects of performance in such a way that they can be fairly tested before acceptance.

A second potential barrier to innovation is the lack of financial incentive for railroads and other equipment owners to invest in premium equipment, particularly when used in free interchange. Depending on the circumstances, the owner's benefits of purchasing premium equipment may be small. Substantial benefits often accrue to the operations and engineering departments of the railroads over whose tracks the equipment is operated. This and other factors result in a tendency for initial cost to dominate some purchasing decisions.

More comprehensive economic tools to develop realistic life-cycle costs of new technology are seen as an important research need to help overcome the investment cost barrier to innovation. This consideration and the need to develop a system dynamics and degradation model, or family of models, led to the identification of the first research topic discussed in the Research Needs and Opportunities section. The first topic, the Vehicle-Track System Performance and Cost Model, and the second, Customer-Focused Train Systems, are viewed as "drivers" of many of the other eight research topics.

The group concluded that the 10 research topics address the most critical needs of the industry in the area of the track-train system and provide a good balance between satisfying the requirements for improved safety and the needs of external and internal customers.

COMMAND, CONTROL, COMMUNICATION, AND INFORMATION

Command, Control, Communication, and Information Systems

H.G. Moody, *Association of American Railroads*

The interest of railroads in advanced command, control, communication, and information (C^3&I) technology is discussed in this paper. One C^3&I project, the Advanced Train Control Systems (ATCS), is described, and research topics in support of that project are proposed. This discussion will serve as a strawman for discussions on research needs to support the broader use of C^3&I technology to allow railroads to increase business and profits.

C^3&I systems have been used by corporations for decision support, operational control, and communication within and outside the organization. Railroads have traditionally been pioneers in the development and implementation of C^3&I systems primarily because of the dispersed nature of their operations and the requirement for timely service. For example, railroads were the originators of the time zone system now in use and were early users of the telegraph for many communication functions, including relaying train orders.

To control a widely dispersed operation with the technology of the day, railroads developed a hierarchal management system that functioned using precise rules. Railroad managers knew the actions an employee would take even though the employee was far from the manager and had limited communication capability. This approach was effective and for a time was the standard used for management in many industrial corporations. However, as a result of changes in railroad markets and technology, a whole new approach to managing organizations is evolving.

The technology that will help railroads meet the new challenges of the freight transportation marketplace is advanced computers linked by high-speed digital data communication. This technology promises to take the railroad industry from a system of hierarchal rules and control to a system in which company departments are fused and railroads become so closely allied with their customers that boundaries between them will dissolve.

C^3&I systems are being implemented to improve railroad productivity, customer service, and service reliability. Although significant progress has been made, even greater progress is in store in the future as railroads take advantage of advanced computer and digital data communication technology.

Background

Since the 1930s, there has been a significant shift away from a transportation system designed to transport comparatively low-value, fungible bulk goods to one designed for high-value, time-sensitive, one-of-a-kind manufactured goods. This change in the market has decreased the railroads' revenue market share of the intercity freight transportation and increased that of trucks, particularly since deregulation of truck and rail transportation in the late 1970s. During the 1980s, the truck market share grew from $70 billion to $150 billion. The market share of railroads has remained at about $30 billion. This has occurred in spite of enormous improvement in the productivity of railroads. This improvement in productivity restored the railroads' financial viability, but did not provide an increase in market share.

The railroad industry was not well suited to take advantage of the shift in the market. The trucking industry was. Railroads went from serving a mass market to serving a niche market. In spite of the decrease in revenue market share, the railroads today move more freight than ever.

The reason for the revenue market share shift to the motor carriers is shown in Figure 1, from a survey by Temple, Barker & Sloane Inc. This figure shows where and to what degree motor carriers have a service quality advantage over railroads. One conclusion some have drawn from this survey is that the railroads have no competitive advantage to use to regain market share. However, an examination of the specific indices (e.g., service reliability), which show trucks with a 99 percent or better on-time performance and the railroads with between 50 and 95 percent, reveals that considerable improvement could be made by railroads. If this improvement is made, there is no reason why the railroad industry cannot gain market share from the trucking industry (*1*).

In addition to the need to improve service reliability or the quality of the transportation product, railroads need to improve customer service. The day-to-day relationships between railroads and shippers must be problem free and seamless.

C^3&I systems now being developed and implemented by railroads are key to improving service performance, regaining market share, and improving the bottom line in the decades to come.

These systems generally fall into two areas: industry information systems such as Interline Service Management (ISM), Automatic Equipment Identification (AEI), Train II, Interline Service Settlement (ISS), and Rate Electronic Data Interchange Network (REN) and command, control, and communication systems such as ATCS.

ISM is an information system supported through management processes, such as car scheduling, on each railroad. It is designed to be interline to allow carriers to provide seamless one-stop service to customers. In many markets, more than half the traffic is interline. The system will rely on accurate estimated times of arrival (ETAs) and estimated times of interchange being developed and transmitted to other railroads. The support processes include service commitment to the customer, shipment monitoring, problem resolution, post-trip analysis, and customer access. Each railroad is responsible for following through on its commitments through disciplined operation.

AEI is a system of mandatory tagging of all freight cars and optional tagging of other equipment with a passive transponder that contains such unique information as the car number

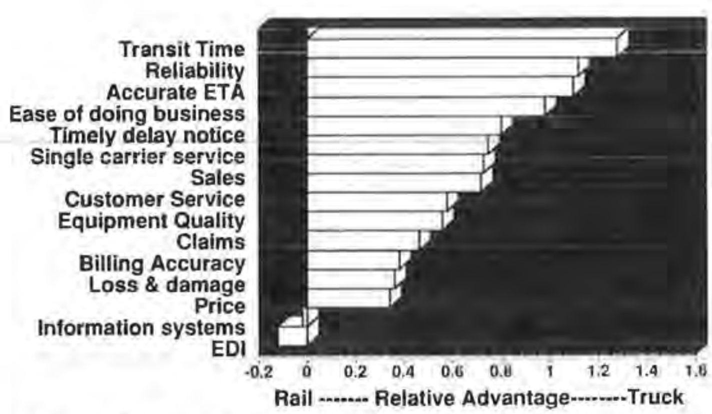

FIGURE 1 Areas in which motor carriers have an advantage over railroads (source: Temple, Barker & Sloane, Inc.).

and the owner's recording mark. Through a network of wayside readers, precise car location will be established and can be used to support such systems as ISM and the freight car management programs of railroads.

Train II is an industry data base containing information on car status, movement, and interchanges and is accessible by all participating railroads. It is used for such processes as car hire settlement, customs billing, car grading, car movement activity, and interline tracing.

The ISS system is designed to provide timely information to carriers for settling interline rail transportation bills. REN is a companion system of providing prices to railroads for price quotation to the customer.

These projects are a few of the examples of the efforts of railroads to generate real-time information to provide seamless service to their customers. Many of these projects are in the development stage and are often interrelated. A recent industry-directed Interline Customer Satisfaction Strategy program has been instituted to coordinate the interrelated system requirements for these systems and the data base industry reference files.

One way to differentiate between the two systems is that one is designed to operate the railroad (ATCS), and the other is designed to collect, store, and communicate essential information to railroad managers and their customers. Some ATCS applications, such as work-order reporting, support the information systems.

The details of non-ATCS information systems will not be discussed further here, but railroads are making significant efforts to implement these real-time systems to provide seamless service. There is no doubt that once these systems are implemented, the relative advantage of truckers in this area will be significantly reduced. It is apparent to all who are involved in developing and maintaining these systems that there is much to be gained from proceeding with these programs in an organized fashion instead of with one independent application at a time.

ATCS is discussed in detail here. Topics are what ATCS is, what railroads are doing with it and what it can do for the railroads, and what needs to be done. The last topic includes a discussion of the role of research in ATCS. The discussion of that role may lead to a broader discussion of the research needs in information systems as well.

WHAT IS ATCS?

ATCS is a broad-based command, control, and communication system that uses computers and digital data communication to connect the dispersed elements of the railroad, the locomotives, track forces, and wayside devices to the dispatch office, and through that connection to the railroad management information system (MIS). A simplified schematic of the system and its likely connection to corporate MIS are shown in Figure 2. With this digital data link, ATCS shares information with complementary management systems, improving the effectiveness of both.

This link is designed for multiple applications, which are divided into two areas: business applications and train control. The requirements for train control put more demands on the data link and the computers than do the business applications. The business applications include work-order reporting, locomotive health monitoring, and maintenance-of-way work reporting. Other applications may easily be added.

ATCS train control uses in-track transponders and onboard odometers to determine train speed and location. By using knowledge of the track stored in the onboard computer (OBC) and the precise reporting of the location of all trains to central dispatch, it is possible to make the headways with ATCS specific to each train and not be dictated by the longest, heaviest train.

The data communication link uses six 900 Mhz mobile data radio channels specifically allocated for railroad use throughout the United States and Canada. The network is based on the seven-layer open-systems interconnect model as adopted by the International Standards Organization. With the form, fit, function approach of the ATCS system architecture, components and systems built by different companies will "plug and play." This approach has been shown in the past to reduce system costs by up to 30 percent.

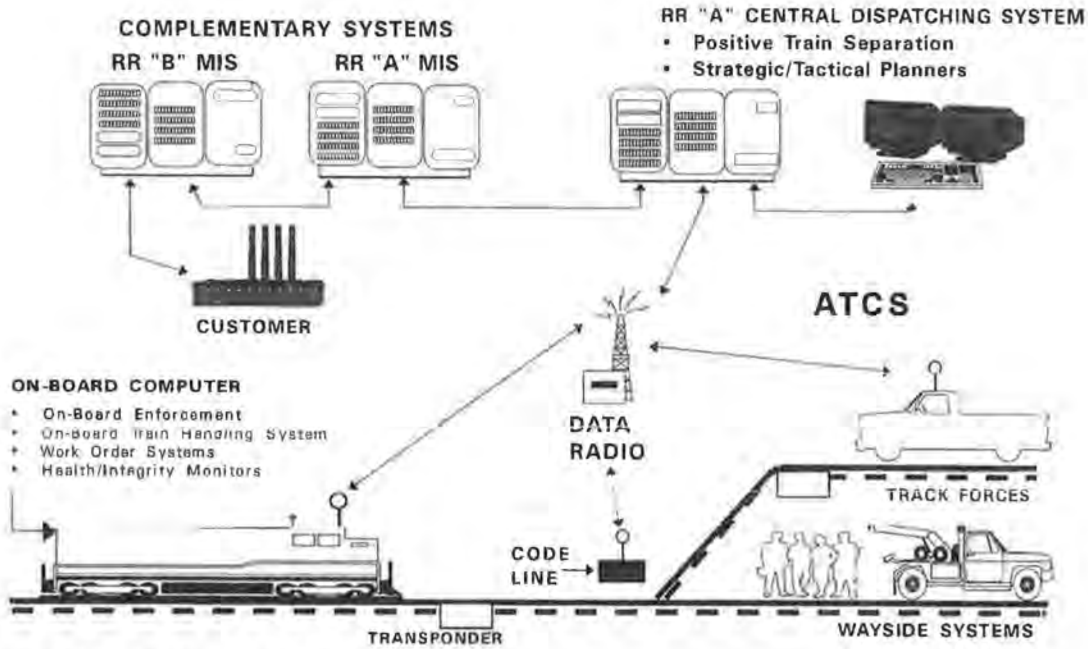

FIGURE 2 ATCS and its relationship to other systems.

The system architecture is detailed in 31 specifications. These specifications are dynamic documents that allow for graceful migration to various applications and incorporation of improved technology while retaining backward compatibility. The architecture is designed to meet specific railroad requirements. The specifications are under industry configuration control. Early in 1993, Version 3.0, the first to contain a complete set of specifications defining the train control application software, was released (2).

What Railroads Are Doing With ATCS and What It Can Do for Railroads

Both the Canadian National and Burlington Northern Railroads have done extensive business cases for ATCS. The Association of American Railroads (AAR) recently updated those business cases and provided the resulting report to its members.

Both business cases demonstrated good potential internal rates of return, about half achieved with hard dollar savings and half with soft dollar savings. The industry is currently examining the long-range case for ATCS and the next steps to take.

There are four current applications and one potential application examined in the business cases that bear out the value of ATCS as a system that can support multiple applications. The way these applications are being developed and implemented is referred to as a building-block approach. This approach allows for a logical migration path across the railroad and allows each railroad to choose the path that fits its needs.

Work-Order Reporting

The first substantial business application for ATCS is work-order reporting. This application was pioneered by Union Pacific Railroad (UP) in 1989. The project on the UP is expected to be complete in 1994. Work-order reporting is the real-time reporting of pickups and setouts. It substantially improved the quality of information in the UP car scheduling system. As a result, customer service and service reliability have improved. Both Canadian National and Norfolk Southern have had ATCS work-order reporting pilots.

Work-order reporting systems that do not use the ATCS data communication network are being studied and implemented at the Consolidated Rail Corporation (Conrail) and CSX Corporation.

Code Line Replacement

Several railroads, including CSX, Norfolk Southern, CP Rail System (formerly Canadian Pacific), Southern Pacific, and Atchison, Topeka and Santa Fe (ATSF), have used the ATCS data communication link for code line replacement projects. ATSF has decided to use its application systemwide. Code line replacement uses the data link to replace the pole line for transmitting signal codes to and from the dispatch office. Code line replacement has already proven to reduce costs and improve the responsiveness of the system.

Locomotive Health Monitoring

Burlington Northern Railroad has had locomotive health monitoring in place since 1992 to report the health status of 100 locomotives to the mechanical department. This application uses the Burlington Northern 160 Mhz data communication link and is expected to improve locomotive availability and reliability.

These early applications have resulted in the installation of a substantial portion of the data communication network. As this installation occurs, the additional applications would use this installed base.

Train Control

Both Canadian National and CP Rail System have train control pilots in place. CP Rail System expected to operate trains on its pilot from Calgary to Edmonton in late 1993. Canadian National is expected to put its British Columbia North line project into operation in 1994.

Train control is the most complex and offers the greatest benefits of this group of applications. ATCS train control is expected to provide the following benefits:

- Reduced headways to allow for increased line capacity. Independent studies indicate that a 25 percent increase is possible.
- Improved service reliability. ATCS has the capability to allow railroad operations to recover from delays and to improve meets and passes.
- Fuel savings from train pacing.
- Improved safety of operations from the use of digital data communication of movement authorities and from the enforcement of movement authorities and speed limits.
- Reduction in track damage and derailments due to excessive speed and poor train handling.
- Improved equipment use.
- Reduced dispatcher workload from the use of digital authorities to replace voice authorities.

Train control has within its application a migration path from current systems to full system. The current pilot program on Canadian National and CP Rail System are both on "dark" territory. This is a step along the train control migration path and may involve eventual conversion to ATCS movement authorities. Figure 3 is a schematic of the draft migration path showing current applications and three paths from centralized traffic control (CTC), automatic block signal (ABS), and track warrant control (TWC) systems to ATCS train control.

The path from CTC to ATCS train control will be used to show how this migration could be done. The first step is already being done with code line replacement. The first version of the train control software will allow for train monitoring overlay on CTC. This version will require equipping locomotives with the location system, an OBC, and a data radio. Transponders will

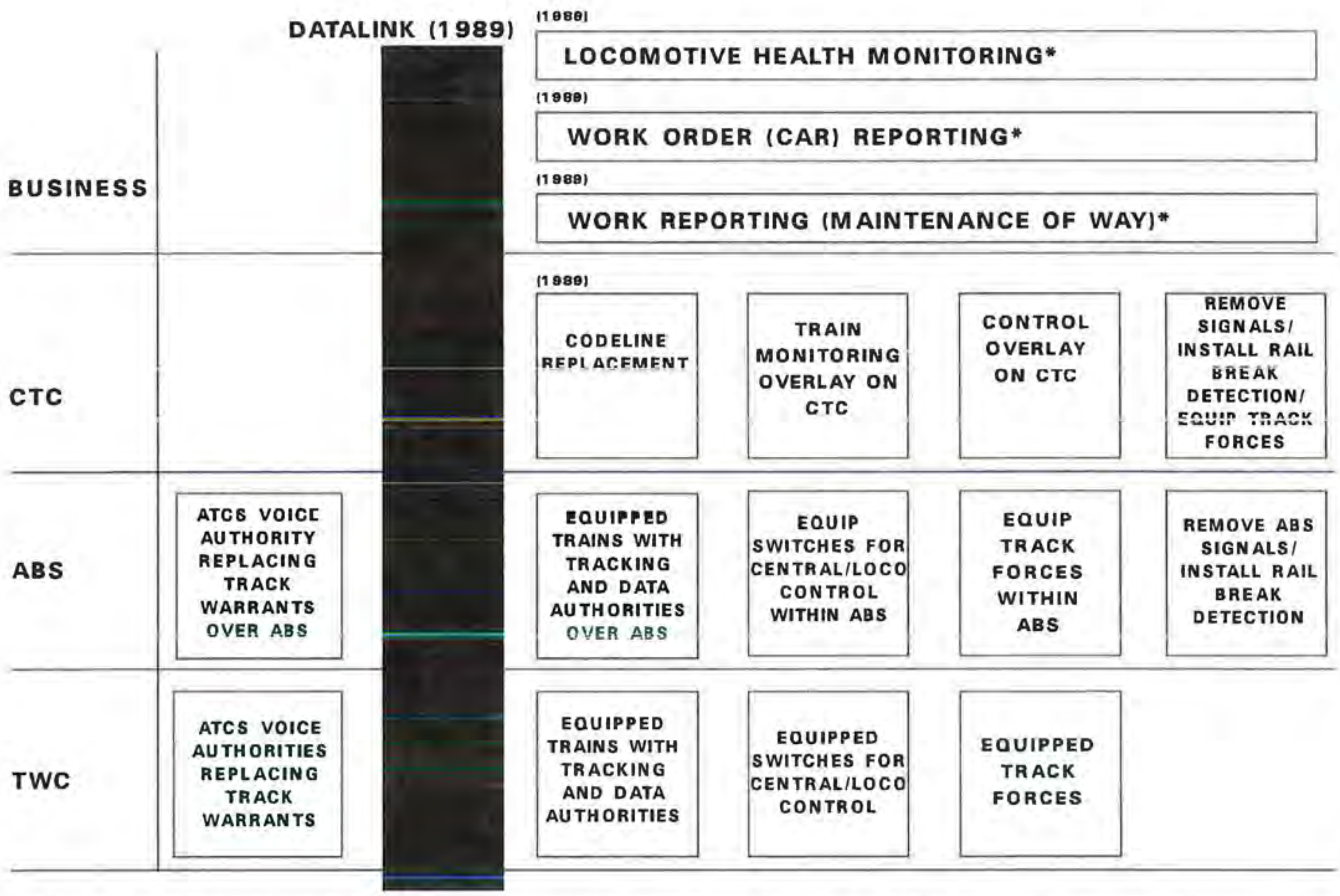

FIGURE 3 ATCS migration paths for railroads (numbers in parentheses indicate earliest date that specifications and industry software are available; asterisks indicate that industry standards apply, but industry software does not).

be placed in the track at the required locations. The next version of the train control software will be a "control overlay." This version will allow equipped trains to operate using ATCS movement authorities while obeying CTC signal indications in the field. The final version will allow the full use of ATCS authorities and removal of signals, with the installation of a rail break detection system. This version will allow the railroad to take full advantage of the capacity increase from ATCS. This description of a potential migration path is preliminary. A detailed description of these paths shown in Figure 3 is being completed for the ATCS project; this document should be completed in 1994.

While the train control application is being considered, railroads will continue with their business applications on a specification compliant data communication network. This will provide the railroads with the capability of building the train control application on the installed network if proven financially feasible.

Complementary Systems

Complementary systems that support ATCS and that ATCS supports were mentioned previously to set the stage for a broader discussion of how these C^3&I systems relate to each other and what might be done to improve the opportunities for a smooth overall system of managing railroad operations. These systems include the following:

- Car distribution,
- Yard and terminal management,

- Strategic traffic planner and service design plan,
- Automatic equipment identification,
- Motive power management,
- Crew calling,
- Wayside and vehicle-borne detectors,
- Grade-crossing health monitoring, and
- Remote control of locomotives.

WHAT NEEDS TO BE DONE

The role of research in C^3&I programs is considerable. There is current support in the Washington Systems Center (WSC) Customer Service Division of the AAR Research and Test Department for the information systems previously mentioned in this paper. ATCS is a project of the Operations and Maintenance Department, although a support project on locomotive cab electronics integration is supported in WSC.

The following work projects, which could be supported through research, would support the ATCS program. These projects are proposed not to the exclusion of others in support of information system but as a catalyst for discussion.

Rail Break Detection System

Before full train control can be hosted on territory where there is CTC or ABS, a means of providing rail break protection will need to be found. Many variants of the current direct current track circuit have been proposed, as has the use of time domain reflectometry and improved inspection techniques. The principal requirements of the new system will be low cost and reliability equal to that of the current system.

Tactical Planner

One of the needs expressed by several members of the ATCS Steering Committee is for a dispatch planner to allow more efficient meet and pass planning and recovery from train delays. This type of planner would rely on the precise train location information and the quick feedback loop available with ATCS to minimize deviation from plans. The tactical planner would use as input train schedules from the strategic planner (built to execute service design plan). This project would develop the requirements, design the system architecture, complete the functional specifications, and possibly construct a prototype.

Health Monitors

With an extensive data communication link, health monitoring of field devices and locomotives is possible. The field devices would include grade-crossing equipment, condition and failure monitoring devices, and signal circuits. Although health monitoring of locomotives is now available, one of the continuing efforts is to reduce the amount of data transmitted to a minimum. This research project would determine the requirements for a health monitoring system, the indices to be measured, and how the information should be analyzed and communicated. One of the benefits of locomotive health monitoring should be the reduction of scheduled maintenance intervals.

Ergonomic Evaluations

Considerable effort has been made to determine the ergonomic requirements for the man-machine interface (displays). Further evaluation may be appropriate as new applications are added. AAR has a recommended practice for the operating display on the locomotive which used ergonomic guidelines to help develop the industry design. This effort would first need to establish if there is a requirement for a detailed study.

Risk Analysis

ATCS is a complex safety system. A safety analysis was conducted for the ATCS program by Draper Laboratories, and a failure modes and effects analysis was published in ATCS Specification 140. However, further upper-level failure analyses may be necessary to determine if all the potential faults have been analyzed.

Predictive Braking Algorithm

At the top level of ATCS enforcement of movement authorities and speed is a functional requirement. Although extensive work has been done on a predictive braking algorithm, no completely satisfactory algorithm has been developed. A host of inefficient reactive braking systems is available, none of which provides all the capabilities needed to meet ATCS requirements. The four steps in this project are as follows:

1. Build and test an effective 1-min predictor. This system would determine the train location and speed continuously 1 min from its current position.
2. Develop through simulation and testing an appropriate braking curve algorithm. This curve would be compared against engineers' actions in a simulator.
3. Install the algorithm in locomotives equipped with an OBC, and in the background compare actual braking performance with predictive braking performance.
4. Test the final system to prove that the system will stop the train effectively.

Determination of the Dollar Value of Improved Service Reliability

In the Canadian National and Burlington Northern business cases, a value was assumed for increased revenues from improved on-time service. This value was determined from surveys and from analysis of confidential contracts. More work needs to be done to reduce the spread of these values. The results of this work would reduce the uncertainty of "soft dollar" benefits in the assessments of projects with these types of benefits.

Conclusion

The projects proposed here by no means constitute the complete list of research projects in the C^3&I area. What this short list points out is that a substantial amount of work remains to be done to take advantage of computers and digital data communication to improve the railroads customer service, product quality, safety, and productivity.

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Discussion Group Summary: Command, Control, Communication, and Information

The command, control, communication, and information (C^3&I) group of conference participants stated their goal to be to revolutionize the railroad industry and bring it into the 21st century in an environmentally sensitive, energy efficient, safe way. It was the participants' view that the primary constraints limiting the railroad industry's ability to develop new products and expand transportation service are not in track and rolling stock, but in C^3&I systems.

The mission of research and development in this area is to identify opportunities for, capabilities of, and limitations in C^3&I systems to support the operating processes and organizations required to safely meet the evolving needs of current and future customers, facilitate the implementation of these systems, and provide economic justification for them.

Major Issues

The major issues in C^3&I systems are as follows:

- Customer needs and service:
  –Determination of whether customer service needs are accurately reflected in the requirements for C^3&I systems and
  –Determination of whether the systems deliver the benefits;
- Economics:
  –Identification of the price and market elasticities of transit time and time variance and
  –Assessment of the cost of delaying or not making the investment in these systems;
- Technological:
  –Identification of the alternative C^3&I technologies,
  –Development of accurate software algorithms, and
  –Management of data, data requirements, use of data, and use of expert systems;
- Organizational:
  –Implementation of structural changes (i.e., reengineering train operations),
  –Modification of organization culture to take advantage of technology, and
  –Modification of the industry culture;
- Safety:
  –Determination of which accidents are affected by C^3&I technology and
  –Delivery of improvements; and

- Implementation:
  - –Determination of how to stage systems implementation,
  - –Establishment of funding, and
  - –Development of flexibility to accommodate change.

Research Areas and Priorities

The following research areas were identified to support and develop the use of C^3&I technology in the railroad industry. These research topics were the highest priority projects selected from a large group of projects. They are ranked in priority order, and those at the top of the list are critical research projects.

Customer Service Needs

Current customer transportation needs and the gaps with current service offerings should be identified through the use of generally accepted marketing analysis techniques. Requirements to bridge the gap in the future should be established to ensure that customer needs are identified. This analysis would establish the service capabilities that shippers desire and would be willing to pay for above and beyond the service capabilities they are now using. The research will determine the elasticity of demand for improved service for price and market share.

Customer needs will drive the requirements and design of C^3&I systems. Customer needs will also determine how business processes are redesigned to ensure that the new C^3&I systems deliver benefits to customers. These studies will allow for a complete evaluation of the investment in new C^3&I systems and their capabilities to bridge the service gaps.

Business Process Redesign and Organizational Implications

The ways in which business processes must be redesigned to better meet customer requirements and the capabilities of new or redesigned C^3&I systems to support new business processes should be identified. Customer needs should drive the business process redesign to provide more reliable, faster, and simpler service. On the other hand, the capabilities of the new C^3&I systems will facilitate business process redesign in ways not previously possible due to limitations in availability and timeliness of information. Business process redesign will be required to fully exploit the capabilities of the C^3&I systems and to ensure that the benefits are provided to customers, managers, and others.

Soft Benefit Evaluation Methodology

A methodology should be developed to determine the soft dollar benefits from investing in new C^3&I systems. Such benefits include increases in prices or market share from improved delivery time and reliability; the value of having faster, more accurate information for decision support; and the value of offering new services to customers. Included in the development of such methodology would be techniques to better determine price or market share elasticities resulting from improved service reliability or transit time.

Soft benefit evaluation methodologies are needed to fully evaluate the financial implications of investing in C^3&I systems. Although some anticipated benefits from these systems are hard benefits, such as improved equipment use, many others are soft benefits. If soft benefits are left out of the analysis, they are implicitly assigned a value of zero, which can mislead managers. It is critical to evaluate the full range of benefits to accurately assess the value of an investment from C^3&I systems. Techniques developed to evaluate soft benefits could be applied for other research projects and investments.

Control Software Development

Control software for advanced C^3&I systems should be developed. This software would cover the strategic or tactical planner and the train control software. The train control software would include the central, locomotive, field systems, and maintenance of way vehicles. Part of this development process would be the evaluation of existing algorithms and, if necessary, the development of new algorithms capable of functioning in real time, such as those for meet-and-pass planning and for train stopping. In addition, the information and network requirements that allow for integration and information exchange with other systems must be defined and developed. C^3&I systems must be integrated with existing business and management systems such as automatic equipment identification, interline service management, advanced train control systems work order, and others. Development of this software is essential to the effectiveness and the efficiency of the C^3&I systems.

Broken-Rail Detection

Some railroads are considering elimination of existing signal systems with the implementation of a new C^3&I system for train control. This project would develop a system to replace the functional capability of current track circuits to detect broken rails.

This new technique would be developed as a low cost, more reliable means of detecting rail breaks. Because of its high cost, less than half the track in the United States currently has broken-rail protection.

Industry-Wide Deployment and Implementation Plans

Industry-wide agreements on operating rules and practices required to implement, operate, maintain, and upgrade advanced C^3&I systems requiring interoperability should be established. Examples include agreements on a common data communications network and on the ongoing operation, maintenance, and upgrade of common systems, including performance standards and assignment of responsibility.

A detailed business plan and a physical plan should be developed to implement advanced C^3&I systems by feature or application, or geographic area, starting from current systems. The plan must meet the criteria of minimizing technical and financial risk while maximizing customer needs and financial return and must ensure the safety of the system. The plan will quantify the benefits of each stage of implementation.

Safety Benefits

The safety benefits from crew performance assistance capabilities, such as train-handling assist, should be identified. The incremental safety benefits from each phase of implementation of a C^3&I system should also be identified. Because these systems will be implemented in phases, it will be necessary to analyze and quantify the safety benefits at each phase.

Resource Opportunities

In addition to the traditional funding of research needs from railroads, there may be opportunities to have government funding from a variety of sources, including the following:

- Defense conversion funds or funding available from the Advanced Research Project Agency of the U.S. Department of Defense for train control software development;
- Funds from the Intermodal Surface Transportation and Efficiency Act of 1991 through the Federal Railroad Administration or the Federal Transit Administration or funding through Transport Canada for general safety studies and implementation; and

- Funds from the National Railroad Passenger Corporation (Amtrak) or Via Rail for positive train separation or speed control research.

SUMMARY

C^3&I technology offers enormous potential to meet evolving customer needs and to facilitate the work of those who operate and manage railroads. It also represents the potential for a revolutionary change in how railroads are operated. Because these changes are significant, because the investment required is large, and because some of the benefits are difficult to measure, making a decision to invest in advanced C^3&I systems is a challenging task for management. Thus the most important priority research programs are customer needs, business process redesign, and soft benefit evaluation methodology. The first, customer needs, is required, not only because it will define how the system will provide needed benefits, but also because it drives the design of C^3&I systems and business process redesign. The second, business process redesign, is required because it will enable the railroads to realize the full magnitude of the benefits and deliver them to shareholders and customers. The third, soft benefits methodology, is required because it will enable managers to compare the full benefits of advanced C^3&I systems to the magnitude of the required investment.

Discussion Group Summary: Human Factors Research

Conference participants in the human-equipment interaction group decided that human factors issues were of sufficient importance to warrant development of a separate list of priority research projects. Each project was rated "high," "medium," or "low" on three criteria: priority, cost, and likelihood of a useful product.

Definition of Ranking Criteria

The following are definitions of the criteria used to evaluate the research requirements identified.

Priority

- High: The conduct of this research is vital to the avoidance or alleviation of critical safety or operational problems.
- Medium: The conduct of this research would provide information or permit the development of techniques that would have a positive impact on safety or result in operational improvements.
- Low: The conduct of this research could provide information that might lead to advances in understanding safety or operational processes.

Cost

The cost criterion refers to the total cost to provide the specified product.

- High: More than $750,000,
- Medium: More than $250,000, and
- Low: Less than $75,000.

Likelihood of a Useful Product

- High: Successful completion of the work will involve the following:
  - –Use of proven techniques that have been used successfully in other fields,
  - –Use of data sources known to contain relevant material, and
  - –Product development costs that can be accurately estimated based on known costs for similar work.
- Medium: Successful completion of the work will involve or require the following:
  - –Identification and adaptation of existing methods or techniques,
  - –Identification of data sources that have relevant material or collection of new data through the adaptation of available techniques, and
  - –Product development costs that may vary significantly from initial estimates and should be revisited as the work progresses.
- Low: Successful completion of the work will involve or require the following:
  - –Development of new methods or techniques (because no existing methods or techniques are appropriate),
  - –Development of new data sources and collection of data specifically for this project because no appropriate or relevant data sources are known to exist, and
  - –Initial development costs that can be given little confidence.

List of Priority Research Projects

Display Design

Railroad-specific guidelines and design principles for advanced automated visual and auditory displays should be developed. These guidelines and design principles should include consideration of physical placement of equipment, color contrast schemes, synthesized and digital voice technology, and application of such advanced concepts as tele-presence (use of a comprehensive sensor and communications system to portray a scene or environment to an individual in a remote location).

This project was ranked as follows:

- Priority: medium,
- Cost: medium, and
- Likelihood of useful product: high.

Mental Workload

Research should be conducted on the mental workload implications of new developments in command, control, communication, and information (C^3&I) and other advanced automated systems. In particular, the following issues should be addressed:

- Mental overload and underload (boredom),
- Task scheduling,
- Single-operator cabs,
- Operator versus automated system autonomy, and
- Task allocation between and among the on-board operator, the C^3&I operator, and the automated system.

This project was ranked as follows:

- Priority: high,
- Cost: medium, and
- Likelihood of useful product: high.

Ergonomic Evaluation

An extensive workplace study should be performed of exposures to ergonomic and environmental factors that may result in short- or long-term adverse effects on health and productivity.

Specific research should be focused on a prioritized risk assessment that results in the development of user-friendly equipment, appropriate training, and a safer workplace. Factors to be considered would include air quality, vibration, electromagnetic radiation, lighting, noise, communication capability, cumulative trauma disorders, musculoskeletal injuries, and visibility.

This project was ranked as follows:

- Priority: high,
- Cost: low, and
- Likelihood of useful product: high.

Management of Technological Change

The effective use of human resources will become more important as advanced technology is introduced into railroad operations. This research project would involve investigation of management practices and organizational structures that facilitate employee acceptance of technological change. A particular concern is fostering employee and manager acceptance and enthusiasm for the introduction of advanced technology. Work should include development and validation of methods to improve employee involvement, health and well-being, and job satisfaction. Possibility exists in this area for joint funding efforts such as through Cooperative Research and Development Agreements.

This project was ranked as follows:

- Priority: high,
- Cost: medium, and
- Likelihood of useful product: medium.

Job Definition, Worker Selection, and Worker Training

This project will entail development of formal descriptions of job activities, tools, and work practices for most railroad work tasks. On the basis of these descriptions, worker selection and training methods will be developed and validated to match formal job requirements. Specific attention to requirements of the Americans With Disabilities Act should be included in these activities. This project is currently assigned a low priority but may become more important as new technology such as C^3&I is introduced.

This project was ranked as follows:

- Priority: low,
- Cost: high, and
- Likelihood of useful product: medium.

Human in the Loop Distributed System Simulation

Guidelines and demonstrations should be developed, particularly with regard to advanced C^3&I and automated train control systems, by which available computer models and simulations of subsystems can be interconnected with one another and run in real time with displays, controls, and real human operations. Such simulations would be used initially for system interoperability development and verification, and later for training. Experience of the U.S.

Department of Defense, the National Aeronautics and Space Administration, and the aircraft and nuclear power industries may be useful in this regard.

This project was ranked as follows:

- Priority: high,
- Cost: high, and
- Likelihood of useful product: high.

Human System Error and Recovery Analysis

Guidelines and demonstrations should be developed for collecting and analyzing data on human fitness for duty, human error, and machine failure. For example, a system for reporting errors that do not result in accidents might be set up, similar to that of the Federal Aviation Administration (FAA), which encourages participation yet protects the anonymity of the reporter.

This project was ranked as follows:

- Priority: high,
- Cost: medium to high, and
- Likelihood of useful product: high.

Warning Systems

Hearing protection worn by railroad employees and noise generated by equipment may compromise warning systems, such as those used to alert track maintenance forces of approaching trains. This research would involve investigation of requirements and systems to provide adequate warning in such environments while still providing for hearing protection.

Intelligent vehicle-highway systems research will likely include the investigation of warning systems to alert drivers approaching highway-rail grade crossings of approaching trains. This research will require technical input and guidance from the railroad industry to ensure the proper integration and interfacing with railroad command, control, and communication systems.

This project was ranked as follows:

- Priority: medium,
- Cost: medium, and
- Likelihood of useful product: high.

SERVICE MANAGEMENT

Service Management in the Railroad Industry

Carl D. Martland, Patrick Little, and Joseph M. Sussman, *Massachusetts Institute of Technology*

Many elements must be included in an overall effort to improve railroad freight service management. An understanding of the nature and causes of railroad unreliability is essential to gain an understanding of the dimensions of the problem and the opportunities for improvement. There are many different approaches to improving railroad service, and coordinated efforts will be required in many different areas.

This paper was prepared for the joint Transportation Research Board (TRB), Association of American Railroads (AAR), and Federal Railroad Administration (FRA) Conference on Railroad Freight Transportation Research Needs, the first such conference held in nearly 20 years. Many changes have taken place since the previous conference (*1*), as suggested in the accompanying text box.

Papers presented at the previous conference in 1975 provide useful background on service management in the rail industry. Sussman addressed service measurement, terminal performance as a major determinant of service reliability, and shippers' requirements. He commented on the need for demand models that could, on a commodity- and level-of-service-specific basis, predict what types of demand would occur as a function of changes in service quality. The relationship between service reliability and shipper behavior was identified as an important research need, including concerns with shippers' car detention, car ordering, and regularization of demand by shippers as it would relate to the quality of service provided (*2*).

Sussman also addressed the supply side of service reliability, demonstrating how various operating policies would lead to different levels of service. Operating practices, information systems, and cost models were highlighted, along with capital investment decisions and their relationship to service. Finally, institutional change as a mechanism to achieve better service was outlined with particular focus on work rules, network shape, fractional per diem (soon thereafter implemented as "hourly car hire") and organization structure. The dichotomy between operations and marketing staffs on railroads was emphasized—the former being concerned primarily with cost control, the latter primarily with service—with adjudication of their differences often occurring at the level of the chief executive officer (*2*).

A number of other papers touched on concepts related to service management. Briggs (*3*) commented that holding down rates as a mechanism for avoiding large traffic losses may lead to a railroad's inability "to spend sufficient amounts of money to assure that the physical plant is regenerated." This ties service quality, indirectly through revenue generation, to the ability to refurbish the physical plant. Ostrow focused on the need to develop traffic flow data that can be

Significant Changes Since 1975 in Service Management and the Environment for Service Management

Service Management

- General recognition of the importance of equipment utilization;
- Greater senior management concern for service;
- Better coordination of operations and marketing;
- Higher level of professional education among railroad managers; and
- Greater interest in intermodal transportation.

Environment

- Resolution of the Northeast rail crisis;
- Railroad rationalization (mergers, line abandonments, and line consolidation);
- Deregulation of the rail and trucking industries;
- Technological revolution in computers and communications;
- Technological advances in railroad equipment and line operations, allowing heavier axle loads and higher traffic densities;
- Vastly improved rail infrastructure; and
- Significant progress in labor-management cooperation.

the foundation for market research (*4*). This essentially addresses customer needs as well as the needs of the operating department in optimizing their performance. Davies (*5*) noted, "The railroad industry must implement costing procedures that will enable more effective planning, control and pricing of its production." Implicit within this notion is the ability to provide highly reliable service at a reasonable operating cost.

Dingle (*6*) concluded that the "design of operation management organizations is a basic research need." In other words, the ability of the railroad to produce high-quality service is directly tied to the organizational structures designed to produce this service. Williamson (*7*) bemoaned the lack of research and understanding of railroad terminals and stated, "The United States railroad terminal has only started receiving serious attention in the past 10 years. This attention needs expansion." Finally, Hoppe (*8*) added, "It is in the dynamic planning of operations where yard design needs considerably more effort."

In summary, the previous conference identified many themes relevant to service and service management: recognition of customer needs is critical; providing cost-effective, high-quality service is important; data systems and dynamic planning models are essential; and performance within terminals is a major determinant of service quality.

The first section of this paper, Customer Requirements and Logistics Costs, indicates which aspects of freight service are important and why. The section on Origin-Destination Analysis presents an overview of typical service levels, which shows that there does seem to be considerable opportunity for improving service. In the section on Systems Analysis, the basics of service and capacity management are outlined. Broad options for improving service management are identified in the section on Improvement Strategies. The section on Cross-Cutting Themes includes a discussion of five themes: future market requirements, productivity, advanced technology, human factors, and safety. Summary and Conclusions is the last section.

Customer Requirements and Logistics Costs

The freight transportation market is complex, competitive, and constantly evolving. Freight flows depend on the types of commodities that are produced and consumed, where they are produced and consumed, and the options available for transportation. A particular mode or carrier may prosper or fail because of changes in any of these three areas. Many a rail line has failed because of the movement of the industry away from the line (and consolidation of production in larger, more efficient facilities). The emergence of vibrant export economies in

Asia led to rapid rise in container shipments across the Pacific and across the United States; clipper ships, the Erie canal, and the 40-ft boxcar succumbed to better technology.

There are three broad categories of freight traffic. Basic raw materials, such as coal and mineral ores, almost always move in large shipments by rail unit train or by water. Intermediate goods, such as cement, fertilizer, edible oils, food-grains, bulk chemicals, bulk steel goods, oil products, and automobile parts, are subject to intense intermodal competition. The share of railroads depends on the degree of concentration of flows and the degree of adaptation of rail service, equipment, and infrastructure to the particular requirements of this traffic. For general agriculture and manufactured products, flexible, rapid, dock-to-dock truck service is ideal. Increasing regional and local production implies smaller shipment sizes and shorter hauls. Increasing product differentiation and higher value imply smaller shipment size and greater demand for quality service.

Customers base their transportation decisions on logistics costs. From this perspective, the most important characteristics of freight service are the ones that have the greatest impact on logistics costs. Expressing each element of logistics in terms of customer characteristics, commodity characteristics, and carrier characteristics highlights the importance of average trip time and reliability, along with price and loss and damage (*9*).

For some commodities, the value of inventory or the needs of the production process lead shippers to demand short trip times with little or no variation in the trips (such as just-in-time processes). For other commodities, most notably bulk goods, the value of the commodity may be considerably lower than the equipment in which it moves; consequently, shippers do not object to holding inventories and safety stocks and require only that a certain volume is moved within a relatively long window (*10*). The prices customers are willing to pay also vary. Some customers may be willing to pay a substantial premium to ensure high-quality service, whereas others may not. In both cases, customers' decisions are based on the logistics costs that they face. If the service provided is matched to a customer's desires and is consistent with expectations, the service may be considered reliable, even if that service would not be acceptable to a different customer.

Origin-Destination Analysis

The basic elements of the origin-destination (O-D) trip are described in this section, existing levels of reliability are examined, and some of the best opportunities for improving service are identified.

Trip Plan

The trip plan, or car schedule, describes how a shipment is supposed to move from its origin to its destination. The trip plan lists the pickup time, the sequence of trains that the shipment will move on, the yards where it will be classified, and the estimated time of arrival (ETA) at the destination. For a typical boxcar movement, the trip plan might be as follows:

- Pickup at 1600 on Day 0 by Local 1,
- Arrive Class Yard A at 2100 on Day 0,
- Depart Class Yard A at 1200 on Day 1 on Train AB,
- Arrive Class Yard B at 0200 on Day 2,
- Depart Class Yard B at 0100 on Day 3 on Train BC,
- Arrive Class Yard C at 1500 on Day 3,
- Depart Class Yard C at 1200 on Day 4 on Train CD,
- Arrive Class Yard D at 0800 on Day 5,
- Depart Class Yard D at 0500 on Day 6 on Local 2, and
- Place at Siding at 1000 on Day 6.

For an intermodal shipment, the trip plan is likely to involve only a single train. The plan would be much simpler than for a boxcar, as the following list suggests:

- Arrive origin terminal before 2200 cutoff for Train A,
- Depart at 0100 on Day 1 on Train A,
- Arrive destination terminal at 1200 on Day 2 on Train A, and
- Available for pickup at 1500 on Day 2.

A unit train movement would have a plan similar to that of the intermodal shipment:

- Empty train arrives for loading at 0700 on Day 0,
- Loading completed by 1500 on Day 0,
- Unit Train 101 departs at 1600 on Day 0,
- Unit Train 101 arrives at 0400 on Day 2, and
- Unit Train 101 available for unloading by 0700 on Day 2.

Trip plans can be derived from the operating plan. Local train schedules determine when cars can be picked up and delivered, and the blocking plan determines the route through the network, including the classification yards. Block-to-train assignments and train connection standards determine the specific trains that will be used.

A fundamental question concerns the minimum time that must be provided in a trip plan for a car to make a connection at a class yard. In some cases, connections are scheduled to be made in just a few hours; more commonly, 8 to 12 hr is the minimum time scheduled for a connection. In extreme cases, 20 hr or more might be the minimum time for scheduling a connection. If the minimum time is 12 hr, the scheduled yard time required for a connection to a train that departs daily is between 12 and 36 hr. Longer scheduled delays are required for trains that operate less frequently.

Customer Commitments

The trip plan is not the same thing as the commitment to the customer, and many shipments are made without a specific commitment to the customer. In general, the trip plan may be faster or slower than the commitment, but a realistic commitment usually adds a buffer to protect against potential delays. In any case, the trip plan becomes the goal for the operating department in implementing the plan. If the operating plan produces unacceptable trip plans, the operating plan should be changed or the customer commitment renegotiated.

Measurements are an important aspect of service management. Both absolute and relative measures are needed. Absolute measures include the average trip time, trip time distribution, standard deviation, and *N*-day percent (the percentage of shipments arriving within a window of *N* days); carriers frequently use such measures in their control systems. However, shippers are likely to be much more concerned with measuring performance relative to commitments.

Railroads must therefore be able to monitor customer commitments at the level of the individual customer and the individual shipment. Closely related to this is the need for service measures to be structured in a way that leads carriers to detect and diagnose service failures (*11*). Railroads must develop mechanisms for determining whether variation from the trip plan is sufficiently significant to require active intervention (such as running extra service or notifying the customer). Some shipments may have to be "sacrificed" for others of a higher priority during times of resource shortages or under severe operating difficulties. Even greater than these concerns, however, is that a customer-focused service plan requires that railroads carefully negotiate service commitments with customers to ensure that the service offered meets customers' needs, is achievable, and is profitable.

Origin-Destination Reliability

The levels of rail service vary by market segment. As part of a study conducted for AAR, the AAR Affiliated Laboratory at the Massachusetts Institute of Technology (MIT) analyzed performance for 10 percent samples of boxcar, double-stack train movements and covered hopper unit train movements during a 12-month period beginning in December 1990 (*12,13*, Kwon, unpublished data). For each car type, the average trip time and the reliability of trip times were calculated for the highest volume movements. The data in Table 1 show that the service provided to boxcar traffic was significantly slower and less reliable than that provided to the other two classes. The 2-day percent for a typical boxcar movement was only 49 percent, which means that only half of the cars arrived within 2 days. Although weekends, holidays, and the possibility of alternative routings may have caused some of the variation in trip times, it is clear that the service provided to general merchandise shippers was unreliable. Shippers who use double-stack services between some cities, on the other hand, are able to take advantage of faster and more reliable service.

Causes of Unreliability

The AAR Affiliated Laboratory at MIT recently reviewed previous work on railroad reliability (*14*). After a brief summary of some of the most important results of this earlier work, some recent results are presented.

Early Studies

FRA sponsored a series of studies on railroad reliability in the early 1970s. These studies were focused primarily on general merchandise freight service. A general conclusion was that reliability is closely related to the operating plan and the ability to carry out that plan. Terminal reliability was identified as a major problem because 10 to 30 percent of the cars studied missed connections at each yard as a result of inbound train delays, yard congestion, or inadequate outbound train capacity. Delays related to track failures or equipment failures (including bad orders and locomotive failures) were not found to be major factors for either train or O-D reliability. Meets and passes and other operating problems accounted for a much higher percentage of line delay time than did engineering failures.

In 1975, the Freight Car Utilization Program (FCUP) was initiated by the industry with support from FRA and AAR. Through a series of studies related to various aspects of rail service management, FCUP showed that service problems reflected underlying institutional and organizational problems. FCUP's Industry Task Force on Reliability Studies concluded that railroads lacked the desire, organization, data, and resources to provide reliable service (*15*). The task force recommended that senior management take the lead in providing a commitment to better service, developing an operation and service plan, and providing the necessary resources to implement the plan. On the basis of these recommendations, FCUP then sponsored case studies of operation and service planning on the Boston & Maine and Santa Fe

TABLE 1 Service Characteristics of Rail Freight Service

MOVEMENT TYPE	MEAN TYPE (DAYS)	2-DAY (%)
Boxcar (average)	7.2	49
Unit train	5.3	61
Double-stack train	3.3	86

NOTE: Ten percent sample of Train II data, December 1990 through November 1991.

railroads. The MIT Service Planning Model (*16*), which was developed in these case studies, is still in use today and supported by an industry users group.

Additional research, particularly in the areas of meets and passes and other operational improvements, was conducted by carriers and other interested parties in the 1980s. This effort was driven in large measure by the desire to assess the value of large-scale line control systems such as advanced train control systems (ATCS) and Advanced Railroad Electronics System (*17*). These studies, focused almost entirely on line operations, found that most train delays were due to dispatching and operations and not the reliability of the underlying hardware (track, signals, or equipment).

Recent Results

Recent research by the authors addressed the current causes of unreliable service on the basis of rail industry data (*18*). Three types of data were analyzed. A Class I railroad provided customer service data showing the nominal reasons for delays to individual shipments relative to customer commitments. Two other Class I railroads provided detailed root cause analyses of train delays. Finally, TTX Company provided detailed mechanical data for double-stack cars that experienced delays.

The customer service data reflected more than 93,000 cars handled in 4 selected months in 1991 and 1992. Causes of delay were grouped into the following six categories:

1. Power availability delays, which include delays to trains caused by power not being in position to move the requisite tonnage (24.4 percent of all train delays);
2. Terminal delays, which include yard congestion, cars not switched in time, cars moved on other than scheduled trains, and so forth (20.2 percent of all delays);
3. Train delays, which reflect management decisions about which trains to run and with what resources, including maximum tonnage, annulment due to lack of traffic, train consolidations, and the like (20 percent of all delays);
4. Mechanical delays, which include bad orders of cars or locomotives (16 percent of delays);
5. Line delays, which reflect delays en route, such as track work, curfew, train meets, and so forth (13.3 percent of delays); and
6. Other delays, which include derailments, unknown causes, no bills, and the like (6.1 percent of all delays).

As can be seen, power availability was a significant problem for this railroad. What is even more striking, however, is that terminal and train delays were almost as large and together accounted for more than 40 percent of the delays to shipments. It is noteworthy that even if the railroad had "perfect" technology, only 30 percent of the delays would disappear; 65 percent of the delays required better management of resources (terminal management, train management, and power distribution).

Two railroads provided train delay data. One of the railroads undertakes an annual study of train operations in detail in order to understand the root causes of failures to maintain the schedule. The other railroad has recently begun to monitor train performance on a continuing basis. The results of the root cause analysis results are summarized in Figures 1 and 2. Figure 1 shows the department within the railroad that assumed responsibility for delays; Figure 2 provides more detail for the Transportation Department, which was responsible for the largest number of train delays. The largest single cause of delays was train meets, which is consistent with the results of earlier studies reported previously. The second largest cause was yard congestion. This is surprising because the study was focused on delays to trains (i.e., cars that had already made connections) and not individual shipments or cars. It seems likely that if the study were focused on individual cars, the share of delays due to yard and terminal problems would be even greater. The third and fifth largest causes of delays, crew rest and crew shortage, further highlight the concerns raised by the customer service study.

Data from the second carrier are presented in Table 2. Although not identical to the root cause data, the results are generally consistent. Transportation operations account for approx-

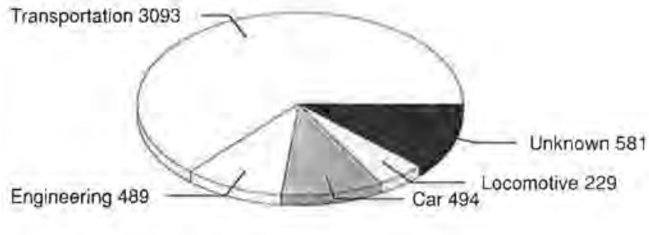

FIGURE 1 Train delays by department (source: MIT Affiliated Laboratory).

imately one-half of the delays to trains, and yard delays to road trains are substantial enough to raise questions regarding the impact of terminals on service to shippers.

Finally, managers from TTX Company assisted in determining the extent to which mechanical problems had affected double-stack cars that had experienced delays on a set of highly reliable corridors. Of 5,539 loaded trips in the overall sample, 195 were delayed 1 to 5 days beyond the mean travel time. Of these delayed trips, 31 were holiday trips, representing 15.9 percent of the delayed shipments, 39 cars (20 percent) had mechanical events during their trips, but only 8 cars (4.1 percent) had mechanical events that required that equipment be sent to the repair shop.

In other words, 80 percent of the delays to high priority, high quality shipments were left unexplained after accounting for mechanical delays and holiday disruptions. This suggests that mechanical reliability is not the root cause of unreliability, even for cars that are only rarely in terminals.

All the recent work, then, suggests that freight reliability appears to be more a matter of management than of railroad technology. The delays to cars and the delays to trains that may be attributed to failed equipment, track, or technology are modest, whereas those due to the management of resources constitute a clear majority. This finding suggests that the focus of research to improve service reliability must be shifted in a manner that will provide tools to manage the railroad and not to technologies and hardware.

Systems Analysis

A small number of extremely important systems management issues do much to determine the levels of service reliability. These issues include long-term decisions concerning capacity, the annual budgeting process, and the incentive system set up for rewarding operating and marketing officials. Recent studies have reiterated the tight links among capacity, line perfor-

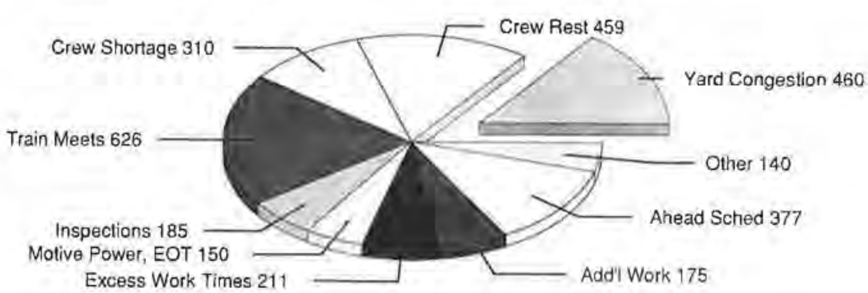

FIGURE 2 Train delays caused by transportation department (source: MIT Affiliated Laboratory).

TABLE 2 Functional Areas Responsible for Train Delays

	PERCENTAGE OF TRAIN DELAYS	
FUNCTIONAL AREA	NOV. 1992	FEB. 1993
Road (transportation)	30	39
Yard (transportation)	15	13
Maintenance of way	2	2
Communications and signals	1	1
Maintenance of equipment	4	8
Foreign (interchange)	13	16
Passenger train delays	0	0
Other	35	21

NOTE: Data are from a Class I Railroad.

mance, and terminal performance. Modest adjustments in train arrival times and connection times can compensate for capacity problems in terminals.

A fundamental concern is how to handle the peaks and valleys of demand. Because of the importance of cost control and the lack of a reservation system, railroads do not attempt to provide capacity to handle peak demands. Instead, there are various ways in which priority shipments can be handled expeditiously at all times and empty cars and low-priority freight can be handled when capacity is available. In fact, a major opportunity for the industry is to achieve a better understanding of the true costs and potential benefits of market segmentation and service differentiation.

Another fundamental concern is how to adjust capacity to what is required for current service levels. The fixed plant is often taken as a given in service design, but significant changes may be made over time. The most visible breakdowns in service are related to situations in which demand exceeds supply, as when extraordinary delays resulted from attempts to ship too much grain to Gulf Coast ports during Russian wheat deals during the 1970s.

A third fundamental concern is related to the constraints imposed by the infrastructure. Limits on axle loads and dimensions are likely the most important. During the past 20 years, the industry has reduced the cost of bulk operations by creating a track structure capable of handling first 100-ton and then 112-ton loads (i.e., axle loads of 33,000 to 36,000 lb). The most rapidly growing segment of rail business, double-stack container traffic, was made possible by technical innovations in equipment and by investments in raising clearances on major routes across the country.

Service Management

Given the existing physical plant and equipment, what service should a railroad offer? Service design, implementation, and monitoring and evaluation are three critical aspects of service management discussed in this section.

The basic elements of service design are as follows:

1. Service philosophy and objectives
2. Potential demand
    a. Market segmentation
    b. Potential traffic (based on historical flows, customer information, or demand models)
    c. Sensitivity of traffic to service parameters
3. Service requirements
4. Operating or service plan
    a. Service planning algorithms and models

   b. Capacity planning and trade-offs—locomotives and crews
   c. Achievable terminal work plans
   d. Marginal costing of service options and plans
5. Equipment plan: capacity planning and trade-offs—freight cars
6. Infrastructure plan: capacity planning and trade-offs—line and terminal
7. Pricing strategy

The whole process of service management is driven by a railroad's basic service philosophy and the objectives pursued by senior managers. The importance of service relative to costs, which may show up in the relative weights given to budget adherence and service measures in the annual reviews of operating officials, will permeate all of the decisions related to service management, particularly service design. Senior managers also determine whether the operating plan provides realistic goals to all managers.

Assuming that senior managers intend the plan to provide the basis for all operations, several important steps should be followed. The first steps are to assess the potential demand and customer requirements for specific market segments that may be defined in terms of commodity, customer, or geographic characteristics. A knowledge of the elasticity of demand in various markets to service parameters will be helpful in trading off trip times, reliability, price, equipment, and other elements of rail service (*19*). Railroads generally rely on their marketing and sales departments to identify opportunities for attracting new traffic or for improving the profitability of service to existing traffic.

The next step is the development of the operating or service plan. Since service levels result from the implementation of the operating plan, the development of an operating plan is, in effect, also the development of a service plan. Although academics may argue that the service requirements come first, as a practical matter, the operating plan is a more useful starting point. The operating plan exists, and it leads to a predictable level of service. A railroad seldom redefines its entire plan but frequently modifies the plan to take advantage of marketing opportunities or to adjust the plan to current traffic flows. The marketing department can identify (using surveys, models, or intuition) where service is inadequate, and the plan can then be adjusted as needed.

A notable weakness in service design is the normal treatment of terminal operations as a "black box." As discussed previously, trip plans (i.e., car schedules) must specify train connections at classification yards. These connections are normally based on cutoffs, which are negotiated by headquarters and field personnel; they are seldom, if ever, based on terminal plans or detailed studies of yard performance. Although detailed simulation models may be used to study terminal capacity, the authors know of no models that are used routinely to assist managers in moving cars through terminals. Hence, terminal managers do not have well-defined terminal operating plans, nor do they have tools to assist them in creating better plans or in estimating the incremental costs of different strategies for operating terminals. It is clear from the summary of boxcar service presented previously that rail carload service is often unreliable; cars seldom follow their trip plans, in large part because of problems in moving reliably through terminals.

The next steps in service design are the development of plans for equipment and infrastructure that provide adequate capacity for implementing the plan. As noted previously, failure to provide adequate resources for implementing the plan will lead to significant service problems. FCUP published a useful series of reports on various aspects of fleet management (*20*).

The final aspect of service design is pricing. The objective is to provide a service at a price sufficient to attract customers and also earn a profit. The ability to estimate true incremental costs is critical because so many shared and allocated costs are associated with railroad operations. It is beyond the scope of this paper to address pricing strategy, except to emphasize that prices are based on market conditions (willingness to pay), with incremental costs as a floor.

Implementation

The key elements in successful implementation of a service plan are as follows:

1. Well-documented operating or service plan
2. Coordination among control center, officers, and crews
   a. Precision execution of planned operations
   b. Work order generation and feedback
3. Near-term estimates of traffic and operating conditions
   a. Car status data base (terminals and trains)
   b. Freight car scheduling
   c. Interline Service Management
   d. Near-term forecasting strategies and methods
   e. Customer orders
   f. Customer-provided information on planned shipments
4. Capacity management (short-term supply and demand)
   a. Train departure planning (what time, what traffic)
   b. Train annulment, consolidation, and extra trains
   c. Emergency response to incidents
   d. Recovery from unplanned events
5. Track time allocation
   a. Train priorities, meet and pass planning, and ETAs
   b. Maintenance-of-way windows
6. Customer support
   a. Customer service center technology
   b. Trip plans, car location, and delay notification
   c. Logistics information systems (e.g., pipeline)
   d. Billing systems (electronic data interchange, computerized rates)

The first of these elements is a well-documented service plan. Although this might seem to be a truism, some of the AAR/FCUP studies of the late 1970s and early 1980s found that the operating plan being implemented in the field did not correspond with the operating plan as developed by senior staff, or with the service plan being offered to customers by the marketing department.

Attention must be paid to keeping the plan current as it is modified in response to changing conditions. This requires that information systems be put in place that allow line and staff managers to determine the current plan and be alerted when significant changes occur.

Closely allied with this is the need for coordination between those parts of the organization responsible for exercising control (e.g., dispatch centers, operations control centers, and so forth) and the field staff who carry out the plan. Many railroads are currently focusing attention on this problem. Burlington Northern, for example, is moving strongly in the direction of "precision execution," under which central management assumes responsibility for developing an achievable plan to provide service and field personnel are responsible for carrying out the plan (*21*). Other developments in this area include the development of sophisticated work order systems that allow for virtually real-time direction and monitoring of individual train crews using aspects of ATCS.

The causality studies cited earlier highlighted the importance of management of resources instead of development of new technologies as the key to improving service reliability. Central to the successful management of resources is the need for accurate information regarding traffic levels, operating conditions, and resource levels. This has led railroads to begin large investments in information technology. Some of these systems are industry wide (at least at the standards level), such as Interline Service Management, whereas others are specific to individual railroads, such as terminal inventory systems. The development of some of these systems is expected to take several years.

Railroads face a difficult problem in matching transportation supply with customer demand. It is necessary to provide adequate capacity during peak periods while avoiding idle resources during nonpeak periods. Capacity in this sense includes not only available space in yards or on lines, but also train and terminal schedules, decisions on annulments and consolidations and other modifications to plans, and responses to emergency conditions. Given the high costs of expanding facilities, this task of matching supply and demand has a direct effect on the ability to profitably implement the operating or service plan.

Although much of the focus of implementing an operating plan is necessarily short-term in nature, long-term functions of the system must still be realized. Track and equipment must be maintained on an ongoing basis. The operating plan must allow adequate time for track crews to inspect, repair, and upgrade the track while permitting the service commitments to be met. Equipment inspection, repair, and maintenance cycles must be met so that locomotives are available to operate scheduled trains, cars are available in acceptable condition for customers, and overall safety requirements are met.

Finally, there is a need for mechanisms to ensure that customers are provided information regarding the status of their shipments, structured to both report on current movements and encourage additional shipments. Railroads are beginning to centralize these responsibilities, which allows for economies of scale in information technology and permits customers to have a single point of contact with the railroad (or even several railroads for interline moves). This centralization is not without its risks, however, as the customer's source of information regarding the shipment is now divorced from the actual provider of the service. This makes the carrier as dependent on the quality of the information systems as is the customer.

Monitoring and Review

The major steps in monitoring and reviewing service, the third continuing component of service management, are as follows:

1. Comparison of actual with planned performance
   a. Service measures
      (1) Line, terminal, O-D, and system
      (2) Trip times and reliability
      (3) Cost
   b. Service goals
   c. Root cause analysis of service failures
2. Budget process
   a. Inclusion of equipment costs
   b. Link between service and budgetary performance—inclusion of service penalties
   c. Incentive systems (bonuses, pay, promotion)
3. Strategic planning
   a. Service philosophies and strategies
   b. Long-term evolution of market
      (1) Customer requirements
      (2) Demand elasticities
      (3) Additional logistics services
      (4) Competitor capabilities
      (5) Technological advances

The first step is to compare actual to planned performance for line, terminal, O-D, and system performance. Performance must include consideration of trip times, reliability, and cost. Service should ideally be measured against customer commitments in terms that are meaningful to the shipper. Service must also be measured relative to the operating plan, at all levels of operation. Information systems need to be able to support root cause analysis of service failures on a routine basis.

The second element of monitoring and review is the budget process. If budgeting focuses on only a portion of costs, suboptimization and misdirection of effort may result. The change to hourly car hire in 1976 helped make hourly car costs more tangible, which led to the inclusion of car costs in most terminal reporting systems, thereby allowing terminal managers to trade off car costs and switch engine costs.

The third element of monitoring and review is the feedback to the strategic planning process. Do opportunities exist for entering new markets? Are customer requirements or competitor capabilities changing? How will technological advances affect operating capabilities?

Summary

In summary, service management is constrained by several factors:

- Overall objectives of the company concerning service, market share, cost, and profitability;
- Capacity of the existing physical plant;
- Capacity of the car and locomotive fleets;
- Performance capabilities of terminals;
- Ability to forecast traffic volumes;
- Ability to formulate efficient and effective plans; and
- Ability to implement plans.

Improvement Strategies

Several broad strategies may be used to improve service reliability:

- Improve the overall objectives to give more appropriate priority to service relative to costs. Senior managers can quickly change the relative incentives for providing good service, meeting budgets, or operating according to plan.
- Improve the operating or service plan. The existing plan may be inefficient in the use of resources; it may be infeasible in terms of current terminal or line capabilities or capacity. It may be ineffective in providing appropriate levels of service for different market segments; it may be inflexible in response to variable traffic and operating conditions.
- Reduce the constraints on operations. Increase the capacity of the physical plant in order to reduce delays related to congestion. Improve track quality to allow higher speeds or heavier axle loads. Since labor agreements have been negotiated that reduce the size and costs of crews, seek improvement concerning work rules. Invest in more reliable equipment that can be used more flexibly in operations.
- Improve implementation of the plan. Operations officers may disrupt service by continuously adjusting the plan in order to cut costs. Train reliability may be low because of poor discipline in originating and in dispatching trains or because of frequent maintenance-of-way activities. Terminal operations may be out of control, causing connections to be missed frequently. There may not be adequate power to implement the plan, and there may be no way to recover once cars fall behind schedule.
- Improve the review process. It is essential to identify problems before they become unmanageable and to correct them before customers are lost. Both the short-term and long-term perspectives are relevant—what's happening to my shipment today and why can't you provide more consistent service this year?

Note that strategies for improving reliability are not the same as those for reducing costs. Whereas improving locomotive reliability may have only a minor effect on O-D reliability, it may have a major effect on locomotive cost.

Cross-Cutting Themes

Service management can be related to five cross-cutting themes that apply to all aspects of rail research. These themes are discussed in the following paragraphs.

Future Market Requirements

Service reliability and service management are important primarily because of the need to compete successfully within the freight transportation market. What customers require and what they are willing to pay for are perhaps the most critical elements in determining how best to improve railroad reliability.

Productivity

At some level, there is a fundamental trade-off between productivity and reliability. To the extent that productivity is emphasized over schedule adherence, managers will diverge from the service plan in order to reduce costs, and they will defer investing in additional capacity.

Advanced Technology

Although technology cannot be viewed as a "silver bullet" to solve all problems, there are areas in which advanced technology can make a difference:

- *ATCS* allow railroads to keep customers informed regarding the status of shipments vis-a-vis their trip plans and can allow the carrier to determine if any special action will be required to meet customer commitments.
- *Automatic vehicle identification and location techniques* could have tremendous impacts on operations in yards, lines, and customer sidings, especially for large shippers for whom shipments by rail constitute an important element in a well-managed inventory.
- *Advanced sensors* that may be used to predict failures of rolling stock and right-of-way and thus ensure improved maintenance could be useful in reducing the effects of in-service failures and improving the scheduling of maintenance activities.
- The development and adoption of *advanced materials* offer opportunities for increasing the mean time between failures and extending the maintenance cycle of both track and equipment.
- Advanced methodologies in the areas of *risk assessment, simulation, and network analysis* may be used to allocate resources and design operating plans to optimize reliability.

Human Factors

The management of resources is at the center of improving reliability for many types of shipments studied. Key areas include the operations control center, terminal operations, and crew management. Although not traditionally considered an aspect of human factors, institutional and organizational issues concerned with the implementation of plans may be critical. Railroads must foster an environment in which the human concerns associated with organizational change are addressed in a positive way. In general, all the railroad's control systems must provide the information needed by people to make better decisions, and must do so with interfaces that encourage them to use the best information possible.

Safety

Safety is an ultimate constraint on railroad operations. Areas related to safety and reliability include the distinction between engineering and performance specifications in establishing safe practices and equipment and whether federal and state safety requirements unnecessarily limit railroads in their attempts to compete in the marketplace. Another important consideration related to safety is the robustness of the rail operation in recovering from accidents or other serious events.

Summary and Conclusions

A framework for considering the many varied approaches for improving railroad reliability has been presented. Customers will base their transportation choices on their logistics costs, which means that different customers will have different requirements. Reliability means knowing those requirements and meeting them. Evidence suggests that railroads are capable of offering different levels of service when demanded, but there is an opportunity to provide the promised levels of service much more consistently. At the heart of the rail industry's service problems is a need for better management of resources and system performance, including operations and service planning, power distribution, train management, and terminal management. Railroads have improved component reliability to a level at which it is a minor part of the overall reliability issue, largely through investment in research and cooperative programs with suppliers. It remains a vital challenge for the rail industry to do the same thing for the managerial problems that currently limit the quality of service.

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Discussion Group Summary: Service Management

The mission of the service management group of conference participants was to identify, define, classify, and rank in priority order the research needs in service management that must be addressed to increase rail freight markets and profitability during the next 15 years.

Identification of Issues

The service management group identified the following issues for discussion:

- Customer commitments:
  - –Clearly define, for all participants, the service commitment made to the customer;
  - –Develop and maintain a large commitment file that accurately captures all the relevant (and changing) factors (e.g., Monday holidays);
  - –Avoid operating plan "gridlock," where commitments on 10 percent to 15 percent of a railroad's traffic make it impossible to change the operating plan; and
  - –Develop scheduling methodologies to meet customer requirements.
- Demand forecasting to support capacity planning and resource allocation.
- Service and price elasticities.
- Service differentiation:
  - –Plan and provide different levels of service (transit time, reliability, etc.) to different classes of traffic paying different rates while operating with the same network and train schedules; and
  - –Determine which connections to hold for and which connections to reschedule.
- Integrated carrier and customer partnershipping, including integrated shipment monitoring.
- Interline train network with fewer yardings, longer blocks, and tactical planning models.
- Barriers to ease of use (ease of doing business) and opportunities to overcome them.
- Causes of service unreliability:
  - –Address train and yard management versus track and equipment technology; and
  - –Accurately trace secondary effects.
- Intermodal equipment design and management.
- Data enhancement technologies to improve data integrity.
- Underlying economics of rail transportation and core competencies needed to capture available economic value.

RECOMMENDED RESEARCH

Economic Analysis of Alternative Railroad Operating Strategies

This economic analysis would include examination of the effect (costs, revenues, profitability, and capital requirements) of undertaking fundamentally different methods of operating a railroad. The alternatives to be modeled include highly disciplined scheduled operations, dynamic and flexible schedules, "slotted" operations (such as those followed by certain foreign railways), and use of schedule and capacity buffers (or recovery periods) to restore system stability. The research should include expanded direct services, operation of multiple train types, classes of service, and priorities over complex networks. The research may use operations research techniques (such as simulation) but should be consistent with the experience of railway companies.

Forecast-Driven Network Management

The proposed forecast-driven network management research will include development of tools and algorithms able to dynamically generate an optimum service plan built around each identified or forecast car or box, its service requirement, and the known network capacities. Included must be continuous network monitoring, with managers called on to make recovery decisions and with all decisions communicated to local operating personnel for execution.

Network Costing System To Support Real-Time Capacity Planning and Yield Management

This research involves the development of costing methodologies that can input information on the current and the predicted near-term status of the rail network and analyze the impact of incremental business on the operating system and resulting costs. This methodology should estimate the economic incremental costs that can be combined with revenue inputs to drive yield management and capacity allocation systems.

Terminal Design and Management

Design concepts, management methods, and technologies to improve terminal performance quality and designed throughput should be identified and evaluated. Performance should be measured relative to constraints on capital investment, physical space, and labor required to operate. A realistic mix of traffic and operating requirements should be based on actual experiences. Under various constraints and combinations of concepts, methods and technologies, the relationships among various performance measures should be expressed.

Economics of Physical Distribution Chain

Research on the economics of the physical distribution chain will increase understanding of the present and future chain (processes, transfer points, and equipment) and identify opportunities for creation and sharing of economic value or rent by railroads. The research would include analysis of aspects of transportation service that affect shipper behavior (e.g., service and price elasticities), examination of changes in the manufacturing process (e.g., flexible manufacturing), inventory management (e.g., just-in-time), sourcing of materials and services, and globalization of markets. Research is also needed to better understand channel and ownership issues (e.g., centralized drayage management, equipment ownership).

Improving Human Resource Contributions to Quality Service

Human resource development, training, management, empowerment, and job satisfaction are among the critical components enabling railroads to increase market share and profitability during the next 15 years. Research is needed on how organizational structures and cultures can best promote employee involvement in and contributions to meeting customers' service requirements. Information access and delivery systems are needed that empower employees on the firing line to make the best possible decisions. Specifically, service performance measurement systems need to be developed that can be communicated with precision and used to build fair and productive incentives for better service.

Information Systems Architecture To Support Service Reliability

This research would accomplish five objectives:

- Identify potential future information system architectural alternatives to support service management across carriers, modes, and national and continental boundaries. It would do so by extrapolating from trends in information technology research and development.
- Determine the costs and performance characteristics of each of these alternatives to perform service management functions.
- Determine the costs and performance characteristics of each of these alternatives to perform other industry functions using integrated (shared) data applications.
- Recommend a preferred, cost-effective alternative.
- Develop a migration plan for the rail industry to reach the preferred architecture.

SUMMARY

- Current reliability levels must improve for the industry to grow.
- The major issues involve management practices instead of basic technology.
- The role of research is to provide vision, knowledge, tools, and methods that will improve future decisions.
- The proposed research will complement current industry work on reference files, automatic equipment identification, advanced train control systems work order, rate electronic data interchange network, interline service settlement, and interline service management, which will address most service deficiencies that are linked to data.
- The recommended research focus is on seven fundamental issues linked to the service plan and its successful execution by the employees.
- The research efforts can be implemented in parallel and are to be done for the industry.

ENERGY AND ENVIRONMENT

Energy and the Environment: The Railroad Perspective

Mark P. Stehly, *The Atchison, Topeka and Santa Fe Railway Company*
Charles E. Taylor and Alfred J. Peters, *Association of American Railroads*

The railroad industry is becoming increasingly more competitive, both among its members and with the trucking industry. The number of railroad industry revenue ton-miles has grown steadily during the past 6 years. This growth has been accomplished by reducing costs considerably and paying more attention to the needs of customers. Overall, the results have been improved profitability and increased shareholder return. Even so, the railroad industry still does not earn its cost of capital.

Railroad transportation, like other modes of transportation, consumes large amounts of diesel fuel and therefore generates nitrogen oxide emissions. On a ton-mile basis, however, railroads generate lower emissions of essentially all pollutants than do trucks. Railroads produce insignificant levels of pollutants, with the exception of nitrogen oxide.

Proposed U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) locomotive emission regulations will add substantial costs for the industry. Little information is available on how best to achieve compliance with the regulations now under consideration. Numerous options are available to reduce locomotive emissions, but each varies tremendously in potential costs. Diesel engine improvements now being developed may be sufficient to meet short-term emissions goals, but it is unclear how the industry will meet the long-term standards being considered. Locomotive changes under consideration include the use of such energy sources as natural gas, methanol, electrification, and hydrogen (fuel cells).

Considerably more research will be required before railroads and regulatory agencies decide on the appropriate long-term standards and the means to achieve compliance. The wide spectrum of research needs means that many diverse groups such as railroads and suppliers, as well as government agencies, national laboratories, and universities, have important research roles. National goals for both energy and environmental quality may be affected by the chosen solutions.

Energy, a Strategic Railroad Resource

Energy, a strategic interest for railroads today, has been a concern since the beginning of railroading. Route engineers were cognizant of the locomotive energy requirements when they surveyed the track locations of the developing railroads. In 1887, A. M. Wellington reviewed train resistance (*1*). Water-level grades, because they were minimal, were considered ideal, even though they often meant longer mileage. Procuring and distributing sufficient quantities of energy were real problems for early railroads. The use of coal in place of wood was an early breakthrough, but on the Santa Fe Railway, the shift to coal created an entirely new problem, which led to the development of the oil-burning locomotive. Former Santa Fe Railway Chairman of the Board John S. Reed discussed the problems in 1982 (*2*). As the Santa Fe Railway extended to California in the 1880s, the coal for use on the West Coast had to be hauled from the Midwest, approximately halfway across the United States, or shipped by sea around Cape Horn. To resolve this difficulty in obtaining coal, the Santa Fe Railway developed the idea in the 1890s of burning fuel oil in the locomotive boiler. This development may sound simple today, but it was a bold experiment at the time and actually took the lives of several men, who died from explosions and backfires in the locomotive firebox. The U.S. Navy continued to burn coal exclusively for many years thereafter. In addition, the Santa Fe Railway purchased extensive oil properties in California so that it would be self-sufficient for fuel.

Typical of other railroads' concern for energy through the years, the Santa Fe, at least three different times in its history, studied electrification as an alternative to on-board burning of petroleum fuels. The first was in the early 1900s, when petroleum products were thought to be soon depleted. The second time was in the 1940s, when the steam engine could not compete with electric motors and diesel engines or electrified lines for the power source. Finally, the energy cost and supply problems associated with large quantities of petroleum imports and the price requirements of the petroleum-producing cartels of the 1970s prompted a third study. In these cases, the large capital requirements and increases in some operating costs combined with long project life and highly uncertain savings doomed electrification as the preferred motive power. Because of the strategic interest and national energy independence issues, it should not be surprising that railroads and energy agencies continually reassess the energy needs for transportation.

ENVIRONMENTAL IMPACTS FROM ENERGY CONSUMPTION: AN OVERVIEW

Some of the environmental impacts from railroads were known relatively early. Much of the benefit from early electrification was to reduce the smoke and particulates associated with steam engines, especially in such urban areas as New York City. These projects occurred as early as 1895 in the United States (*3*). Railroads installed oil and water separators in the 1940s to remove oil and grease from shop wash waters and thereby protect the local water resources. The emphasis on environmental issues has increased to such a level that major railroads now have environmental departments. Remediation of property contaminated by more than 100 years of use, including the use of certain slag and cinder ballast; waste minimization; wastewater treatment; and reduction of railroad impacts on air quality remain important projects for railroad environmental engineers.

Energy and the environment have been interrelated for decades. The generation and consumption of energy have significant environmental impacts, and the reduction of these environmental impacts can change the energy efficiency of a process or piece of equipment. The dilemma posed by this relationship appeared to be either minimization of energy costs at the expense of the environment or protection of the environment at the expense of energy costs.

During the late 1940s and early 1950s, the relationship between air pollution and human health became particularly acute. In Donora, Pennsylvania, between October 27 and October 31, 1948, 20 deaths in an affected population of 13,300 were immediately attributed to the combination of industrial pollution and temperature inversions in the atmosphere. Approximately 40 percent of the residents had some physiological symptom, such as irritation of the respiratory tract. Oxides of sulfur were the most likely culprits (*4*). After similar circumstances occurred in London, England, between December 4 and 9, 1952, about 4,000 persons died within a 2-week period during and following the air pollution episode as a result of exposure to air pollutants mostly from domestic heating fires (*5*).

Many cities instituted vigorous campaigns to reduce air pollution. Industries installed devices to remove pollutants from the stacks. For example, in Pittsburgh, Pennsylvania, between 1946 and 1953, the amount of fly ash and other contaminants was reduced by 46 percent. Weather observations showed that periods of poor visibility caused by pollution were reduced from 1,000 hr/year to 300 hr/year. A major factor was the replacement of steam locomotives by diesel engines on the railroads (6).

Since then, the general role of transportation and energy consumption in creating air pollution has become more quantified. Table 1 presents data on the contribution of various sources (7).

Transportation is the main source of the five major pollutants, particularly carbon monoxide, in the United States. The railroad portion of nitrogen oxide emissions is only 2.8 percent nationwide and less than 0.2 percent each for particulates, carbon monoxide, and hydrocarbons. Although nationwide studies are important, the major impacts of locomotive emissions are manifest at the local level. This is especially true in nonattainment areas in the United States. Nonattainment areas are the areas in which the air quality does not meet health-based standards, and thus people are exposed to levels of air pollutants that can cause disease, injury, or death.

The authors of this paper will explore the current condition of the railroad industry and the role of energy and motive power in determining the health of the industry. The environmental effects arising from energy usage will be discussed in detail. In addition, the alternatives for reducing energy costs and the environmental impacts will be analyzed. Finally, the alternatives for safety and cost attributes will be reviewed briefly.

CURRENT BUSINESS CLIMATE

Characteristics of a Hostile Industry

In 1985, Windermere Associates began a research project to track the evolution of several "hostile" industries (i.e., industries that serve competitive markets). These industries included air express, automatic test equipment, beer, baby diapers, copper, color televisions, tires, and trucking. The purpose of the study was to identify the policies of the few companies that really succeed in tougher times and to compare those policies across industries to highlight patterns of success. The scope included 40 industries and several hundred companies and covered a period from 15 to 30 years. Donald V. Potter, President of Windermere Associates, evaluated the major issues in his article Success Under Fire: Policies to Prosper in Hostile Times (*8*).

The headlines of the 1980s revealed the highly competitive nature of many markets. The extreme competition brought low margins, intense cost controls, and management turmoil. Several large industry leaders failed to survive as independent companies. Potter suggested that the following six phases typify the route of failure for many companies: margin pressure, market share shifts, product proliferation, self-defeating cost reductions, consolidation and

TABLE 1 Estimates of Nationwide Primary Pollutant Sources and Amounts, 1990 (7)

POLLUTANT SOURCE	WEIGHT OF POLLUTANT PRODUCED					
	CO	NO_x	HC	SO_x	Part.	Total
Rail	0.2	0.6	0.1	0.1	0.0	1.0
Other Transportation	41.1	7.7	6.9	0.9	1.7	58.3
Fuel combustion (stationary sources)	8.3	12.3	1.0	18.8	1.9	42.2
Industrial processes	5.2	0.7	8.9	3.4	3.1	21.2
Solid waste disposal	1.9	0.1	0.7	0.0	0.3	3.0
Miscellaneous	9.5	0.3	3.0	0.0	1.3	14.1
Total weight of each pollutant	66.2	21.7	20.6	23.2	8.3	139.8

Note: Data are in millions of tons per year. CO = carbon monoxide, NO_x = nitrogen oxide, HC = hydrocarbon, SO_x = sulfur oxide, Part. = particulate matter.

shakeout, and rescue. The hostility in the marketplace typically arises from expansion of aggressive competition. The expanding competition results from new entrants attracted by the current price structure in the industry. The new entrants typically can compete well with their price, whereas the higher costs of the remaining firms result in returns that become unattractive.

According to Potter, the key to winning in hostile markets is satisfied customers. Management policies that promote reliability create real benefit because reliability is difficult to copy. The winner also reduces the costs of providing benefits to the customer while offering the best value in the market. Losers cut costs by cutting customer benefits. Finally, winners reduce unit costs, thereby creating the most productive cost structure. Units are what customers buy and competitors discount. In many cases, winners add to total costs in order to gain more customer volume over which to spread a somewhat fixed cost structure.

Intercity Freight Transportation: A Hostile Marketplace

The efficient movement of products and goods, both in domestic and foreign commerce, is critical to American competitiveness. For many products, both the raw materials and the finished goods must be transported considerable distances to make the products available to the ultimate consumer. The nation's highway, waterway, pipeline, and air networks all are important in this transportation service. In particular, railroads are major transporters of coal, grain, chemicals, motor vehicles, consumer products, forest products, minerals and ores, and primary metals.

As in most industries, a railroad obtains business whenever the customer chooses that railroad over the competition. A supplier of the transportation service must meet the needs of the customer. In the case of transportation, customers have stated that reliability, price, information, time of arrival, transit time, seamless service, billing accuracy, ease of doing business, electronic data interchange, loss and damage, equipment suitability, sales, and claims are the most important features of the service.

The intercity freight transportation industry now is intensely competitive. Figure 1 shows the intercity freight transportation market for all transport modes in revenue freight ton-miles (9). The total transportation market has grown 16 percent since 1980. The truck market has grown 36 percent, whereas the rail market has grown only 15 percent. In contrast, Figure 2 shows the revenue market share of rail versus trucks (9). Railroad revenues have remained essentially flat for the past 10 years, whereas the growth in gross revenues has accrued to trucking. The combination of these two circumstances means that rail revenues in cents per ton-mile have been declining. Figure 3 shows this trend both in current dollars and constant

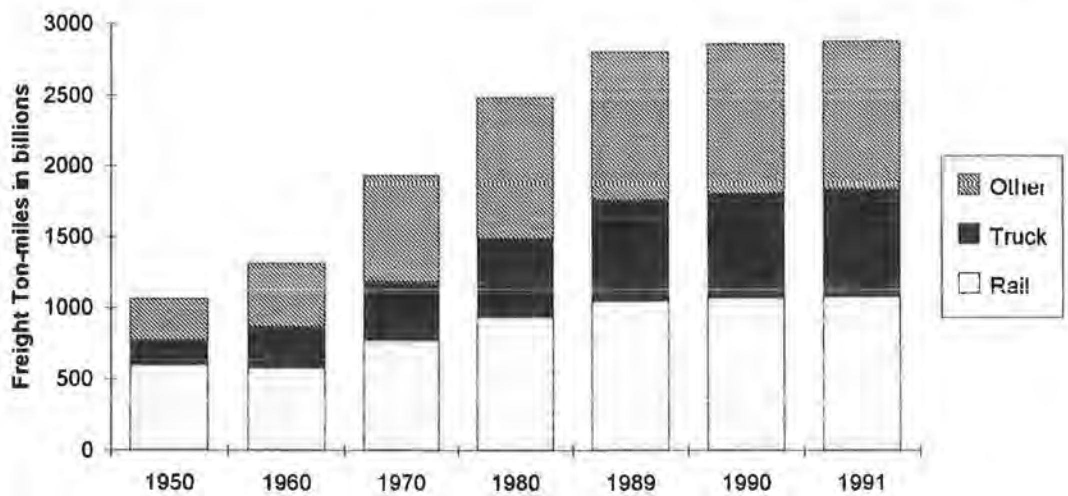

FIGURE 1 U.S. intercity revenue freight ton-mile distribution by mode.

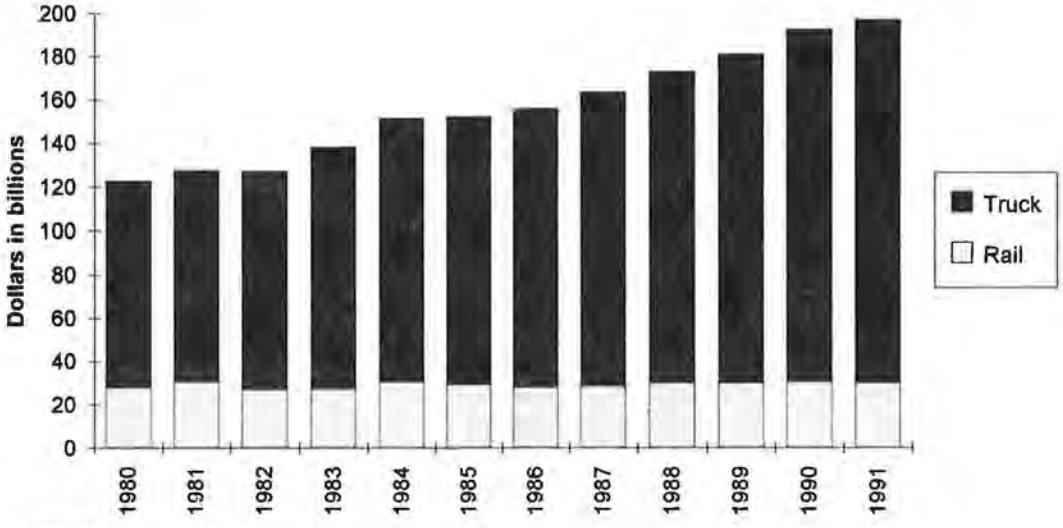

FIGURE 2 Intercity freight revenue by mode.

dollars (*10*). The revenue per ton-mile trend over the past 10 years is an average decline of approximately 2 percent per year in current dollars.

Such long-term downward trends suggest intense competition. The expanding total freight transportation pie is one factor constraining the level of competition. The growth and advantages of intermodalism to the transportation customer and the need to provide seamless and, therefore, convenient service dock to dock means that railroads and trucking firms must cooperate, as well as compete, in the marketplace. Such attributes also tend to constrain the level of competition while maintaining a highly aggressive market.

Railroad Industry Response

Railroads have committed to major programs in quality to focus on customer service and improvement of the overall transportation process. These efforts should improve performance in the many areas affecting the customer. Potter (*8*) believes that a customer's flight to the competition on the basis of quality changes market share more slowly than price discounting, but the change is more permanent. The effect of these efforts on market share and revenues per ton-mile remains to be seen.

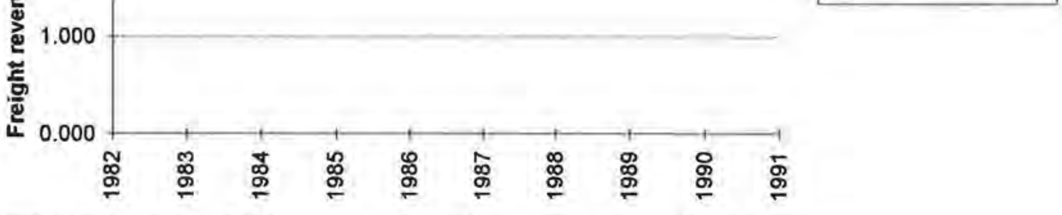

FIGURE 3 Railroad industry average freight revenue per ton-mile.

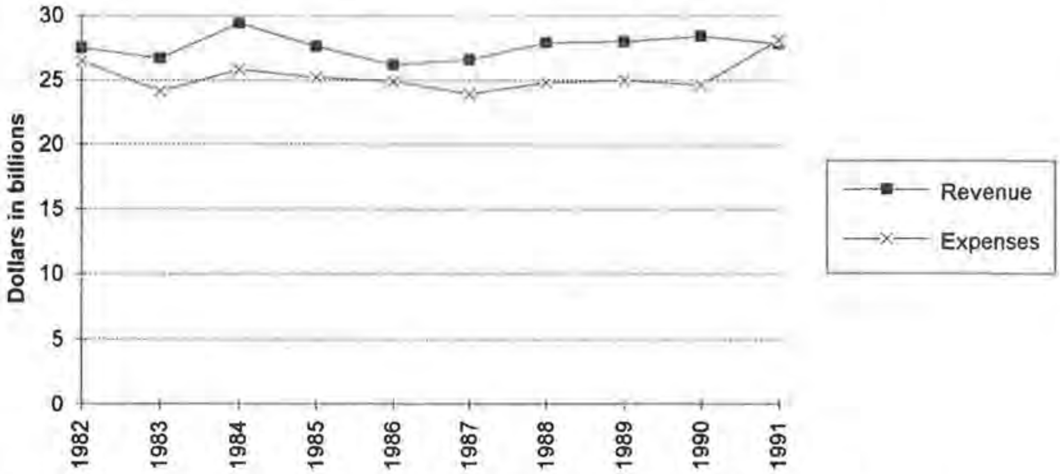

FIGURE 4 **Railroad industry average operating revenues and operating expenses.**

The railroad industry's ability to survive the downward trend in rates has been the result of a substantial decrease in expenses per ton-mile. Figure 4 shows the comparison between operating revenues and operating expenses for the industry (*10*). Cost containment has kept pace with declining revenues for most years since 1982. Further analysis reveals where the gains in productivity and efficiency occurred. Railroad employment is shown in Figure 5 for the past 10 years (*10*). Employment in the railroad industry dropped 36 percent between 1982 and 1991. Although the use of contracted services has increased, the decrease in employment has meant a large improvement in productivity across a broad set of measures, including revenue ton-miles per employee-hour, as shown in Figure 6 (*11*). Not all of the productivity gains were due to reducing employment. Increasing train size by increasing the average tons per train (Figure 7) was responsible for some of the efficiency improvements (*11*). With respect to energy and the environment, the revenue ton-miles per gallon of fuel consumed improved 40 percent between 1982 and 1991, as shown in Figure 8 (*11*).

Financial Health of Railroad Industry

What have these productivity improvements meant in financial terms? The industry average return on investment is gaining but is still below the cost of capital for the industry. The low

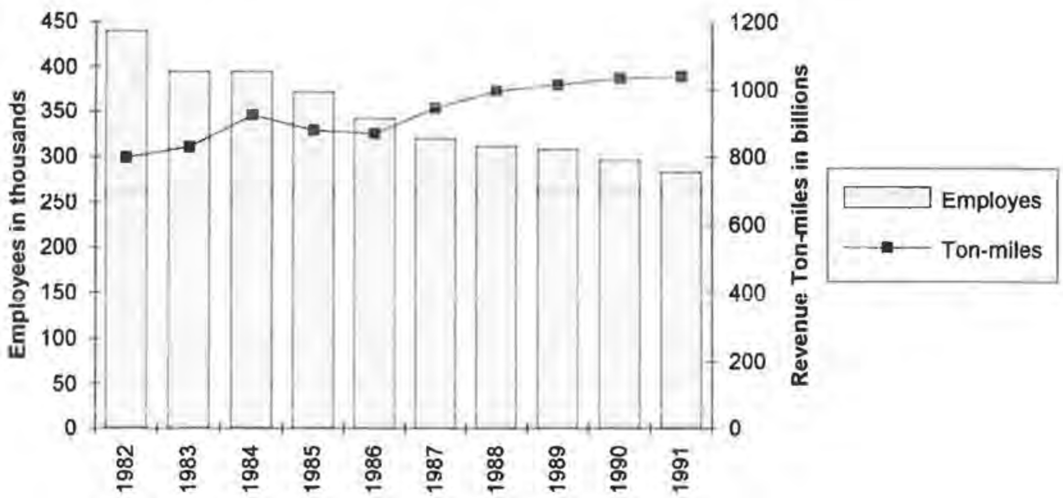

FIGURE 5 **Railroad industry total employment and revenue ton-miles.**

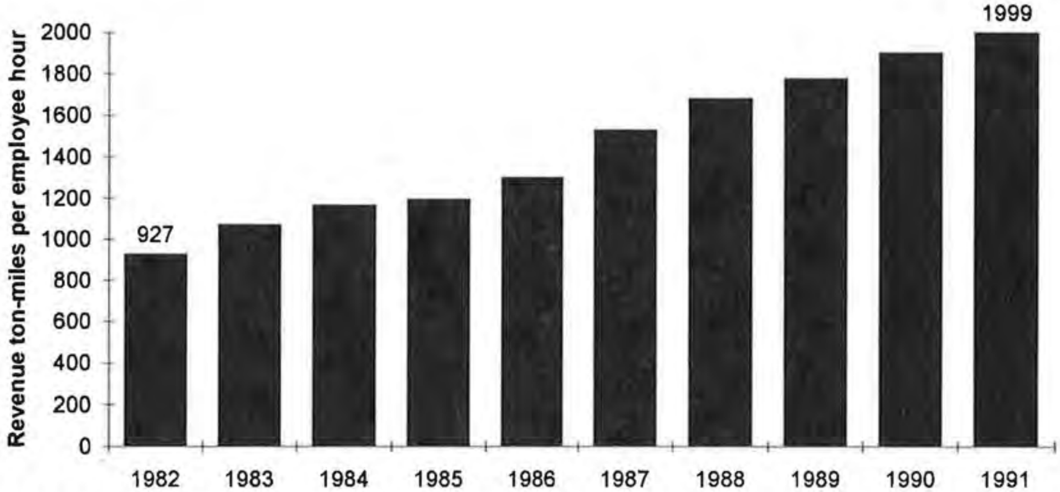

FIGURE 6 Railroad industry average human productivity.

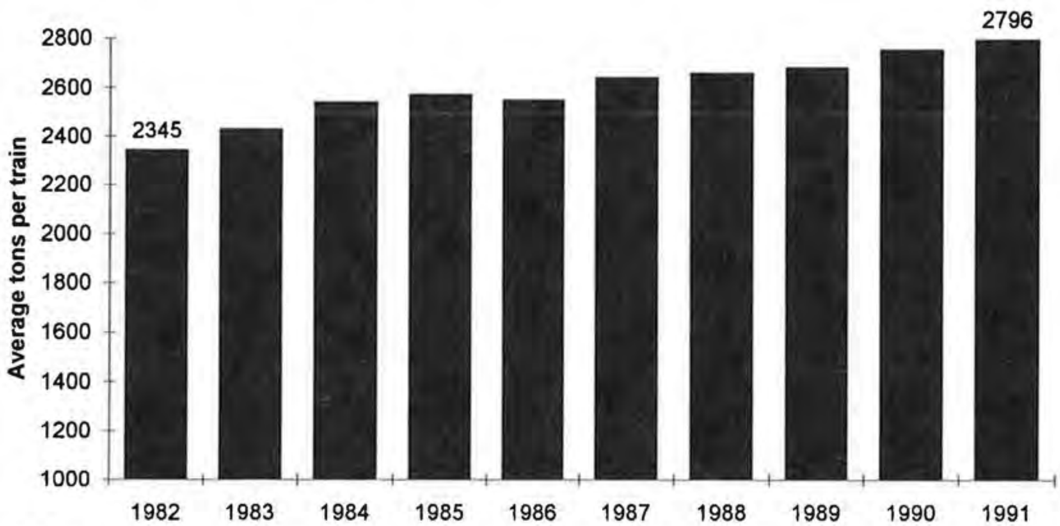

FIGURE 7 Railroad industry average train weight.

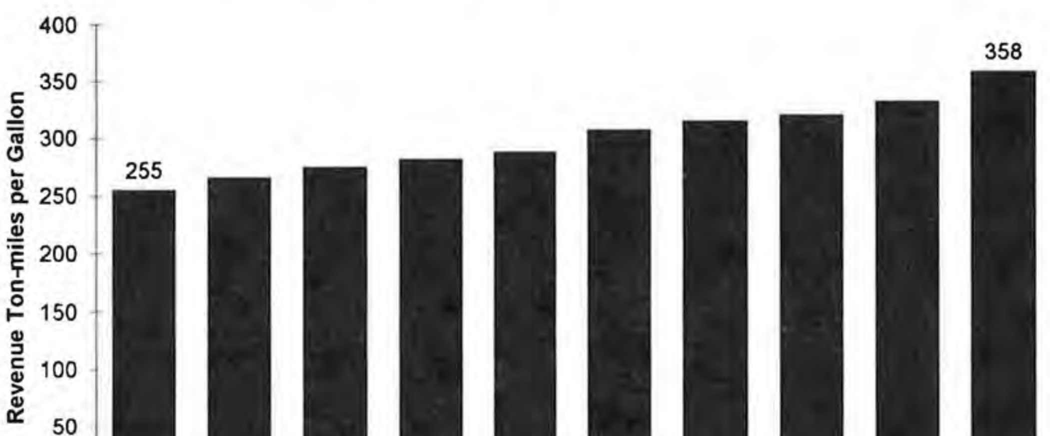

FIGURE 8 Railroad industry average fuel efficiency.

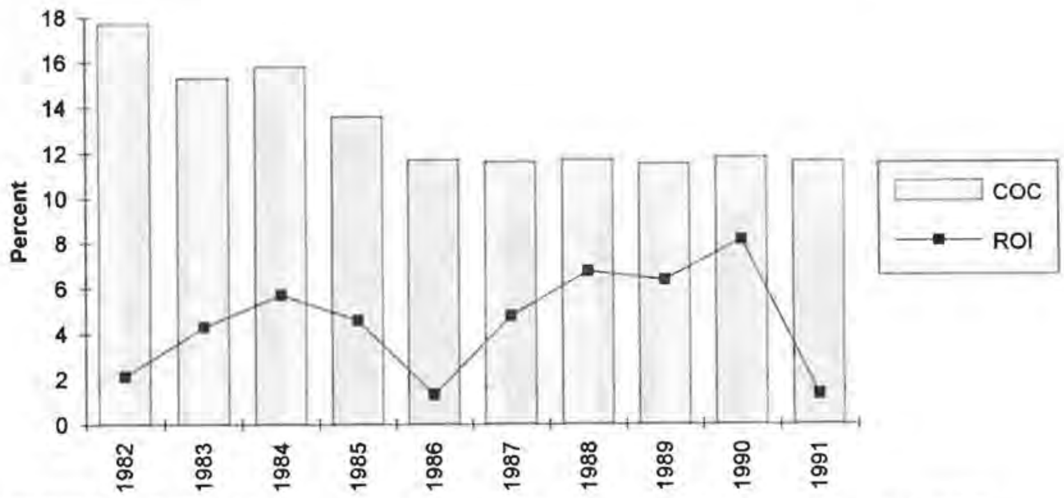

FIGURE 9 Railroad industry average return on investment (ROI) and cost of capital (COC).

inflation rate in the U.S. economy in recent years, along with refinancing of much of the railroad's debt, has lowered the cost of capital to nearly 11 percent from 18 percent in 1982, as shown in Figure 9 (*11*). In addition, the sale of underused fixed assets, such as noncore trackage sales to short lines, together with improved locomotive fleet use and overall cost containment, have lead to steadily improved profits in the industry in recent years.

Although shareholders' return on equity is not as great for the railroads as for regulated utilities (pipelines and electric companies) or the chemical or pharmaceutical industries, railroad returns have improved since 1982, as shown in Figure 10 (*11*). Such improvement must continue for railroads to be the transportation solution for the future.

The Future

A key characteristic of the near term appears to be a continuing 2 percent annual decline in revenues per ton-mile. As noted by Potter (*8*), participants in hotly competitive industries need to be careful not to engage in self-defeating cost reductions. Railroads must avoid cutting costs in ways that impair their ability to satisfy customers. According to Potter, these impairments

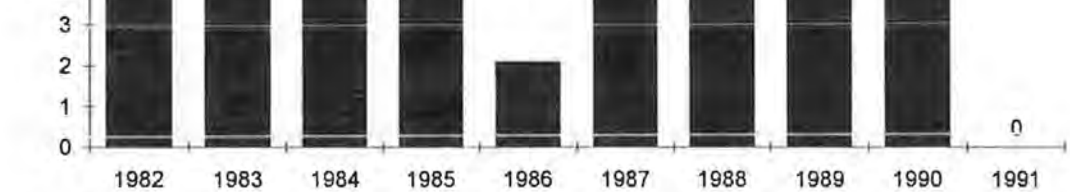

FIGURE 10 Railroad industry average return on shareholder equity.

typically fall into three categories: feature failure, quality slippage, and distribution conflicts. For railroads, failure to keep pace with improving quality standards demanded by shippers may be the most damaging.

Until unit revenues improve, railroads must continue cost containment efforts in line with the steadily decreasing revenue per ton-mile; however, operating cost reductions must not lead to customer dissatisfaction. This is why quality improvement processes are so important and why railroad research is critical. This and future conferences must focus on the strategic needs of the railroads to make them more competitive and define the research that can help propel the industry toward significantly improved customer focus and substantially reduced operating costs. For instance, on Santa Fe, motive power costs, including maintenance and depreciation, consume approximately 10 percent of freight revenues (*11*). Locomotive diesel fuel oil consumes approximately 10 percent of freight revenues (at roughly $0.65/gal). Assuming that revenues per ton-mile continue to decline by 2 percent annually, each cost center has to be cut by 2 percent. Therefore, with annual revenues of more than $2 billion, Santa Fe motive power maintenance costs and fuel costs combined must be reduced by $10 million each year to compensate for the reduced revenue. Attracting new business will require even more improvement. It should be obvious that long-term survivability eventually depends on stabilizing or increasing revenue per ton-mile. This increase or stabilization will occur when railroads reduce their cost structure so that competitors no longer enter the market and when the railroads provide quality service to the customer.

ENERGY CONSUMPTION IN RAIL TRANSPORTATION

Importance to Railroads

After dieselization in the late 1940s and the early 1950s and the resultant greater convenience of energy handling and the greater range of the locomotives between fueling points, railroads became less concerned with fuel. During the 1970s, when severe disruptions occurred in the supply, the cost of diesel fuel increased dramatically. The price for diesel fuel to the railroads in the 1950s and 1960s was approximately $0.10/gal. By 1975, the price was $0.30/gal; it increased to $1.00/gal in 1981 (*10*). The price has since been as low as $0.49/gal (in 1988). Railroads' attention to energy efficiency and consumption increased with the cost of fuel.

In addition, railroads began recognizing that improvement in fuel efficiency was important and the comparison with the fuel efficiency of trucks was equally important in the overall transportation marketplace. In 1981, when fuel represented 12.5 percent of operating revenues for railroads and substantially more for trucking companies, fuel became a strategic factor. Today, locomotive fuel consumes 7 percent of operating revenues and costs nearly $2 billion annually industry wide.

Railroad energy consumption can be reduced in three major ways: shutdown of idling locomotives, reduced train resistance, and improved locomotive efficiency. During the late 1970s and throughout the 1980s, all three methods were examined and used to reduce fuel consumption. Locomotive manufacturers began making locomotives more fuel efficient. In addition, railroads, especially through the Association of American Railroads (AAR) research program, began investigating ways to reduce consumption. New railroad equipment such as the lightweight and aerodynamic intermodal car became commonplace, as did such new concepts as locomotive-mounted wheel-rail lubrication.

These fuel efficiency improvements enable the industry to reduce average fuel consumption annually. The industry average fuel consumption during the past 10 years is shown in Figure 11. The industry average fuel consumption on a ton-mile basis is shown in Figure 8. The decline is approximately 2.5 percent per year in the short term. As noted earlier, all things being equal, the fuel consumption per ton-mile per year must decline by at least the same 2 percent annual decline in revenue per ton-mile.

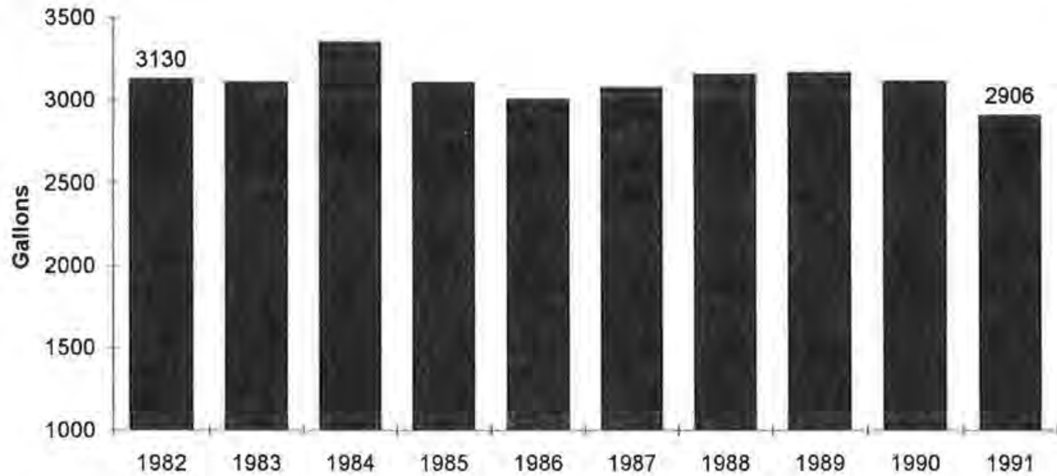

FIGURE 11 Railroad industry total annual diesel fuel oil consumption.

Comparison with Trucks

Abacus Technology Corporation, under contract to the Federal Railroad Administration (FRA) of the U.S. Department of Transportation (DOT), studied rail and truck fuel efficiencies (*12*). Trucks in rail competitive businesses achieve 84 to 135 lading ton-mi/gal. By comparison, in 1990 the railroad industry averaged 332 revenue ton-mi/gal (*10*). Thus railroads' average fuel efficiency is 2.5 to 4 times greater than that of trucks. The Abacus Technology Corporation study compared rail and truck fuel efficiencies on a route- and commodity-specific basis. The comparisons included 60 mi of rail switching or 60 mi of drayage added to each of the rail moves. The truck fuel consumption in the long-distance routes was 1.72 to 5.16 times the railroad fuel consumption on a lading ton-mile per gallon basis.

The Argonne National Laboratory Center for Transportation Research, Energy Systems Division, in 1990 forecast energy demand by mode of transportation through 2010 (*13*). The assumptions for this forecast included substantial improvement in the overall fuel efficiency of trucks. Improved engines, aerodynamics, tires, engine lubricants, and transmissions could yield a 40 to 50 percent overall improvement in fuel efficiency. The truck savings outlined amount to approximately 4 percent per year. Accordingly, a railroad fuel savings of only 2 to 2.5 percent does not keep pace with the competition.

Locomotive Shutdown

The shutdown of idling locomotives is an important means of conserving fuel. Locomotives consume 3 to 5 gal/hr when idling. Because locomotives do not have antifreeze in the radiator cooling water, the engines cannot be shut down in freezing weather without draining the cooling water. Many railroads have policies that if locomotives will not be used within 2 or 3 hr and the temperature will remain above 40°F, the locomotive will be shut down. In most areas of the United States, locomotives can be shut down much of the time when not in use. In 1992, Santa Fe saved 4.2 million gal of fuel by shutting down idling locomotives.

Train Resistance Research

Railroads funded millions of dollars in train resistance research for several years in the mid-1980s to improve fuel efficiency. A major overview of this work can be found in AAR Report R-800, *Vehicle Track Resistance Research, A Summary Document* (*14*). The topics covered include aerodynamic resistance, bearing friction, wheel-rail friction (tangent and curves), grade resistance, inertial forces, suspension damping resistance, and track deflection and damping resistance. Many detailed studies are published as AAR reports and American Society of Mechanical Engineers papers on each of the researched topics. The studies include theoretical analysis and laboratory and full-scale testing. Computer train energy models were developed incorporating all the new information, thereby making evaluation of railroad energy usage much easier. The research was an AAR, railroad, supplier, and academia joint effort. Earlier work was sponsored by the federal government.

An analysis of the fuel consumption of some Santa Fe Railway intermodal trains demonstrates the relative importance of the various causes of fuel consumption and identifies where savings can be achieved and the problems with achieving future savings. The causes of fuel consumption for an intermodal train between Chicago and Los Angeles on Santa Fe is shown in Figure 12. Moving trains up grades consumes 40 percent of the total fuel used. Acceleration of the train adds 10 percent. Aerodynamic losses amount to 30 percent, and wheel-rail friction and bearing losses combined account for 20 percent of fuel consumption. A more detailed study of the savings from reducing train resistance can be found in work by Smith (*15*). Obviously, reducing fuel consumption by reducing train resistance requires altering train and car characteristics and slowing train speeds.

Train Weight

For an intermodal train running between Chicago and Los Angeles, approximately 40 percent of the fuel consumption is caused by moving the mass of the train up grades. This adds to the potential energy of the train; however, the downhill grades are quite long and the energy is dissipated by braking. Thus the potential energy often cannot be used efficiently. On Santa Fe's preferred route in this corridor, trains are lifted through 25,000 vertical ft. Naturally, the savings could be significant if a device could recover this energy. Use of flywheels or other storage devices and regenerative braking on electrified territory would recover the otherwise dissipated energy.

A major effort is needed to control train weight. The train weight includes the lading weight, the locomotive weight, and the tare weight of the cars. Railroads are paid to move lading and, therefore, the lading weight is the only beneficial weight on the train. The weight of the cars and the locomotives is not revenue weight and serves only to carry the lading and move the train safely. The tare weight of cars and the empty car miles is a major issue. On Santa Fe, only 50 percent of the gross ton-miles (not including locomotive ton-miles) are revenue lading ton-miles. Thus the opportunities for improvement are substantial. The weight of the locomotives relative to the horsepower provided is another important factor. A 4,000-hp, four-axle locomotive for intermodal service is attractive because of the greater power/weight ratio than previous locomotives, particularly the 3,000 hp, six-axle locomotive. The ratios of revenue ton-miles to gross ton-miles with and without locomotives become key measures in reducing fuel consumption caused by weight. The empty stanchions on intermodal flats, double-stacked cars with single containers, repositioning of locomotives, and movement of empty cars all affect this key measure.

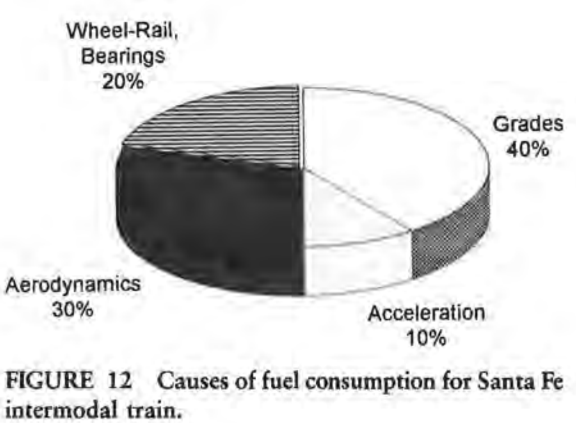

FIGURE 12 Causes of fuel consumption for Santa Fe intermodal train.

Acceleration of Train Mass

Acceleration accounts for 10 percent of the fuel consumption on an intermodal train. This is a product of two factors: train mass and velocity change. Acceleration changes the momentum of the train, and the energy would be recovered usefully if the train were allowed to coast to a stop. However, trains typically are braked for reasons such as adherence to train schedules. Thus the energy used to increase train momentum often is wasted. Because of the large train mass, the fuel consumption to increase train speed is quite high. If the speed is not changed often, the fuel spent is spread over a long distance and becomes a smaller factor. Through training, engineers today must look ahead at speed restrictions for curves, possible slow orders, and movement through turnouts and must accelerate only to a speed that can be sustained for many miles. Slow orders, in general, result in significant fuel and time penalties.

Aerodynamic Drag

Aerodynamic losses account for 30 percent of the intermodal train fuel consumption. Aerodynamic drag is composed of two major train characteristics: skin drag, which is a function of the roughness of the sides and tops of the cars, and pressure drag, which is airflow against generally vertical surfaces. The exterior side posts on coal cars are an example of large surface roughness. A gap in a train due to an empty stanchion, a 40-ft trailer on a platform designed for a 48-ft trailer, or the end sheet of an empty rotary dump coal gondola produces large pressure drag. Aerodynamic losses are a function of the velocity of the train (relative to the air) squared. The aerodynamic drag doubles in moving from 50 mph to 70 mph. Running at 50 mph into a 20 mph headwind results in double the drag compared with 50 mph with zero headwind.

Wheel-Rail and Bearing Friction

Finally, 20 percent of the fuel consumption in intermodal service results from friction in bearings and wheel/rail contact on the gage face of the rail. The bearing losses primarily occur in the sliding seal used to keep water and dust out of the bearing. New designs of labyrinth seals that produce substantial fuel savings are now on the market. The removal of the contacting seal reduces the torque required by 25 to 50 percent, whereas some of the new special seal designs reduce torque by 50 to 60 percent (*16*).

Wheel-rail friction has been studied intensely during the past 8 years. The losses are significant and controllable. The use of steering trucks or the placement of lubricant in the zone of contact greatly reduces the friction. Since the friction also produces wear, the savings from reducing the friction also include reduced wheel and rail wear. The first advantage produced from locomotive-mounted lubricators is a substantial reduction in locomotive wheel replacement due to thin flange. Savings in wheel replacements for this cause can easily reach 50 percent.

Locomotive Efficiency

Beginning with the energy supply disruptions in the 1970s, locomotive manufacturers steadily improved locomotive fuel efficiency. The locomotives purchased within the past 3 years are roughly 20 percent more fuel efficient than locomotives purchased in 1972. The development and use of electronic fuel injection offer perhaps a 1 to 2 percent further improvement in fuel efficiency.

Barriers to Improvement

For the most part, a great deal is known about train resistance and how to decrease fuel consumption by reducing train resistance. The major problem is applying the results of the research. Because the global measurement of fuel efficiency on a railroad is based on the sum total of fuel used for all activities, the impact of any one action is relatively imperceptible. This leads to lack of conviction that the action has a beneficial result. Fuel efficiency varies monthly because of traffic mix, weather, crises of the moment in train operations, and other factors. Indirect means of measurement, such as locomotive wheels replaced for thin flange, are important. In addition, the complexity of changing equipment characteristics means that improvements come slowly and require considerable persistence. Consider the problems with trailer sizes. Significant volumes of 28-, 40-, 45-, 48-, and now 53-ft long trailers exist. These are being mixed on trains, and the desire is to place them on articulated equipment. The result is that the net/tare ratios and the size of the gaps between trailers vary considerably from train to train. The proliferation of varying sizes of equipment means the platforms cannot be optimized for fuel consumption, nor are equipment costs optimized. This needs to be considered with intermodal containers as this segment of the market expands.

The second major barrier to more substantial improvements to fuel efficiency is the low price of diesel fuel. Current prices are in the $0.65/gal range, whereas prices in the early 1980s sometimes exceeded $1.00. On many railroads, the short-term focus of railroad management, the reduction in staff and analytical function for cost reduction purposes, and the low price of fuel combine to make fuel efficiency today a lower priority than locomotive availability and use, labor costs, and other issues.

Consider just the application of locomotive-mounted lubricators. The benefits have been known for more than 5 years. The payback on the investment is typically less than 2 years, yet some major railroads still are not using the technology. Even on Santa Fe Railway, where close attention is paid to the lubricators, the bad order ratio for the equipment is approximately 40 percent. Thus a significant portion of the benefits are left unrealized.

To sustain a continuing 2 percent decline per year in energy consumption, a wide range of programs is needed. The easiest means is to reduce train speed; however, in many instances this likely would reduce customer satisfaction and line capacity and would not be a satisfactory global solution. Small changes in equipment to reduce train resistance also will not achieve short-term results because of the typically small purchases of new equipment each year. A systematic effort to reduce weight, aerodynamic losses, wheel/rail friction, and bearing friction is required. In addition, improvements in operations to segregate time-sensitive loads, slow down trains for which speed is not essential, reduce yard delays, reduce on-line equipment failures, reduce empty car-miles, reduce acceleration losses, avoid over powering trains, and avoid repositioning of locomotives would yield major cost savings for both fuel and equipment. A balanced and sustained emphasis is needed to achieve the required results.

Environmental Impacts From Railroad Activities

Railroads affect the environment in a number of ways. They sometimes generate noise in rail operations that can disrupt the speech and sleep of neighbors. Maintaining rights-of-way, which sometimes involves earthwork, can affect adjacent waterways and wetlands. Maintenance of railroad equipment generates various waste products, such as hazardous wastes at shops and recovered diesel and lubrication oils. Rights-of-way and major terminals can generate fugitive dust, an air pollutant. Discharged wastewater from shops and fueling facilities can pollute streams and other surface waters. Past spillage of fuel and other chemicals at facilities can contaminate soil and groundwater. The transportation of hazardous materials results in infrequent but sometimes catastrophic spillage of chemicals that can immediately affect people, property, and the environment. Finally, the use of internal combustion engines to power railroad equipment generates emissions to the atmosphere. The magnitude of the impact needs to be considered in comparison with the benefits of the service, the alternative means of transportation, and the ability of the railroads to further reduce or mitigate the impacts.

The major environmental impact of the railroads on a mass basis is the emission of nitrogen oxides from locomotives, which contributes to the formation of ozone. Nitrogen oxides are formed during the combustion of the fuel in the engine cylinders. Because air is approximately 78 percent nitrogen and 21 percent oxygen by volume, large amounts of gaseous nitrogen are present in the engine cylinders during the combustion process. Most of the oxygen reacts with the hydrocarbons in the fuel. At the high temperatures in the cylinders, some of the remaining oxygen reacts with the nitrogen to form nitrogen oxide and nitrogen dioxide, collectively called oxides of nitrogen (*17*). Considering the approximately 3 billion gal of diesel fuel consumed each year by the railroad industry, the nationwide nitrogen oxide emissions are roughly 600,000 tons per year. Because the railroads consume small amounts of energy—2.5 percent of the nationwide transportation energy consumption—they are also a small contributor to the air pollution problems.

EPA Study of Railroad Emissions

EPA studied railroad emissions in five areas in the United States that are nonattainment or approaching nonattainment and that had significant railroad activity (*18*). The assumption was that if railroads were shown not to be significant contributors to pollution in these regions, then they should not be major contributors in other areas of the country. The five areas chosen by the EPA for study included Philadelphia, Chicago, St. Louis, Kansas City, and Los Angeles. The National Ambient Air Quality Standards for ozone are violated in each of these regions. In addition, Kansas City, St. Louis, and Chicago have some of the greatest concentrations of rail traffic in the nation. The regions selected, therefore, should represent a worst case for ozone and its precursor, nitrogen oxide emissions, as related to railroad activity. The study techniques were crude because the number of locomotives in an area was based on tallies by FRA railroad inspectors. In addition, all the locomotives were assumed to have duty cycles in these geographic areas equivalent to industry-wide average duty cycles.

The results of the Los Angeles area study are similar to other more detailed studies performed by the railroads and CARB. The results for the other regions have not been verified by more intensive studies and, therefore, the results are crude assessments at best, totally inaccurate at worst. In particular, the results for Chicago appear unreasonable because of the large number of locomotives assumed to be in the area. EPA reached such conclusions as the range in oxides of nitrogen emissions from railroads was 2 to 15 percent of the total emissions of the areas studied. In addition, technological approaches for the reduction of nitrogen oxide emissions from diesel engines generally resulted in increased particulate emissions (smoke) and increased fuel consumption. In general, shutdown of idling locomotives reduces railroad emissions and fuel consumption. However, emissions from "cold starts" could work counter to an optimal shutdown policy. The cost-effectiveness of reducing locomotive emissions appears similar to the cost-effectiveness of controls for automobiles, trucks, and motorcycles, but data for making these estimates are limited.

The EPA recommendations for action included gathering sufficient data on locomotive emissions to permit an accurate determination of railroad emissions and their effects. More information is needed on the particulate emission rates and how they would be affected by reducing nitrogen oxide. EPA further recommended that techniques for the control of locomotive emissions be evaluated with respect to feasibility of application to both new and in-use locomotives, cost of control, and impact on railroad operations. Such studies would reduce the uncertainties in the present estimates and allow determination of the need for federal control of railroad emissions.

CARB Locomotive Emissions Study

CARB and the California railroads performed a detailed study of locomotive emissions relative to other sources of emissions (*19*). The study period was 1987 because that was the date of the most recent detailed inventory. The study concentrated on nonattainment areas in the state. The level of emissions for the Los Angeles metropolitan area is presented in Table 2. Railroads contribute 2.9 percent of the total basin nitrogen oxides, 1.8 percent of the sulfur dioxide, and approximately 0.1 percent each of the hydrocarbon, carbon monoxide, and fine particulates.

TABLE 2 1987 Emission Inventory Estimates by Category for Southern California

SOURCE[a]	HC[b]	CO	NO_x	SO_x	PM 10[c]
Stationary sources	614	219	282	51	1102
On-road sources	602	4278	664	32	59
Other mobile sources[d]	75	512	141	42	14
Total for all sources	1291	5009	1087	125	1175
Trains(*19*)	1.5	4.7	31.5	2.2	.7
Trains: percent of total	.12	.09	2.9	1.76	.06
Trains: percent of total mobile sources	.22	.1	3.91	2.97	.96

NOTE: Data are in tons per day. HC = hydrocarbon, CO = carbon monoxide, NO_x = nitrogen oxide, SO_x = sulfur oxide, PM = particulate matter.
[a] Taken fron CARB's 1987 Emission Inventory Estimates by Category (*19*, pp. 4, 5).
[b] Reactive HC only.
[c] All locomotive particulates are assumed to be PM10.
[d] Includes CARB's estimate of 1987 train emissions.

This contribution does not appear significant at first glance; however, the air quality in the South Coast Air Quality Management District (SCAQMD) (Los Angeles metropolitan area) resists improvement in spite of significant reductions in many sources of pollutants.

In 1989, the state standard for ozone was exceeded 150 days in the Pomona and San Bernardino areas of the SCAQMD (*20*). Health advisory levels were exceeded 80 days in 1989 in the same areas. On the worst days, the air quality was three times the standards. The general trend has been improving, but not quickly. Between 1976 and 1989, the number of days per year exceeding federal standards decreased by 31 percent.

A large number of sources have reduced emissions of photo chemical smog (ozone) precursors (nitrogen oxide and volatile organic compounds) by relatively large amounts (70 to 80 percent). Power plants, industrial boilers, refineries, manufacturing plants, and other facilities have made major reductions. New automobile standards are at only 10 percent of the original emissions. Paint formulations and even charcoal lighter fluid have changed specification to reduce emissions. In the near future, even the emissions of lawn mowers, chain saws, and other small equipment will be regulated.

More is known of railroad emissions and the air quality problems in southern California because of the long-term nature of the problems there. However, the largest number of ozone nonattainment areas are in the East. The area from Baltimore to Boston, much of the Ohio River Valley and the Great Lakes Region, Dallas, Houston, Atlanta, and Birmingham and Montgomery, Alabama, are nonattainment for ozone. Thus locomotive emissions are not air pollution problems in California only. The lesser severity of the problem or the availability of more reasonable reductions from other sources may not require quite the same reductions in railroad emissions as that in southern California. The operational problems that would be created by differing state standards and the current language of the Clean Air Act do not allow for tailoring railroad emission reductions for each nonattainment area.

Results of the Harvard University Six Cities Study (*21*) showed that exposure to air pollution by extremely fine particles in Steubenville, Ohio, amounted to a 26 percent higher risk of dying than from the exposure levels experienced in Topeka, Kansas, or Portage, Wisconsin. The research linked the concentration of fine particles chiefly to deaths from heart and lung diseases. Whether the risk of dying from this cause was significant compared with all other causes of death needs to be considered in evaluating these results. Other studies increasingly conclude that particulates generate significant health problems. At a minimum, the railroad industry cannot limit its focus solely to nitrogen oxides and must consider other pollutants when evaluating nitrogen oxide reductions.

MOTIVE POWER FOR THE FUTURE

The motive power of the future must help the railroads become more competitive than other modes of transportation. Locomotives must be cost-effective while being environmentally friendly, comfortable for the train crews, and safe. The definition of cost-effective must include first cost, reliability, maintenance cost, and fuel efficiency. In the history of motive power development, there have been incremental improvements and occasional radical changes. In the future, there will be consideration of evolutionary improvements such as a 4-degree retard in injection timing, increased cooling of combustion air, and increased injection pressure to reduce emissions. More technological changes include electronic fuel injection, use of alternative fuels such as ethanol, methanol, and natural gas as a sole source or as the major fuel in a dual-fueled engine, and spark-ignited engines. Among the most radical technologies being considered is use of hydrogen-powered fuel cells for the prime mover. The pace of technological development in railroad motive power has increased significantly during the past few years.

Environmental regulations will have a profound impact on locomotive engine design, cost, maintenance, and performance in the next decade. Federal standards on future engines will require manufacturers to incorporate an array of technological changes and will present the railroads with the challenge and opportunity to decide both the prime mover type and fuel of the future. It is impossible to say at this time what impact the cost of federal and state regulations will have on the current engine population. It is possible that those regulations will require major retrofits in the late 1990s and early 2000s, which could burden the railroads and weaken their competitive position in certain markets. It is also possible that some or all older engines (pre-1970 for example) will have to be retired sooner than planned.

Environmental Regulations for New Engines

The Clean Air Act requires that EPA regulate exhaust emissions from all new engines and set standards at "reasonable" levels, given existing technologies and the likely ability of manufacturers to adapt those technologies to locomotive engines at a reasonable cost.

The first EPA specifications for new locomotives will probably be effective no sooner than 1999 or 2000. They are currently expected to set the maximum allowable nitrogen oxide specification at 5.5 to 6.5 grams per brake horsepower hour (g/bhp-hr) and particulates at approximately 0.25 g/bhp-hr. These specifications are similar to EPA truck standards. The current in-use locomotives generate approximately 10 to 15 g/bhp-hr of nitrogen oxide and 0.2 to 0.4 g/bhp-hr of particulate matter. These levels may be attainable by the locomotive engine manufacturers on diesel engines using petroleum fuel. Because of the extensive trade-off between nitrogen oxide emissions and particulate emissions, a stringent particulate standard may severely constrain the manufacturers in reducing nitrogen oxide emissions. The standards appear to be attainable in truck engines; however, truck manufacturers have made more radical engine design changes in the process for trucks than can likely be accommodated in railroad engines. In fact, some engine manufacturers started engine designs from a clean sheet of paper to meet the standards. These manufacturers amortize their design, development, and tooling costs over annual sales of 50,000 units per year, whereas locomotive manufacturers can do so over only 200 units annually. In addition, the locomotive engine is considerably different from truck engines primarily because of the slower engine speed. Engine changes currently under consideration to achieve these reductions include increased charge air cooling, increased fuel injection pressure, electronic fuel injection, and piston and cylinder redesign.

Environmental Regulations for Existing Engines

The long life of railroad engines means that reducing emissions on the existing locomotive engine fleet may be desirable from the regulatory agency viewpoint. One plausible scenario is that EPA would set standards only for new locomotives, and California would set standards for existing locomotives. Other states could petition EPA to adopt the California standards for existing locomotives. Thus all U.S. railroads would be affected by the California standards. Another possibility is that EPA will occupy more of the field. At this time, CARB is considering a market-based "bubble" scheme. Under this scheme, each railroad company will be allowed a maximum mass of emissions by type (nitrogen oxide, particulate matter, carbon monoxide, hydrocarbon, and sulfur oxide), which would decline each year until some point in the future when no further decreases would be needed.

Such a scheme would be an indirect control of engine emissions levels that would allow railroads freedom to optimize technologies and operating practices to reach the required emissions levels. What is unusual for mobile sources is that the users, that is the railroads, not the engine manufacturers, would be responsible for whatever changes to engine technology are necessary to comply with the emissions levels. The actual responsibilities have yet to be determined for manufacturers and users.

The emissions levels considered by CARB are a 70 percent reduction in nitrogen oxide by 2001, 50 percent reduction in particulate matter by 2002, reduction of sulfur oxide through use of low-sulfur highway fuel starting in 1994, and no increases in carbon monoxide or hydrocarbon. A further 10 percent reduction in nitrogen oxide (to a total reduction of 80 percent) would be required by 2009, except in the Los Angeles area, where a total reduction of 90 percent would be required. These reductions are all with respect to the total emissions generated in 1987. Attainment of these levels, if possible at all, would require a combination of the following actions:

- Purchase new, lower-emissions locomotives, re-engine locomotives with new, lower-emissions engines, or both. Use of alternative fuels and electrification of the mainlines may be required.
- Modify existing locomotive engines for reduced emissions.
- Reduce fuel consumption per ton-mile through changes in operating practices and rolling stock, which translates into a reduction in emissions.

Freight railroads in California estimate that operating efficiencies will reduce all emissions by 10 to 25 percent in the various air control districts by 2001. National Railroad Passenger Corporation (Amtrak) officials believe that Amtrak's improvement will be smaller. The nitrogen oxide fleet average would have to be reduced by 45 to 60 percent instead of 70 percent and particulate matter by 25 to 40 percent instead of 50 percent. Such levels on individual engines would be approximately equal to the currently anticipated EPA standards for new engines. It may not be possible to retrofit some older engines. Therefore, it will probably be impossible to meet the proposed CARB bubble levels unless these older engines are removed from service in California. There is also significant doubt that new engines on diesel fuel can achieve the suggested reductions.

CARB has a number of key design considerations in the development of a proposed regulatory framework. In addition to the maximum emission reductions, CARB is concerned with modal shifts to less environmentally friendly modes of transportation, such as trucks. In developing regulations to reduce locomotive emissions, it will be important to ensure that rail costs are not increased to such a degree that traffic shifts to more polluting modes or that harm occurs to major sectors of the California economy such as viability of the southern California ports. CARB also desires performance-based standards, incorporation of both technological and operation measures, flexibility to accommodate different operations, accommodation of future growth, optional market-based mechanisms, compliance with state and federal law, and compatibility with future freight transport policy.

Lowered Emissions Retrofit Technology

Locomotive diesel engines are somewhat modular in design and can accept newer technology in the form of replacement parts during normal maintenance or at the time of an engine overhaul or remanufacture. Nearly every engine in use today has some upgrades that the manufacturer introduced after delivery of the engine. New injectors and improved combustion air cooling typically are retrofittable to some degree in many engines. Obviously, there are limits to the extent that characteristics of new engines can be incorporated into products placed in existing engines.

Prime Mover Technology

Many industry experts predict that, even with the most rigorous development program possible, the conventional petroleum-fired diesel engine will fall short of meeting the emission standards likely to be required by the year 2000 and especially by the year 2010. It is therefore prudent for railroad researchers to be actively evaluating the alternatives. The objectives of this research should be twofold. First, the candidate technologies should be evaluated to determine their suitability for application to the railroad environment, the prospects for development success, and the likely development schedule. Second, they should be evaluated for compatibility with the current diesel-electric practice and with the other candidate technologies so that any phase-in can be as efficient and least disruptive as possible.

On the basis of current information, the following prime mover technologies have been identified as possible alternatives for use by the railroads into the first quarter of the next century. Primary energy sources (energy conversion systems) are natural gas, methanol, multiple small diesel engines (with or without distributed power), electrification, gas turbines, and hydrogen fuel cells. Secondary energy sources (advanced storage systems) are advanced storage batteries and high-speed flywheels.

Primary Energy Sources

Primary energy sources convert chemical energy or stored energy from a source external to the locomotive to electromechanical energy for traction power. As an example, a primary energy source may be an on-board, fossil-fuel-driven prime mover (such as a diesel engine or gas turbine) providing mechanical energy to an electrical generator to produce the electrical energy for locomotive traction motors. Alternatively, it may consist of a current collection device on the roof of the locomotive drawing electrical energy from an overhead distribution system. In turn, the overhead distribution could be fed from a utility supply powered by hydro-electric turbines, or fossil-fuel-fired or thermal-nuclear-powered steam turbines.

Byproducts of the chemical energy conversion process (e.g., combustion exhaust emissions or spent nuclear fuel) are a major concern from the environmental standpoint. Indeed, exhaust emissions is a major issue on which the petroleum-fired engine is being challenged. Therefore, selection of the alternative technologies will be made on the basis of lowest pollution levels, costs, and benefits.

As a source of power for railroad traction, the conventional petroleum-fired diesel engine is a mature technology. Typical engine output powers range from 2,000 hp for road switcher units to 4,300 hp for mainline freight service, with an overall thermal efficiency of 34 to 36 percent. Indications are that the future trend is to increase the power rating toward 6,000 hp/unit for mainline operation. Currently, power levels are limited by a requirement that the prime mover weight and including fuel supply be a maximum load of 65,000 lb per axle, 390,000 lb for a six-axle locomotive.

As previously mentioned, a major disadvantage of the current diesel engine technology is the level of emissions produced by the combustion process, particularly the levels of oxides of nitrogen and carbon dioxide. Typically, existing locomotive diesel engine nitrogen oxide levels are in the 10 to 15 g/bhp-hr range, which is unacceptable for the future. Retrofit technologies (electronic fuel injection, retarded engine timing, and increased charge air cooling) are expected to bring nitrogen oxide emission levels down to 7 or 8 g/bhp-hr, but at the expense of fuel efficiency, smoke, and particulate emissions. This performance may be acceptable in the interim, but not for the long term.

Natural Gas

Natural gas may be used as an alternative fuel in the locomotive diesel engine as a result of a direct conversion of existing equipment or as a design for new engines. The technology is applicable to both two-stroke and four-stroke cycle engines. Currently, the preferred natural gas fuel variant is refrigerated liquid methane, obtained by refining compressed natural gas. Due to the relatively low energy density (in British thermal units per cubic foot) of liquid methane, fuel for the gas-fired road locomotives has to be carried in cryogenic fuel tenders instead of in on-board fuel tanks. The remaining equipment on the locomotive (alternator, propulsion system, and controls) is identical to the conventional diesel electric locomotive. In fact, petroleum-fired and gas-fired locomotives can be operated in the same motive power consist.

Three combustion technologies are currently in use or under development for the use of natural gas as a diesel engine fuel. These technologies are dual fuel pilot injection, direct gas injection, and direct liquid natural gas injection. Each has advantages and disadvantages relative to costs, flexibility of operation, power levels, energy efficiencies, safety, and locomotive emissions. Spark-ignited engines operating on natural gas could power locomotives, especially switch engines. Reductions in the power per engine weight ratio and losses in fuel efficiency as compared with diesel engines would result. Nitrogen oxide and particulate emissions are believed to be quite low.

The current price of natural gas is approximately half the cost of diesel fuel on an equivalent British thermal unit basis. Such a price difference creates interest in natural gas as a fuel on economics alone. Obviously, the future cost is uncertain. The environmental benefit for most of the proposed locomotive natural gas engines is not sufficiently known. Research is under way with locomotive manufacturers and several railroads. Both switch engines and road power are involved. In addition, a group of railroads, suppliers, and some environmental agencies have funded a large study of emissions, infrastructure needs, safety, and the effects on capital cost, operating cost, and maintenance requirements of using natural gas as a railroad fuel. A large amount of knowledge will be collected during the next 2 years.

Electrification

Because electrification is already a mature and established technology, no major technical developments are necessary to implement it. The main barriers to the widespread implementation of electrification are economic. These barriers include capital and operating costs and operational disruption during construction. In addition, the entire system must be constructed before any value is created. One potential impact on operational costs and flexibility is peak-period electrical demand charges. The current evaluation of electrification for southern California reveals a $4 billion to $5 billion first cost, minor locomotive maintenance savings, no energy savings, and substantially increased maintenance-of-way costs due to the catenary maintenance. The early, incomplete California studies of electrification estimate the nitrogen oxide reductions to cost $4,000 to $10,000/ton. By comparison, current EPA proposals for emissions reduction are estimated to cost no more than $400/ton.

Methanol

The use of methanol blends with gasoline is undergoing demonstration field evaluation in automobiles in many locations, including California. The high cost of methanol makes the fuel relatively unattractive as a diesel fuel replacement. Obtaining good ignition of the fuel is difficult in diesel engines. The fuel has been certified in one diesel truck engine complying with the truck nitrogen oxide standards and is regarded favorably by some in the EPA Mobile Sources Office.

Gas Turbines

Gas turbine generator sets for stand-by power are common. They are generally designed to run on a multitude of fuel types, including natural gas. In the past, gas turbine-electric power was used for traction in freight operations on the Union Pacific Railroad. The gas turbine–powered locomotive design is similar to diesel-electric locomotives. The gas turbine prime mover is connected to a traction generator through a gearbox. The main propulsion system is identical to that of the diesel electric locomotive. Three passenger railroad applications have been demonstrated, each with gas turbines driving hydraulic transmissions as part of specially designed, lightweight trains. Two of these designs are still in use in the northeastern United States.

The main disadvantage of gas turbines for motive power is that they are not efficient for partial loads and, therefore, do not follow the railroad locomotive duty cycle effectively. Their performance and fuel consumption characteristics are best suited to constant load applications. However, gas turbines generally produce significantly lower levels of emissions and have power/weight ratios higher than diesel engines. Therefore, they may lend themselves to future applications to locomotives in combination with secondary storage devices or in special high-power use applications.

Fuel Cells

The fuel cell uses a chemical reaction to directly produce electricity. A fuel cell is an electrochemical engine that converts the chemical energy of a fuel and an oxidant directly to electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes. For some of the most promising fuel cells, hydrogen is the preferred fuel. Oxygen is the typical oxidant and can be supplied in the form of air or purer oxygen. Overall energy efficiencies starting with conversion of natural gas to hydrogen are in the 40 to 43 percent range.

Many experts predict that the fuel cell will eventually replace the internal combustion engine. However, major developments are necessary to reach that point technically, let alone from the cost-benefit standpoint. However, of all the alternatives evaluated for this study, fuel cells hold the most promise for meeting the emission levels for transportation that some regulatory agencies are contemplating for the 21st century. There are wide-ranging points of view, but some advocates are projecting that, by the end of the first quarter of the next century, the fuel cell may even replace the internal combustion engine on economics alone. Manufacturers have a long way to go because the cost of the power systems for a Proton Exchange Membrane power cell currently powering a bus is approximately $5,000/kW, whereas locomotive engines cost less than $200/kW. The current durability of the power cells is only 3,000 hr, whereas a minimum of 40,000 hr would be desired for a locomotive. Because railroad locomotives already incorporate electric motor-based propulsion systems, application of fuel cells to the locomotive is less radical than application to automobiles or trucks.

A joint initiative recently undertaken by SCAQMD and the U.S. Department of Energy (DOE) will study the feasibility of two prototype locomotive designs incorporating fuel cell power plants. The two designs under consideration are a road switcher and a high horsepower road locomotive. If considered successful, it is probable that at least one of the designs will be built, provided the necessary funding can be obtained from public and private sources. Funding for the feasibility study is being provided jointly by SCAQMD and DOE. California railroads and AAR, on behalf of the entire railroad membership, have been invited to act as technical advisors to this study.

Secondary Energy Sources (Advanced Storage Devices)

As a general concept, these devices would be used in conjunction with a primary energy source, such as a small on-board diesel generator set, a gas turbine generator set, or overhead electrification. They could also be used to recover much of the potential energy currently lost during braking. The storage system would be sized to provide the peak power demands, or during interruptions to the primary supply, while absorbing power from the primary energy source during periods of low demand and braking. Advanced storage devices could be batteries, flywheels, or a volume of gas that is pressurized to increase its energy content.

The main drawback of batteries typically is the low energy capacity/weight ratio. The military has sponsored research on improving batteries. Similar requirements for some of these applications may allow railroads to benefit from this research.

The use of flywheels for smoothing rotating shaft torque pulsations is well known. For example, internal combustion engines have employed flywheels for that purpose since their invention. Flywheel capacities of 30,000 hp-hr have been predicted by some experts as being imminent. These storage devices could be used to store the energy from a smaller, constantly loaded, prime mover power plant (such as a gas turbine) and release the stored energy during peak power operations and be used to store braking energy.

What Does All of This Mean?

The future seems to be a combination of good news and bad news. The good news is that the transportation sector continues to grow in terms of ton-miles per year. The bad news is that revenues per ton-mile continue to erode at a rate of approximately 2 percent per year. This puts considerable pressure on costs per ton-mile and contributes to intense competition. As the carriers reduce costs, the shippers get more cost-effective service. Shippers continue to demand higher quality service. Railroad labor and railroad suppliers of locomotives, cars, fuel, and other commodities have been partners to major changes that have improved the railroads' competitive position. Such changes must continue and must be focused on satisfying the needs of shipper customers cost-effectively while being safe and environmentally friendly.

The railroads are being pressured to reduce locomotive nitrogen oxide emissions by at least 60 percent because of earlier reductions to trucks and automobiles. In some nonattainment areas, more reductions may be demanded. Even though railroads generate far less nitrogen oxide on a ton-mile basis, the pressure will remain to reduce emissions to the maximum extent technologically feasible, especially in nonattainment areas. The improvement in emissions initially will involve changes to the existing diesel engine running on diesel fuel. More radical alternatives further in the future range from use of natural gas in engines similar to the current engines to hydrogen-powered fuel cells. These technologies will be considered successful only when the railroads' competitive position is enhanced or at least kept comparable with other modes.

The emphasis on train resistance must be elevated further. Too little has been done, to date, in using the knowledge gained during the 1980s. The relatively low cost of diesel fuel, currently, and the uncertainty of the future price pushes railroad management into making decisions lasting 30 years on information that is valid for only a few years. If railroads do not make better decisions for the long term, they will not be competitive in the long term. This is especially true for purchases of cars and locomotives. The railroad industry should be reducing fuel consumption (gallons per ton-mile) by 3 to 4 percent per year. This reduction will require structural changes in the car fleet and car design and in motive power and operational improvements.

What Do You and I Need to Do?

The necessary improvements will not be achieved without better information. Railroad professionals need to jointly describe their vision of the future and develop the research programs to propel the railroads there. Research is needed particularly for hardware, but better forecasts of energy costs, perhaps involving probabilities instead of just a single forecasted price, are also essential. Train energy models make great analytical tools for studying alternatives but do little to help terminals and dispatchers make daily decisions on equipment.

A number of groups, partnerships, and coalitions are providing some answers to some of the questions. The railroads and AAR have a substantial on-going effort. The locomotive manufacturers and some other suppliers aggressively seek improvements. DOE, DOT, air quality management districts, and national laboratories are involved in projects with the railroads and suppliers. A number of universities and firms, such as Southwest Research Institute, contribute as well.

The major issue is how to develop the joint vision and how to coordinate the work to avoid duplication, unnecessary research, and untimely information. The challenge for railroad professionals is to put aside much of their self-interest and perhaps suspicion and cooperatively create research initiatives that will be to their mutual benefit. The collective action should achieve considerably more than what individuals could accomplish. Furthermore, time is of the essence because energy dependence and air quality problems resist change, to the mutual detriment of all.

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Discussion Group Summary: Energy and the Environment

The mission of the energy and environment group of conference participants was defined as follows:

- Energy/locomotive: Identify train systems and technologies that optimize energy consumption, minimize emissions, and feature lowest life-cycle costs consistent with competitive and regulatory environments.
- Environment: Identify railroad-related environmental issues that involve air emissions, wastewater discharges, noise pollution, land-polluting activities, and solid waste production. Environmental effects of both general rail operations and the transportation of hazardous materials and waste products must be considered.

Identification of Issues

- Global environmental factors: greenhouse effect, ozone depletion, water quality;
- Pollution and waste: emphasis on pollution prevention and waste minimization, consideration of new technologies;
- Compliance: expanded use of audits, performance standards for industry and contractors, proactive involvement by railroads to achieve sensible regulation;
- Environmental impacts on business: environmental positives associated with the rail mode, waste transport business opportunities, environmental components of life-cycle costing, shareholder and analyst sensitivity;
- Risk: risk assessment for evaluating transportation of chemicals, risk-based approach to environmental cleanup;
- Human factors: greater public attention to environmental performance, employee awareness and training for expanding regulation, senior management attention to environmental and energy factors;
- Energy supply: alternative sources, energy storage, optimal engine operation;
- Train systems: power distribution, train consists, human factors and worker protection, train control, information, and communication; and

- Technology: finite life design, modularity and optimum design, operating constraints such as drag and mechanical resistance.

Research Needs Identification: General Considerations

A responsible approach to the research priorities will include, at a minimum, the following:

- Literature search,
- Minimized time to market,
- Technology transfer analysis,
- Maximized use of joint funding and research opportunities,
- Realistic life-cycle cost analysis and return on investment (ROI),
- Consideration of safety, reliability, and maintainability in proposed solutions,
- Consideration of sequence and interaction with other projects, and
- Upward compatibility of technology.

Energy/Locomotive Research Needs

The following energy/locomotive research needs statements are listed in priority order, with the first being the highest priority.

Alternative Power Sources and Storage

Description and Scope

- Alternative Fuels:
  - –Diesel fuel 2,
  - –Natural gas,
  - –Methanol,
  - –Ethanol,
  - –Coal,
  - –Electricity, and
  - –Others;
- Alternative prime movers:
  - –Reciprocating pistons,
  - –Turbines,
  - –Fuel cells,
  - –Electrification,
  - –Linear induction motors, and
  - –Others;
- Optimal fuel efficiency versus emissions;
- Possible retrofits to existing fleet; and
- Energy storage and recovery devices:
  - –Batteries (electrochemical devices),
  - –Flywheels (electromechanical devices),
  - –Inductive capacitors (electrical devices), and
  - –Others.

Relationship to Mission

- Optimizes fuel consumption and minimizes emissions production,
- Responds to regulatory requirements,

- Improves life-cycle costs, and
- Improves competitive advantage.

Expected Benefits

- Reduces costs,
- Complies with regulatory environment,
- Promotes domestic energy independence, and
- Improves energy efficiency of the train system.

Train System Technology

Description and Scope

- Train makeup and design;
- Power distribution;
- Power-weight ratios;
- Load-tare ratios;
- Man-machine interface:
  - –Crashworthiness,
  - –Crew environment, and
  - –Noise, vibration, and the like; and
- Trainline information systems:
  - –Braking and
  - –Diagnostics.

Relationship to Mission

- Reduces energy consumption,
- Reduces emission production,
- Improves life-cycle cost, and
- Enhances competitiveness.

Expected Benefits

- Improves customer service,
- Lowers cost,
- Improves crew environment,
- Improves safety,
- Improves reliability,
- Exploits the advantages of rail transport, and
- Offers opportunity for effective partnerships with other modes.

On-Board Systems

Description and Scope

- Train control:
  - –Braking,
  - –Car performance, and
  - –Train handling;
- Integrated systems (e.g., integrated cab electronics and locomotive systems integration);
- Health monitoring:
  - –Prime mover or propulsion system and

–Emissions;
- Diagnostic monitoring;
- Fuel management;
- Man-machine interface; and
- Wayside communication.

Relationship to Mission

- Reduces energy consumption,
- Reduces emissions production, and
- Improves life-cycle costs.

Expected Benefits

- Reduces costs (fuel and maintenance),
- Improves operational performance (i.e., service reliability),
- Facilitates man-machine interface,
- Improves asset utilization, and
- Improves safety.

Finite Life Design

Description and Scope

- Optimal equipment life:
  –Modularity of design,
  –Durability versus weight trade-off, and
  –More rapid technology turnaround; and
- Support of competitive advantage:
  –Quick time to market,
  –Adaptable technology,
  –Level playing field with respect to regulations, and
  –Minimization of future uncertainties.

Relationship to Mission

- Lowers energy consumption through weight reduction,
- Improves life-cycle costs, and
- Enhances competitive advantage (quick response to customer needs).

Expected Benefits

- Lower cost per revenue ton-mile,
- Improved ROI, and
- More rapid adaptation of new technology.

Train Resistance

Description and Scope

- Aerodynamic drag:
  –Train makeup and
  –Car and locomotive design;
- Mechanical resistance:

–Lightweight materials,
–Wheels, axles, bearings,
–Trucks, and
–Wheel and rail lubrication;
- Curve and gradient.

Relationship to Mission

- Optimizes energy consumption and minimizes emission production.

Expected Benefits

- Lowers energy consumption,
- Lowers emissions, and
- Lowers costs.

ENVIRONMENTAL RESEARCH NEEDS

The following research needs statements are listed in priority order, with the first being the highest priority.

Pollution Prevention

- Needs: Significant environmentally sensitive releases, emissions, and waste streams generated from railway facilities, equipment, rolling stock, operations and maintenance practices and procedures should be identified, quantified, and ranked in priority order. Alternative materials, techniques, processes, using such tools as risk-based analysis and life-cycle costing, should be identified and assessed. This project would address specific items such as crashworthiness of locomotive fuel tanks, noise pollution, and exhaust emissions.
- Benefits: This project is expected to reduce future operating costs, enhance safety performance, and improve the public image of the rail industry.

Risk Analysis

- Needs: Research needs associated with environmental risk analysis are as follows:
  –Develop and refine model and necessary data to evaluate risks associated with rail transportation of chemicals and nuclear wastes;
  –Develop methods to identify and assess the environmental risk resulting from railroad operations and to ensure that materials and processes that pose minimized risks are used; and
  –Conduct analyses to assess the potential risk associated with in-place contaminants typical of railroad property.
  Needs associated with past and present conditions should be considered.
- Benefits: Research in this area should enable better business decisions, facilitate seamless transportation service, and reduce future environmental liability costs.

Remediation

- Needs: Remedial action is required in connection with environmental impairment at railroad facilities. There is a direct need to identify, develop, and improve or optimize remediation technologies applicable to railroad related contaminants, site conditions, and operations.

Specific technologies to be investigated include in-situ and ex-situ approaches to treating diesel fuel, hydrocarbons, wood preserving chemicals, lubricants, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, solvents, and other contaminants that affect rail operations.

- Benefits: Research in this area should enable reductions in environmental operating costs, enhance real estate business opportunities, and make environmental issues more transparent with respect to railroad operations.

Standard Environmental Protocols

- Needs: The multiple interface among railroads, suppliers, contractors, customers, and government agencies can be more efficiently supported if standardized environmental protocols are developed and implemented. Possible areas for standards development include (a) compliance audits, (b) internal and external environmental awareness programs, and (c) environmental training programs.
- Benefits: Seamless transportation and reduced costs through a standardized approach would result.

Regulatory and Legislative Management

- Need: Data should be gathered and research conducted to support the industry in participating in the legislative and regulatory process. Research activities would provide resources to proactively promote scientifically based, economically feasible environmental laws and regulations.
- Benefit: Sensible environmental laws and regulations would result.

Life-Cycle Costs

- Need: Methods for quantifying total environmental costs associated with products and operating process used by the rail industry should be identified and developed. This work would include costs of disposal, treatment, worker exposure, environmental risks, liabilities, and compliance. The inclusion of total environmental costs in life-cycle costing will result in more accurate evaluation of overall railroad operating costs.
- Benefit: Better business decisions and reduced operating costs would result.

SUMMARY

- Energy and environmental matters are dynamic and subject to substantial changes on short notice. As much as possible, research efforts related to environmental and energy matters should be designed to accommodate such changes.
- Rail transport features many aspects that are positive for energy and the environment. Research efforts should take these positive aspects into account.
- Virtually any research project that relates to railroad physical plant or operating processes will produce environmental and energy impacts. Environmental and energy factors must be considered early and as mainstream issues in project development.
- Both energy and environmental affairs are directly affected by significant external factors such as governmental regulation, supply and demand constraints, political pressures, and public opinion. These external factors must be given all due consideration in the business decision-making process associated with energy and environmental research activities.

RESPONSES FROM LABOR REPRESENTATIVES

Responses from Labor Representatives

Representatives from railway labor organizations were invited by the Transportation Research Board to a follow-up meeting [along with staff of the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA)] to present their suggestions and recommendations on research priorities. Representatives of the following labor organizations attended this meeting: Railway Labor Executives' Association, Brotherhood of Locomotive Engineers, Brotherhood of Maintenance of Way Employes, American Train Dispatchers Association, Brotherhood of Railroad Signalmen, Transportation Communications Union, and Transport Workers Union. (A list of attendees is presented at the end of this conference proceedings.) Subsequently, written comments were received from representatives of the Brotherhood of Locomotive Engineers, Brotherhood of Maintenance of Way Employes, and American Train Dispatchers Association. Excerpts of the written comments related to research needs and priorities of the appropriate research topics are provided in this section.

Future Trends and Visions

Excerpts of comments submitted by a representative of the Brotherhood of Maintenance of Way Employes: The conference session on future trends in freight transportation and logistics developed a vision for railroad research, which stated that railroads, suppliers, labor organizations, customers, universities, and governments must join together to create breakthroughs in safety, profitability, and growth as part of a global distribution network. This vision must be fully reevaluated—collectively—with all interested parties to fully develop an effective, practical means of implementing the vision foundations with emphasis on improved safety and human resource development, which are vital to achieving any objective. A collective approach is particularly important before implementing the rail employees surveys and the employee training and retraining called for as part of a human resource development research program. Finally, all long-range research recommendations should be set forth in a clear mission statement, and mission statements for specific subject areas should include employee concerns and input as well as input from shippers.

INFRASTRUCTURE

Excerpts of comments submitted by a representative of the Brotherhood of Maintenance of Way Employes: In the summary on infrastructure, it was noted that the track structure is more critical than ever before, particularly as line capacity problems emerge and there is little redundancy of track or equipment. Additionally, it was recognized that the existing track structure may be inadequate for future increases in car weights and speeds. Labor representatives agree with these statements and point out that there are also safety implications of increased car weights and speeds. Track safety standards should be considered in ongoing infrastructure research.

Although AAR maintains that performance standards should replace existing standards, exhaustive evaluation and comparison of performance standards against historically proven design and engineering standards must be conducted to determine if performance standards are appropriate or practical. Any viable standard must be able to be measured, inspected for compliance, and be adaptable to uniform regulation. Performance standards generally do not meet these criteria.

When addressing track-train dynamics, the infrastructure group stated that it was unanimous in its determination of the need for performance standards instead of the current design standard specifications. This statement requires several caveats. First, the group's determination is void of any objective input or evaluation that may have been offered by acknowledged experts responsible for the practical application, enforcement, and remedial action of such standards—namely the employees. Second, valid concerns related to measurement, inspection, and corrective remedial action with respect to performance-based standards have yet to be satisfactorily addressed. Finally, the appropriateness and practical application of performance standards must be objectively questioned. Improvement and enhancement of proven systems should supersede any notion of system replacement with performance standards using a pass or fail rationale.

The infrastructure group raised numerous questions concerning maintenance strategies relative to (a) structural versus component replacement, (b) rail grinding, (c) ultrasonic testing, and (d) maintenance versus renewal or replacement. Each of these questions requires a full evaluation of all data available throughout the industry before final conclusions are reached. Individual carriers should be requested to provide their records to augment those obtainable through FRA, which may be deficient with respect to maintenance schedules. Employee input should be considered for inclusion in any final recommendation concerning maintenance practices and strategies.

The infrastructure group also identified bridge integrity as a concern. Currently, although FRA has regulatory oversight of the nation's track structures with broad authority to prescribe standards in all areas of railroad safety, there is no federal regulation or oversight with respect to railroad bridge construction, maintenance, inspection, and repair. The research recommendations should fully address the need for comprehensive bridge safety standards, which address these vital structural areas, to ensure the continuity and uniformity essential to complete rail infrastructure safety. In addition, a study should be undertaken of the feasibility of installing a mechanism, which can be incorporated in the automatic block system (or equivalent train control system), to indicate when bridges are displaced. The National Transportation Safety Board (NTSB) made such a proposal to FRA September 12, 1980, in Safety Recommendation R-80-36. The research agenda should include related NTSB and FRA records.

COMMAND, CONTROL, COMMUNICATION, AND INFORMATION

Excerpts of comments submitted by a representative of the American Train Dispatchers Association: Participants in the command, control, communication, and information (C^3&I) group noted that hard benefits will stem from improvements in the areas of command, control, communication, and information, and that these hard benefits can be quantified. The group also pointed out that if soft benefits are left out of the equation, they will be implicitly assigned a value of zero, which can be misleading. It is essential to develop methods of evaluating soft benefits. An example of soft benefits would include changes in the "pool crew" system. The erratic work schedule in this area contributes to fatigue, sickness, and safety problems. Although the performance of train and engine crews is discussed, there is no mention of the pool crew problem.

Noise reduction should also be a factor in measuring soft benefits. Hearing loss caused by excessive noise is a problem in many crafts in the railroad industry. Any improvement in communication in the field would enhance safety.

It was recommended that there should be industry-wide agreement on operating rules, which is essential.

Excerpts of comments submitted by a representative of the Brotherhood of Maintenance of Way Employes: Recommendations should include concomitant provisions for training, retraining, and education as part of any operating or regulatory scheme to ensure effective implementation and continuity of operations.

The C^3&I group reported on the development of control software for advanced systems pertaining to train control applications and their effect on wayside and maintenance-of-way vehicles. The protection and detection of maintenance-of-way forces and their equipment and vehicles have long been a concern of labor. Appropriate flagging, detection, and train control methodologies are a must for a safe industry. Research recommendations should embrace implementation of immediate procedures for the protection of employees and equipment with a view toward a long-term strategy. The research agenda should also include evaluation of labor proposals for flagging protection and maintenance-of-way operations being performed on "live" track as well as adjacent tracks.

The C^3&I group stated that "the most important priority research programs are customer needs, business process redesign, and soft benefit evaluation methodology." This statement should be reevaluated and redefined to include employee input and emphasis on safe operations.

In addressing broken-rail detection, group participants mentioned the potential elimination of existing signal systems with the implementation of a new C^3&I system for train control. The practical application of implementing such plans, focusing on functional system performance while under traffic and during maintenance repair and renewal projects, should be evaluated.

Human Factors

Excerpts of comments submitted by a representative of the Brotherhood of Locomotive Engineers: Over the years the largest amount of research resources has been allocated to studies related to railroad structures and equipment—"hardware." Although human performance has not been entirely ignored, research dollars have been limited. In the future, more attention should be focused on research related to improving employees' ability to perform their jobs in a safe and efficient manner; issues such as work environments, hours required to work, reporting procedures, job training, and ergonomics should be examined. Employees, for the most part, do not control these factors, but they must deal with them on a regular basis. Railroads are still dangerous and difficult places to work. As lines are eliminated, train speeds are increased, and traffic density on a particular line of railroad escalates, so does the potential for errors. These problems can be overcome, but only if the human factors associated with today's railroad operations are given the attention they warrant.

Excerpts of comments submitted by a representative of the Brotherhood of Maintenance of Way Employes: The human factors research agenda needs to be totally reevaluated and reprioritized with input from all interested parties—collectively and simultaneously—with equal input from labor perspectives. Although many of the human factors research projects are indeed valid, no consideration was offered with regard to the role of labor representatives, collective bargaining agreements, or reprieve from reprisal should employees report deficiencies in a particular system or program.

Excerpts of comments submitted by a representative of the American Train Dispatchers Association: The research project on ergonomic evaluation was appropriately given a high priority. Factors such as air quality, vibration, lighting, noise, and communication capability are overdue for improvement. However, it was disappointing to see that worker selection and training were given a low priority in the list of research projects. A reevaluation of this priority rating is needed.

The selection of employees, their training, and their mental work load are vitally important areas that are almost completely neglected by rail carriers. The training of train dispatchers—an area that is almost totally inadequate, with the exception of a few carriers—was mentioned specifically. The prevention of one accident by the establishment of better training programs would be beneficial for the carriers, employees, shippers, or passengers involved.

Steering Committee Biographical Information

David N. Wormley, *Chair,* is Dean of the College of Engineering at The Pennsylvania State University. He previously was a member of the faculty at the Massachusetts Institute of Technology (MIT), where he served as Head of the Department of Mechanical Engineering and Associate Dean of Engineering. He received bachelor's and doctoral degrees in mechanical engineering from MIT. He also served as the first Director of the Association of American Railroads (AAR) Affiliate Laboratory Program at MIT. His research is focused on the dynamic analysis, optimization, and design of advanced control systems, transportation systems, and fossil fuel energy systems. Dr. Wormley is a member of the National Science Foundation Advisory Board to the Engineering Directorate, Education Advisory Group of the National Society of Professional Engineers, and editorial board of the *International Journal of Vehicle Mechanics and Mobility*, and he is a Fellow of the American Society of Mechanical Engineers (ASME). He has received the ASME Lewis Moody Award and a National Aeronautics and Space Administration Certificate of Recognition. He currently serves as a member of the Transportation Research Board (TRB) Executive Committee.

L. Stanley Crane retired as Chairman and Chief Executive Officer of Consolidated Rail Corporation (Conrail) in 1989, after serving in these positions since 1981. He previously worked for the Southern Railway Company, where he began as a laboratory assistant and eventually became Chairman. He was Director of Industrial Engineering for the Pennsylvania Railroad Company from 1963 to 1965. He received a bachelor's degree in engineering from George Washington University. He is Director Emeritus of American Security Corporation and American Security Bank National Association, Fellow of ASME, Fellow and Past President of ASTM (American Society for Testing and Materials), and Trustee of George Washington University. He is also a member of the National Academy of Engineering and a former member of the TRB Executive Committee. Mr. Crane has received the Association of Railroad Advertising and Marketing award for outstanding service to the railroad industry of the United States and Canada, American Railway Development Association Distinguished Service Award, National Defense Transportation Association Award, and Transportation Association of America Seley Award. He has been named Man of the Year by *Modern Railroads* and Chief Executive of the Year in the Railroad Industry by *Financial World.*

David DeBoer is Vice President of Greenbrier Intermodal Corporation. His involvement with freight transportation, from both the private and public sector perspectives, has grown from a variety of positions with the Southern Pacific Transportation Company, Interstate Commerce Commission, Federal Railroad Administration (FRA), Reebie Associates, Trans World Airlines, and New York Central System. He received bachelor's and master's degrees from the University of Michigan. Mr. DeBoer is a founding Director of the Intermodal Association of North America. He has served as Director of the Trailer Train Corporation (now TTX) board and as a member of the Transportation Research Forum board and the TRB Committee on Intermodal Freight Terminal Design and Operations. He is the author of the book *Piggyback and Containers—A History of Rail Intermodal on America's Steel Highway.*

Steven R. Ditmeyer is Vice President of Marketing and Business Development in the Locomotive Division of MK Rail Corporation. Before joining MK Rail Corporation, he worked at the Burlington Northern Railroad as Chief Engineer, Research, Communications, and Control Systems and as Director of Research and Development. Other transportation-related experience includes positions at FRA, Alaska Railroad, the World Bank, Organization of the Joint Chiefs of Staff, and Missouri Pacific Railroad. He received a bachelor's degree in industrial management from MIT and a master's degree in economics and a certificate in transportation from Yale University. He is a Charter Member of the Senior Executive Service of the U.S. Government, member of the American Railway Engineering Association, and Fellow of the Permanent Way Institution in the United Kingdom. Mr. Ditmeyer has received a Joint Service Commendation Medal, a special commendation from FRA, and the AAR Outstanding Technological Achievement Award.

Robert E. Gallamore is General Director of Strategic Analysis at Union Pacific Railroad. He previously spent 5 years in corporate strategic planning with Union Pacific Corporation and a brief period in the securities industry. Before joining Union Pacific, his public sector positions included two at the U.S. Department of Transportation—Deputy Federal Railroad Administrator and Associate Administrator for Planning at the Urban Mass Transportation Administration. He earned master's and doctoral degrees at Harvard University. He has received the Senior Executive Service Meritorious Achievement Award and is a member of the TRB Committee on Freight Transport Regulation.

E. Thomas Harley is Manager of Railroad Operations at LTK Engineering Services. He previously served as Chief Mechanical Officer, Vice President—Equipment, and Senior Vice President—Equipment at the former Trailer Train Company (now TTX). Earlier he held positions in equipment maintenance, mechanical engineering, and research at Conrail, Penn Central Transportation Company, and the Pennsylvania Railroad. He received a bachelor's degree in mechanical engineering from Northwestern University. He is Past President of the Locomotive Maintenance Officers Association; former member of the AAR Research Committee; ASME Fellow and member of the General Committee of the Rail Transportation Division; and member of the Car Department Officers Association, Union League Club of Chicago, and New York Railroad Club.

John E. Jones, Jr., is Director of the Engineering Technology Division at Oak Ridge National Laboratory. The Engineering Technology Division is primarily involved in technology development related to energy conversion and utilization, manufacturing technology, and transportation technology. The division manages the U.S. Department of Energy's Materials for Lightweight Vehicles Program and the Advanced Propulsion Technology Center and is contributing to plans for the New Generation Vehicle Initiative. Mr. Jones received a bachelor's degree in mechanical engineering from the University of Kentucky. He is a member of ASME, the American Nuclear Society, and the National Management Association.

Paul E. Nowicki joined The Atchison, Topeka and Santa Fe Railway Company in 1979 and has held several positions in marketing management. Currently, he is General Director, Intermodal Marketing. He previously worked for Texas International Airlines. He received a bachelor's degree from the University of Wisconsin and a master's degree in business administration from

Northwestern University. Mr. Nowicki is currently assisting the National Commission on Intermodal Transportation.

Michael D. Roney is Manager of Track Technology at CP Rail System. He previously held track and maintenance-of-way development positions with the Melbourne Research Laboratories, Canadian Institute of Guided Ground Transport, and CN/CP Arctic Railway Study. Mr. Roney is a registered professional engineer in Ontario. He received bachelor's and master's degrees from Queen's University in Canada. He is a former Chairman of Committee 2, Track Measuring Systems, of the American Railway Engineering Association and is a member of the Roadmasters Association of America.

E. Donald Sussman is Chief of the Operator Performance and Safety Analysis Division at the Volpe National Transportation Systems Center. Before that, he was Research Psychologist at Cornell Aeronautical Laboratories (now CalSpan Corporation). He received a doctoral degree in experimental psychology from Iowa State University. He serves as U.S. delegate and member of the Technical Advisory Group to the Subcommittee on the Effects of Human Exposure to Mechanical Shock and Vibration of the International Organization for Standardization. He is a former Chair of the TRB Committee on Ride Quality and Passenger Acceptance and holds several patents for human performance evaluation devices.

Joseph M. Sussman is the JR East Professor and Professor of Civil and Environmental Engineering at MIT. He is also Director of the AAR Affiliate Laboratory Program at MIT. He previously served as Director of the MIT Rail Research Group. He received a bachelor's degree from City College of New York, a master's degree from University of New Hampshire, and a doctoral degree from MIT. He is a member of the American Society of Civil Engineers, Transportation Research Forum, and American Society of Engineering Education. Dr. Sussman is Chairman of the TRB Executive Committee and served as Chairman of the TRB Committee for the Study of Long-Term Airport Capacity Needs.

Henry B. Wyche, Jr., is Assistant Vice President, Environmental Protection, at Norfolk Southern Corporation. Before assuming his current position, he was Director, Environmental and Shop Engineering. He previously held various engineering positions with Southern Railway Company (predecessor to Norfolk Southern); Keck & Wood, Inc.; and J.S. Singletary Construction. He received a bachelor's degree from North Carolina State University and a master's degree from Georgia Institute of Technology. He is a registered professional engineer in several states; registered land surveyor in North Carolina; member of the American Society of Civil Engineers, National Society of Professional Engineers, and American Railway Engineering Association; Chairman of the Botetourt County, Virginia, Planning Commission; and former member of the TRB Committee on Hydrology, Hydraulics, and Water Quality.

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CONFERENCE ON RAILROAD FREIGHT TRANSPORTATION RESEARCH NEEDS

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