Field Experience with GPS based Train Control System

Burkhard Stadlmann, Stefan Mairhofer, Gerhard Hanis

1Upper Austria University of Applied Sciences, School of Engineering and Environmental Sciences
Outline

1. The Train Control System
2. Safety
3. Experience with GPS based location
4. Operational Experience on navigation quality
5. Possible improvements
1 The Train Control System

- Background of the train control system
- Basic idea
Background:

Improved safety using this kind of operational train control is necessary

- Failure of one single person can cause an accident

Examples of accidents in Austria (Year 2002):

- Danube river line: Failure of the train controller

- Mur valley: Driver did not wait for the crossing train
Basic Idea

Leave the operational principle as it is
But

> Entire operation gets computer aided support

- On-Board-Computer
  > Train location based on dGPS
  > Supervision of movement authorities

- Data Radio System
  > Stationary repeaters are the only line side installations needed

- Central Computer
Central Computer

Core application
- Administration of the movement authorities
- Train distance monitoring for collision avoidance alarm
- Communication to the trains

GUI
- Representations of the line
  - schematic representation
  - Scaled electronic train diagram
- Relational data base for the time table
TCS GUI – Train Runnings

Black lines: scheduled train runnings
Green lines: actual train runnings
Red arrows: movement authorities
The On-board Computer

On-board Unit

- GPS based train location
- Data communication with the central computer
- Supervision of the correct execution of all movement authorities
- Visualisation for the train driver
- Dynamic passenger information in the train

Photo: St&H
Movement Authority Supervision

No movement authority at all → brake

Movement authority available:

- Reminder by acoustic signal 400 m in front of the end
- Speed too high → brake
- Speed control 100 m in front of the end
- No reaction → brake
- Roll over → brake
- End of movement authority

Movement Authority
2 Safety

- Technical safety
- Human supervision
Safety

Leave this kind of operational train control as it is, but support it by a computer

- No redundant hardware

- Reduction of safety targets compared to standard signaling systems

A basic system, safe enough and low cost?
Technical Safety

- Software redundancies and numerous plausibility checks
- Telegram security and safety according EN 50159
  - Message authentication code according to Euroradio
- Train’s location is based on a redundancy of location sensors
- Movement authority only valid, if it is acknowledged by train-driver and on-board-computer
- Supervising the correct execution of a given movement authority
- Implementation of an highly independent collision-avoidance algorithm
Human Supervision

- Checking the train location, if an unreliable location is determined e.g.
  - GPS - errors
  - Long time poor visibility of the satellites

- All safety relevant actions need an explicit input by the train driver and/or the central train controller.

- Human supervision assures safety if technical safety is not sufficient.
3 Experience with Train Control System and its GPS based location

- Train location
- Accuracy and Reliability of Train Location
- GPS Reliability
- Operational Experience
Train Location

RTCM data

Train location with line based coordinates

location algorithm

digital line atlas

 Foto: St&H
Accuracy of Train Location

Accuracy of odometer is influenced
- Slip during normal drive
- Braking situations

Accuracy of GPS is influenced
- Topographic situations
- Shadowing by buildings and trees
- Used type of GPS receiver

Resulting accuracy is better than 10 m
- No track specific location
- System features allow this positioning error
Reliability of Train Location

Reliable train location

- disturbances

Unreliable train location

- Automatic Information to the engine driver and to the train controller

- Human supervision assures safety
Result of Train Location

GPS-location

- GPS based location is reliable but not safe enough
- Short lack of GPS-data due to topographic situation is no problem
- System safety is not based on train location alone
  - System is safe due to the combination of reliable train location and human supervision
  - Human supervision is important if train location is indicated being not reliable
  - Unreliable train location may result in an unnecessary emergency brake
- Long or even permanent disturbance of GPS-data will lead to a breakdown of the system
  - Operation will continue using radio based oral communication ("old fashioned system")
**GPS Reliability (1)**

- Since 2006 nearly 700 million location calculations based on GPS
- No dangerous incidents caused by GPS errors
- Problems caused by GPS errors (error rate appr. $10^{-5}$)

*Static measurements of the used TCS GPS-sensors over a duration of 2 days*
*left: on-board receiver, 5m Radius; right: reference receiver, 2m Radius*
GPS Reliability (2)

- Problems caused by GPS errors
  - Some minor positioning errors
  - Shadowing caused by trees and within the depot (tin roof)
  - Missing RTCM correction data due to problems of the data radio channel

- Consequences for higher SIL (Safety Integrity Level)
  - Actual failure rate may be seen near SIL 1
  - SIL 2 or SIL 3 needs additional sensors
Operational Experience

- Full operation of the system since 2006 on appr. 90 km of lines
- Two additional lines (appr. 70 km) line will be equipped next year
- 24 / 7 operation around the year
- Each day appr. 180 trains running
- 1.1 million train km per year
- 50,000 data telegrams per day
- Train control system leads to safe and easy operation
4 Possible improvements

➢ Track-Selectivity using Inertia Sensors
➢ Track-Selectivity using Position Balises
➢ Differential Correction Optimization
Track-Selectivity (Inertia Sensors)

Differential GPS and supplementary sensors

- Standalone GPS detection of parallel tracks lacks reliability
- Via GPS, a comprehensive digital line atlas is needed, which requires every track to be precisely measured and stored
- Additional single-axis angular rate sensors can detect switches

Measurement of angle at switch crossing

(Cross-) Correlation of reference and measured angles

Comparison of a reference and a measured curve supports track-selective location
Track-Selectivity (Balises)

Using Balises

- Position balises for referencing the location algorithm and for signalling and track-clearance purposes
- RFID Devices
  - ETCS Balises (European Train Control System)
  - Surface Acoustic Wave Identification Systems

*Picture of a Surface Acoustic Wave Identification System used in the TCS*

*Top: Balise Reader mounted on trains*
*Bottom: 2 Passive Balise Tags*
Track-Selectivity (Balises)

**Balises in the TCS**

- Surface Acoustic Wave system is used
- Passive balise tags mounted on track sleepers can be detected by a train-side balise reader for track-selective navigation
- Balise tags are mounted at crucial points and at track junctions
- Balises provide a reference for GPS and odometer calibration
  - The digital line atlas stores a list of balises together with their GPS location
  - GPS and odometer errors are referenced on each crossed balise
- To fulfill higher safety requirements, redundancy of navigation sensors is needed
  - Triple-navigation via GPS, Odometer and Balises supports safety against single failures
Optimize Differential Corrections

**RTCM correction data**

- The central computer sends RTCM Message Type 1 corrections over a radio communication system to the trains.
- Before sending the messages, plausibility checks on the corrections are made.

**Using EGNOS**

- To reduce RTCM outages in the system, it was investigated to generate the corrections from EGNOS.
- Via the ESA SISNeT service the SBAS message was decoded and subsequently converted into corresponding RTCM messages.
5 Outlook
Outlook

- New Lines will be equipped in Austria
  - 2011: 55 km
  - 2012: 15 km
- Improved location algorithm using balises for official SIL 2 certification
- Further research using EGNOS integrity information
Thank you for your attention!