Command, Control, Communication, and Information Systems

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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

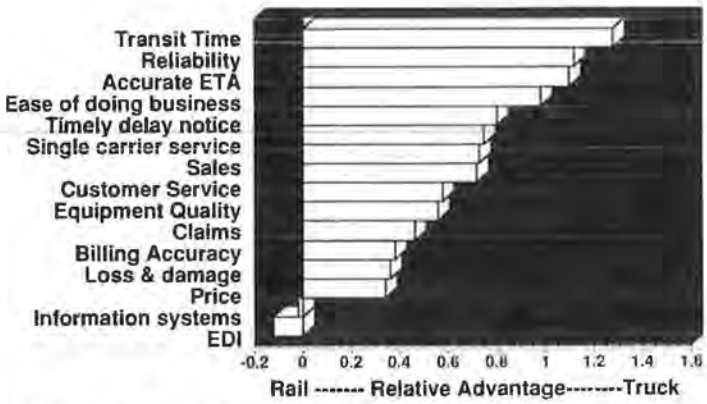

FIGURE 1 Areas in which motor carriers have an advantage over railroads (source: Temple, Barker & Sloane, Inc.).

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.

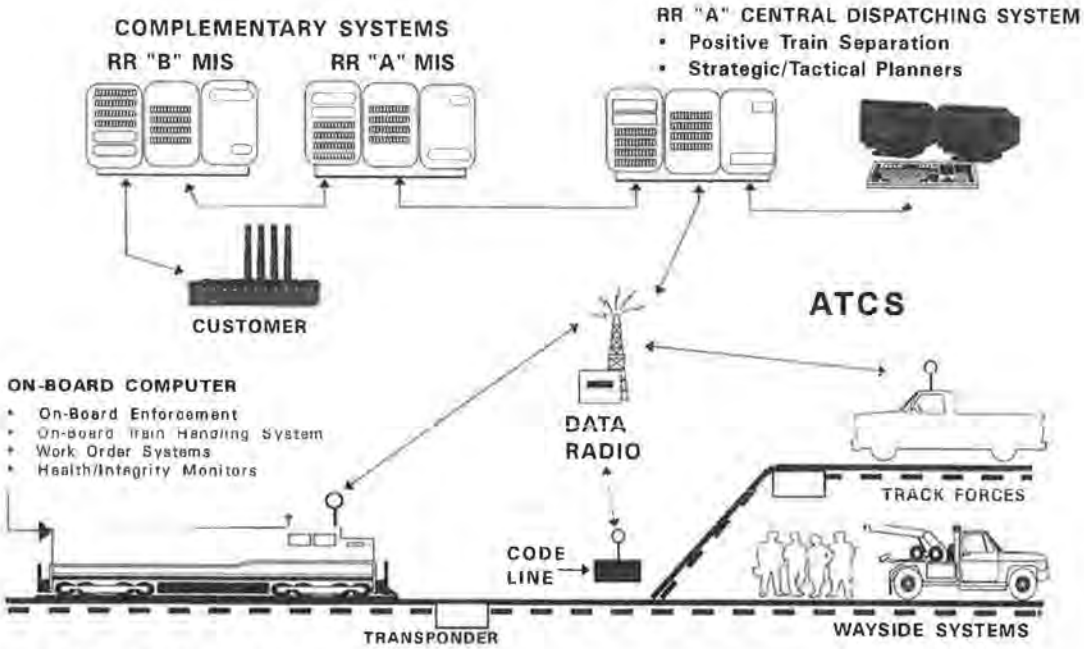

FIGURE 2 ATCS and its relationship to other systems.

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

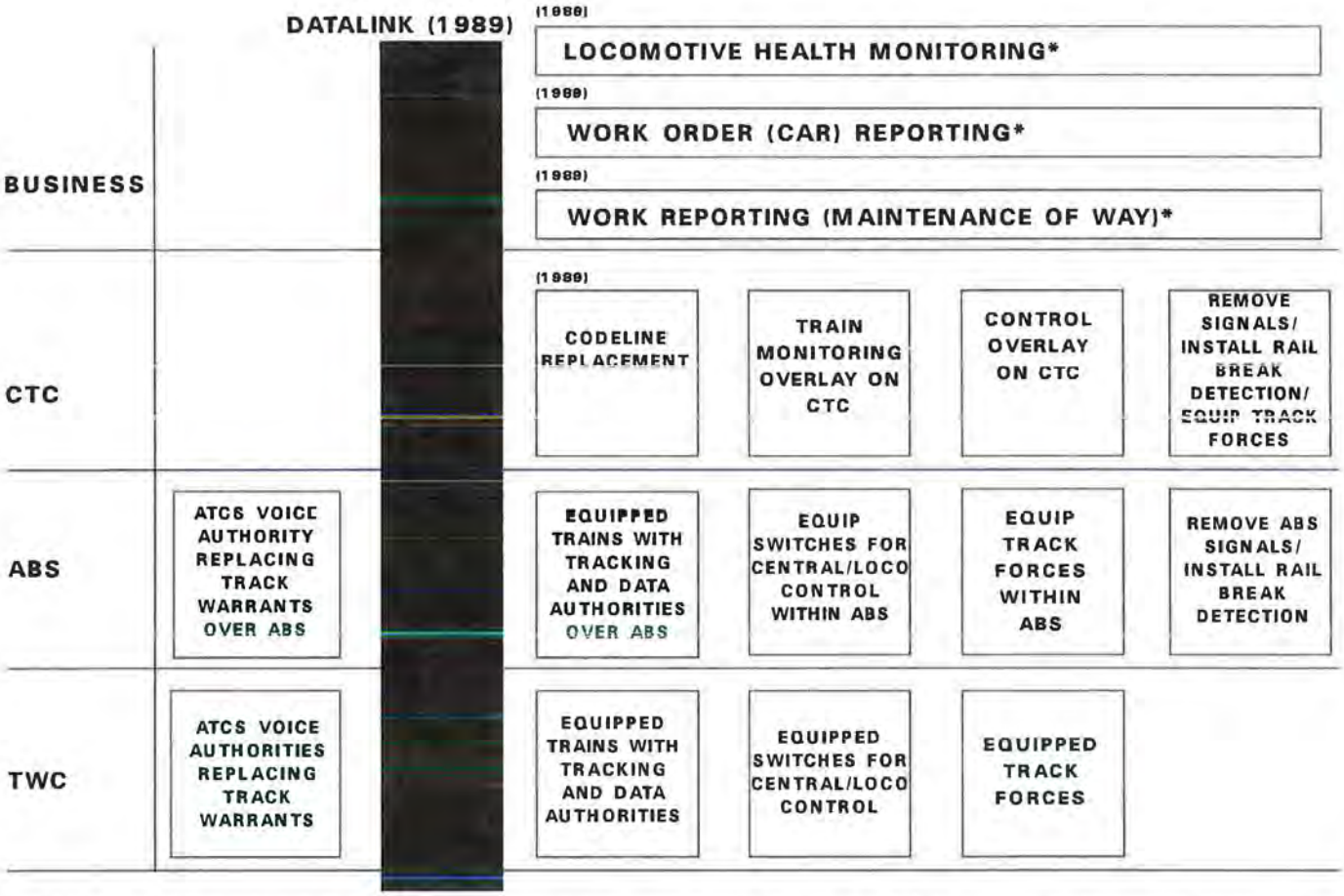

FIGURE 3 ATCS migration paths for railroads (numbers in parentheses indicate earliest date that specifications and industry software are available; asterisks indicate that industry standards apply, but industry software does not).

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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