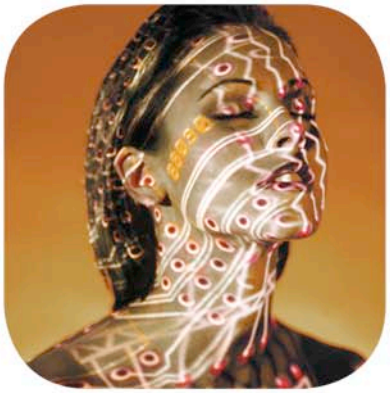

Field Experience with GPS based Train Control System

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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:

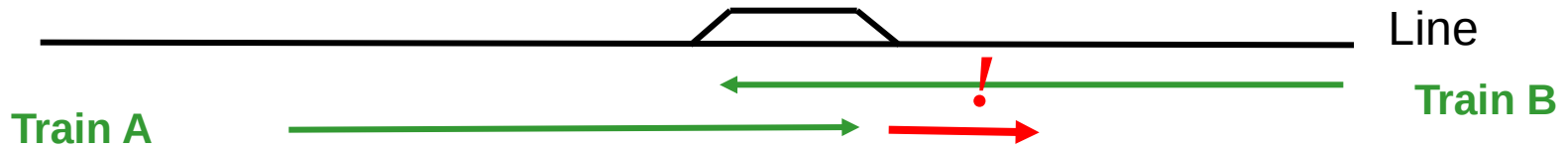
Improved safety using this kind of operational train control is necessary

- 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



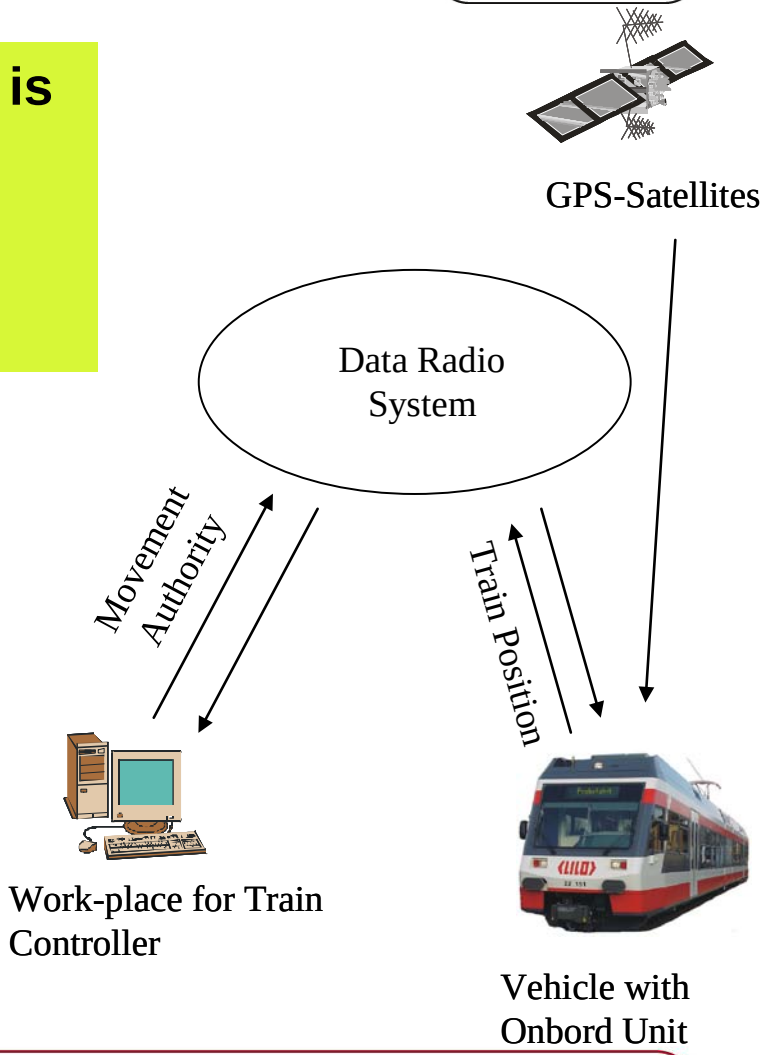
Basic Idea

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

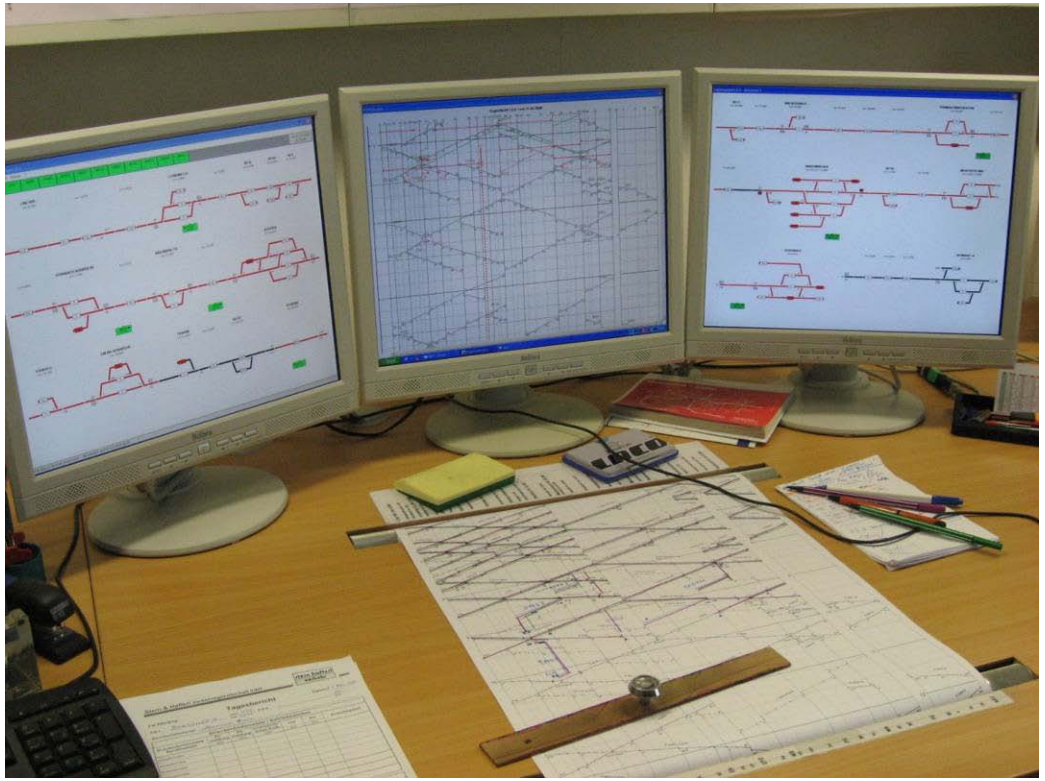
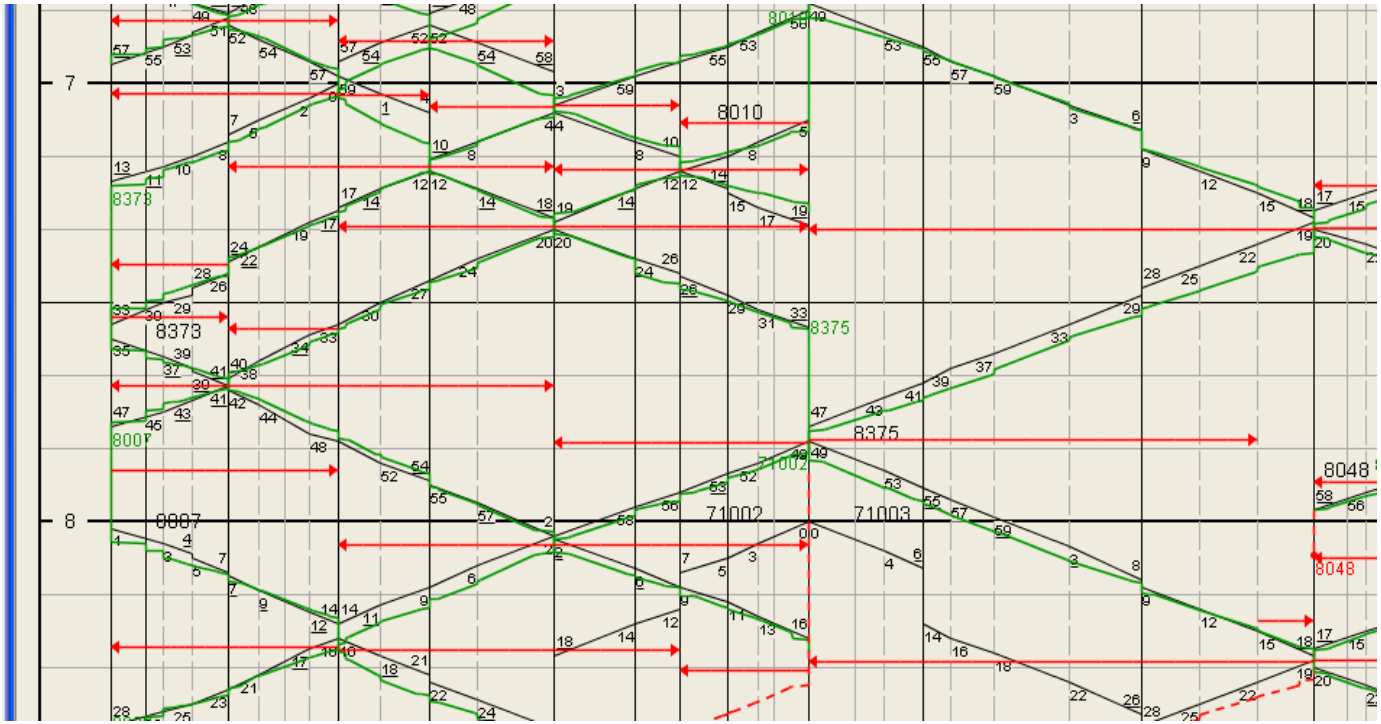


Foto: St&H

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

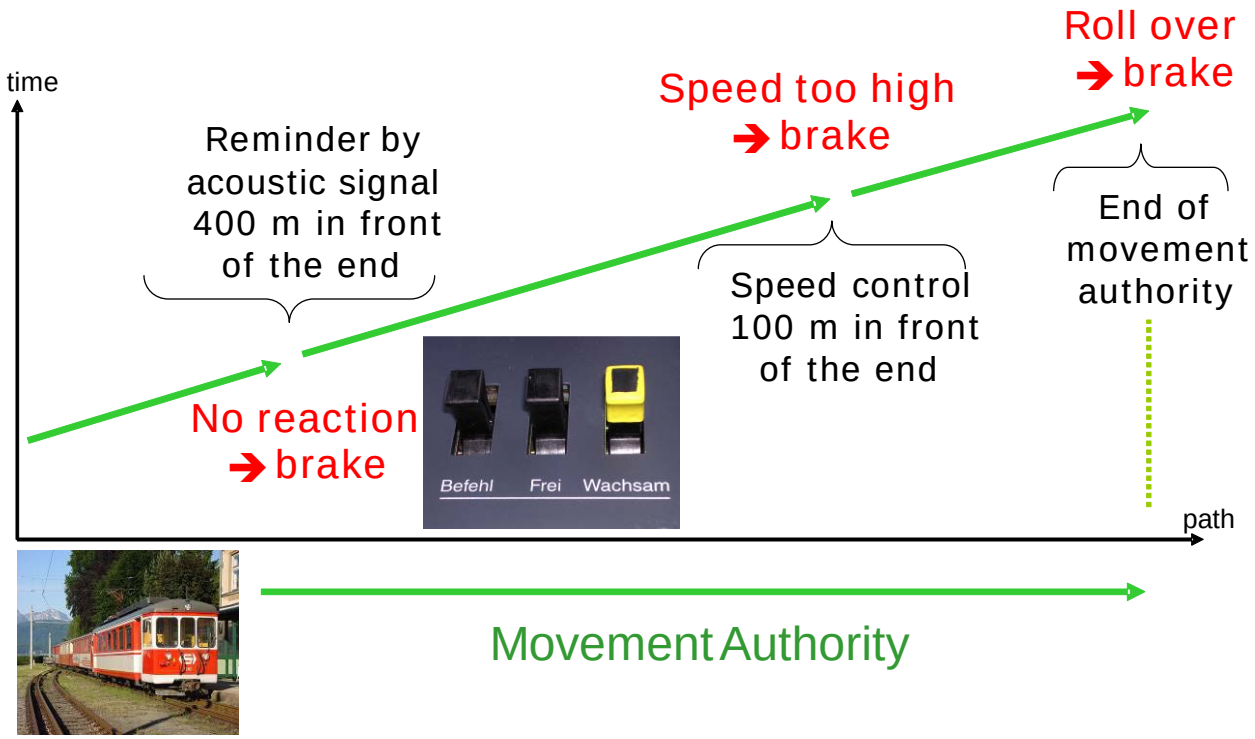
- GPS based train location
- Data communication with the central computer
- Supervision of the correct execution of all movement authorities
- Visualisation for the train driver
- Dynamic passenger information in the train

Foto: St&H

Movement Authority Supervision

No movement authority at all ➔ brake

Movement authority available:



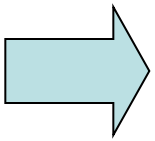
2 Safety

- 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

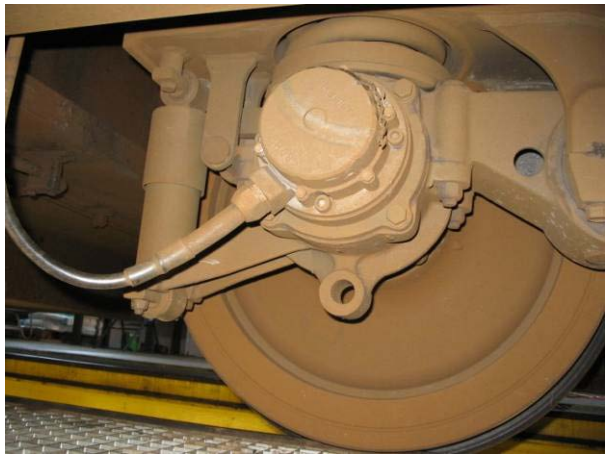


Foto: St&H

location algorithm

digital line atlas

Train location

with line based coordinates

Accuracy of Train Location

Accuracy of odometer is influenced

- Slip during normal drive
- Braking situations

Accuracy of GPS is influenced

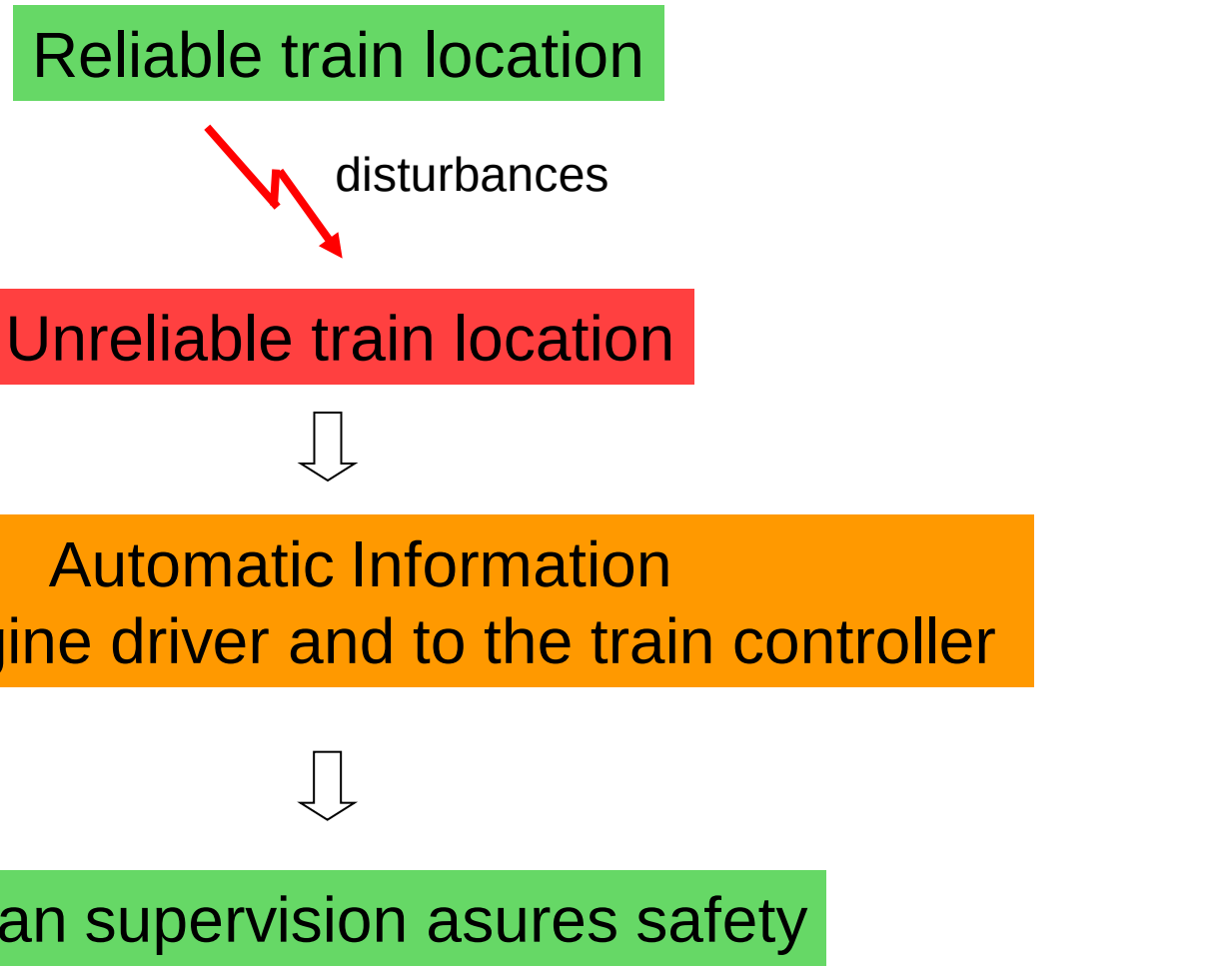
- Topographic situations
- Shadowing by buildings and trees
- Used type of GPS receiver

Resulting accuracy is better than 10 m

- No track specific location
- System features allow this positioning error

Foto: St&H

Reliability of Train Location



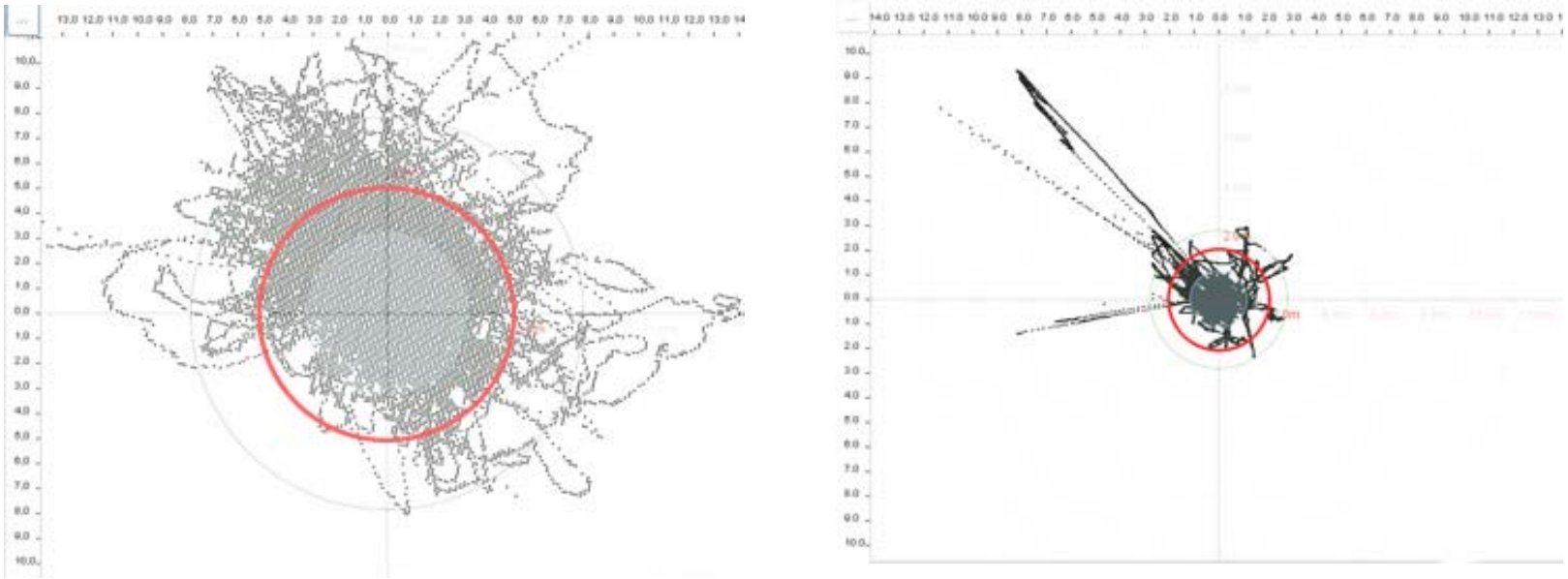
Result of Train Location

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

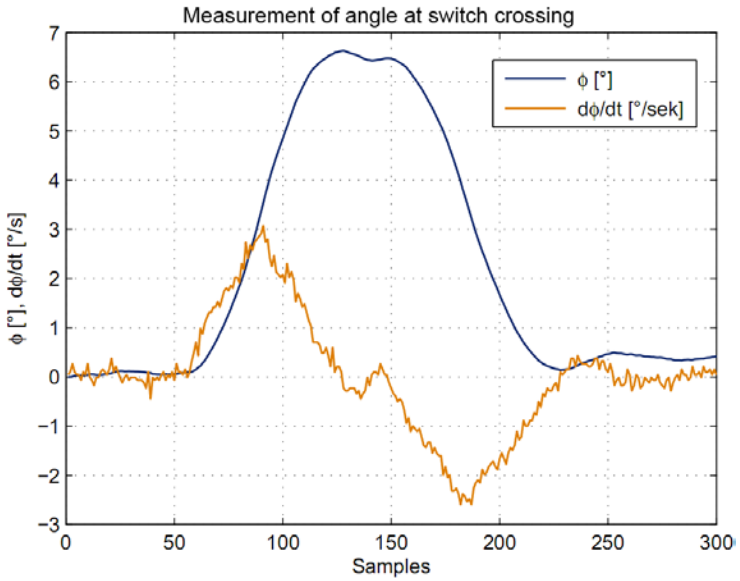
4 Possible improvements

- Track-Selectivity using Inertia Sensors
- Track-Selectivity using Position Balises
- Differential Correction Optimization

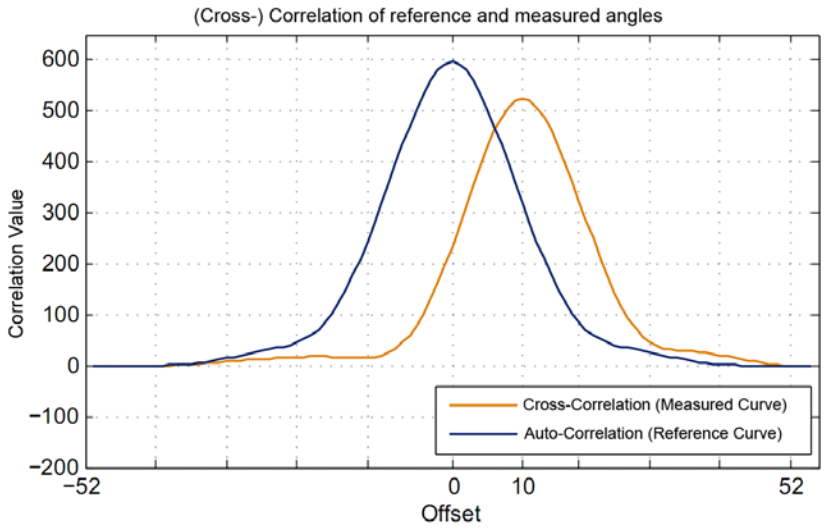
Track-Selectivity (Inertia Sensors)

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



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 (**E**uropean **T**rain **C**ontrol **S**ystem)
  - 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 inAustria
  - 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!