ABSTRACT

In November and December 2000, Amtrak placed in service its Advanced Civil Speed Enforcement System (ACSES) on a section of the Northeast corridor between New Haven and Boston. This system, supplied by ALSTOM Transport Information Solutions, provides enforcement of civil speeds and interlocking stop signals. The commissioning of this section allowed Amtrak to initiate 150 MPH revenue service operation for its new “Acela Express” high speed train service.

ACSES, a transponder based system, is derived from a system originally developed in Sweden, and used for many years in France and Belgium. This paper provides a description of the basic operating principles of ACSES and its relationship to the existing Northeast Corridor ATC system. The lessons learned in applying this technology to an existing operating system along with Amtrak’s perspective on its performance since commissioning are presented. The next phases of the project and its expansion to provide transmission of temporary speed restrictions via an ATCS Specification 200 compliant radio network are also included. The capability of loading the temporary speed restrictions to the on-board computer will allow enforcement of temporary speed restrictions without requiring the placement of temporary transponders. The final system configuration, including data transmission to the locomotives via radio and transponders working in conjunction with the cab signal system, provides Amtrak with a flexible, modular form of PTC that can be incrementally applied, both on the wayside and on
board, without degrading existing services. This is enabling Amtrak to meet its service improvement goals in priority order, as funding becomes available.

INTRODUCTION

In 1991, Amtrak’s Northeast Corridor (NEC) had an excellent automatic train control (ATC) system consisting of a 4-aspect, continuously coded cab signal system with speed control. This system essentially repeats the wayside signal aspects in the cab, and enforces the speeds associated with each of these aspects. ATC has served the NEC very well, and is considered superior to any of the various ‘intermittent’ systems, as it continuously monitors conditions ahead of the train, responding to these changes and displaying them to the engineer within 3 to 5 seconds. While ATC’s superiority over intermittent systems in this respect goes unchallenged, it is perhaps less well understood that the latest “state-of-the-art” communications based PTC systems, currently under development, will likely take 4 to 7 times longer to reflect a change in conditions ahead than good old cab signals. Operationally, especially where high speed trains are involved, this longer time to reflect changes is a significant consideration, as much as three quarters of a mile longer at 150 MPH.

The original 4-aspect ATC enforced speeds at 20 MPH, 30 MPH, 45 MPH and 80 MPH when speed control was first added to the cab signal in the early 1950’s, but by 1991 maximum speeds in the NEC had increased from 80 MPH to 125 MPH. This left a big gap between the enforceable speeds of 45 MPH and 125 MPH, but with the 1991 infrastructure Amtrak was still
well-served by the 4-aspect ATC system in the NEC. By this time speed control had been applied to all trains in the NEC, mandated following the Chase, Maryland collision.

Then, the decision to implement high-speed rail (HSR) operation forced Amtrak to re-think everything:

1. Maximum operating speeds of 150 MPH.
2. 80 MPH crossovers between main tracks.
3. FRA requirements for civil speed enforcement for high-speed trains and for all trains operating in the high speed train territory.
4. FRA requirements for positive stop enforcement at interlocking home signals.

The solution that Amtrak adopted is a blend of ‘expanded’ ATC and a new (to Amtrak) off-the-shelf technology from Europe involving transponders placed in the center of the track. This solution retained the continuous monitoring advantage of the continuous cab signal technology, while adding capability to the overall system through the introduction of intermittent transponders with their ability to put larger packages of information on-board the train at intervals along the track. The “blend” enabled Amtrak to take advantage of the inherent strengths of each technology.

Looking at the four requirements for HSR listed above, the solutions needed to meet these additional criteria must:

A. Be cost effective.

B. Be easy to implement incrementally on both the wayside and on-board.
C. Retain the safety inherent in the ATC, where conditions ahead are continuously monitored and changes reflected within 3 to 5 seconds.

D. Precisely locate the beginning and end of civil speed restrictions, to avoid loss of precious seconds inherent in the enforcement process.

Following guidelines A through D, Amtrak found that requirements 1 and 2 would best be met by ‘expanding’ the ATC. A 250 Hz frequency was added to the original 100 Hz carrier frequency. A code of 270 pulses per minute was added to the original codes of 75, 120, and 180 pulses per minute. The 250 Hz was carefully selected to fit into a ‘slot’ in the frequency spectrum, heavily populated by other track circuit frequencies, two traction frequencies (25 Hz and 60 Hz), and the odd harmonics of each of these traction frequencies.

The resulting ATC solved the original HSR requirements 1 and 2 very well, as well as meeting guidelines A, B, and C. The ‘expanded’ ATC, now called the ‘9-Aspect Cab Signal System,’ has the following additional speeds:

- 80 MPH for the new high speed crossovers and to permit better headway
- 150 MPH for the new maximum operating speed
- 60 MPH and 100 MPH for future use

The new codes and speeds were assigned in such a way that they could be added to the wayside infrastructure incrementally without downgrading the operation of any existing 4-aspect cab signal equipped trains. As the on-board equipment is upgraded, these trains can take advantage of the new codes and speeds.
But the new ‘expanded’ ATC did not meet HSR requirements 3 and 4, nor guideline D. This required the introduction of the transponder technology, which became known as the Advanced Civil Speed Enforcement System (ACSES). ALSTOM Transportation Information Solutions and its subcontractor PHW, INC are supplying the ACSES system. The ATCS specification 200 compliant radio equipment is being supplied by Safetran Systems, Inc. (wayside and office), and Nexterna, Inc. (formally AMCI) (on-board).

**ACSES TRANSPONDERS**

The primary functions of ACSES are to enforce civil speed limits and to enforce stops at interlocking home signals displaying a stop aspect. ACSES consists of transponders mounted in the center of the track. Each transponder contains a ‘plug’ with an encrypted message consisting of 255 bits, 180 bits for information, 72 bits for security (safety), and 3 bits are not used. An antenna under the engine or lead unit radiates 27 MHz power down into the roadbed, pulsed at 100 kHz. The wayside transponders are passive, and they use this radiated power to activate the transmission of the encrypted return message at 4.5 MHz. The on-board antenna then captures the message, which is decoded by the on-board computer (OBC). The OBC translates this information to display and enforce civil speed limits and positive stops at home signals.

There are two, three, or four transponders in each set, separated by a distance of 10 to 13 feet. Transponder sets are located at known “signal” or insulated joint locations where maintainers already have ready access and other equipment to maintain. The transponders provide the distance to the beginning and end of each speed restriction, which almost never coincides with
‘signal’ locations. Using the on-board tachometer to measure the distance traveled from the last transponder set, the onboard system correctly enforces the speed restriction. ACSES requires that transponder sets be separated by no more than 2.7 miles to ensure accurate operation of the tachometer within a 5% error factor. All permanent transponders are ‘linked’ to ensure fail-safe operation.

Positive Train Stop (PTS) enforcement at the interlocking home signals is accomplished by encrypting the necessary information, including the distance to the home signal, on a transponder set at the distant signal. For redundancy, this same information is encrypted on the pre-distant signal set. To implement this function, a unique blend of the cab signal system with the ACSES system was developed. If the cab signal system is cut-in and receiving an aspect better than “Restricting”, the PTS is not enforced. If the cab signal is cut-in and receiving a “Restricting” aspect (no valid code on the track), the PTS is enforced. If the cab signal is cut out, the PTS is enforced by the ACSES system. Under the conditions where the cab signal is cut out, or it is displaying a “Restricting” aspect, the home signal may actually be displaying an aspect more favorable than “Stop Signal”. To allow trains to continue and not be forced to stop, an ATCS Specification 200 compliant radio system is being used to provide the signal status to the on-board system. An encoder at each interlocking monitors the status of the home signal and sends a radio message to the train. If the received message indicates that the home signal is displaying an aspect other than “Stop Signal”, the PTS is not enforced. The interlocking message also contains other data that will be described below to allow the on-board system to enforce the correct civil speed limits within the interlocking and to select the correct temporary speed restrictions (TSR).
**Transponder Data**

Each transponder has a removable and re-programmable ‘plug’ that contains the encrypted data for that specific transponder. The data is specific to its location. A set of transponders (2 to 4) contains all the local data required for both directions of travel. If changes occur to the infrastructure, only the data in the transponders in the area affected need be changed. There is no need to update a database on any on-board system. Each transponder contains a set of fixed data including:

- Location in terms of a railroad identification number, railroad line number, milepost location of the set, the transponder location number within the set, and the track number
- Linking distance to the next transponder set in each direction

In addition each transponder can be programmed with additional optional data depending upon the local infrastructure characteristics. Optional transponder data includes:

- Current maximum line speed for each of the 5 train types. (See Note 1)
- Distance from the transponder to the start of a civil speed restriction
- Length of the civil speed restriction
- Speed limit for each of the 5 train types for the civil speed restriction (See Note 1)
- Distance to the home signal
- Controlling grade between the transponder and the home signal (See Note 2)
- Address and operating frequency of the local ATCS radio base station
- Start and end locations of phase breaks or voltage change breaks
Note 1: The 5 train types are:

- A = “Acela Express” (high-speed train) with tilt enabled,
- B = “Acela Express” (high-speed train) with tilt disabled and ‘Acela Regional’ (Metroliners),
- C = All other passenger trains,
- D = Mail baggage and express trains, and
- E = All freight trains.

Note 2: The ‘controlling grade’ is the steepest downgrade or least steep upgrade.

**ATCS RADIO NETWORK**

An ATCS Specification 200 compliant radio system is being implemented as part of the ACSES system. This radio is used to provide the information necessary for the train to override the PTS when the home signal is not displaying a “Stop Signal” aspect, and the cab signal is cutout or is displaying a ‘Restricting’ aspect. The radio system will also provide the on-board system with additional information regarding the interlocking it is approaching, and it will be used as part of the second phase of ACSES to allow temporary speed restrictions (TSRs) to be uploaded to the on-board system from Amtrak’s dispatchers. Once loaded on the on-board system, the TSRs will be enforced in the same manner as other civil speed restrictions. The system always enforces the lowest received speed for its train type and location.

**Radio Data**
The data provided over the radio system includes:

- Interlocking home signal status (stop or go)
- Civil speed limits through the interlocking based on switch positions and speed on the exit track
- Exit track from the interlocking identified by number
- Start location and length of temporary speed restrictions (TSRs)
- Temporary speed limits for passenger and freight trains

A system block diagram is shown in Figure 1. The initial phase of ACSES, currently in service on a portion of the NEC and being installed in additional segments, provides the civil speed and positive stop enforcement functions. The next phase of ACSES will provide the radio release of the positive stop enforcement and the uploading of the TSRs to the on-board system for enforcement. This phase requires the installation of the wayside and office radio system, along with the TSR server and the network servers. As shown in the figure, the office equipment and the connections to the wayside radios are being implemented in a redundant manner to achieve high system availability.

**OPERATION EXAMPLES**

**Civil Speed Enforcement**

Referring to Figure 2, as train approaches a civil speed restriction it passes a transponder set. The data provided by the transponder set informs the on-board computer of the distance from the
transponder set to the start of the restriction, the length of the restriction, and the speed limit of
the restriction. The on-board system computes a braking curve and a warning curve based on the
braking characteristics preprogrammed for it, targeting the start of the speed restriction at the
speed restriction speed limit. The warning curve is a fixed offset from the brake curve. For
passenger trains it represents an eight second offset.

The train uses the on-board tachometer to track its location with respect to the start of the
restriction. As long as the train speed is less than or equal to the warning curve speed, the
system takes no action and does not display the speed restriction until the train reaches the start
of the restriction. If the train speed exceeds the warning curve speed, the locomotive engineer is
given an audible warning and the speed restriction is displayed as a changed speed in the track
speed display. If the warning is not acknowledged or the brake curve speed is exceeded, the
system enforces a penalty full service brake application. On passenger trains only, release of the
penalty brake application is permitted after the train speed is below the target speed. Once the
train reaches the end of the speed restriction, the system displays the new speed limit and
removes the speed restriction enforcement. It is the engineer’s responsibility to ensure that the
entire train has cleared the restriction before the train speed is increased.

Each transponder contains the linking distance to the next transponder. If the next transponder is
not encountered within a preset tolerance of the prescribed distance:

- the engineer is given an audible warning which must be acknowledged,
- the engineer’s Aspect Display Unit (ADU), displays ‘- - ‘ to indicate that ACSES is
  not functional, and
maximum allowable speed of the train is enforced at 125 MPH for passenger trains exceeding that speed. (Passenger trains between New Haven, CT. and Boston, MA. are further restricted to 110 MPH by operating rules).

This protects the engineer against reliance upon the system when there is a possibility that the on-board data does not include the next speed restriction. Once the system finds a transponder set with correct data the ACSES system updates the ADU to the correct civil speed limit and normal ACSES operation may be resumed.

**Positive Stop Enforcement**

Referring to Figure 3, as the train approaches an interlocking it crosses a transponder set (DS) that provides the on-board system with the distance to the home signal (HS). The on-board ACSES sets a 0 speed target 100 feet before the home signal and, using the controlling grade information received in the transponder message, calculates the brake and warning curves. If the train speed exceeds the warning curve and the ATC system is cut-in and working, ACSES generates a PTS request by de-energizing an input to the ATC system. If the ATC system is receiving a valid code and displaying better than a “Restricting” aspect, the ATC ignores the PTS request, and does not enforce it. If the ATC system is not receiving a valid code and is, therefore, displaying a ‘Restricting’ aspect, ATC accepts the PTS request, and enforces it. If the ATC system is cut out, then ACSES enforces the PTS.

In all cases, if a valid radio signal is received indicating that the home signal is not displaying ‘Stop Signal’, then the PTS request to ATC and the ACSES enforcement is cancelled. The ACSES system will also receive, as part of the radio message, the civil speed limit through the
interlocking. The system will enforce the lower of the speed limits received, the cab signal speed, the civil speed limit received from the transponders, or the civil speed limit received via the radio. The civil speed limit received by the radio may, of course, vary depending upon the train’s route through the interlocking. This is done to keep the track speed display correct for engineer’s acceptance of the system. It is also useful as back-up protection against overspeed derailments on interlocking crossovers, should the cab signal (which normally provides such protection) fail en-route.

Temporary Speed Restriction (TSR)

The current system used by Amtrak’s dispatchers for implementing TSRs will be maintained. The dispatchers add or delete TSRs within the system, using TSRB Forms or Form D’s. This data is provided to the engineers as faxed hard copies prior to their trips, or as verbal information via the radio during their trips. In the second phase of ACSES, the TSR data will be provided digitally to the TSR server (See Figure 1) connected to the three Amtrak CETC (Centralized Electrification and Traffic Control) centers in Philadelphia, New York and Boston via a Wide Area Network (WAN). The TSR server will manage this data and generate TSR data messages for the trains upon request. The project includes coordination with the parallel non-ACSES delivery of the TSR forms, to reduce the burden on the dispatcher, to require only one “transaction” for each generated TSR and its corresponding enforcement through ACSES.

The on-board system requests TSR data updates as it traverses the system. These requests are triggered by special data packages in the appropriate transponders. The TSR data is always
uploaded with all the TSRs the train could encounter in the radio coverage area it is entering, plus the next two radio coverage areas in the direction it is traveling. The TSRs for all tracks in the train’s direction of travel are included in the upload. This allows the train three opportunities to get the TSR data before it needs it, while keeping the data “fresh” (i.e., the time frame between reception and application is kept relatively narrow, minimizing the effects of TSR changes en-route). The on-board system uses the radio data received from the interlockings to determine what tracks it will occupy in and after it passes through each interlocking. Using this data, the on-board system can anticipate the application of TSRs on other tracks as it traverses the interlocking. The on-board system treats the TSRs in the same manner as speed restrictions received from the transponders. The enforcement methodology is exactly the same. The system always enforces the lowest speed limit it receives for any particular location and train type.

INSTALLATION AND APPLICATION

One of the real challenges on this project was developing the track database to assign the correct speed limits for every train type over every foot of track in a multiple track environment. This challenge was compounded because Amtrak, FRA, and Bombardier were still trying to decide what underbalance values were appropriate for the new trainsets. Every time this value changed, the speeds on many curves changed. The Track Department became painfully aware that it was no longer a simple process of calling the Rules Department and issuing a speed change. Now they had this C & S Department in the middle that had to coordinate enforcement of the new speeds, including the programming and installing of the transponder plugs, which took a finite time period that was never previously required. This, of course, arises out of the decision to
enforce permanent track speeds, introducing a new fact of life that must be faced, regardless of the form of PTC installed.

The Rules Department had to develop a whole new Timetable format with 5 columns to accommodate all the train types, to replace the much simpler 2 or 3 columns that prevailed for years. The C & S and Rules Departments labored long to come up with a good set of Operating Rules to simplify explanation of what to do with this new “thing”, how it worked, and what to do when it failed.

It was also necessary to have much better precision as to exactly where the curves were. In the old Timetable speed columns, it was only necessary to be good to the nearest tenth of a mile (the engineer “knew” where the curves begin and end), but when ACSES enforces the speed of the curve, the engineer expects it to “see” the curve like he does. Therefore, we try to get display and enforcement as close as 30 feet to the point where the tangent meets the spiral at each end of the curve, if possible.

Fortunately, as speeds changed and curve locations were more precisely located, the individual local changes in the database were relatively easy. Remember, the only infrastructure data the on-board system needs is the data it picks up at the last transponder set it passes over. The programming changes can be quickly installed and then verified using the Wayside Maintenance Tool. Storing the infrastructure data in small bite-sized packages along the right of way has advantages. A master database is maintained at headquarters.
Another challenge was that of installing ACSES on 17 different locomotive, power car, and cab control car types. This was very satisfactorily met with two basic packages to meet all applications.

Application of ACSES has involved working with three commuter operators (NJT, CDOT, and MBTA) and two freight operators (P&W, and CSX). NJT is implementing its own enforcement system. Amtrak and NJT, along with Alstom and NJT’s supplier, are working closely to insure interoperability. In the case of all the other operators, it is a matter of applying the “Amtrak” system to the operator’s vehicles, to operate their trains intermingled with Amtrak trains in various portions of the NEC.

One feature of the system that has greatly facilitated testing and ‘commissioning’ of the transponders is a transponder message package called “construction package.” Temporary transponders containing this message package are placed at each end of a new section to be tested. The installed messages tell the passing revenue service trains to ignore this section. When testing is completed, the ”construction packages” are removed, and the section is in revenue service.

**OPERATING EXPERIENCE**

Permanent civil (track) speed enforcement has been very smooth in application and well accepted in operation. Some of Amtrak’s more aggressive runners have had to learn to start applying brake a little sooner than before, because of the safety factors that must be built into any system of this nature. However, they have learned that braking sooner also means that they do
not have to put quite as much brake on to achieve the same speed at the same place. Positive stop (PTS) has also worked well, but Amtrak is currently testing some new on-board software designed to improve this feature. Operationally, the least acceptable feature of ACSES is the enforcement of temporary speed restrictions using temporary transponders. To keep the application simple and quick when the need arises, Amtrak places temporary transponders that have no linking and no location information, as all that would take too long to develop for each individual application. Therefore, the transponders only have the essential speed information and whether to enforce (approaching the restriction), or to release (upon passing the restriction). This means engineers have to go to full service braking immediately upon passing the advance sign, unless they are already below the target speed. This is far from an ideal arrangement, and relief will have to await full implementation of ACSES Phase II. This will bring TSR delivery directly to the train via data radio, with all the features that currently provide satisfactory enforcement of permanent restrictions.

INTEROPERABILITY

Amtrak has, from the beginning of this project, worked closely with New Jersey Transit to ensure complete interoperability of their 9-aspect ATC system and their Advanced Speed Enforcement System (ASES) transponder based system. This will not only allow NJT to continue to run many trains on the NEC, but it also ensures ready availability of these ‘wedded’, off-the-shelf, proven, cost-effective, easily installed technologies for future applications.

CONCLUSION
ACSES as an overlay upon Amtrak’s basic ATC system has enabled Amtrak to accomplish all of its HSR requirements within the stated guidelines. With the use of temporary transponders for temporary speed restriction enforcement, ATC/ACSES today meets all the requirements for PTC that have been recently developed by the FRA/RSAC process. The current activities to expand the system to allow the transfer of TSRs from the dispatcher to the on-board system for enforcement will further enhance the PTC characteristics of the system.

ACSES is currently in revenue service on 198 track miles of the NEC without the radio functionality. ACSES Territory will soon be expanded to 410 track miles, and radio functionality will be added. The portion of ACSES in service in New Jersey today is allowing HSR operation at speeds up to 135 MPH. This is limited only by the fixed tension catenary system in this area. The in-service portion in Rhode Island and Massachusetts is allowing HSR operation at speeds up to 150 MPH.

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Figure 1

System Block Diagram
Figure 2

Civil Speed Enforcement

Figure 3

PTS Enforcement