NETWORK-CENTRIC RAILWAY OPERATIONS
UTILIZING
INTELLIGENT RAILWAY SYSTEMS

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**Abstract**

Network-centric railway operations and intelligent railway systems represent a “unified theory of railway operations” in which positioning systems, sensors, computers, advanced mathematical methods, and digital communications are used to collect, process, and disseminate information to improve the safety, security, operational effectiveness, and productivity of railways. Intelligent Transportation Systems (ITS) for highways and mass transit are based on the same technologies, as are the National Airspace System and maritime vessel tracking systems. Major parcel delivery companies, pipeline operators, law enforcement, and emergency response services also use these technologies. Military services utilize these technologies for network-centric warfare; railways will use them for network-centric railway operations. Intelligent railway systems can either be implemented as independent systems, in which case their benefits will be limited, or they can be implemented as integrated, networked systems, in which case the benefits will be compounded. The railway industry is urged to consider adopting an integrated approach when implementing these systems to achieve network-centric railway operations.

**A. Introduction**

Intelligent railway systems were first described in the US Secretary of Transportation’s report, *The Changing Face of Transportation*, published in 2000, and were expanded upon in the Federal Railroad Administration’s (FRA’s) *Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations*, a report to Congress published in March 2002. The FRA, railways, and the railway supply industry have been working on the development of intelligent railway systems for command, control, communications, and information (C3I), as well as for braking systems, grade crossings, defect detection, and planning and scheduling systems. These technologies can prevent collisions and overspeed accidents, prevent hijackings and runaways, increase capacity and asset utilization, increase reliability, improve service to customers, improve energy efficiency and emissions, increase economic viability and profits, and enable railways to measure and control costs and to “manage the unexpected.”

Intelligent railway systems will enable railways to improve their responsiveness to military deployments and to respond with flexibility and agility to rapid changes in the transportation marketplace.

Following the terrorist events of September 11, 2001, and especially following the terrorist bombings of trains in Madrid, Spain, on March 11, 2004, in London, England, on July 7, 2005, and in Mumbai, India, on July 11, 2006, railway security has received increased attention. Intelligent railway systems will enable railways to prevent some types of terrorist incidents from occurring, and, should incidents occur, these technologies will enable railways to detect them, notify appropriate authorities, and recover more rapidly from the incidents. Railways will have continuous, real-time information with which they can manage their operations.

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4 Weick, Karl E. and Kathleen M. Sutcliffe, *Managing the Unexpected*, San Francisco: Jossey-Bass, 2001. The authors, two professors at the University of Michigan Business School, describe high-performance organizations that successfully “manage the unexpected” and explain why railroads today cannot be considered to be such organizations.
B. The Architecture of Network-Centric Railway Operations

Network-centric railway operations utilizes a “system of systems,” having capabilities that result from the interoperability of many systems and the integration of many processes. Significant benefits can be obtained from interoperability and integrated implementation, rather from free-standing, “stove-piped” implementation.

The following figure illustrates a preliminary architecture for network-centric railway operations, showing how the intelligent railway systems fit together and identifying the key communications links for standardization. It is a top-level interconnect diagram and is based on conventions developed by the Architecture Development Team for the ITS National Architecture. This type of diagram is known as a “sausage diagram” in which the “sausages” represent the various communications links that move information between nodes in the gray rectangles representing crews and vehicles, fixed installations along the railway rights-of-way, control and management centers, and customers. The links can be owned by railways or by commercial telecommunications carriers and they can be microwave radio, fiber optic cable, buried copper cable, cellular telephones, communications satellites, traditional pole lines, and the Internet.

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C. Network-Centric Railway Operations and the Intelligent Railway Systems

Following are descriptions of 32 technologies, programs, and systems, either developed or under development, which comprise intelligent railway systems. Network-centric systems are governed by Metcalfe’s Law, which asserts that the power of a network is proportional to the square of the number of nodes in the network. The power or payoff of network-centric railway operations will come from information-intensive interactions between large numbers of computational nodes in the network.⁷

1. Prerequisite systems for Positive Train Control (PTC)

a. **Digital data link communications networks** provide the means for moving command and control instructions and general information to and from nodes throughout a railway: locomotives, cars, maintenance-of-way vehicles, wayside interface units at switches and wayside detectors, train control centers, yards, intermodal terminals, passenger stations, maintenance facilities, and operating data systems. Customers and emergency responders will also be linked to the networks. Data link communications will replace or supplement many of today’s routine voice and fax communications with non-voice digital messages and will effectively increase the capacity of available communications circuits and frequencies. Voice communication will continue to take place, but it too will be carried over the digital network. Data link communications will utilize radio frequencies and mobile radios to communicate to, from, and between mobile assets, and will use a variety of transmission media (owned either by railways or commercial telecommunications carriers) to communicate between fixed facilities. The various backbone media along with the mobile radios form an integrated communications network. Railway communications network control centers manage the integrity of the telecommunications network as well as its maintenance. With data link communications, the information is digitally coded and messages are discretely addressed to individual or multiple recipients. In the US, the Federal Communications Commission has assigned to the railway industry 182 frequencies in the VHF band (160 MHz) and 6 pairs of frequencies in the UHF band (900 MHz). Several large railways have purchased, on the open market, frequencies in the VHF 220 MHz band for their implementations of PTC. The UHF frequencies are being used for digital communications, and some railways have converted some of their assigned VHF frequencies from analog voice to digital communications. The conversion is expected to accelerate during the coming decade. The Union Internationale des Chemins de Fer has developed the GSM-R (Global System for Mobile – Railway) mobile radio standards for railway digital data link communications in Europe.

b. **Differential GPS (DGPS)** is an augmentation of the Global Positioning System (GPS) that provides 1- to 2-meter positioning accuracy to receivers capable of receiving the differential correction signal. In the United States, the US Coast Guard established a Maritime (now Nationwide) DGPS network which operates according to international standards that they developed and are now used in over 45 nations. DGPS receivers placed on locomotives and maintenance-of-way vehicles will calculate location, speed, and time, and that information will be shown on in-cab displays and transmitted back to the train control center over the railway’s digital data link communications network. DGPS provides a GPS integrity monitoring capability; it gives an alarm to users within 5 seconds of detecting a fault with the signal from any GPS satellite. DGPS signals are available to any user who acquires the proper receiver, and there is no user fee. In most countries, DGPS is operated by their respective coast guard organizations. Tests of an additional High Accuracy DGPS (HA-DGPS) signal to provide real-time 10- to 15-centimeter positioning accuracy have been conducted; further deployment of the signal is currently under consideration.

8 2008 Federal Radionavigation Plan, published jointly by the US Department of Defense, the Department of Homeland Security, and the Department of Transportation (DOT), states, “The predictable accuracy of the DGPS Service within all established coverage areas is better than 10 meters (2drms). The DGPS Service accuracy at each broadcast site is carefully controlled and is typically better that 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath interference and propagation distortions. Typical user equipment is able to achieve 1-2 meter horizontal accuracies in real-time, throughout the coverage area. High-end user equipment may achieve accuracies better than 1 meter, throughout the coverage area, by compensating for the various degradating factors.” [http://www.navcen.uscg.gov/pubs/frp2008/2008_Federal_Radionavigation_Plan.pdf](http://www.navcen.uscg.gov/pubs/frp2008/2008_Federal_Radionavigation_Plan.pdf)

9 Radio Technical Commission for Maritime Services RTCM SC-104 and International Telecommunications Union ITU-R M.823
c. **Automatic Equipment Identification (AEI)** tags, also known as radio frequency identification (RFID) tags, have been installed on both sides of all freight cars and locomotives in the US and Canada since 1995. The requirement was established by a railway industry consensus standard, not by FRA regulation. AEI readers, installed along the track at yards, terminals, and junctions, interrogate the tags over UHF radio frequency (900 MHz), and the tags respond to the readers with the unique alphanumeric code identifying each car and locomotive. The readers assemble the information from all locomotives and cars on a train and then transmit the train list to the railway’s operating data system over the digital data link communications network or over dedicated telephone lines. The operating data system combines the train list with data from other files – waybill databases (showing car contents, shipper, and consignee) and the Umler file – and sends a train consist back over the data link to the locomotive cab where it is stored in the PTC on-board computer (for use in calculating braking distances) and displayed on the PTC display. Because PTC systems know at all times the precise location of every train, AEI data, when combined with information from PTC, permits railways to know at all times the precise location of every car and shipment. Some railways have installed substantial numbers of readers and have integrated them with their operating data systems; others have not. Installation and integration of the full network of readers is expected in the next few years. AEI readers will also be integrated with wayside equipment sensors to provide positive identification of vehicles with defects.

2. **Positive Train Control and directly related systems**

   a. **Positive Train Control (PTC) systems** are integrated C³I systems for controlling train movements with safety, security, precision, and efficiency. PTC systems will improve railway safety by significantly reducing the probability of collisions between trains, casualties to roadway workers and damage to their equipment, and overspeed accidents. The US National Transportation Safety Board has had PTC on

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10 Association of American Railroads (AAR) Standard S-918-94, effective March 1, 1992, was based on a draft standard developed by the International Standards Organization (ISO) for AEI tags on containers. There are, at present, voluntary AEI tagging standards for containers (by the ISO) and truck trailers and chassis (by the American Trucking Associations), and they are compatible with the AAR standard for railway vehicles. If these voluntary standards were to become mandatory, railroads would be able to automatically track the location of containers and trailers when they are being transported on railcars and when they are in intermodal terminals.

11 Umler is the Uniform Machine Language Equipment Register, maintained by Railinc, a subsidiary of the AAR, and provided to each railroad. It is a data file containing identification, ownership, and physical information for every freight car in service on the US and Canadian railroads.

12 A “train consist” (pronounced CON-sist) is a list, in sequence, of the specific locomotives and cars that comprise a train, and includes train and car length and weight, car type, loaded or empty status, car contents, routing, special handling requirements, and destination.
its “most wanted” list of transportation safety improvements since 1990. PTC systems are comprised of digital data link communications networks, continuous and accurate positioning systems such as DGPS, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches (both powered and manual) and wayside detectors, and train control center computers and displays. They will incorporate modules to permit them to record and retain the precise location, time, and circumstances of unplanned events such as derailments and grade crossing accidents. PTC systems also interface with tactical and strategic traffic planners, work order reporting systems, and locomotive health reporting systems. PTC systems issue movement authorities to train and maintenance-of-way crews, track the location of the trains and maintenance-of-way vehicles, have the ability to automatically enforce movement authorities, and continually update operating data systems with information on the location of trains, locomotives, cars, and crews. Current signal systems provide only a limited number of instructions (two to five different speed levels plus stop, conveyed by either one, two, or three colored lights) to train crews at widely spaced (2- to 20-mile) intervals; PTC can provide instructions to trains or maintenance-of-way vehicles to operate at any speed, and can provide them at any location along the track. The remote intervention capability of PTC will permit the train control center to stop a train should the locomotive crew be incapacitated. With PTC, train spacing is no longer governed by fixed track blocks, but rather is determined by virtual, or moving, blocks based on train length, weight, and braking capability and track geometry. In addition to providing a greater level of safety and security, PTC systems also enable a railway to run scheduled operations and provide improved running time, greater running time reliability, higher asset utilization, and greater track capacity. They will also assist railways in measuring and managing costs and in improving energy efficiency. Pilot versions of PTC (known then as the Advanced Railroad Electronics System (ARES) and the Advanced Train Control System (ATCS)) were successfully tested a decade-and-a-half ago, but the systems were never deployed on a wide scale. Other demonstration projects are currently in planning and testing stages in the US and in Europe.

Because of a head-on collision of a commuter train with a freight train at Chatsworth, California, on September 12, 2008, which resulted in 25 fatalities, the

13 NTSB’s “most wanted” list is found at the NTSB web site: http://www.ntsb.gov/Recs/mostwanted/rail_issues.htm
14 Zeta-Tech Associates, Quantification of the Business Benefits of Positive Train Control, Federal Railroad Administration, March 15, 2004. The authors calculated the internal rate of return for an investment in PTC for the US railroads as falling in the range of 44% to 160%, depending on costs of implementation and the capturing of benefits. They also determined that an investment in PTC on the US railroad network would result in the avoidance of a large investment railroads would otherwise have to make to increase capacity on an estimated 8,300 route miles of railroad (about 8% of the network) that are currently operating at or above design capacity. This would be worth $1.1 billion in annualized costs avoided. The report is available at: www.tsd.org/papers/FRA%20PTC%20final%20report%2003-16-04.pdf
US Congress passed the Rail Safety Improvement Act of 2008 (Public Law 110-432) that requires the implementation of PTC on all rail lines in the US that carry either passengers or toxic-by-inhalation hazardous materials by the end of 2015.

b. **PTC displays** – In-cab PTC displays will provide status information and command and control instructions to train crews in both graphic and textual form. They will display train position and speed as calculated by the positioning system, the upcoming route profile, speed limits and temporary slow orders, in-train forces, actual and recommended throttle and brake settings, speed control instructions and movement authorities as received over the data link from the train control centers, on-board locomotive health information from all locomotives on the train, and data from on-board and wayside equipment, track, and commodity sensors. The displays will incorporate a method for the train crew to acknowledge receipt of the speed control instructions and movement authorities. The displays will also show the train consist; setout, pickup, and special handling instructions for cars from work order reporting systems; weight distribution along the length of the train; data from the end-of-train device and ECP brakes; and any other information that will be sent over the data link. Train control center displays for dispatchers will show the precise location and speed of each train and maintenance-of-way vehicle, train consists, locomotive health, performance against schedule, and the plans generated by the tactical and strategic traffic planners. The challenge in developing the displays is to insure that all necessary information, and no unnecessary information, is displayed. Liquid crystal and plasma screens currently being installed on locomotives and at train control centers have the capability to display the information that will be generated by the intelligent railway systems.

c. **Track forces terminals (TFTs)** provide the means for moving PTC and other information and instructions to and from permanent way workers and maintenance-of-way vehicles. A TFT consists of a laptop computer or personal digital assistant (PDA), data radio, and positioning system receiver. The TFT sends position reports from the field to the train control center over the digital data link communications network, and it displays authorities received from the train control center to the roadway workers. With a TFT, permanent way workers will obtain authorities without talking to a dispatcher. The TFT will display the location of all trains in the vicinity, and the crew will determine when the track will be unoccupied and use the TFT to request track occupancy for that time. The train control center computer checks the proposed authority for safety, and if it is safe, the dispatcher grants the authority which then appears automatically on the dispatcher’s display and on the TFT. At the completion of track work, the TFT can be used to place a slow order (temporary speed restriction) on the track by transmitting the information to the train control center computer. The TFT will also be used to transmit administrative data (e.g., gang time, machine usage and status, material usage and requirements, and production reporting information) to track maintenance facilities and the railway operating data system. TFTs should
significantly improve the productivity of permanent way crews without compromising safety. They will allow them to plan their access to the track and obtain longer “windows” to accomplish their work.

d. **Wayside track sensors** are installed to provide route integrity information to the PTC system. They identify a number of defects that occur on and alongside the track as well as identify conditions and obstructions along the track and to transmit the information so that the train will be stopped or slowed if necessary and permanent way crews will perform repairs as required. Among the conditions and defects that will be detected by wayside sensors are switch position, broken rail, misaligned track, high water, rock and snow slides, excessive rail stress, misaligned bridges and trestles, blocked culverts, earthquakes, and general security and integrity information regarding track and structures. Information from such sensors is now usually transmitted to train crews by wayside signal indication. Once data link communications networks are installed, the information will be transmitted from wayside interface units at the sensors to train crews, train control centers, and permanent way maintenance facilities.

e. **Locomotive health monitoring systems** consist of sensors mounted on engines, traction motors, electrical systems, air systems, exhaust systems, and fuel tanks on locomotives. Most new locomotives are equipped with most of these sensors. Today, the data from all units in the train consist are displayed to locomotive crews and collected in on-board computers for retrieval when locomotives arrive at maintenance facilities. In the future, the data will be transmitted over the digital data link communications network to train control centers, maintenance facilities, and motive power distribution centers to permit real-time monitoring of locomotive performance and efficiency, improved diagnosis of problems, and more effective assignment of locomotives to trains. Each of those centers and facilities could make an inquiry over the data link to a locomotive to receive a health status report. Data generated by the locomotive health monitoring systems will also be collected at maintenance facilities and analyzed to permit maintenance to be done on an as-needed rather than on an arbitrary time schedule. Traction motor performance in both traction and dynamic braking modes will be monitored. Locomotive health monitoring systems will improve locomotive utilization, save time in maintenance facilities, and keep trains on schedule. They will also improve locomotive energy efficiency and emissions. Event recorders for after-the-fact investigations will record throttle and brake information collected by the monitoring systems and combine it with the precise location and time information generated by the DGPS receivers.

f. **Energy management systems (EMSs)** are separate computer programs installed on locomotives to optimize fuel consumption and emissions. An EMS will receive information on track profile and conditions, speed limits, the train consist including train length and weight, locomotive engine fuel performance characteristics, information from the locomotive health monitoring systems on
engine and traction motor performance, and target times at specific locations as determined by the tactical traffic planner. It will then determine a recommended train speed that meets service requirements while minimizing fuel consumption and/or emissions and providing good train-handling characteristics, and it will display the recommended throttle and brake settings on the in-cab PTC display.

g. **Work order reporting systems** send instructions over the digital data link communications network from the train control center to train crews regarding the setting out and picking up of loaded and empty cars enroute. When crews acknowledge accomplishment of work orders, the system automatically updates the on-board train consist information and transmits information on car location and train consists back over the digital data link communications network to the railway’s operating data system and to customers. Work order reporting information will be displayed in locomotives on the same screens that will display PTC instructions and information. One major railway has deployed a work order reporting system using a dedicated digital data link communications network.

h. **Tactical traffic planners (TTPs)** at train control centers produce plans showing when trains should arrive at each point on a dispatcher’s territory, where trains should meet and pass, and which trains should take sidings. As the plans are executed, a TTP takes the very detailed train movement information provided by the PTC system and compares it with desired train performance. If there are significant deviations from plan, the TTP will re-plan, adjusting meet and pass locations to recover from undesired lateness, taking into account weather conditions, traffic patterns, and track and train speed limits. “Pacing” instructions can be sent to a train to call for a speed reduction to avoid stopping and restarting. TTPs make use of sophisticated non-linear optimization techniques to devise an optimal dispatching plan that reduces the time that trains wait at passing sidings on single-track lines and at crossovers on multiple-track lines. Once a TTP prepares a plan, the dispatcher need only accept it. Then the computer-assisted dispatching system of PTC produces all authorities needed to execute the plan and sends them over the digital data link communications network to trains and maintenance-of-way vehicles. Some prototype TTPs have been developed and tested.

i. **Strategic traffic planners (STPs)** – TTPs cannot function without knowing the schedule for each train. STPs measure train movements against a set of externally defined schedules that include information on scheduled block swaps and connections, both internal and with other railways and other transportation modes. Integrating a flow of information about actual train performance from the TTP, the performance of connections, and detailed consist information for all trains from operating data systems, STPs make cost-minimizing decisions on whether, and how, train priorities and schedules might be adjusted on a real-time basis. STPs are the highest-level real-time on-line control system in the PTC hierarchy. STPs will be able to display the performance of trains against schedule, the real-
time location of every train by type (e.g., coal, intermodal, grain, intercity passenger), and the location of trains at future times based on current performance. The US Federal Aviation Administration has implemented an STP called the “Enhanced Traffic Management System” to provide central flow control for the National Airspace System; the same philosophy will apply to STPs for railways.

j. **Crew registration and time-keeping systems** will use identification techniques such as the US Department of Homeland Security’s proposed Transportation Worker Identification Credential, other electronic card keys, passwords, or biometrics such as fingerprints and retinal scans to insure that only authorized crew members are permitted to control locomotives and maintenance-of-way vehicles. The train control center will issue a movement authority only when it has confirmation that the designated crew is on board and logged in. The times that train crew members log on duty on the locomotive, depart their initial terminal, arrive at their final terminal, and log off duty will be automatically sent over the digital data link communications network to the train control center and to the operating data system. This will eliminate manual record-keeping and data entry chores and insure that accurate times are entered in the operating data system for payroll purposes.

k. **Intelligent weather systems** consist of networks of local weather sensors and instrumentation—both wayside and on-board locomotives—combined with national, regional, and local forecast data to alert train control centers, train crews, and maintenance crews of actual or potential hazardous weather conditions. The sensors will collect information on temperature, atmospheric pressure, rate of change of temperature and pressure, precipitation, and wind speed and direction and transmit it over the digital data link communications network to train control centers. This information will provide both advance and real-time warning of weather-caused hazards such as flooding; track washouts; snow, mud, or rock slides; high winds; fog; high track-buckling risk; or other conditions which require adjustment to train operations or action by maintenance personnel. Weather data collected on the railway will also be automatically forwarded to government and commercial weather forecasting centers to augment their other data sources. Intelligent weather systems are included in the ITS National Architecture.

l. **Emergency notification systems** installed at train control centers provide for the automated notification of all involved organizations following railway accidents, incidents, or threats. They provide for better coordination and control of the involved organizations: railway response crews; police, fire, and emergency medical services, as well as other appropriate local, state, and national authorities. The systems are tied to geographical interfaces. When reports of accidents, incidents, or threats arrive over the digital data link communications network with precise and accurate geographical coordinates, the emergency notification system
can identify the correct emergency responders for that locale, notify them, and provide them with accurate location information. The systems monitor the timing of the call-outs and the arrival of emergency services at the scene so that performance can be analyzed. The systems enable the faster resolution of problems and resumption of rail service.

3. Other intelligent railway systems for control centers

a. **Locomotive scheduling systems** use data regarding train schedules, physical terrain, locomotive characteristics, locomotive health information, locomotive servicing and maintenance schedules, and expected train consists to assign locomotives to trains, making use of linear programming algorithms. Improved train consist information coming from a car scheduling and reservation system will result in better locomotive allocations. Keeping trains and, therefore, locomotives on schedule is necessary to execute future locomotive assignments. Locomotive scheduling systems have been developed and are in use on most railways. Providing the locomotive scheduling systems with real-time information on locomotive health, current and future locations of trains, and expected train consists will significantly improve the utilization rate of locomotives.

b. **Car reservation and scheduling systems** – Freight car reservation systems allow customers to reserve freight car capacity and routing in advance; freight car scheduling allows railways to plan the movements of individual freight cars to match up with known customer demand. Scheduling of the movement of cars will reduce cross hauling of empty cars and reduce delays to loads and empties at intermediate yards. This reduces fleet size requirements and improves asset utilization. Car reservation and scheduling systems, which are similar to airline seat reservation and scheduling systems, can only work when railways operate on a schedule, and, in turn, car reservation and scheduling systems provide information to locomotive scheduling systems and are a prerequisite for yield management. One major railway developed and used a car scheduling system for a number of years. However, the railway’s inability to keep its trains on schedule meant that cars often had to be reassigned to different trains in the course of their journeys.

c. **Train crew scheduling systems** – When train operations are scheduled and stay on schedule, train crew assignments can also be scheduled a number of days or weeks in advance. That will result in predictable work hours for most crew members, and will enable them to schedule regular periods of sleep and recreation, reducing family and social tensions and emotional and physical stress and fatigue. Train crew scheduling systems will use information from the STP and from PTC along with information about crew members (seniorities, current locations, schedule preferences, most recent assignment worked) and US Hours of Service Act and labor contract provisions to match up trains and crews most cost-
effectively. Some European railways with scheduled operations currently use such long-term train crew scheduling systems.

d. **Yield management systems** enable railways to establish variable pricing policies that maximize profit by linking the price charged for a service to customer demand. Applicable to both freight and passenger railway operations, yield management requires reservation and scheduling capabilities, and sophisticated information systems to keep track of changing capacity, complex service variables, and multiple prices. With yield management, railways can identify opportunities for filling up existing capacity with lower-priced services for customers who are less service-sensitive. At the same time, it will show when and how much to increase prices for service-sensitive customers shipping or traveling at peak times. Amtrak and all major airlines use yield management systems to enhance their revenues.

e. **Travelers advisory systems** use real-time train location information generated by positioning system receivers on locomotives and transmitted over digital data links to provide intercity passenger train and commuter train riders with expected arrival times of their trains. The information is displayed on dynamic message boards at stations and on map displays posted on the Internet. The information is used by the passenger railways, which are often tenants on freight railways, to automatically collect data on the on-time performance of their trains. These systems have been typically implemented as freestanding systems using cellular or satellite communications, but they will be integrated with other systems, using information from the PTC system and transmitting it over the railway’s digital data communications network.

f. **Data archiving systems** enable railways to retain data generated by intelligent railway systems and make them available for analysis. Intelligent railway systems produce huge amounts of fine-grained data. When summarized and analyzed, these data are useful for many purposes beyond their immediate applications. Additionally, archived data from different railways can be shared, combined, or compared if they have compatible structures. Data archiving systems are included in the ITS National Architecture.

4. **Other train-borne intelligent railway systems**

a. **Electronically-controlled pneumatic (ECP) brakes** – Current train air braking systems in the US use air transmitted through a single brake pipe to both power the brakes and to transmit the signals to initiate brake applications and releases. As a result, air brake applications and releases are sequential along the length of a train. New ECP brakes use an electronic signal to initiate brake applications and releases, and thereby permit the simultaneous application of all brakes on a train, substantially shortening the braking distance and reducing in-train coupler forces and slack action. Shorter braking distances mean that trains can run faster, thereby
increasing track capacity and improving asset utilization. ECP technology enables the air system to supply air continuously to each car for charging brakes, so brakes can be applied or eased as needed. This is not possible with current train air brakes. ECP brakes use a wire line along the train to convey the electronic signals from car to car. The wire line also enables data to be collected from onboard equipment, track, and commodity sensors and moved to the locomotive where it will be displayed to the train crew and transmitted over the digital data link communications network to train control centers, maintenance facilities, and customers, as appropriate. ECP brakes have been tested on unit coal trains and double-stack intermodal container trains in the US, Canada, and Australia, and have been shown to improve train energy efficiency and train running time and to reduce wear on wheels and brake shoes. More widespread deployment of ECP brakes is expected in the coming decade.

b. **Car on-board component sensors** installed on rolling stock identify a number of defects and provide information so that the train can be stopped if necessary and maintenance crews can perform repairs as required. Among the defects and conditions that will be detected by the on-board sensors are overheated bearings and wheels, impacts and vibrations from flat or derailed wheels or corrugated track, excessive truck hunting, excessive longitudinal forces, and braking system status. Information from the sensors will be transmitted over the ECP brake system’s communications channel to the locomotive cab, where it will be observed by the train crew, and transmitted over the digital data link communications network to train control centers and maintenance facilities. The sensors could also be queried from trackside interrogators. If problems are detected, the train will be stopped and train or maintenance crews will perform repairs.

c. **Car on-board commodity sensors** are being installed on freight cars to monitor the status of the commodities being carried. Among the parameters that can be measured by the on-board sensors are temperatures, pressures, vibrations, load position, radiation, gases, and biohazards. The security of shipments will also be monitored. The presence of stowaways in closed cars, containers, and trailers can also be determined. Information from the sensors will be transmitted over the ECP brake system’s communications channel to the locomotive where it will be observed by the train crew and transmitted over the digital data link communications network to train control centers, maintenance facilities, and customers. The sensors could also be queried from trackside interrogators. If problems are detected, the train will be stopped and train or maintenance crews will perform repairs. Some customers and freight car owners are now using proprietary sensor and satellite communications packages to obtain the data, including location information, directly from the cars, bypassing railway information channels.

d. **Vehicle-borne track monitoring sensors** installed on inspection cars, and
perhaps eventually on locomotives, identify a number of track geometry and rail integrity conditions so that trains can be stopped or slowed if necessary and maintenance crews can perform repairs as required. Among the defects that will be detected by the on-board sensors are rail flaws, broken rail, misaligned track, and excessive rail stress. Ride quality data can also be collected with accelerometers and used to determine track misalignment. Information from all these sensors, combined with precise location and time information generated by the DGPS receivers, will be displayed in the inspection car or locomotive cab and will be transmitted from the car or locomotive via the digital data link communications network to train control centers, maintenance crews, and maintenance facilities.

e. **Passenger train inventory management and emergency notification systems**, by being able to transmit information on seat and compartment occupancy directly to passenger service management centers, enable railways to sell space that would otherwise go unoccupied. They also enable crews of dining and other food service cars to request restocking of items in short supply. In case of on-board emergencies, they permit notification of the locomotive crew, control centers, and emergency responders.

f. **Vehicle-borne track lubrication systems** use DGPS positioning information and digital track maps determine precise locations of curves at which vehicle-borne track lubrication systems are activated. The result is significant reduction in train resistance, train energy consumption, rail and wheel wear, and the amount of lubricant used.

5. **Other infrastructure-based intelligent railway systems**

a. **Wayside equipment sensors** are installed along the track to identify a number of defects that occur on rolling stock components and to transmit information about the defects so that trains will be stopped if necessary and maintenance crews can perform repairs as required. Among the defects that will be detected by the wayside sensors are overheated bearings and wheels, deteriorating bearings, malfunctioning brakes, built-up wheel treads, worn wheels, cracked wheels, flat wheels, derailed wheels, excessive truck hunting, dragging equipment, excessive lateral and vertical loads, skewed trucks, and excessively high and wide loads. AEI readers integrated with the sensors provide positive identification of vehicles with defects. Information from the sensors is now usually transmitted to train crews by voice-synthesized VHF radio. In the future, the information will be transmitted from wayside interface units at the sensors over the digital data link communications network to train crews, train control centers, and maintenance facilities. The Association of American Railroads’ (AAR’s) Integrated Railway Remote Information Service (InteRRIS™) consists of a network of wayside equipment sensors with integrated AEI readers that send data to a central computer that analyzes the data for trends and sends out appropriate alerts and
warnings to railways and car owners. A railway can have access to data regarding all cars, regardless of ownership, on its own track, as well as data regarding all of its cars on other railways’ track.

b. **Intelligent grade crossings** – Intelligent Transportation Systems (ITS) for roadways interact with intelligent railway systems at highway-rail intersections (HRIs). Information about train location and arrival times, generated either by a PTC system or track circuits or off-track sensors, will be transmitted from train control centers to highway traffic control centers via the digital data link communications network, to motor vehicle operators, cyclists, and pedestrians via roadside traffic information signs, and to motor vehicle operators also via dedicated short-range communications (DSRC) radios to in-vehicle displays or audio warning systems. Similarly, sensors at HRIs will send information to train control centers and trains over the digital data link communications network should an HRI be blocked by an accidentally- or intentionally-stalled vehicle. Demonstrations of intelligent grade crossing devices have been conducted in eight states. Architecture elements to describe the HRIs have been added to the ITS National Architecture, and work on the development of standards for intelligent grade crossings has been started to insure that there will be national interoperability.

c. **Yard management systems (YMSs)** provide the essential link between the movement of trains and the movement of cars. The YMS will receive real-time information on the location and make up of each train on the system and will keep track of all cars in the yard. It will receive goals and objectives from the STP. This will allow the YMS to determine the best way to make up trains, that is, the time sequence in which arriving cars should be classified, the time sequence in which they should be pulled from the lead tracks, and the time and physical sequence in which outbound trains should be made up. The YMS will account for the time that trains will be arriving, the times they should be departing, and the time required for each yard operation to be performed. It will supply a forecast of yard departure times for each of the trains to the STP so that it will be able to perform better its job of creating time targets for smooth system functioning.

d. **Security systems** consisting of closed-circuit television (CCTV) cameras and infrared presence detectors are being deployed at bridges and tunnels, and even on some locomotives, to provide detection of intruders and obstructions. At present, the images and alarms are monitored by railway police security centers that notify railway and local police field forces to respond on site as necessary. At some sites, a loudspeaker is installed with the camera and detectors to permit the security center to notify intruders to depart the premises. As the number of such CCTV and detector installations increases, the images and data will be combined on large, clickable maps. Anything that moves will get an icon on the maps. Digital borders and automated image processing systems will be used to determine the presence of undesired persons or objects. Information from other
sensors (infrared, chemical sniffers, RFID) will appear on the maps, supplying details humans can not otherwise see.\textsuperscript{16} Appropriate information will be transmitted via data link to train control centers and train and maintenance crews in addition to security forces.

e. \textbf{Supervisory control and data acquisition (SCADA) systems} will monitor all the wayside and on-board systems and system components and report their status via the digital data link communications network to appropriate control centers and other organizations on the railway. The status of all systems will be known so that the appropriate level of dependency on each system can be determined. Just as PTC systems will permit the railway operating department to conduct operating efficiency tests without having to go into the field, the SCADA systems will reduce the field inspection requirements of systems and components.

\textbf{D. Human Factors Issues}

The development of the various displays being developed for PTC systems, including those for train crews and dispatchers and the TFTs for permanent way workers, will require the involvement of railway employees and human factors professionals to insure that the displays provide the proper information content and form to permit the employees to carry out their jobs in an optimal fashion. The displays should provide all the information the employees need, and only the information the employees need, and they should provide it in the most comprehensible manner. The graphic display, in addition to the textual display, of movement authorities should help train crew members understand the authorities and prevent misunderstandings. Crew alertness monitoring systems enable railways to monitor the stress and fatigue of train crews. Comprehensive training programs are required for train crews and railway maintenance personnel on the use of all the new systems. The scheduling of trains and the implementation of train crew scheduling systems will significantly reduce stress and fatigue of train crews.

PTC and digital data link communications will also reduce stress and fatigue of dispatchers by reducing their communication load, improving their communication efficiency and speed, increasing their communication precision, and changing their communication focus from information-gathering and movement authorization to traffic planning and problem solving.\textsuperscript{17} Data link communications will supplement, but not eliminate, voice radio communications.

The management structure of railways, and the flow of information within that structure, will have to be aligned with the new systems to enable railways to take advantage of new information and the digital communications network. The implementation teams that are established for intelligent railway systems need to have representatives from all departments on the railway that will be affected by the implementation. Some railways have tried to implement projects with teams that are too small, and, as a result, implementation of those projects has been less than fully successful. In order for management to get “buy-in” from each department, each department needs to know it is appropriately represented on the implementation team. The leader

\textsuperscript{17} Ditmeyer, Steven R. and Michael E. Smith, “Data Links and Planning Tools: Enhancing the Ability to Plan and Manage Train Operations,” \textit{Rail International}, April 1993, pp. 69-77.
of the implementation team should report to the chief executive officer of the railway to insure that participation and cooperation of all affected departments and department heads takes place.

One railway demonstrated two approaches to implementing a locomotive health monitoring system. At one locomotive maintenance facility, the superintendent announced that the purpose of the system was to better monitor the performance of the shop mechanics. At another facility, the superintendent said that the purpose of the system was to improve the performance of the locomotives they serviced. At the first facility the employees fought the system, while the second facility was recognized as having the best performing locomotive fleet on the railway. Clearly, attention needs to be paid to how these new systems are presented to the work force.

E. System Security and Information Assurance
An overarching issue that affects the design and deployment of network-centric railway operations and intelligent railway systems is the security of information. It must be incorporated in intelligent railway systems before deployment. Data regarding trains, cars, crews, and shipments must be kept secure, and unwarranted extraction of information from the digital data link communications network must be prevented. Authentication of data insures that content is genuine, unaltered, and complete. Encryption is the security mechanism that converts plaintext into cyphertext that is unintelligible to those who do not have access to the appropriate key. Archiving of data from intelligent railway systems must also be done in a secure manner through the control of access privileges to prevent loss of data.

F. Security Benefits
In addition to safety and business benefits, network-centric railway operations with intelligent railway systems enhance the security of railway operations and protection of critical infrastructure elements by providing railway domain awareness. PTC systems monitor of location and speed of all trains, provide on-board enforcement of all movement authorities, and have the ability to remotely intervene to stop trains. Wayside track sensors provide the capability to monitor all switches (both powered and manual), bridges, and tunnels, and the information from them is transmitted from wayside interface units to train control centers. Intelligent grade crossing systems can determine if highway-rail intersections are blocked by accidentally- and intentionally-stalled vehicles, and notify trains. Crew registration systems insure that only authorized crew members are permitted to control locomotives and maintenance-of-way vehicles. Car on-board commodity sensors and wayside equipment sensors provide additional information about the integrity of shipments, questionable cargoes, and the presence of stowaways.

The integration of waybill databases (showing car contents, shipper, and consignee), the Umler file, and databases receiving data from PTC systems (location of trains), AEI systems (train lists), and work order reporting systems (cars at customers, in yards, and on repair tracks) will enable railways to monitor the real-time location of all cars and all shipments, and especially hazmat shipments, and provide that information on a need-to-know basis to their employees, customers, and appropriate government agencies. Having the real-time information will also enable railways to predict arrival times at specific locations more accurately. CCTV systems provide visual images of critical infrastructure for monitoring at railway police security centers.
Emergency notification systems enable train control centers to identify and verify emergencies and to provide notification of emergencies to emergency responders, hospitals, public sector authorities, and railway officials.

**G. Impediments to Implementation**

The implementation of network-centric railway operations with intelligent railway systems has not been without impediments. Major ones are the magnitude of the costs, the availability of capital to the railway industry, and the competition for capital within railway companies. Railways need to understand that a well-executed investment in intelligent railway systems, by increasing asset utilization, will reduce the capital needed for locomotives, cars, and track. Also, PTC may actually be less costly than in-kind replacement of existing signaling systems.

In the early 1990’s, US railway chief executives considered the implementation of PTC, ECP brakes, and other intelligent railway systems, but decided instead to use available railway capital for mergers and acquisitions, believing that the mergers and acquisitions would yield a higher rate of return. The mergers, which resulted in four large railways that carry over 90 percent of the rail freight in the US, were not well executed, however, and did not generate forecasted returns. Consequently, the major railways do not believe they have the capital needed for investment in network-centric railway operations and intelligent railway systems. In fact, several of the large railways struggled to handle increases in freight traffic in recent years caused by increased imports, the truck driver shortage, and highway congestion prior to the recent economic slowdown. However, they invested in the construction of double-track, which provides capacity benefits in only a limited territory, rather than in tools to help them better manage their traffic flows over their entire network.

When railways perform cost-benefit analyses for capital investment decisions, they often separate benefits into two categories: “hard” benefits consisting of reductions in staff and fuel consumption and “soft” benefits consisting of improved running times, greater reliability, improved services, greater capacity, increased revenues, increased traffic, and the like. The soft benefits are often discounted heavily. Railways also feel they are under pressure by the investment community to deliver near-term rather than long-term returns on their investments. As a result, railways recently have been viewing PTC more as a mechanism for reducing train crew size rather than increasing track capacity and improving asset utilization. This has had the unfortunate effect of generating union opposition to PTC, a system they had previously embraced for enhancing the safety of their members.

The implementation options for intelligent railway systems are varied; not all railways will want to invest in all of the systems. Some railways have used improper decision criteria to establish the architecture of new systems. They seek to minimize the cost of specific subsystems rather than optimize the benefits and costs of the entire system. One major railway instructed its contractor to design a PTC system that would minimize the cost of telecommunications (by minimizing the number of messages transmitted); another wanted the cost of locomotive onboard systems minimized. Such decisions will, by raising other costs or reducing functionality, result in ineffective deployment or no deployment at all. Yet another railway implemented several of the intelligent railway systems – specifically train location, locomotive health
reporting, and work order reporting – but used a dedicated communications channel and radio for each system rather than having them share a common channel and radio. The challenge with intelligent railway systems is for a railway to optimize the relationship between total system benefits and total system costs, not just subsystem benefits and subsystem costs.

Some railways want the logic of new PTC systems to be the same as the logic of their existing operating rule books and signaling systems, which is based on knowledge of which track blocks are occupied and different procedures and priorities for trains and maintenance vehicles. This implementation scheme results in congested communications channels and reduced capacity and efficiency. PTC systems based on the new and different paradigm with knowledge of the precise location and speed of all trains and maintenance vehicles can provide closer headways and greater capacity while simultaneously increasing safety. The new paradigm is based on the concept that a railway is, in reality, a one-dimensional system with branches, and that “two things cannot occupy the same space at the same time.”

The investment in traditional wayside signal systems is completely along the track, and signal systems are traditionally purchased by-the-mile. In contrast, the largest portion of an investment in PTC is in equipment on locomotives and maintenance-of-way vehicles, with smaller portions going into equipment along the track and at the train control centers. If rail traffic, for some reason, stops running over a line with a signal system and shifts to another line, the signal system on the original route has only scrap value. If rail traffic, for some reason, stops running over a line with PTC and shifts to another line, the PTC-equipped locomotives shift over to the new line with no write-off of old investment and no new investment required.

A tension exists between investments in legacy systems and modern systems. Some members of the railway signaling community—railway signal engineers and signal maintainers, signal suppliers, and signal regulators—point out that PTC systems do not automatically incorporate broken-rail protection, which is integral with track circuit-based signal systems. That is correct; with PTC, the decision to incorporate broken rail protection is a separate, independent decision. The signaling community is also skeptical of PTC systems because they feel that PTC systems have less reliable components (e.g., radios, DGPS receivers, on-board computers, liquid crystal and plasma displays, etc.) than traditional wayside signaling systems, whose components are all very robust and reliable, having been designed to meet fail-safe standards. However, the reliability of components is not the sole determinant of system safety. The architecture of existing signaling and train control systems is such that it permits one person, either a locomotive engineer or a dispatcher, to make a mistake (because of fatigue, illness, drugs, inattention, distraction, carelessness, visual or aural impairment, or some other reason) that can cause two trains to collide. The safety of PTC systems derives from an integrated architecture that provides checks and balances which limit the impact and propagation of human error. Analyses have shown that the probability of a collision or overspeed accident occurring with PTC is one one-hundredth of the probability of a collision occurring with existing signal systems.\footnote{Weinstein, William W., Philip S. Babcock IV, and Frank Leong, \textit{Safety Analysis of ARES}, Cambridge, MA: The Charles Stark Draper Laboratory, Inc., October 1987, Report CSDL-R-2013, for Burlington Northern Railroad; and Weinstein, William W. and Andrei L. Schor, \textit{Safety Analysis of the ATCS}, Cambridge, MA: The Charles Stark Draper Laboratory, Inc., April 1990, Report CSDL-R-2098, Rev. 1, for the AAR.}
Railways are currently not organized well for implementing intelligent railway systems. The groups responsible for telecommunications and for train control systems are often in disparate parts of railway organizations. Telecommunications staff often reports to the information systems department, while train control staff often reports to the track engineering and maintenance department. Network-centric railway operations require that telecommunications and train control staffs either be amalgamated or have an extremely close working relationship.

Some railways are reluctant to write off, or to view as sunk costs, investments in physical assets such as wayside signal systems that would no longer be needed when PTC systems are implemented. Rather, they want to incorporate as much of their “legacy” technology as possible into new command and control systems.

Interoperability issues affect some but not all of the intelligent railway systems. Locomotives equipped with radios using common frequencies and protocols, with common positioning systems, and with computers using common logic are necessary if PTC is to be implemented widely. Other systems, such as tactical and strategic traffic planners, locomotive health monitoring systems, work order reporting systems, and wayside equipment sensors, do not require railway industry agreement.

Some railways see a barrier in the cost of getting started. Because PTC is a locomotive-based rather than track-based system, they believe that all locomotives have to be converted at once because of the difficulty in assigning equipped locomotives to specific territories. However, those same railways currently assign their AC-traction locomotives to specific heavy-haul territories. Since implementation of PTC will take place region-by-region, PTC-equipped locomotives could be phased in and managed on a region-by-region basis.

Network-centric railway operations may take as much as a decade to implement, well beyond the tenure of many senior railway executives. Most railway senior managers have received their promotions because of their success in downsizing facilities and operations; few have experience in managing growth. Even fewer have the knowledge of the mathematics of network flows. Railways today lack staff with knowledge of these new network-centric technologies; additional staff with the proper skills will have to be hired or trained with an extensive professional capacity building program.

When new technologies are adopted and when methods of operation change, it is only natural that some individuals, and even institutions, will be resistant to change. Those with knowledge of signal systems feel threatened by the adoption of a different train control technology. Some in management will want to move the new, different, and more complete information through the existing stovepipes of the hierarchical structure, rather than directly to those managers and operators who can take immediate action based on the information. The US military encountered this problem during Operation Iraqi Freedom.\textsuperscript{19}

Some railways in the US and abroad have expressed concern about US DoD control of GPS. They are reluctant to implement train control systems that rely on GPS, or augmented GPS, for train location, speed, and time information because of concerns that DoD may unilaterally degrade or terminate GPS signals during a time of war or national emergency. To address this concern, President Bush announced that DoD is eliminating from the next generation of GPS satellites the selective availability feature that in the past could have been used to degrade GPS signals. When the constellation of Galileo navigation satellites is placed in orbit by the European Union around 2010, the concern about using satellite signals for railway applications may be reduced further.

Suppliers are reluctant to invest much money in the development of intelligent railway systems without some assurance that railways will commit funds to deploy them. In fact, some railway managements have argued that since there are no off-the-shelf intelligent railway systems, they cannot implement them. Recognizing this situation, the US government and the European Union each sponsor R&D and demonstrations for a number of the components of intelligent railway systems. However, until railways decide that they want to implement these systems, and demonstrate their commitment with contracts with suppliers, development of some of the systems will be delayed.

Some railway marketing departments have expressed uncertainty about the response of their customers to service improvements that might result from the implementation of intelligent railway systems. Those marketing departments doubt their customers’ willingness to pay more for better service, or to shift more traffic from highways to railways. Even though the railways have little data to show their customers’ elasticity of demand for significantly improved service, they have substantial data showing their customers’ responses when railway service deteriorated and recovered following the recent mergers.

Quite often, railway managements require that individual departments provide the justifications for proposed capital investment projects because, historically, the costs and benefits of a project have accrued to the same department. For example, mechanical departments provide the justifications for investments in new locomotives and maintenance facilities, and engineering departments provide the justifications for investments in tunnel elimination and bridge replacement projects. Many, if not most, of the intelligent railway systems would generate benefits that would accrue to departments other than the department that installed them. If intelligent railway systems are to be implemented, railways must also establish new, broader-based capital planning and budgeting processes that recognize the integrated nature of these systems and that there are multiple beneficiaries of each system.

The breaking up of railways into separate operating and infrastructure companies, a trend now occurring in Europe and a trend that some urge be adopted in the US, could be a further impediment to the implementation of intelligent railway systems. The costs and the benefits of the individual systems will not fall in the same proportions between operating companies and infrastructure companies. Negotiating processes involving engineers, economists, financial analysts, and lawyers would have to be established to allocate costs and benefits among the new
entities. These processes, while not impossible, would add complexity to any deployment of intelligent railway systems.

Some railways were reluctant to acknowledge that intelligent railway systems would result in safer operations because of concerns about the liability that they could incur should accidents happen before the installation of the systems is completed or on lines where the systems are not installed. Railway lawyers also seem concerned that the availability of archived data from intelligent railway systems could be detrimental to railway interests if they had to provide it to plaintiffs’ attorneys in court trials.

When, in the early 1990’s, the California Air Resources Board expressed an interest in using data from locomotive health monitoring systems to determine locomotive idling time and locomotive emissions, railways became disinterested in using locomotive health monitoring systems. Railways and regulatory agencies – safety and environmental – will need to reach accommodation with one another regarding provision of archived data from intelligent railway systems. It is imperative that regulatory agencies do not discourage the implementation of new technology in their zeal to have access to newly-available data.

Finally, some railways were reluctant to invest in intelligent railway systems, and especially PTC and ECP brakes, before they knew what safety regulations would be issued by the FRA. The regulatory process there can be long and tortuous. It took FRA over seven years to issue a permissive rule on PTC. Some railways were reluctant to test and evaluate such systems, lest the FRA finds that the systems improve railway safety and efficiency and issues new regulations mandating the implementation of the systems. In a move seemingly made to fend off such regulations, one railway told the FRA that the quality of its operations was so good that there was no room for any improvement. The AAR went on record with the FRA stating that they believe the benefits to the railway industry from the application of PTC and related systems are less than the costs. The logic of this is not clear, since the investment in PTC will be in lieu of, not in addition to, current railway spending on signaling systems. It appears that PTC will be less costly than signaling systems it replaces, while offering significant benefits not offered by

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20 A similar situation existed in the US in the 1930’s, shortly after Automatic Train Control (ATC), a system to enforce wayside signal indications, was developed to address the problem of collisions involving passenger trains. Congress passed, and President Franklin D. Roosevelt signed into law, the Railroad Signal Inspection Act of 1937 which directed the Interstate Commerce Commission (ICC, which was responsible for railroad safety regulation until the FRA was created in 1967) to order the installation of ATC when it was determined to be necessary in the public interest. However, the law also specified that railroads were not to be held negligent for not installing ATC on portions of their track not covered by ICC orders. This law remains on the books, and could conceivably be applied to the implementation of PTC.

21 Many railroads, and some officials of the FRA, believe that only safety benefits can be used to justify an FRA regulation. However, Executive Order 12866, “Regulatory Planning and Review,” dated September 30, 1993, states; “Further, in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits (including potential economic, environmental, public health and safety, and other advantages; distributive impacts; and equity), unless a statute requires another regulatory approach.”

the existing systems. These issues, however, became irrelevant in the US following the passage of the Rail Safety Improvement Act of 2008 that requires the implementation of PTC.

**H. Conclusion**

All these issues and impediments can appear daunting to the organizations that are faced with the implementation of network-centric railway operations with intelligent railway systems. Furthermore, the deployments of ITS, new air traffic control systems, maritime vessel tracking systems, and even the military’s network-centric warfare systems are not occurring without some complications. Nevertheless, network-centric railway operations are key to making railway operations—freight, intercity passenger, and commuter—safer, reducing delays, reducing costs, raising effective capacity, increasing reliability, raising productivity, improving customer satisfaction, improving energy utilization, reducing emissions, increasing security, and making railways more economically viable.

Network-centric railway operations will enable railways to manage unexpected situations by providing real-time information about current operations and the current environment. That will enable managers and dispatchers to have more knowledge of the status of the entire railway, thereby enhancing operational security and the protection of critical infrastructure. Information will flow to the right people who have the ability to take corrective actions.

Railway customers will benefit significantly from the improved running time and service reliability resulting from the implementation of network-centric railway operations. Railways face the challenge of capturing some of those benefits in the form of increased revenues.

Network-centric railway operations and intelligent railway systems, as described in this paper, represent a “unified theory of railway operations.” Intelligent railway systems can either be implemented as independent systems, in which case their benefits will be limited, or they can be implemented as integrated, networked systems—a “system of systems”—in which case the benefits will be compounded. The railway industry is urged to consider adopting an integrated approach when implementing these systems to achieve network-centric railway operations.
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