IDEA

Innovations Deserving
Exploratory Analysis Programs

High-Speed Rail IDEA Program

A TRACK SENSOR FOR PREDICTING TRAIN ARRIVAL TIME

Final Report for High-Speed Rail IDEA Project 50

Prepared by:

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This investigation was performed as part of the High-Speed Rail IDEA program supports innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.

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A TRACK SENSOR FOR PREDICTING TRAIN ARRIVAL TIME

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IDEA PROGRAM

Funding and technical support for this project was provided by the High-Speed Rail IDEA Program. The mission of the High-Speed Rail-IDEA Program is to foster innovation in rail transportation by providing start-up R&D funding and support for promising but unproven concepts.

The High-Speed Rail-IDEA Program is funded by the Federal Railroad administration and managed by the Transportation Research Board (TRB) of the National Research Council. The High-Speed Rail-IDEA Program is one of four IDEA programs managed by TRB. The other three are Highway IDEA, Transit IDEA, and Safety IDEA.

- NCHRP Highway IDEA, which focuses on advances in the design, construction, safety, and maintenance of highway systems, is part of the National Cooperative Highway Research Program.
- Transit IDEA, which seeks advances in efficiency, safety, and maintenance of transit systems, is part of the Transit Cooperative Research Program and funded by the Federal Transit Administration.
- Safety IDEA focuses on innovative approaches to improving railroad, intercity bus, and truck safety. The program is supported by the Federal Motor Carrier Safety Administration and the FRA.

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ABSTRACT

This research examined Time Domain Reflectometry (TDR) as an alternative method for detecting approaching trains and predicting train arrival time for Highway-Railroad Grade Crossings (HRGC) and other applications. The ideal train predictor should provide a constant warning time for motorists, independent of train speed, of 20-seconds or more depending on the crossing configuration. Existing HRGC predictor systems are based on measuring the rate of change of impedance for the conductive loop formed by the track and train shunt as the train enters the HRGC approach. This method has sufficient range and accuracy for most existing applications, and is very reliable, but a survey revealed warning time variations of 20 to 90 seconds depending on train speed, ballast conditions and installation. This wide variation can mean unnecessary traffic delays and possible driver uncertainty that prompts risky behavior. Furthermore, emerging trends such as increasing passenger train speeds and traffic light preemption are pushing the limits of present crossing predictors to provide sufficient range and/or advance warning time.

The proposed TDR-based method would use the two rails as a two-wire differential transmission line. Coded electrical pulses transmitted into the track at the crossing would travel to the train and be reflected back to the crossing by the train shunt, and the round trip time delay would allow the distance to be determined, hundreds of times a second. To test the proposed method, the electrical transmission line properties of railroad track were first determined, including variations for tie type, track ballast quality and moisture content. An electrical analog was then constructed to allow bench development and testing. The research plan then called for preliminary field testing on the Precision Test Track at the Transportation Technology Center, Inc. (TTCI), followed by compatibility testing with the two leading U.S. signal manufacturers, and then a final field trial and demonstration on one of the loop tracks at TTCI.

Two key problems emerged during bench testing, both related to the conductance measured between the two rails, referred to in the industry as “ballast leakage”: (1) the relatively poor real-world insulation between the rails leads to a high attenuation rate for differential signals propagating along the rails, and (2) this attenuation is highly dependent on the signal frequency with lower frequencies less affected. Research revealed that the high attenuation could be overcome by applying signal correlation processing methods that can detect extremely weak signals. However, this required the use of increasingly lower frequencies in order to achieve the target range of 8,000 to 12,000 feet, but lowering the frequency also increased the pulse time so that it became impossible to distinguish between the initial transmitted signals and the reflected signals. At present, for existing tracks with less than ideal insulation between the rails, pulse frequencies that are low enough to reduce attenuation to acceptable levels have pulse durations that cause transmit/receive timing overlap, and frequencies high enough to avoid transmit/receive overlap provide only limited range.

KEY WORDS

Highway-Railroad Grade Crossing
Train Predictor
Time Domain Reflectometry
Traffic Preemption
High-Speed Train
Grade Crossing Warning Systems
Train Arrival Time Prediction

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EXECUTIVE SUMMARY

In order to provide safe and efficient operation of active warning systems at Highway-Railroad Grade Crossings (HRGC), an accurate prediction of train arrival time is needed. The industry goal is to provide a constant warning time independent of the train speed, and satisfy the Federal Railroad Administration (FRA) regulatory requirement for a minimum warning time of 20 seconds. For most present-day applications, the existing loop impedance method reliably provides the minimum warning, but this method has limited accuracy, particularly if the train is accelerating or braking during the prediction period. One survey performed in Knoxville, Tennessee found variations between 20 and 90-seconds with an average of 42-seconds. This variation means that some traffic is delayed unnecessarily, and also raises secondary safety issues where motorists falsely interpret that they have additional time to cross ahead of a train, or become impatient at a long delay and try to bypass the warning system. Another problem is that longer warning times are needed, 60 seconds or more, to implement traffic light preemption, i.e., the re-sequencing of traffic lights in the vicinity of the crossing to minimize interruption of traffic flow. Also, the range is not adequate to allow enough warning time for anticipated future high-speed passenger services in those situations where grade crossing elimination or separation is not an option.

This research sought to develop an alternative train arrival prediction method to overcome these problems. The proposed method was based on Time-Domain Reflectometry (TDR) where the two rails behave as a two-wire differential transmission line. Signals transmitted into the track at the crossing would travel to the train and be reflected by the train shunt back to the crossing, and the round trip time delay would allow the distance to be determined. Note that the high speed of electrical pulses traveling in the track means that test cycles could be repeated hundreds of times per second. One goal was to improve prediction accuracy by continuously measuring the precise distance to the approaching train, and including train acceleration or deceleration in the arrival calculation. A second goal was to extend the range beyond the present method so that the same 20-second typical warning time could be provided at increased train speeds, in anticipation of high-speed passenger trains. An additional goal was to provide additional warning time to facilitate traffic signal preemption, and allow improved traffic flow by clearing as much traffic as possible over the crossing before train arrival, and allow traffic not crossing the railroad to move freely during train occupation.

A bench system was assembled to test the proposed concept. The test system used 1,000 ft rolls of transmission line cable to simulate the track propagation delay, with precision attenuators to provide the equivalent signal loss at various detection ranges. Electrical matching networks were used to simulate the characteristic impedance and frequency response for a range of typical railroad track conditions, both wet and dry.

During the bench system development, various problems were encountered. Progress was made to solve some technical problems, but others could not be resolved. One significant breakthrough was solving the problem of the high signal attenuation rate of typical railroad track that is caused by ballast and tie conductance, particularly where dirt, mud, moisture and other contaminants are present. Current flow between the rails, also known in the railroad signaling industry as “ballast leakage”, dissipates the differential electrical signal travelling along the rails, about 100 to 150 dB for the target train detection range of 8,000 to 12,000 ft. By applying advanced signal processing methods, this amount of attenuation was successfully managed using signal correlation techniques to recover the highly attenuated signals. A signal coding and modulation method was developed that allowed the use of pulses as short as a single half-cycle. These signals were successfully recovered and correctly identified in the presence of noise and other similar signals (with different modulation codes) at simulated track distances up to 5 miles for dry track and 3 miles for wet track. Since TDR is based on signals travelling to and from the reflector, this distance corresponds to a detection range of 13,200 ft. and 7,920 ft. respectively.

The major unresolved problem related to the need to use low frequency pulses, due to the low-pass frequency response of typical railroad track, which in turn related back to the tie/ballast conductance. In accordance with transmission line theory, this conductance produces an inductive component in the transmission line impedance, so that attenuation increases with frequency. This set up a dilemma in the system design: lower frequencies must be employed to limit attenuation to manageable levels, but lower frequencies mean longer pulse widths that cause timing problems due to the end of the transmit pulse overlapping the beginning of the received pulse reflected from the approaching train.

Most of the research effort was an attempt to solve the problem of overlapping transmitted and received pulses. First of all, the pulse length was limited by using a single half-cycle. Improvements were then made to ensure that at the end of the transmit pulse, the transmit amplifier was rapidly switched off. Further improvements were achieved by constructing a receiver amplifier with rapid recovery from the high voltage transmit pulse, and then adding a gating stage to block any residual signal from the transmit pulse. All of these efforts improved the potential range, but not enough to meet the project design goals.

A second approach to solving the signal overlap problem was devised, based on developing a 2-wire/4-wire “hybrid”. In theory, a hybrid should allow simultaneous pulse transmission and reception (i.e., reception of the reflected pulse could begin before the transmitted pulse was completed). There was partial success when the transmission line impedance was constant. However, when the transmission line impedance was varied to simulate changing track conditions (ballast moisture content, etc.), the balance of the hybrid was disturbed so that the transmitted pulse was no longer cancelled properly in the receiver port. A possibility for future research would be a self-adaptive hybrid that continuously monitors track impedance and adjusts the hybrid to maintain cancellation of the transmit pulse from the received signal. Developing such a hybrid is a research effort that is beyond the scope of this project.

Another unresolved problem was the availability of a suitable test track for field trials. Testing was planned to take place on the Precision Test Track at the Transportation Test Center, Inc. facility near Pueblo, Colorado. The advantages of this track were the controlled access with no rail traffic, lack of signaling (no risk of damaging or being affected by existing wayside equipment), and the ability to have the track modified as needed (e.g., uncoupling bolted joints to create electrically isolated test sections). However, during a detailed on-site assessment of the track, a major problem with the track condition became evident. Along both rails, dirt had built up to and over the tie plates and foot of the rail, and the ballast conductance was found to be much higher than for typical railroad track. Running a ballast sweeper along the track would have improved the situation, but dirt build up throughout the ballast and under the rail and tie plates would still be an issue. What would be needed for future research is a track with ballast conductance low enough to suit conventional track circuits, but with track circuits not installed (or able to be disconnected during testing).

Overall, TDR might still be worth considering for extending the range and accuracy of HRGC train predictors, but practical implementation was more complex than expected. The problems of applying TDR to the task of train arrival prediction all relate to the level of conductance between the rails. Some specialized applications may be technically feasible, such as electrified rail where the rails are usually well insulated from the ties and ballast, and hence each other, but a means of separating the returning reflected pulse from the original transmitted pulse is needed for more general railroad application. What would be required is a hybrid with very high isolation between the transmitter and receiver ports, and the ability to adapt to the varying impedance due to changing track condition.

1. BACKGROUND AND OBJECTIVES

The objective of this research was to develop an alternative method of detecting trains approaching a Highway-Railroad Grade Crossing (HRGC), and estimating the arrival time to activate the crossing warning system. Where active warning systems such as flashing lights, bells and gates are provided at HRGC, motorists need an adequate warning time to safely recognize the danger and slow to a stop before the train arrives. However, if the warning time is consistently too long, motorists may come to believe they can ignore the initial warning. Inconsistency is also a problem, as motorists who are expecting a short delay might interpret a long delay as a false warning, and then attempt to bypass the warning system.

The Federal Railroad Administration (FRA) regulatory requirement for active warnings is to provide motorists with a minimum 20-second warning. The existing train detection method is based on measuring the impedance of the loop formed by the measuring system, the two rails, and the first axle of the train. This method has proven reliable, and the railroad industry is generally successful at meeting the regulatory minimum warning time of 20 seconds. However, in one survey the actual time was found to vary from 20 to 90 seconds [Stephen H. Richards, K.W. Heathington, and Daniel B. Fambro, "Evaluation of Constant Warning Times Using Train Predictors at a Grade Crossing with Flashing Light Signals", Transportation Research Record, Transportation Research Board, Washington, D.C., 1990, pp. 60-71], with a 42-second average. This excessive warning time means that motorists are often forced to wait unnecessarily, and inconstant warning time also makes driver response less predictable.

Another problem is that a longer warning time is necessary to implement highway traffic signal preemption. To improve traffic flow at road intersections near HRGC, traffic signal timing cycles and sequences can be modified to give preference to traffic across the railroad ahead of the train arrival. This helps clear this traffic and helps the traffic not crossing the railroad to continue moving while the crossing is occupied. However, 60 or more seconds advance warning is required to make meaningful improvements to traffic flow.

Finally, the trend towards higher passenger train speeds means that trains will need to be detected at a greater distance to still provide the required warning time. "High speed" generally refers to operating speeds of 90 MPH or greater. For train speeds over 95 MPH in the Northeast Corridor and 125 MPH elsewhere, railroad and highway traffic must be grade separated, but it is likely that some high-speed services will operate below these limits, at least over some track sections, so HRGC warning systems might be required to operate up to the speed limits, plus some additional safety margin for over-speed. To provide a guaranteed 20-second warning, the train must be first detected approximately 35 seconds before reaching the HRGC. This allows an additional 5 seconds to confirm detection and calculate speed and arrival time, and a 10 second safety margin. The present train predictor method has a range in the order of 4,500 ft. The following figure indicates that this is not adequate to provide the necessary warning time (let alone any preemption time).

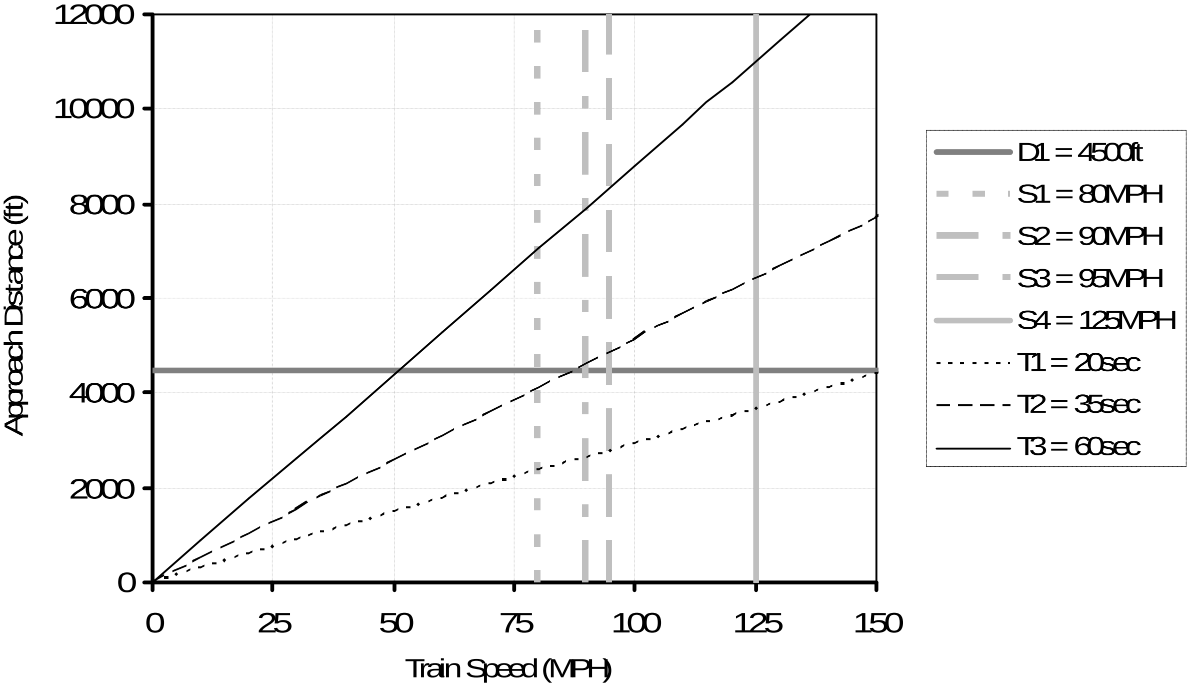


FIGURE 1 Required detection range versus train speed and warning time.

Figure 1 presents some of the relationships between train speed, warning time, and the required detection range. This figure includes:

D1 (4,500 ft.)	Typical upper detection range for existing crossing predictors.
S1 (80 MPH)	Maximum allowed train speed in the Northeast Corridor for conventional warning gates.
S2 (90 MPH)	Beginning of “High-Speed” services.
S3 (95 MPH)	Maximum allowed train speed in the Northeast Corridor for four-quadrant warning gates.
S4 (125 MPH)	Maximum allowed train speed in U.S.A. before mandated grade separation.
T1 (20 sec.)	Minimum regulatory warning time.
T2 (35 sec.)	Practical warning time including 5 second equipment response and 10 second safety margin.
T3 (60 sec.)	Warning time required to provide traffic signal preemption.

The figure shows that in theory, existing crossing predictors could provide the required 20-second warning for train speeds well past the 125 MPH limit (where grade separation becomes mandatory). However, this does not allow for any equipment response time or safety margin. A more practical warning time requirement is 35 seconds, which would only allow for train speeds up to 88 MPH. This would not allow for high-speed trains operating in the Northeast Corridor with four-quadrant warning gates, or conventional gates elsewhere in the U.S.A. Also note that in order for the present crossing predictors to provide a 60-second warning time for traffic signal preemption, train speeds must be limited to 51 MPH.

The next-generation train predictor needs to operate with train speeds up to at least 125 MPH. Figure 1 shows that this requires a detection range of 6,417 ft to provide a 35-second warning, and 11,000 ft. if a 60-second warning is needed for traffic preemption. For high speed trains operating with quad gates in the Northeast Corridor, the range would need to be a minimum of 4,877 ft., increasing to 8,360 ft. if preemption is needed. Based on this analysis, the target detection range for this research was set between 8,000 and 12,000 ft.

2. IDEA PRODUCT

The anticipated product of this research was an alternative train predictor, having extended range and accuracy. This research determined that a TDR-based train predictor is probably not possible to implement on most existing railroad tracks due to excessive conductance between the two rails.

3. CONCEPT AND INNOVATION

The purpose of this research was to develop and test a prototype sensor for detecting approaching trains. The key technological principal was Time Domain Reflectometry (TDR), based on using the track as an electrical transmission line. TDR is commonly used to detect and locate breaks and short circuits in long communication and power distribution cables, and relies on detecting the reflection caused by any changes in the characteristic impedance of the cable. The distance to the reflector is calculated by establishing the velocity of electromagnetic wave propagation in the cable, and then calculating the distance to the break or short by measuring the time delay between transmit and receive.

Every transmission line has an associated characteristic impedance that is determined by the physical cross section and the electrical properties of the conducting and insulating materials used in construction. An electrical fault in the transmission line will cause a local deviation from the characteristic impedance. Any signal arriving at the fault will have some of the signal energy reflected with the remainder continuing on. The proportion of energy reflected is determined by the degree of impedance mismatch. A complete short circuit or a complete open circuit represents the maximum possible mismatch and causes a 100% reflection. A smaller mismatch reflects part of the energy, according to the degree of mismatch, with no energy reflected if there is no mismatch. The phase of the reflected signal identifies whether the fault is a higher or lower impedance than the characteristic value, so that a reflection from an open circuit can be easily distinguished from the reflection from a short circuit. The time delay between transmitting and receiving the pulse can be used to calculate the distance to the fault for a known propagation velocity.

For occupied rail detection, the two rails would act as the transmission line (although the signal attenuation rate is relatively high due to less than perfect insulation between the rails) and the first axle of the train would provide the short circuit or shunt between the two rails. Electrical pulses would be transmitted into the track at the HRGC as a differential pulse between the two rails that would travel outward in both directions. The shunt of an approaching train would reflect these signals back to the HRGC connection point, and the time delay would determine train distance. Tests would be repeated hundreds of times a second to provide speed and acceleration, and from this the exact arrival time would be calculated. If the direction of the approaching train was needed, two connection points could be used, say, either side of the crossing, and the timing difference would indicate the direction to the train. Since train detection is based on electrical pulses conducted along rails, the sensor would be compatible with many existing tracks and construction methods designed for electrical track circuits.

To ensure correct and safe operation, both rails would need to provide electrical continuity. A broken rail would prevent the signal reaching an approaching train. Fortunately, a broken rail would also change the transmission line impedance and reflect the pulses. In fact, the timing and phase of the reflected signal would identify the broken rail and provide the exact location.

Another critical technology is signal correlation; matching the received signal to the transmitted coded pulse and then integrating these results over many test cycles (with allowance for timing changes due to train speed). Signal processing would be required to detect the highly attenuated returning echo signals because the track is a poor transmission line due to tie/ballast conductance, etc. (Note: This same signal processing method would also be useful to extend the range of a conventional track circuit.)

4. INVESTIGATION

The performance objective was to improve on the range and accuracy of existing crossing predictors. The required range was determined to be between 8,000 to 12,000 ft for typical, track circuit-quality railroad, wet or dry conditions (see section 1 above for a discussion of warning requirements).

The bench prototype was based around existing laboratory-grade digital-to-analog and analog-to-digital instrumentation. A high-power linear amplifier and low noise receiver was also employed. Software was written to generate, transmit, receive, digitize and analyze signals to perform Time domain Reflectometry. Several reels of coaxial transmission line cable were used to simulate varying lengths of railroad track. Baluns and matching networks were built to convert the unbalanced coax impedance into a balanced impedance close to the predicted railroad track characteristics. Precision attenuators were used to simulate different rates of track attenuation, reflector distances and shunt resistance. A hybrid and two directional couplers were also built to test the concept of allowing the transmitted and reflected pulses to overlap in time. The bench prototype design is depicted in Figure 2 below.

An initial goal of this design was to allow field measurement of actual track impedance to validate the theoretical modeling. The idea was to separate the transmitter and receiver modules so that they could operate at either end of a test section of track. Since the exact track length would be needed to derive all the propagation constants, it seemed reasonable to use GPS receivers at each end to provide timing information as well as exact location. A long-range WiFi link was successfully developed to allow the control PC at one end to control all functions and coordinate the transmit and receive functions.

This would have provided a convenient field test system for measuring track properties across a range of track types and locations. The problem encountered was that to provide precise velocity measurements, a coherent timing source was needed between the two ends. In theory, the timing references derived from the GPS modules should have been coherent to within 10 nS. In practice, the modules from two different manufacturers both exhibited much larger variations that would have made the collected measurements of signal propagation unusable.

Even after working extensively with both manufacturers, including many firmware updates, this timing problem could not be resolved. In retrospect, it would have been simpler to design RF transmitters and receivers to distribute a common reference clock. Once the GPS approach was abandoned, a much simpler but far less flexible alternative plan was devised. The idea was to use the coax from the bench track simulation, and simply transfer the signal from the receive end of the test track section back to the transmit end. With the signal generation and signal digitization at the same location, a common timing reference was easy to accomplish. An initial calibration, with the coax looped by itself, would provide the coax delay time that would be subtracted from all subsequent measurements. Note that a critical requirement of this approach would be to run the coax down the centerline of the track, so as not to disturb the electrical balance of the two rails acting as a differential transmission line. It should also be noted that this method of synchronizing timing between two sites is suggested for experimentally determining track propagation characteristics, and would not be suitable as part of a commercial system due to installation and maintenance problems and the susceptibility to vandalism.

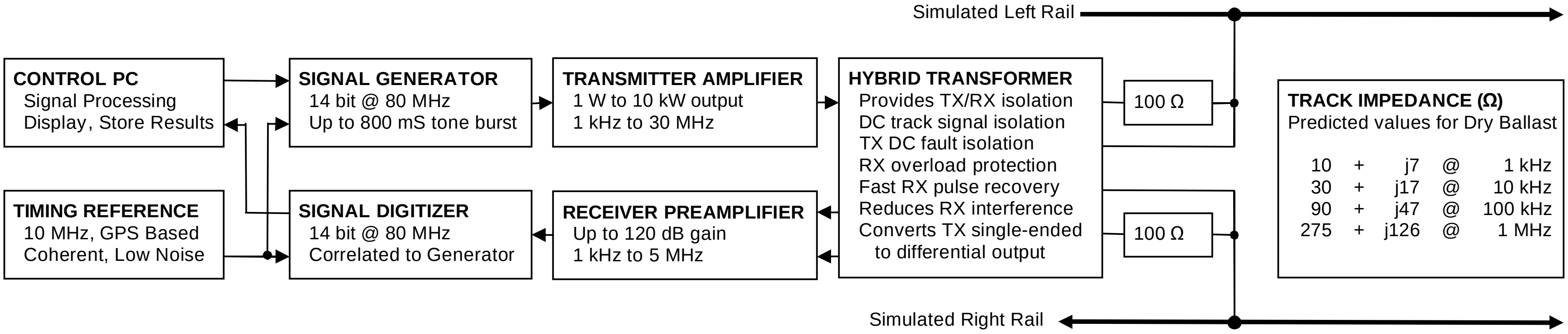
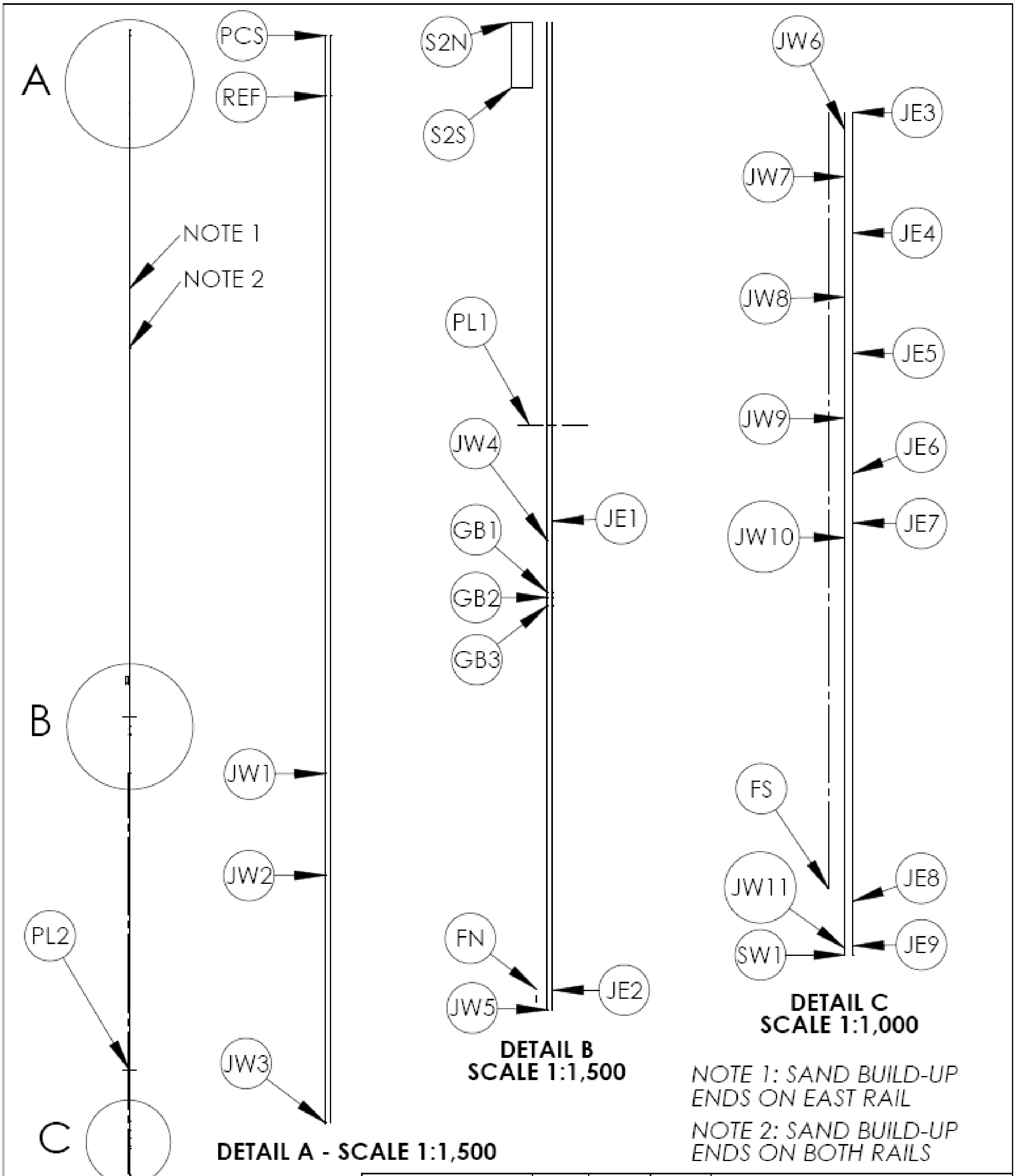


FIGURE 2 Bench Test System Block Diagram.

Another component of the original experimental design was to field test the system at the Transportation Technology Center, Inc. (TTCI). For the first round of testing, the plan was to use the Precision Test Track (PTT). The advantage of this track would have been that there are no signaling systems connected, so there would be no risk of either damaging existing wayside equipment or having it interfere with the results. Another advantage would be the low traffic usage, so that this initial field testing would not interfere with other TTCI test programs. The PTT would be used to develop the TDR test system. These results would then have been taken to the two major USA signaling companies, with the aim of bench testing the prototype system to determine compatibility with their existing signaling equipment. The research plan was then to return to TTCI, and perform a final round of testing on one of the loop tracks. This testing would have determined the prototype reliability and accuracy using the regular traffic performing other TTCI testing.

A site visit was made to map out the mechanical and electrical features of the PTT. The survey results are presented in Figure 3 below, and the legend is provided in Table 1 following. Unfortunately, after analyzing some preliminary electrical measurements, it became clear that the PTT was not suitable for the proposed research. The main problem was the amount of dirt and dust within the ballast and, in many areas, over the tie plates and the foot of the rail. Even if this was removed (perhaps using a ballast sweeper and/or high pressure water), the amount of dirt mixed into the ballast would probably still cause problems with “ballast leakage” i.e., electrical conduction between the rails. Figure 4 is an example of the dirt buildup over the tie plates and foot of the rail for some areas of the PTT. In discussions with Richard Reiff of TTCI, it was his opinion that the PTT ballast condition represented some of the U.S. tracks that already had signaling or where signaling was desired, and that any train sensor should be able to cope with these conditions.

To develop the proposed sensor method, close to ideal conditions are required to first develop the method into a working field prototype. If the sensor performs in these conditions, then it might be possible to fine-tune the method to cope with greater amounts of ballast conduction. The concern is that attempting to first test the method on a track with high ballast conductance such as PTT would be a waste of time, money and effort, since if there is no measurable signal there would be no way to know what adjustments to make to improve signal reception. Opportunities to test on tracks with low ballast conductance are being pursued separately from this contract.



TTCI PTT TRACK SURVEY
SCALE 1:15,000

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NEXT ASSY USED ON
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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
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THREE PLACE DECIMAL ±
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DO NOT SCALE DRAWING

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COMMENTS:

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TTCI PTT TRACK SURVEY

SIZE A
DWG. NO. 1 of 1
REV.
SCALE:1:15000 WEIGHT: SHEET 1 OF 1

FIGURE 3 PTT Survey.

TABLE 1 PTT Survey Legend

Name		**Location**				**Joint Information**	
Code	Description	Feet	Mile	Meter	Rail	Gap	Bolts
PCS	Passenger Car South End	-58.2	-0.011	-17.7			
REF	Reference Point	0.0	0.000	0.0			
JW1	Joint West #1	652.1	0.124	198.8	W	7/8"	4
JW2	Joint West #2	750.0	0.142	228.6	W	3/4"	6
JW3	Joint West #3	988.7	0.187	301.3	W	3/4"	4
	Sand Ends Both Rails	2428.0	0.460	740.1			
	Sand Ends East Rail	3000.0	0.568	914.4			
S2N	Shed 2 North End	6168.0	1.168	1880.0			
S2S	Shed 2 South End	6231.0	1.180	1899.2			
PL1	Power Line #1	6555.8	1.242	1998.2			
JE1	Joint East #1	6648.3	1.259	2026.4	E	5/8"	4
JW4	Joint West #4	6666.9	1.263	2032.1	W	1/2"	4
GB1	Gauge Bar #1	6716.9	1.272	2047.3			
GB2	Gauge Bar #2	6721.8	1.273	2048.8			
GB3	Gauge Bar #3	6729.8	1.275	2051.2			
FN	Fence North End	7098.9	1.344	2163.7			
JE2	Joint East #2	7099.8	1.345	2164.0	E	3/8"	4
JW5	Joint West #5	7118.8	1.348	2169.8	W	1/2"	4
PL2	Power Line #2	9951.3	1.885	3033.2			
JE3	Joint East #3	10451.1	1.979	3185.5	E	0"	6
JW6	Joint West #6	10462.2	1.981	3188.9	W	0"	6
JW7	Joint West #7	10492.6	1.987	3198.1	W	0"	5
JE4	Joint East #4	10528.6	1.994	3209.1	E	0"	6
JW8	Joint West #8	10569.7	2.002	3221.6	W	0"	6
JE5	Joint East #5	10605.8	2.009	3232.6	E	1/4"	6
JW9	Joint West #9	10647.2	2.017	3245.3	W	3/16"	6
JE6	Joint East #6	10682.7	2.023	3256.1	E	0"	6
JE7	Joint East #7	10714.6	2.029	3265.8	E	0"	6
JW10	Joint West #10	10724.1	2.031	3268.7	W	0"	6
FS	Fence South End	10949.3	2.074	3337.3			
JE8	Joint East #8	10957.4	2.075	3339.8	E	3/8"	6
JE9	Joint East #9	10986.0	2.081	3348.5	E	0"	6
JW11	Joint West #11	10987.5	2.081	3349.0	W	1/16"	?
SW1	Switch #1	10991.8	2.082	3350.3			

FIGURE 4 PTT Picture of Dirt and Dust Build-up in Ballast.

5. PROJECT PANEL

The HSR-50 panel members were:

Jeff Gordon, Department Of Transportation, Volpe Center
Bob Kubichek, University of Wyoming
Bob McCown, Federal Railroad Administration, Retired
Don Plotkin, Federal Railroad Administration
Rich Reiff, Transportation Technology Center, Inc.

The HSR-IDEA Program Officer was:

Chuck Taylor, Transportation Research Board

The panel members and Program Officer participated in the initial telephone conference and the following questions were discussed:

Q1. Will this system attach at a single point on the track or is this more like a track circuit?

A1. A simple version could attach at the crossing. The pulses would be transmitted, reflected by the approaching train (off the first axle shunt), and received back at the same connection. The distance and speed of the train would be calculated by the time delay. This setup would not know the approach direction of the train. If that is required, a second connection would be needed near the crossing, i.e., the transmitter and one receiver on one side of the grade crossing and a second receiver on the other side (say, 5 to 20m apart). The direction of the slight delay between the two received signals would give the train direction. (Note: a train coming from the other direction would still be detectable independently as a second echo pulse.)

Q2. What is the expected range and accuracy?

A2. According to the calculations done in HSR-38, a range of 1 to 1 ½ miles should be possible for most conditions. Distance accuracy could be within a few meters if the pulse velocity is accurately known. The pulse velocity will vary slightly with conditions such as ballast moisture, but a passive test reflector (e.g., 100 ohm shunt resister) placed, say, 1 km from the crossing would allow the system to automatically calibrate. This test reflector could also be part of a system self-test, i.e., if the reflector is not detected in the expected distance range, a system failure would be assumed.

Compared to the loop resistance method, the accuracy will only be slightly affected by the track shunt impedance. Shunt sensitivity is often tested at around .06 ohm. Using the TDR method, a shunt impedance of 10 ohms or even higher would be nearly as "visible" as an ideal shunt. The loop resistance method can not distinguish between a varying shunt impedance and equivalent large changes in distance (i.e., rail has an extremely small resistance per foot). The TDR method would see a small change in echo amplitude as the shunt varied, but the timing would still give the accurate distance.

Q3. How will specific site conditions affect range and accuracy (mineral deposits, salt on the crossings, ballast contamination, water, mud)?

A3. If the condition is reasonably consistent over a long distance, it will probably be taken care of during initial calibration and by using a reference reflector. If the condition is only over a short distance, it would have a proportionally small effect on the signal timing and amplitude. For example, if the signal speeds up or slows down due to a location with mud in the ballast, the effect on echo timing may not be significant if the track condition represents just a fraction of the overall signal path. Also, the change in track impedance caused by the mud would produce a small reflection, but it should be easy to recognize that it is not the 100% reflection caused by a track shunt, and since it would not be moving, the software could determine that it was definitely not an approaching train.

Q4. Obstructions can greatly reduce WiFi range and reliability. Will this be a problem for these tests?

A4. Probably not. TTCI site is very flat and very few trees or buildings. The PTT track section that will be used is straight and has no obstructions. The loop track testing will not use separated TX and RX stations so the communications range will be much shorter.

Q5. If the first axle of an approaching train is making poor or intermittent contact across the rail, the system may see intermittent reflections from subsequent axles. Could pattern recognition be used to correct for this possibility?

A5. Yes. The key point is that if reflections were seen from the first and second axles, the software would need to determine that both intermittent reflectors were traveling at the same speed, and it was probably part of the same train. If reflector location can be determined accurately enough, it may also be possible to measure the distance between the axles as part of confirming that this is a valid reflector.

Q6. What will be the effect of power control electronics in trains?

A6. The prototype system will be able to sample all signals over a broad bandwidth. I will check this data for other signals at TTCI, including train AC-chopper signals. To get an adequate test range, the final system will use signal correlation to recover the highly attenuated echo signals. Signal correlation helps suppress other signals that do not match the transmitted signal pattern. I will also check for interference from radio stations, power lines, etc.

Q7. Why is the signal generator operating at 80 Mhz to produce a 10 Mhz signal?

A7. 80 Mhz is overkill, but this is to use our existing signal generator. Although it probably won't be necessary, the high sample rate could be used to synthesize a 20 MHz output data rate with four times over-sampling. This would provide an extra 2 bits of signal accuracy, i.e., 16 bit signal accuracy instead of 14 bit.

Q8. What will be the liability issues for testing at TTCI?

A8. Analogic Engineering, Inc. has the liability insurance specified in our contract. Any mechanical alterations to the track that might affect safety, such as unbolting or adding joints, will be limited to the PTT tests in Stage 2. These tests will not involve train movements. Stage 3 testing on the loop tracks will use existing electrical connections or temporary clamp connections to the rail, clear of the running surface. This work will only proceed after testing to ensure electrical compatibility with other equipment and approval by TTCI staff.

The following comments and suggestions were made:

- Track at TTCI may be close to ideal conditions, i.e., very dry. Expect that conditions may reduce range at other test locations. Experience indicates that using a fire truck to drench the ballast does not accurately simulate rain-soaked track.
- Consider if the two track connections could be used for an island circuit. It is critical the gates go up within 2 or 3 seconds once the train has cleared the crossing.
- WIFI will be used to control and collect data between the three test stations. Need to coordinate to ensure compatibility with existing data communications and learn from other TTCI projects related to track communications systems. .
- Be aware that many other signals may be present in track apart from track circuit signals; electrified rail can have large induced rail currents from AC chopper circuits, as well as power lines, cab signaling, etc.
- Need to develop a cost estimate compared to conventional crossing predictors.

6. FINDINGS AND CONCLUSIONS

The proposed TDR-based train predictor does not appear to be feasible due to the conductance (i.e., ballast leakage) between the rails for typical railroad tracks. If it were possible to reduce the level of conductance, the pulse frequency could be increased to avoid the transmit/receive signal overlap problem. Note that existing track circuit methods would also benefit from reduced ballast conductance. A possible solution is a specialized "hybrid" – a device that allows transmitted and received signals to share the same transmission line port connection by separating the signals. This is usually accomplished by subtracting the transmit signal from the total signal on the transmission line port, leaving just the incoming (received) signal. Hybrids are relatively simple to design and implement where the transmission line impedance is purely resistive and constant. However, in this case the track transmission line impedance is inductive (and therefore frequency dependant) and varies with track conditions, so the hybrid would also need to determine and adapt to track conditions. This would be difficult to achieve, particularly with the very high difference in transmit and receive signal levels required (up to 70 dB).

7. PLANS FOR IMPLEMENTATION

There are no present plans for implementation. Analogic Engineering, Inc. has been contacted by STI-Global and signed mutual Non-Disclosure Agreements in order to pursue technical collaborations. One possibility for continuing research into the more promising aspects of this research is a new 50-mile CWR mining line, for which STI-Global are consultants on train control and communications. The track has no signaling, but is of very high quality construction designed for up to 30-ton axle loads. The plan is to adapt the bench system for field use, and test the maximum range that an electrical pulse can be transmitted from one location and reliably received at a distant location. In this case, there is no pulse overlap problem, and the processing methods developed in this research should provide a longer range than conventional signaling. The main purpose would be to provide broken rail detection, but with fewer wayside installations. Access to this track would also allow the testing that had been planned at TTCI to establish the TDR range (i.e., pulse-echo mode with the transmitter and receiver at the same location), but on signaling-quality track and without the concern of interfering with other track circuit systems.