Real Time Kinematic Global Navigation Satellite Systems in Railroad Transportation

Peter J Dailey

West Virginia University
College of Engineering and Mineral Resources
Department of Civil Engineering
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Agenda

- Motivation for the Research
- Research Purpose and Objectives
- Experiments 1-3
  - Research question to be answered
  - Specific Objectives & Method
  - Results
  - Conclusions
  - Implications

Motivation

1. Loss of carload freight revenue relative to overall freight growth

   Carload freight has quality of service issues (Moorman)

2. Inspection of railway is critical and labor intensive

   Labor intensive reliance on inspector skill and diligence

3. Dependance on wired track circuits for train location

   Est. replacement cost of track signals: $125,000/mile

Yard Profile Survey Differential Level

CSX/NS SOA Track Measurement for Defect Detection

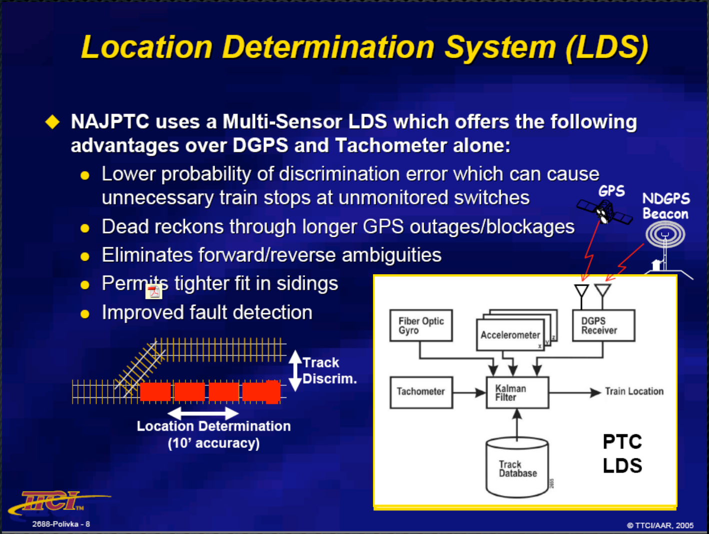
- CSX TGC-2
  - heavy / train / $$$
- NS TGC
  - heavy / train / $$$
- CSX GRMS-2
  - light / self-propelled / $$$
- CSX GRMS-1
  - light / self-propelled / $$$

RTK GPS Railway Measurement

May 2010

The *Swiss Trolley* - Glauss

FRA LDS Concept 2005



COTS GPS/GNSS Augmentation Services

- Standard Positioning Service, USDOD no augmentation
  - 25 m stated, 12.8 m horizontal in practice
- Space Based Augmentation Systems (SBAS), geosynchronous
  - WAAS, FAA: 3-5 meters horizontal
  - Subscription services: OmniStar
- Ground Based Augmentation Systems (GBAS)
  - NDGPS, USDOT: 1-5 meters, experimental (noCOTS) 10 cm horizontal. GPS correctors only via MF radio - 200 baud limitation
  - RTK GPS/GNSS VRS: 1-2 cm horizontal. GPS, GLONASS, Galileo correctors via VHF or cellular

Research Purpose

Determine RTK GPS/GNSS's ability to

1. Measure yard profiles

   Affect humpyard throughput, resulting in increased service reliability

2. Bridge a gap in mainline railway inspection methods

   Track geometry cars & visual inspection

3. Provide a reliable wireless location determination system

Research Objectives

- Design an experiment to asses RTK GPS onboard a locomotive
  - Obtain a data set for profiling the bowl area of a humpyard during car handling operations
- Design an experiment to asses RTK GNSS onboard a track inspector’s Hi-Rail
  - Track XYZ data > String line model > track information
- Design an experiment to asses RTK GNSS as the sole measurement component of a wireless track vehicle location determination system (LDS)

Commercial Constraints on Research Activity

Safety and access considerations of a Class I railroad

- Availability of track foul time ($1,500 fine per occurrence)
- Training Requirements of USC 49§214 On-Track-Worker Safety
- All field work superintended by a rail company employee-in-charge (subject to availability)
- $5M insurance policy, required by rail company for access

Instrument Constraints

- Commercial, off the shelf (COTS) GPS/GNSS instruments and systems
  - Dual frequency RTK GPS/GNSS receivers
    - ‘survey grade’
  - RTK VRS server
    - Networked CORS and IT infrastructure

Experiment 1
Hump Yard Profile Survey

Determine track grades in a hump yard by an RTK equipped locomotive during humping operations.

The Hump Yard

An efficient mechanism engineered and constructed for the specific purpose of breaking apart a consist and reassigning individual units for outbound shipment

- AKA: Automatic Classification Yard, Freight Terminal, Class Yard
- Characterized by
  - An elevated inlet
  - Remotely operated electro-mechanical switching
  - Automated railcar speed control

Hamlet Terminal Video Study Influence of Grade on Throughput

1. Car stall blocks group switch, classification to blocked group impossible
2. Hump operations interrupted
3. Trim engine moves to clear stall
4. Total of 21 minutes to clear switch

Hump Yard Grades Affect Freight Service Quality

- Grade degradation and settlement due to
  - Railcar loading forces
  - Weather & geology & time
  - Outdated grade design
    - Journal bearings to frictionless roller bearings

Research Question

Can RTK GPS instrumentation attached to a locomotive, be used to survey an automatic classification yard during humping operations?

Hump Yard Profile Survey Purpose & Objectives

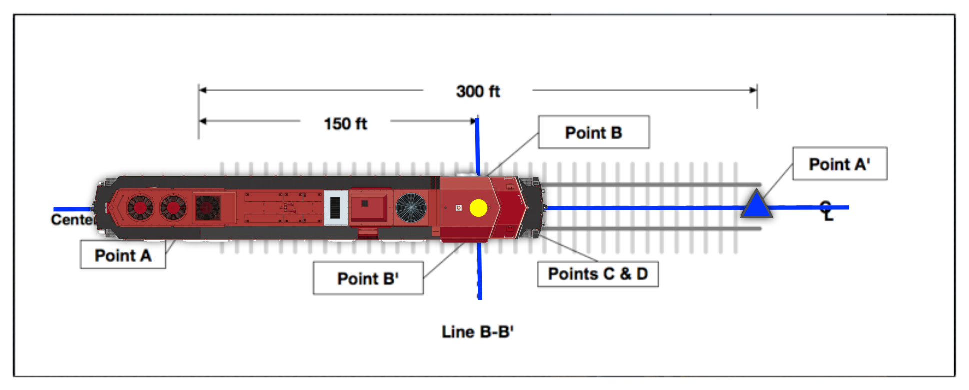
Profile the bowl area of a humpyard in support of yard-wide resurfacing project

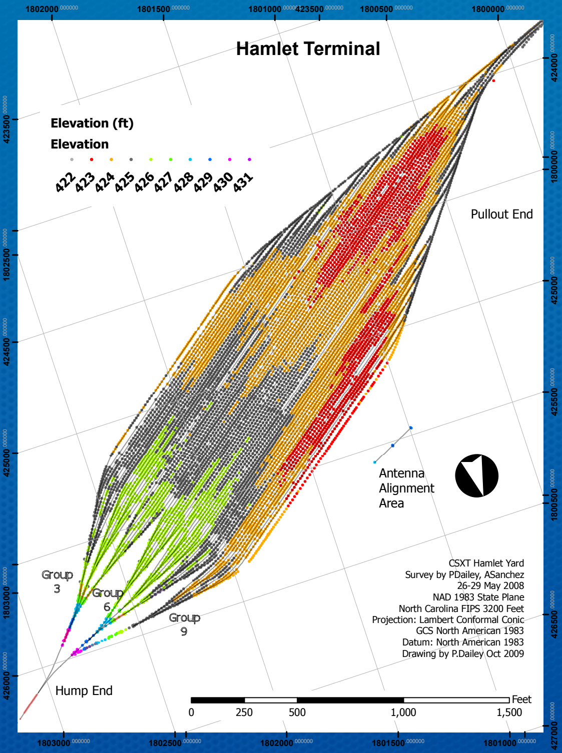
- Develop antenna alinement procedure
- Collect a data set by RTK GPS equipped locomotive
- Maximize safety for surveyors
- Minimize impact on continuous car handling operation
- Minimize use of trained safety support personnel
- Determine multipath influence on GPS elevation

Experiment 1
Hump Yard Survey

- COTS RTK GPS Reference Station
- COTS RTK static instruments
- COTS RTK mobile instruments and mount

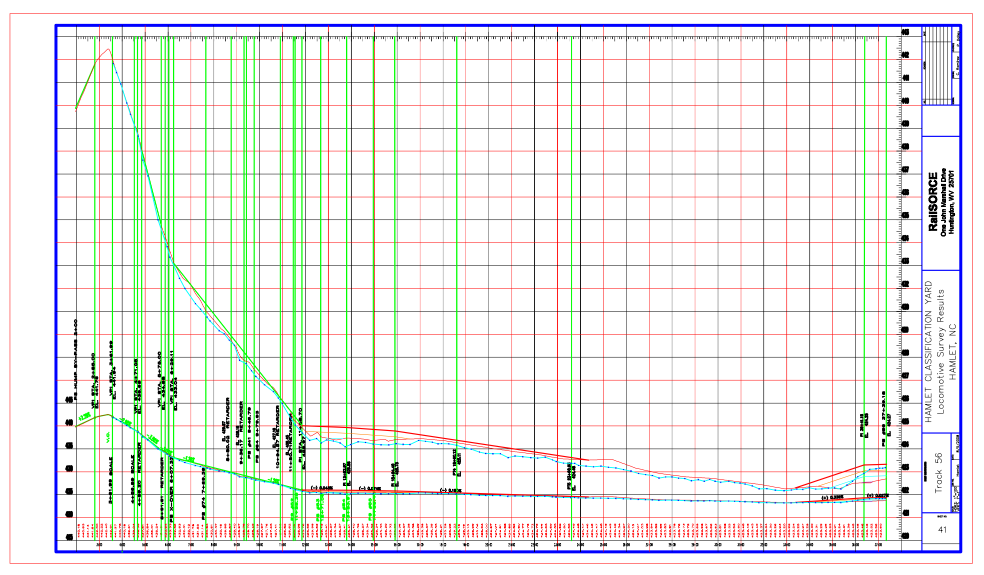
Antenna Alignment Procedure





Hamlet Terminal
Elevation (ft)
Elevation
422 423 424 425 426 427 428 429 430 431
Pullout End
Antenna Alignment Area
Group 3
Group 6
Group 9
Hump End
CSXT Hamlet Yard
Survey by PDailey, ASanchez
26-29 May 2008
NAD 1983 State Plane
North Carolina FIPS 3200 Feet
Projection: Lambert Conformal Conic
GCS North American 1983
Datum: North American 1983
Drawing by P.Dailey Oct 2009
0 250 500 1,000 1,500 Feet

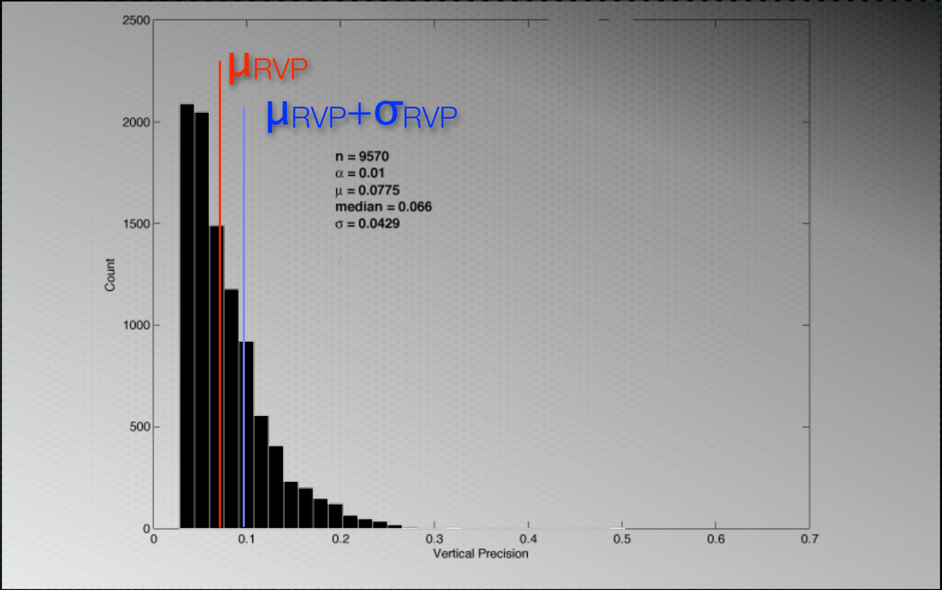
Group 7, Track 56

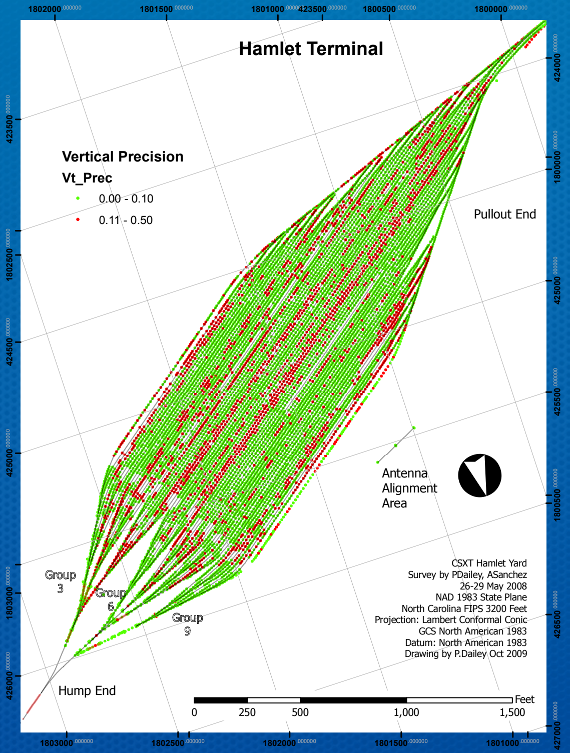


Multipath Analysis

	Reference Station cycle slips / total obs.	Locomotive Relative Vertical Accuracy
μ_{RVP} σ_{RVP}		0.08 ft (2.4cm) 0.043 ft
MP1 cycle slips 1575.42 MHz, λ = 19 cm	121 / 9,112 1.32%	
MP2 cycle slips 1227.60 MHz, λ = 24.4 cm	119 / 9,112 1.30%	

Relative Vertical Precision




Hamlet Terminal
Vertical Precision
Vt_Prec
0.00 - 0.10
0.11 - 0.50
Pullout End
Antenna
Alignment
Area
Group
3
Group
6
Group
9
Hump End
CSXT Hamlet Yard
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26-29 May 2008
NAD 1983 State Plane
North Carolina FIPS 3200 Feet
Projection: Lambert Conformal Conic
GCS North American 1983
Datum: North American 1983
Drawing by P.Dailey Oct 2009
0
250
500
1,000
1,500
Feet

Result

Objective	Value
Track observations	9,570
Safety, exposure hours	6
Labor efficiency, man hours	97
Time to completion, days	4-1/2
Nominal observation stationing, feet	10
Operation disruption, hours	2

Conclusions

- Greater data density than differential level survey
  - 10 ft vs 100 ft stations
- Safer than differential level survey
  - 6 vs 1500 exposure hours to ground hazards (est. Kerchoff & Szwilski)
- Faster than differential level survey
  - 4-1/2 days vs 25 days
- Fewer labor hours than differential level survey
  - 100 vs 500 man-hours (est. Kerchoff & Szwilski)
- Less disruptive to yard operations
  - 2 vs 500 hours

Conclusions

- RTK GPS elevations do not indicate abnormal distortion from multipath signal reflections
- RTK GPS unaffected by weather
  - Day-long locomotive survey in torrential rain

Implications

- Follow up on resurfacing project:
  - Operator skill and judgement used during regrading
    - Not data driven - what are the as-built grades?
- Implies additional research needed to implement RTK GNSS measurement on track resurfacing equipment
  - Similar to COTS machine control in construction applications

Experiment 2
Track Alinement

Determine degree of curvature (D_C) from an RTK equipped track inspector's Hi-Rail during routine inspection of mainline track.

Visual Track Inspection

- FRA Mandate
  - Every track at least every 2 weeks
  - Inspection duties include light repair
- Rail companies specify increased frequency based on
  - Load MGT/yr
  - Cargo
  - Inspection History

String Line Method

Degree of Curvature (D_c)

$$R^2 = (R-m)^2 + \frac{1}{4}c^2$$

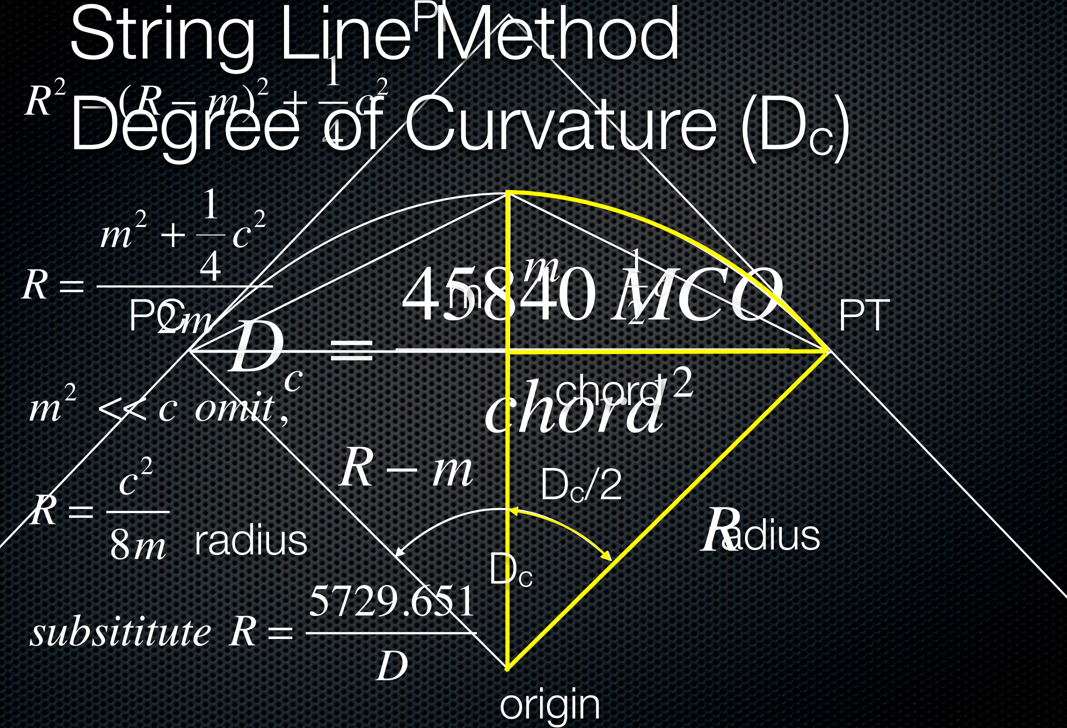
$$R = \frac{m^2 + \frac{1}{4}c^2}{2m}$$

$m^2 << c$ omit,

$$R = \frac{c^2}{8m}$$ radius

$$subsititute\ R = \frac{5729.651}{D}$$

$$D_c = \frac{45840\ MCO}{chord^2}$$



Research Question

Can RTK GNSS instrumentations mounted to a track inspector’s Hi-Rail be used to determine the degree of curvature (D_C) across mainline track comparable with specialized track geometry cars?

Mainline Track Alinement Purpose & Objectives

Determine the D_c across a track inspectors area of responsibility

- Equip a track inspector’s Hi-Rail with RTK GNSS instruments in communication with a VRS server to maximize observation accuracy
- Obtain a data set of track position across an inspector’s 29 mile area of responsibility.
- Model the FRA sting line method for determining D_c from XYZ
- Develop a method to compare model vs. D_c measured with a track geometry car

M

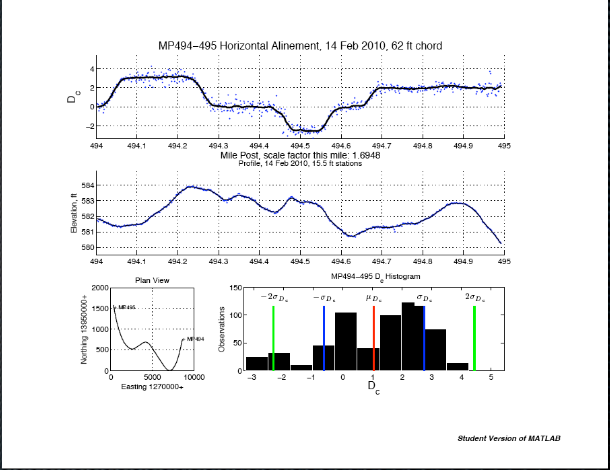
Experiment 2 Results

- Continuous segment of mainline track
    - 29 mile traverse of a track inspector's area of responsibility
- Networked CORS & VRS server minimize proximity error
- Expected LOS due to overhead obstructions

Survey	Observations
A	18,095
B	15,225
C	22,866
D	19,993
E	21,001

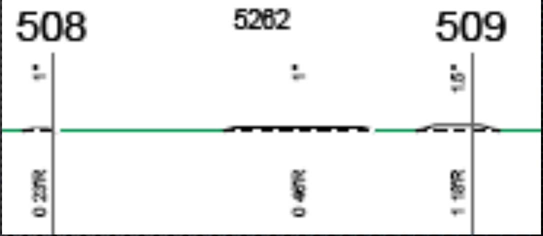
Results
XYZ to D_c Model Output

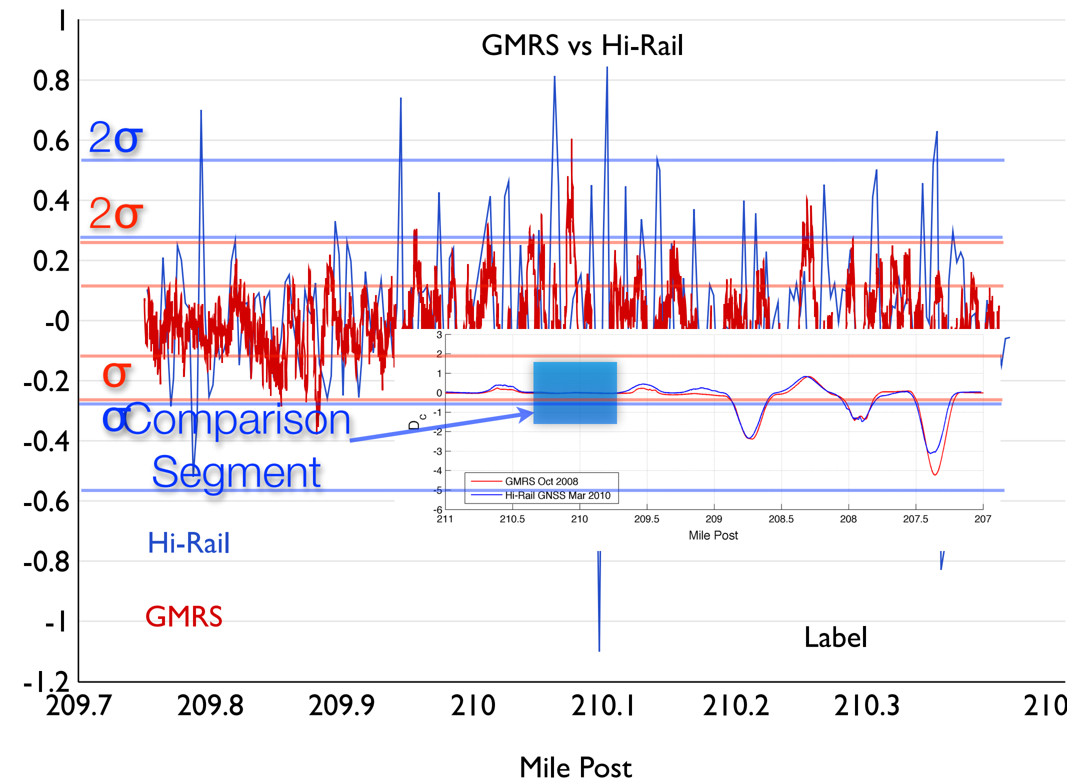
- MP 494-495
  - curves
- MP 499-500
  - tangent
- MP 500-501
  - exit spiral
- MP 521-522
  - LOS



Model Discrepancies with Rail Company Track Charts

- MP 508.9 curve direction
  - TC: 1°18’ right
  - Model: ... left
- MP 521.15 curve length
  - TC: 1°00’R @ 0.15 mi
  - Model: 1°00’R @ 0.65 mi





GMRS vs Hi-Rail
2σ
2σ
σ
σ
Comparison Segment
Hi-Rail
GMRS
Label
Mile Post
1
0.8
0.6
0.4
0.2
-0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
209.7
209.8
209.9
210
210.1
210.2
210.3
210
GMRS Oct 2008
Hi-Rail GNSS Mar 2010
Mile Post
211
210.5
210
209.5
209
208.5
208
207.5
207

Conclusions

- XYZ to D_C model verified by rail company track charts
- Hi-Rail not equivalent to track geometry car
- Present GNSS signals for continuous track observations impeded by LOS from overhead obstructions

Implications for Measuring Alinement Defects

§213.9 Classes of track: operating speed limits

9(a) Except as provided in paragraph (b) of this section and §213.57(b), 213.59(a), 213.113(a), and 213.137(b) and (c), the following maximum allowable operating speeds apply:

Over track that meets all of the requirements prescribed in this part for	The maximum allowable speed for freight trains is	The maximum allowable speed for passenger trains is
Excepted	10	N/A
1	10	15
2	25	30
3	40	60
4	60	80
5	80	90

Table 1

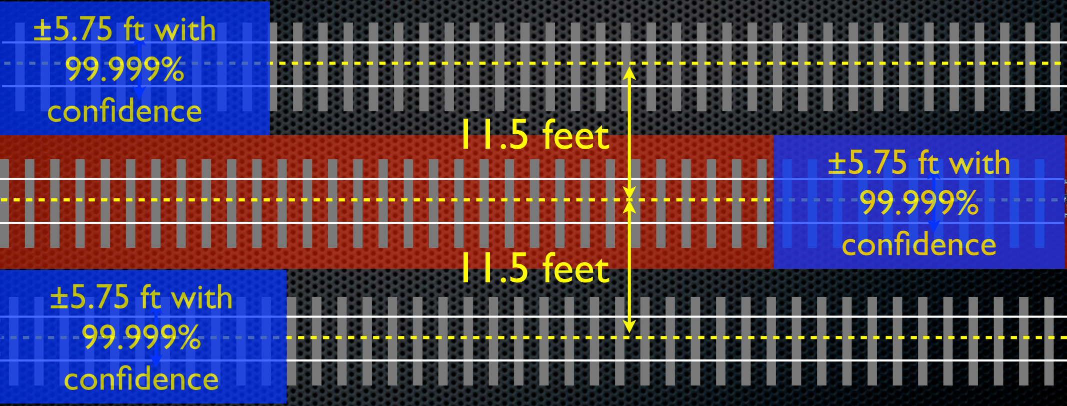
Implications

- Further modeling will enable track class 1-4 alinement defect detection
- Additional GNSS sensor(s) will expand determination of
  - Superelevation (roll axis)
  - Grade (pitch axis)
  - Twist (roll axis change over a distance)

Experiment 3 Determining Track Occupancy

Assess the ability of RTK GNSS to determine the track occupancy of a track vehicle meeting the definition of a location determination system.

FRA Wireless Track Occupancy



1995 Federal Railway Administration Report

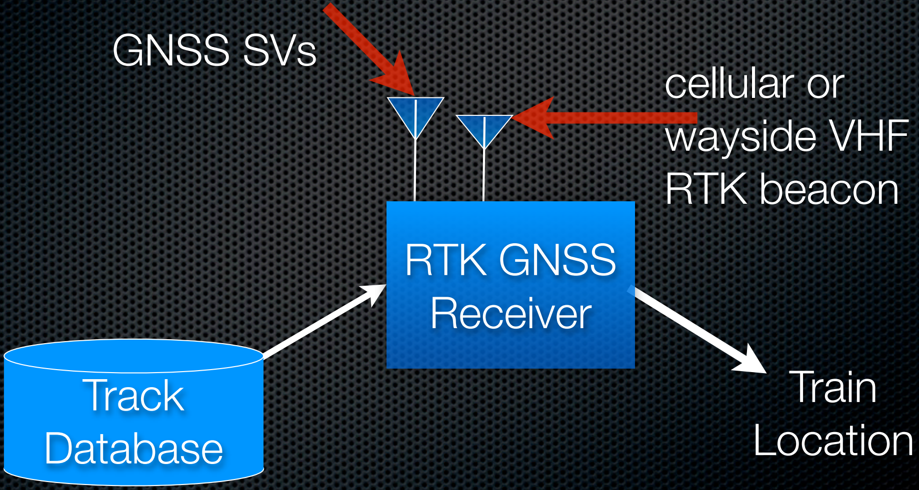
Motivation

- Track occupancy presently determined by wired track circuits
  - Insulated joints between CWR segments
    - Axle completes low voltage circuit across rails
  - Proximity switches (magnetic)
  - Loop detectors
- Replacement value for signals: $125,000 / mile (Moorman)
- No wired circuits or signals = “Dark Territory”

Motivation

- Railroad Safety Improvement Act of 2008
  - Class I railroads, as well as intercity passenger and commuter railroads, must install PTC on main line tracks by Dec. 31, 2015.
    - Act defines mainline as > 5 MGT/Y

Research Postulates that RTK GNSS will simplify LDS



Research Question

Can RTK GNSS determine track occupancy meeting the FRA specifications for a location determination system?

Track Occupancy Purpose & Objectives

Determine if RTK GNSS track measurement can meet the definition of a LDS

- Develop a test for determining track occupancy on multiple parallel track from RTK observations for
  - A tangent track segment
  - A circular curve track segment

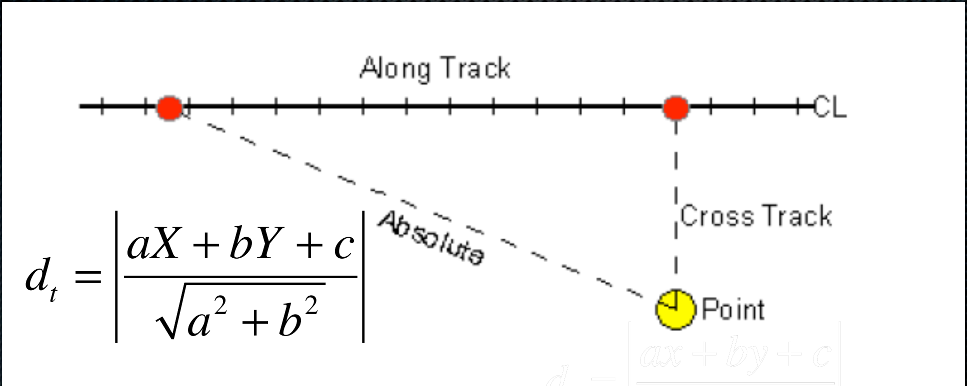
Observation Data

- Mainline tangent and circular track segments
  - Three parallel tracks
  - Five traverses
- Tangent: CSX Kanawha Subdivision

  MP 498.9 to 500.2
- Curve: Kanawha Subdivision

  MP 500.2 to 500.7

Tangent Segment



$$d_t = \left| \frac{aX + bY + c}{\sqrt{a^2 + b^2}} \right|$$

$$d_t = \left| \frac{ax + by + c}{\sqrt{a^2 + b^2}} \right|$$

Distance to reference centerline is cross track error

(Allen, et.al.)

Track Occupancy Null Hypothesis - Tangent

- Z-test uses standard deviation of X-track distances from reference tangent dataset
  - Eliminate track roughness from test tracks
- Test that the mean is a random sample from a normal population with a cross track error less than half a centerline to centerline distance of 11.5 feet
- CI = 100(1-α)
  - α=0.00001

$$h_0 : \mu_d \leq \frac{11.5}{2}$$

$$h_1 : \mu_d > \frac{11.5}{2}$$

Hypothesis Test Result Tangent Track

Track	N	μ_d	σ_d	Reject h_0?
2_A-2_A	1,189	0.13’	0.08’	no
2_B-2_A	1,244	0.13’	0.08’	no
3_C-2_A	1,152	13.10’	0.35’	yes
1_D-2_A	1,158	13.51’	0.20’	yes
3_E-2_A	1,156	13.05’	0.31’	yes

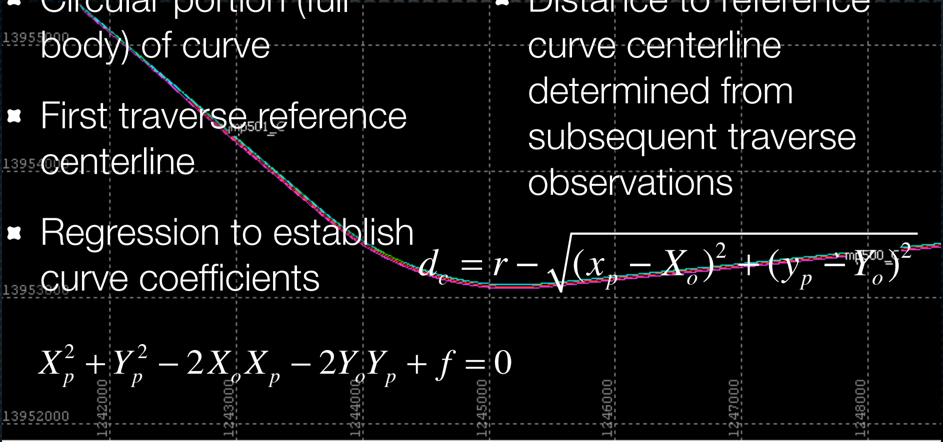
Curve Segment

- Circular portion (full body) of curve
- First traverse reference centerline
- Regression to establish curve coefficients

- Distance to reference curve centerline determined from subsequent traverse observations

$$d_c = r - \sqrt{(x_p - X_o)^2 + (y_p - Y_o)^2}$$

$$X_p^2 + Y_p^2 - 2X_oX_p - 2Y_oY_p + f = 0$$



Hypothesis Test Result
Circular Curve Track

$Track_{traverse}$	N	μ_r	σ_r	Reject h_0?
2_A-2_A	85	0.00'	0.03'	no
2_B-2_A	98	0.03'	0.04'	no
3_C-2_A	98	-14.53'	0.16'	yes
1_D-2_A	97	13.93'	0.10'	yes
3_E-2_A	92	-14.57'	0.14'	yes

Conclusions

- Given a priori track centerline locations and a network RTK VRS server, track occupancy can be determined by single epoch RTK observations over a wide area meeting the accuracy requirement for an LDS.

Implications-Railroad

- Simplified occupancy determination local to an LDS onboard a locomotive, Hi-Rail, or other track vehicle
  - RTK receiver, communication with VRS, database, processor
- Self-determined RTK positions transmitted through wayside voice repeater enable real time tracking or track occupancy determination external to track vehicle
- Applicable to any ~~track~~ vehicle
- Applicable to individual on-track workers

Implications-Transportation

- Highway: vehicle/human interaction
  - Lane deviation alerts driver
- Air: Precision approach and landing
  - To any airfield w/o barometric altimeter
- Waterway: River bed profile mapping & water level for bridge clearance

Self-guided Vehicles