Railroad Operation Using the Advanced Train Control System

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The basic approach taken in the development of the Advanced Train Control System (ATCS) has been that railroad operations can be made safer and more efficient by applying modern command, control, and communications technology. By using precise speed and location information, the system is able to provide more timely and precise traffic information than traditional train control systems. This allows ATCS to benefit from "moving block" operation, where the separation necessary for safe operation is dynamically determined from traffic levels and capabilities of trains (e.g., braking distances and location updates). Smaller train separation is made possible with a resultant increase in line capacity. Major design elements employed by ATCS are the data communications system and information-processing nodes that reside at the central dispatch office, on board locomotives, on board work vehicles, and in field devices. The use of these elements will have a significant impact on the manner in which dispatchers, enginemen, and foremen conduct their daily operations. These elements also provide for numerous applications besides train control.

Insight is provided into railroad operation with the Advanced Train Control System (ATCS). The basic architecture and operation of ATCS as currently specified are described. Alternate applications of ATCS will also be explored. Those who wish to investigate the operations and operating logic of ATCS more thoroughly are referred to *ATCS Concept of Operations* issued by ARINC Research Corporation in 1991.

The ATCS concepts had their origin in Canada. In the late 1970s, several Canadian railroads, including the Canadian National, British Columbia, and Canadian Pacific, studied the potential for using technologically advanced computer and communications systems to provide a new system of train control. In the fall of 1983, the Canadian railroads were joined by several United States railroads, among them the Burlington Northern, Norfolk Southern, and Seaboard System (now a part of CSX Rail Transportation), soon followed by the Union Pacific and Southern Pacific. By 1984, through an agreement with the Association of American Railroads and the Railway Association of Canada, a central project office was established.

In 1985, ARINC Research Corporation was retained to design the system architecture with oversight provided by railroad officials. Railroad operating officers, equipment suppliers, and ARINC then participated in component specification drafting committees to discuss requirements and architectural elements. By 1988, the ATCS specifications were written and distributed to interested parties. These specifications are dynamic documents that will evolve with technology and railroad implementation of ATCS. The ATCS project is currently managed by the Association of American Railroads with oversight provided by a railroad industry steering committee and an executive committee.

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The overall architecture of ATCS, basic railroad operation with ATCS, and potential spin-offs from the ATCS architecture are discussed. The paper concludes with some challenges for the application of advanced technology to rail operations.

SYSTEM DESCRIPTION

ATCS has five major elements. Four of these elements are the various information-processing nodes that reside at the central dispatch office (the central dispatch computer), on board locomotives (the on-board computer), on board work vehicles (the track forces terminal), and in the field (the wayside interface unit). These nodes are designed to replace most of the voice communications that are required in today's operations and to determine vehicle location and speed and the status of wayside devices. The nodes collect, process, and distribute data with minimal input from dispatchers, enginemen, and foremen.

Dispatchers are constantly updated by computers on what is happening on the railroad. Enginemen and foremen are constantly updated by their computers on what their vehicles are doing and are prompted to take required actions. The fifth element, and system keystone, is the modern data communications network that ties the various information-processing nodes together (Figure 1).

Data Communications System

The ATCS data communications system is responsible for the interchange of data between the dispatch system, locomotives, gangs, and field devices. The communications system consists of three major pieces: a communications handler, which behaves like a telephone exchange in that it routes messages to the appropriate point; a set of radio base stations; and mobile data radios (Figure 2).

The data communications system (in conjunction with the information-processing nodes) significantly reduces the need for voice communications. This eliminates the time and effort required to raise someone on the radio, read the information, and write the information down—all of which can be very time consuming. Instead, once orders and requests are entered into computers, the users can move on to other activities. The majority of information flows to and from the cen-

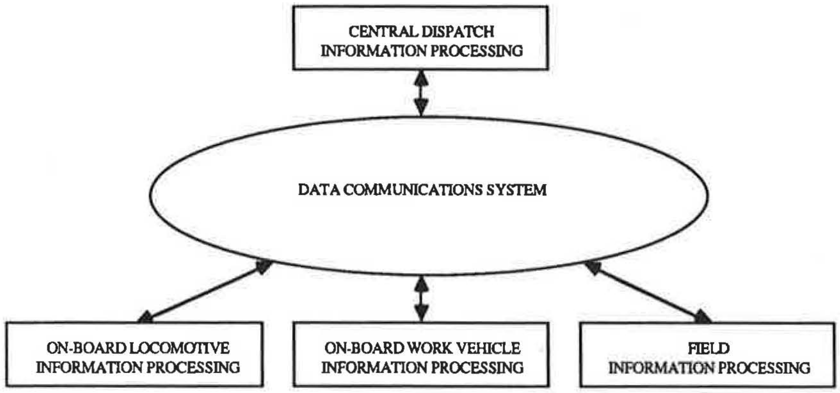

FIGURE 1 A modern data communications system ties the various information-processing nodes together.

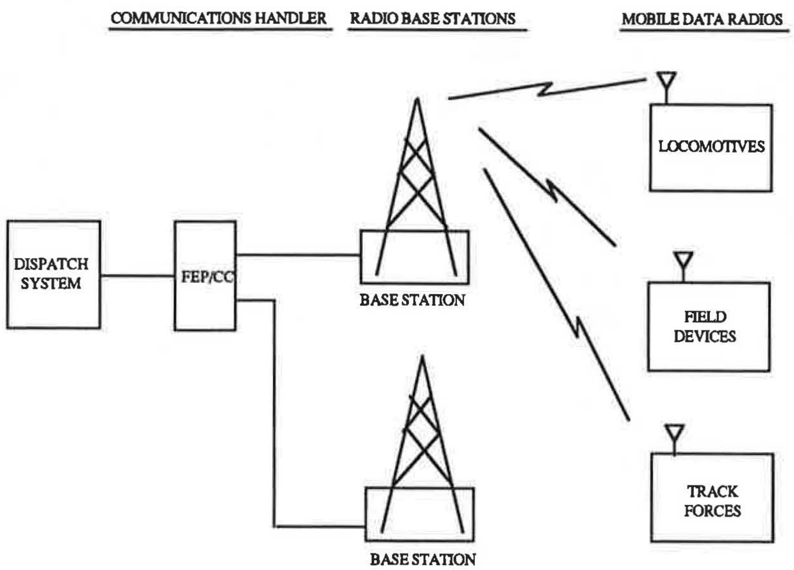

FIGURE 2 ATCS data communications system.

tral dispatch system, although the data communications system is not limited to such transfers.

Dispatch System

The function of the dispatch system is to manage the movement of trains throughout the rail network with the objective of guaranteeing safe operations without incurring train delays. The central dispatch system determines whether a particular movement is safe by checking for human and machine errors.

Key elements of the ATCS dispatch system are the dispatching consoles, the management system, the safety system, and the corporate management information system (MIS) interface. Dispatching consoles provide the interface between the dispatchers and the rest of the ATCS dispatch system. Consoles are not part of the ATCS design, although certain information that is exchanged between the consoles and the remainder of the dispatch system is specified in the design.

The management system handles all the operations planning aspects of dispatching that do not directly affect safety. This element of the dispatch system does not need to be implemented identically on each railroad to ensure interoperability.

The safety system handles all safety-related aspects of dispatching and is functionally standardized. Although the exact design of the hardware for the central safety system is not specified, the system must be capable of checking for errors and must deal with detected errors in a safe manner. The reaction of the system to such errors ranges from refusal to grant an authority (in the case of a dispatcher requesting an unsafe authority) to shutting down the dispatch computer and reverting to manual operation in the case of a hardware failure. In this fashion, the system has been designed to handle faults gracefully.

The final element in the ATCS dispatch system is an interface to various MISs that might be employed by the railroads to coordinate schedule tracking, work order reporting, locomotive utilization, maintenance planning, crew scheduling, or other applications. The form of the data interchange between the dispatch system and MISs is not part of the ATCS design, because the form and existence of these data systems is railroad-specific.

Locomotive Systems

The function of the locomotive system is to provide automatic location tracking and reporting, predictive enforcement, and automated transmission of movement authorities, and switch monitor and control information via the data communications system. A mobile communications package, an on-board computer, and a display are the only equipment requirements for automated transmission of movement authorities and switch monitor and control information. The mobile communications package, which is used to transmit and receive information, is a mobile data radio.

Automatic location tracking and reporting is accomplished with the use of locomotive-mounted interrogators and track bed transponders. Interrogators activate the passive transponders by emitting a signal that is coupled to the transponders. Each transponder contains unique, coded identification information that is transmitted back to the locomotive interrogator while the interrogator and transponder are still near each other. The identification information is sent to the on-board computer where the coded identification information is matched to an exact location. The on-board computer then communicates this location information to other ATCS users such as the dispatch system. Odometer signals are used by the on-board computer to interpolate between transponders. Odometer error is zeroed each time a transponder is encountered.

Predictive enforcement ensures train compliance with speed and authority limits. Information provided by brake, throttle, and axle sensors is fed to the on-board computer to calculate braking distance and eventual speed.

Work Vehicle Systems

The primary function of the work vehicle system is to provide the capability for a track maintenance foreman to communicate with the central dispatch system and other vehicles via the data communications system. The system is designed to support various data input and output functions, including location tracking and reporting; switch monitoring and control; requesting, securing, and releasing authority for track occupancy; requesting and receiving slow orders for designated mileage limits; transmitting slow order requirements to the central dispatch system; transmitting track work reporting to the central dispatch system; releasing slow orders; and requesting and receiving advisories. A mobile communications package, a track forces terminal (a scaled-down onboard computer) and a display are required to provide these functions.

Field System

The primary function of the ATCS field system is to provide remote monitor and control of wayside devices. Communication between the field system and the dispatch system is conducted via the data communications system as well as land lines (e.g., pole line, telephone company line, fiber-optic line). In those cases in which devices are not able to communicate directly with the dispatch system, information is relayed to the dispatch system by locomotives. Locomotives and work vehicles also communicate with the field system for their own purposes.

An ATCS field system is made up of a wayside interface unit and a mobile communications package. The wayside unit provides the interface between existing field devices and the mobile communications package. Many field devices can be connected to the ATCS communications network via a single wayside unit and mobile communication package.

Within ATCS, field devices are classified as either controllable or noncontrollable. Controllable devices are all field devices that can change a route, either by providing alternate paths or by physically interrupting the path. These devices include power-operated switches, hand-operated switches, movable bridges, and railway crossings at grade. If the devices are appropriately equipped, they can be controlled by ATCS (i.e., from locomotives, work vehicles, or central dispatch). If the devices are not equipped for remote control they can at least be equipped for remote monitoring, which provides for efficient determination of the route through the device.

Noncontrollable devices are all field devices that do not provide alternate paths or physically interrupt a path. ATCS is designed to monitor these devices remotely for status indications. Noncontrollable devices include occupancy detectors, intrusion detectors, train defect detectors, track integrity indicators, and route integrity indicators.

Specifications

The field system, dispatch system, locomotive system, and work vehicle system all use the communications system to exchange information in a timely manner. Specifications that emphasize functionality rather than dictate design have been developed for these systems. The ATCS specifications represent the minimum necessary to provide for component interoperability. They define a system architecture that is open in the sense that interfaces (but not the contents of any computer or radio or any other box) are explicitly specified, which should reduce user costs by providing for expanded sources of supply. There are, however, aspects of system operation that do not impinge on component interoperability and must therefore be specified by the procuring railroad. Items that must be specified by the procuring railroad include the specifics of man-machine interfaces (e.g., use of a mouse versus command-line interfaces at dispatch consoles); procedures for dispatcher position changes; the form and format of data bases; the specifics of interfaces to corporate data systems (e.g., form and format of data queries and responses); and any special add-on devices or computer programs that adapt "standard" ATCS to individual railroad operating practices.

SYSTEM OPERATION

Railroad operation under ATCS can be considered in five categories: start-up, general operations, emergency handling, shutdown, and impact on people using the system. Start-up refers to activities related to putting trains and gangs together and preparing them for departure. General operations concerns activities related to the normal operation of trains and gangs, such as setting routes, issuing authorities, and traveling toward destinations. Emergency handling refers to activities taken to continue safe railroad operation in the presence of unusual circumstances such as emergency stops and route defects. Shutdown refers to activities related to terminating trains and gangs. ATCS will have a significant impact on the manner in which people run the railroad. This impact is discussed at the end of this section.

Start-Up

Activities related to putting trains and gangs together and preparing them for departure include initialization, notification of conditions along intended routes, and route data download. Initialization requires the dispatcher to identify a controlling locomotive or a work vehicle that is valid and available. Just how this is done is railroad-specific, although one can imagine some sort of motive power MIS that the dispatcher might access. The dispatcher must also inform the system of car consist, power consist, crew, intended route, and destination; when this has been done, the initialization process is complete.

ATCS then checks conditions along the intended route. Conditions might include track condition notices, track work permits, and advisories. Track condition notices convey temporary conditions such as temporary slow orders and stop and inspect orders. A track work permit is an authority for a gang foreman to conduct work on or along track that may render the track temporarily impassable. Advisories include any other conditions that warrant special attention such as severe weather.

The next step in the start-up process is the route data download (via the data communications system) to the vehicle. The data download, which does not require dispatcher involvement, consists of initialization data, condition data, and physical plant data for the intended route. Physical plant data include speed limits, transponder locations, communication coverage limits, highway crossing locations, switch locations, and information on many other factors that are required by on-board computers for general operation of trains and gangs.

General Operations

General operations concerns activities related to the normal operation of trains and gangs. These activities include requesting authority, setting switches along the intended route, issuing authority, and tracking the progress of trains and gangs toward their destinations.

After start-up and notification (via the data communications system) that the train crew or gang is ready to leave, the dispatcher decides the type of authority a train or gang should have and informs the central dispatch computer. The dispatch computer then decides whether the authority is appropriate and permissible; the requested authority is permissible if it does not conflict with other authorities already held by trains and gangs. The dispatch computer then "reserves" and sets the route the dispatcher has requested for the authority. Once a route is reserved any subsequent requests for conflicting routes will not be granted.

ATCS sets the route without dispatcher interaction by commanding all necessary switches into the position needed for the requested route. ATCS also verifies that the field logic agrees that the requested position is safe and awaits confirmation from the field devices that they are in the correct position before issuing the requested authority. A train or gang that has been issued an authority is ready to proceed toward its destination.

If the requested route conflicts with another authority, the system will request a decision from the dispatcher as to the disposition of the request. The dispatcher also has the ability to restrict (that is, reduce) the limits of authority after an authority has been issued. Authorities are cleared (released) by the system as a result of train location, control-point occupancy indications, report at indications, or dispatcher request.

Because train location is automatically reported to the dispatch system (at a rate determined by the central dispatch system rather than at some preengineered block-length interval), track can be released for use by other trains more quickly than with today's fixed block systems, thereby increasing system capacity. The progress of equipped trains and gangs is tracked by the system based on messages sent automatically over the data link from locomotives and gangs; unequipped trains and gangs require voice communication between the engineman or foreman and the dispatcher. Although the dispatch computer tracks the location of every train and gang, the reverse is not true. Each train or gang computer is only aware of its location relative to its issued authority. An enforcement system is used to keep trains within authority and speed limits.

Train-Specific

ATCS automatically enforces train speed and movement authority limits through automatic brake applications. Enforcement is designed to stop a train within its limits of authority if it is expected to exceed its authority limits. The enforcement system is also designed to allow trains to operate within a speed-performance envelope defined by the on-board computer but will stop a train if a speed limit would otherwise be exceeded. The system is designed to allow the engineman maximum opportunity to retain full control of the train including sufficient capability to execute an emergency brake application at any time.

Gang-Specific

A track work permit may be issued only to work crews. A permit is a bidirectional authority that may have other authorities within its boundaries; however, all movements within boundaries set by the permit require the foreman's explicit permission in addition to a movement authority.

A foreman requests a track work permit from the computer terminal in his vehicle. If there are no conflicts with other trains and track forces, the permit will be issued by the system.

The foreman may also request that a track condition notice be issued to take track out of service or to inform other trains of temporary changes in track conditions. The foreman is also capable of removing a track condition notice or releasing a track work permit that he has been granted.

It is important to note that these permits and notices can be issued and released by the system without any input from the dispatcher; it is, however, a simple matter for the dispatcher to issue a permit or notice if so required. In either case, the system will preclude the issuance of authority for track that is out of service and will notify any trains or track forces that will be affected.

ATCS will prompt an engineman on how to conduct his operation as a track work permit or track condition notice is approached and traversed. The need to record and track such information is handled by the system as are any communications between the train and track force.

Emergency Handling

Emergency handling refers to activities taken to continue safe railroad operation in the presence of unusual circumstances, such as emergency stops, rogues, route defects, and other potentially dangerous situations. ATCS is designed to advise all affected system users of emergency brake applications or other emergencies upon notification from the train or the dispatcher. The system is also designed to detect and handle unexplained track occupancy indications (rogues) and trains exceeding or predicted to exceed their authority limits. ATCS will notify the dispatcher of any reported route defects and advise the dispatcher to notify any affected trains that it could not contact via the data communications system. Reported route defects might include high water, broken rail, or a switch becoming unlocked. Finally, the system will notify gangs to clear the track promptly when potentially dangerous situations arise.

Shutdown

Shutdown refers to activities related to terminating trains and gangs. A train is cleared from the on-board computer and the central dispatch computer upon reaching its final destination. The dispatcher has the capability to cancel a train that is being created. Similar capabilities exist for gangs.

Impact on People

The technology used to implement ATCS will have a significant impact on dispatchers, enginemen, and foremen. ATCS should relieve the dispatchers from most of the mechanics of dealing with trains and work gangs. This will allow more time for dealing with the broad, tactical requirements of running the railroad. The potential for improved traffic throughput is clear.

Enginemen should find that the more timely flow of information will allow for more efficient operation of their trains. Under current signal system operations, the engineman only receives information at fixed points and may be forced by rule to operate at a lower speed than necessary until the next signal. Under ATCS, information is provided to the train as soon as it is available.

The enginemen should also benefit by having all information germane to current operating conditions integrated on a single display. It will no longer be necessary to keep a mental picture of allowed speed, authority limits, applicable bulletins, slow orders, and work orders. Finally, the ability to determine and properly control switch conditions from the cab should make switching operations much more efficient.

Work gangs should find operation under ATCS to be more efficient, because most of the day-to-day information exchange will take place without the need to gain a dispatcher's attention. In addition, because track work permit and track condition notice speed restrictions are enforced on the locomotives, there is greater assurance that special instructions will be adhered to.

Many applications besides train control are made possible by the data communications system and the various information-processing nodes that are used by ATCS. Some of these applications are discussed in the following section.

SPIN-OFFS

The five ATCS elements provide for numerous applications besides train control. Many railroads may find it beneficial to implement some of these applications, which include work order reporting, locomotive health reporting, code line replacement, and track forces management, prior to implementing train control.

It is reasonable to expect that the work order reporting process could be significantly streamlined by using the data communications system to provide a timely exchange of information on pickups and setouts between a locomotive and a central dispatch system. Work orders could be sent to the on-board computer as part of the data download and completed work could be reported immediately with the on-board computer. Work order changes could also be sent to the locomotive while it was en route or doing work. The potential for improved efficiency is obvious.

Locomotive health monitoring can be used to evaluate locomotive performance and to diagnose failures. On-board sensors would be used to monitor important mechanical and electrical parameters continuously, feeding information to the central dispatch system or another central facility via the data communications system. Remote monitoring at the central system might be used to optimize fueling procedures, detect incipient failures, or to diagnose transient or intermittent failures. Such a system could eventually lead to scheduling maintenance when necessary rather than on a fixed schedule.

The ATCS design elements could also be used for code line replacement. Code messages would be generated as they are today and then run through a converter to format them into an ATCS data system message. The code messages could then be exchanged between locations and vehicles by using the data communications system. Another potential application of the ATCS design elements is track forces management. Voice communication between dispatcher and foreman might be significantly reduced by using the data communications system to transmit work requests and to report work completed. Paperwork might also be minimized, because the computers could be used to record and retrieve pertinent information.

These are but a few of the many potential applications that could be implemented with the ATCS design elements. Improved performance and reduced costs that might result from these applications could be used to pave the way for advanced train control.

CONCLUSION

ATCS has been designed to improve railroad efficiency and safety. Form, fit, and function specifications have been developed for the system and the system design elements. These specifications provide for standard data interchange among components built by various vendors for a single railroad and among various railroads.

Specification of hardware and software requirements has made it possible for suppliers to initiate preliminary and then detailed design efforts. Hardware and software integration and testing is an ongoing process being conducted at a number of test beds such as the Canadian National Toronto ATCS Test Bed and the Canadian National B.C. North Line installation.

Successful completion of system integration and testing should lead to full-scale production and deployment. Deployment need not be an "all at once" occurrence as a result of the modular system design.

Although ATCS has been designed for train control, many other applications of the system design elements could improve railroad efficiency, service reliability, and profitability. These include work order reporting, locomotive health monitoring, code line replacement, and track forces management. The challenge facing railroads and their integrators will be to integrate the vast amount of information flowing to decision nodes properly so that the people charged with making the tactical operating decisions are not overwhelmed, and the full potential of ATCS is realized.