Positive Train Location (PTL) - Supporting Next Generation Methods of Train Control and Operations

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Research Areas

- Train Control
- Intelligent Transportation Systems (ITS) (CV/AV)
- Grade Crossing Safety & Trespass Prevention
- Modelling & Simulations
Research Portfolio

Train Control

- Positive Train Control (PTC)
  - PTC Test Bed, I-ETMS, ACESS
  - Freight/Pass Advanced Enforcement Algorithm (AEA)
  - Positive Train Location (PTL)
  - Employee-In-Charge Portable Terminal (EIC-PRT)
  - Monitoring Analysis of Integrated Networks (MAIN)
  - Enhanced Overlay PTC (EO-PTC)
  - Advanced Track Circuit Research

- Next Generation PTC
  - Quasi-Moving Block (QMB)
  - Full Moving Block (FMB)
  - Onboard Broken Rail Detection
  - Centralized Interlocking Feasibility and Design

Automated Train Operation (ATO)

- System Safety Analysis
- System Requirement Development
- Sensor Test Bed Development

Communication

- Communication Test Bed Upgrade at TTCI
- Wireless Communication Roadmap
- Wideband Software-defined Radio

Train Control Cyber Security

- Security Methods in Low Bandwidth Environment
- Improved PTC User Authentication
Research Portfolio

Intelligent Transportation Systems (ITS) (CV/AV)

- ITS Research
  - Grade crossing taxonomy research
  - Higher Performance Digital Radio
  - DSRC Performance evaluation for railroad Applications
  - Automated vehicles requirement for grade crossing
  - Rail Crossing Vehicle Warning (RCVW)
Research Portfolio

Grade Crossing Safety & Trespass Prevention

• Crossing Technology Research
  • Hump Crossing Scanning and database update
  • Automated Lidar grade crossing data extraction
  • Vehicle and pedestrian detection at grade crossing

• Trespass Prevention
  • Trespass detection using drones
  • Using Artificial Intelligence (AI) for trespass prevention

• Human Factors Studies
  • Driver Behavior Analysis
Research Portfolio

Modelling & Simulations

• Simulation
  • Generalized Train Movement Model

• Modeling
  • GrageDec.Net garde crossing online tool
Click on Reports
Then, click on Research Results or Technical Reports
Positive Train Location (PTL)
GPS Tracking

7 visible satellites
Motivation for PTL Research

- Safety and operating efficiency of modern train control including PTC systems dependent on:
  - Accuracy and confidence of location of head of train (HOT),
  - Accuracy and confidence of location of end of train (EOT), and
  - Train length accuracy.

- Current Interoperable Train Control (ITC) implementation of Positive Train Control (PTC) relies on GPS for HOT location determination with 15m accuracy at 95% confidence level

- EOT location is derived from GPS position of HOT, crew-entered train length, and known switch position.

- These uncertainties limit PTC system safety benefits, operational efficiency, and line capacity.
Examples of Impact of Train Position Uncertainty

- True location of HOT
- GPS HOT position report at 95% confidence

PTC cannot positively identify which track is occupied by the train

Without EOT location PTC cannot positively determine if train on siding is clear of main track

Without positive HOT and EOT location PTC cannot positively determine which tracks are occupied by a train
GPS with Differential Correction

- GPS with differential correction provides positioning **accuracy of 3m** at 95% confidence.

Trains on adjacent tracks may report same location!

GPS w/ differential Correction HOT position report at 95% confidence

GPS with differential correction insufficient to positively resolve track occupancy of trains.
How accurate is PTL required to be?

<table>
<thead>
<tr>
<th>Positioning Technology</th>
<th>Accuracy</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>15 m</td>
<td>95%</td>
</tr>
<tr>
<td>GPS w/ differential correction (e.g., WAAS)</td>
<td>3 m</td>
<td>95%</td>
</tr>
<tr>
<td>PTL</td>
<td>0.35 m</td>
<td>95%</td>
</tr>
</tbody>
</table>

Comparison of relative positioning accuracies at 95% confidence using 12-foot track centers (drawn to scale)
PTL Benefits

- Eliminate human errors in manual entry of train length and track selection at train initialization
- Positive track discrimination
- Automatic safe release of authority behind the train in dark territory
- Positive determination of switch and block clearing
- Rear-of-train protection when shunting cars
- Increase track capacity through closer following moves
- Supports implementation of moving block
PTL Development Timeline – Phase I

Phase I (2011-2012) - FRA Grant to Railroad Research Foundation to identify and evaluate of improved location technologies and develop a Proof of Concept (PoC) PTL systems to meet the following requirements without aid of external reference or satellite subscription service (partial list):

• Performance Requirements*

<table>
<thead>
<tr>
<th>Key Performance Parameter</th>
<th>Value</th>
<th>Confidence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT/EOT Position Error</td>
<td>&lt;= 1.2 m</td>
<td>99.999999997%</td>
</tr>
<tr>
<td>Train Velocity Error</td>
<td>&lt;= 0.1 mph</td>
<td>99.99%</td>
</tr>
<tr>
<td>Train Heading Error</td>
<td>&lt;= 1°</td>
<td>95%</td>
</tr>
</tbody>
</table>

* To accomplish this, the PTL system must be capable of providing position accuracy of < 18cm (1 σ) along- and across-track standard deviation.

• Functional Requirements
  • System availability of 99%
  • Support HOT/EOT communications for freight trains up to 5 miles in length and passenger trains up to 1000 ft.
  • Track HOT/EOT navigation state in all environments (with and without GPS) and maintain for at least one hour
  • Monitor and report PTL health status to onboard PTC system
Phase II (2013 – 2017) – FRA awarded TTCl task order contract with Liedos (winning contractor from phase I) to expand the development of the PoC PTL system for integration and testing with an ITC-compliant PTC onboard system on revenue-service tracks.

- Integrate PTL HOT hardware onto ACC card chassis
- Integrate PTL EOT hardware with ETD
- Effort overseen by PTL Advisory Group made up of representatives from FRA, VOLPE, BNSF, UP, NS, and CSX
- Railroad members of PTL Advisory Group are supporting revenue-service testing
PTL Phase I Testing at Transportation Test Center (TTC)
Evolution of PTL Hardware

Phase I
Proof-of-Concept “Breadboard” Hardware

Phase II
PTL-HOT Sensors Integrated onto AAR-Standard Application Card Cage (ACC) Card (Left)

PTL-EOT Sensors Integrated into Ruggedized Housing that fits within ETD (Right)
Phase II Hardware As-Installed

PTL Head-of-Train Hardware

PTL HOT application card hosted within AAR-standard ACC chassis installed in locomotive

PTL HOT antennas (GPS and 900 MHz HOT-EOT comms) installed on mag-mount platform on locomotive roof (mag-mount temporary solution used for testing)

PTL End-of-Train Hardware
(ETD hosts PTL’s antennas [GPS and 900 MHz HOT-EOT communications], and provides power to PTL)

PTL EOT hardware internally integrated within ETD
PTL Testing at TTC

Rigorous testing of the PTL functionality, hardware, and software at TTC using 3 trains which resulted in software algorithm refinements, hardware circuitry modifications, and the 900 MHz radio link reconfiguration.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clockwise and Counter-clockwise loops around primary tracks with constant and variable speed operation.</td>
</tr>
<tr>
<td>2</td>
<td>Determine position of the train during static operations.</td>
</tr>
<tr>
<td>3</td>
<td>Determine position accuracy at initialization in a variety of configurations (on surveyed, un-surveyed, and mixed configurations)</td>
</tr>
<tr>
<td>4</td>
<td>Determine HOT and EOT accuracy during switching (coupling / uncoupling operations) under a variety of track conditions</td>
</tr>
<tr>
<td>5</td>
<td>Determine navigation accuracy during radio communication failures</td>
</tr>
<tr>
<td>6</td>
<td>Test position operations under severe multi-path conditions as well as antenna blockage conditions</td>
</tr>
<tr>
<td>7</td>
<td>Determine navigation accuracy for variety of dynamic and track conditions including breaking scenarios</td>
</tr>
<tr>
<td>8</td>
<td>Determine navigation accuracy under high-speed conditions (~100 mph) and during rapid acceleration/deceleration</td>
</tr>
<tr>
<td>9</td>
<td>Determine navigation accuracy for various GPS denied conditions including tunnels and extended outages</td>
</tr>
</tbody>
</table>
PTL Railroad Field Testing

BNSF, UP, NS, and CSX performed the revenue-service testing for thousands of miles and millions of data samples over repeated routes with variety of terrains (mountain, plains, urban canyons, foliage) to test HOT, EOT, 900 MHz radio link performance.

HOT Antenna Bracket and Antennas (Directional Radio 1, Omni-Directional Radio 2, and GPS)

HOT Radios, Battery, and data Logger

BNSF Test Route

NS Test Route
## PTL Test Results

### Ideal Configuration*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Accuracy</th>
<th>Confidence</th>
<th>PTL Spec.</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT ↔</td>
<td>0.15m (1 σ)</td>
<td>Twelve 9's</td>
<td>&lt;= 0.18m (1 σ)</td>
<td>Ten 9's</td>
</tr>
<tr>
<td>HOT ↑</td>
<td>0.18m (1 σ)</td>
<td>Ten 9's</td>
<td>&lt;= 0.18m (1 σ)</td>
<td>Ten 9's</td>
</tr>
<tr>
<td>EOT ↔</td>
<td>0.11m (1 σ)</td>
<td>Fifteen 9's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOT ↑</td>
<td>0.27m (1 σ)</td>
<td>Five 9's</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Revenue Service Configuration**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Accuracy</th>
<th>Confidence</th>
<th>PTL Spec.</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT ↔</td>
<td>0.18m (1 σ)</td>
<td>Ten 9's</td>
<td>&lt;= 0.18m (1 σ)</td>
<td>Ten 9's</td>
</tr>
<tr>
<td>HOT ↑</td>
<td>0.24m (1 σ)</td>
<td>Five 9's</td>
<td>&lt;= 0.18m (1 σ)</td>
<td>Ten 9's</td>
</tr>
<tr>
<td>EOT ↔</td>
<td>0.396m (1 σ)</td>
<td>Five 9's</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOT ↑</td>
<td>0.461m (1 σ)</td>
<td>Five 9's</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Ideal test configuration, GNSS antenna had full visibility to GNSS constellations, EOT on flat car track database

** Non ideal test configuration, partially blocked GNSS/WAAS antenna EOT integrated with ETD, no track database, radio link spotty
PTL Test Results Conti.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Accuracy</th>
<th>Confidence</th>
<th>PTL Spec.</th>
<th>Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity Err</td>
<td>0.09 mph</td>
<td>99.99%</td>
<td>&lt;= 0.1 mph</td>
<td>99.99%</td>
</tr>
<tr>
<td>Heading Err</td>
<td>0.05°</td>
<td>99.98%</td>
<td>&lt;= 1°</td>
<td>95%</td>
</tr>
</tbody>
</table>

PTL range requirement to support HOT/EOT communications for freight trains up to 5 miles in length and passenger trains up to 1000 ft.

- Field testing revealed that the use of a 900 MHz frequency for EOT-to-HOT communications was insufficient to accommodate PTL range requirements subject to ETD rear car masking.
- 900 MHz band exhibited significant fall off > 0.8mi.
- Lower 160, 220, and 450 MHz frequencies has demonstrated notably extended range performance
- Using Wide Band Software Defined Radio (WSDR) and Diversity Combining leveraging multiple low frequency bands is presently in progress and is anticipated to notably enhance this challenging communication link.
Wabtec started producing PTL based technology and offer it as part of its product lines. Class I railroads have purchased and deployed in revenue service many units.
Next Generation HOT/EOT (NGHE)

In 2019 FRA R&D continued the development of the HOT/EOT to enhance performance and develop ConOps and interoperable requirements for NGHE. Project Goals are:

- Safety
  - Meet industry safety goals associated with EOTD initiated emergency brake applications
  - Provide EOT point protection during reverse moves
- Enable emerging methods of operation
  - Include PTL EOTD Functions
  - Quasi Moving Block (QMB)
  - Full Moving Block (FMB)
  - Road Remote Control Locomotive (Road RCL)
  - Automated Train Operation (ATO)
- Improved communication robustness between HOTD and EOTD
  - Authenticated Communication
  - Communication Repeater Use
  - Multiple Communication Links
- Capable of meeting operational constraints
  - Low power consumption
  - One person lift and carry
Relationship of Train Control Technologies

- PTL
- NGHE
- PTC
- QMB
- FMB
- Road RCL
- ATO

PTL includes NGHE. PTC enables QMB. FMB enables Road RCL. ATO improves the system.
PTL Impact

Fixed Block

Full-Moving Block

Dispatching System

Safety Server

BOS

MA Request

MA Confirmation

Checks MA Integrity

Switch Cmds

Switch Position

MAs

Location Reports

Train1

Train2

Movement Authority (MA)

Margin

Track Circuit

Train2

Train1

MA

CP

WIU

WIU

CP

MA

Want to know more about the impacts of PTL on railway operations?

Visit the U.S. Department of Transportation's Federal Railroad Administration website for comprehensive information.

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PTL Impact
Positive Train Location (PTL) - Supporting Next Generation Methods of Train Control and Operations

QUESTIONS?

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## Train Control Technologies

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<tr>
<th>Positive Train Control (PTC)</th>
<th>PTC is a safety and train control system that provides enforcement of mandatory directives to prevent train to train collisions, train overspeed, and work-zone incursions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quasi Moving Block (QMB)</td>
<td>QMB is a train control system that reduces train spacing and improves line capacity. In QMB operation, the convention signal blocks are retained, but exclusive PTC enforceable movement authority extensions, based on the end of train position of the leading train (with a safety margin) are used to manage train spacing between control points. Movement authority extensions are provided when (1) the when end of the leading train leaves a track circuit boundary, and (2) when the leading train reports its end of train position and “rolls up” its authority. Conventional track circuits provide broken rail/rolling stock roll-out detection in place.</td>
</tr>
<tr>
<td>Full Moving Block (FMB)</td>
<td>FMB is a train control system that optimizes train spacing and line capacity. In FMB operation, conventional signal are not used and train spacing relies on exclusive movement authorities based on the end of train position of the leading train. Simplified track circuits or alternative approach provides broken rail and rolling stock roll-out detection.</td>
</tr>
<tr>
<td>Road RCL</td>
<td>Road RCL provides line of road control of train movement locomotive(s) by an operator who is not in the locomotive cab.</td>
</tr>
<tr>
<td>Automated Train Operations</td>
<td>ATO is supported by the cooperative operation of PTC, providing enforcement of mandatory directives, energy management systems, providing control of train propulsion and brakes, and sensor systems, which detect and respond to environmental hazards. ATO enables safe and efficient train operation with reduced crews.</td>
</tr>
<tr>
<td>(ATO)</td>
<td></td>
</tr>
</tbody>
</table>