THE UNIVERSITY OF MELBOURNE

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**Supervisor**: Allison Kealy

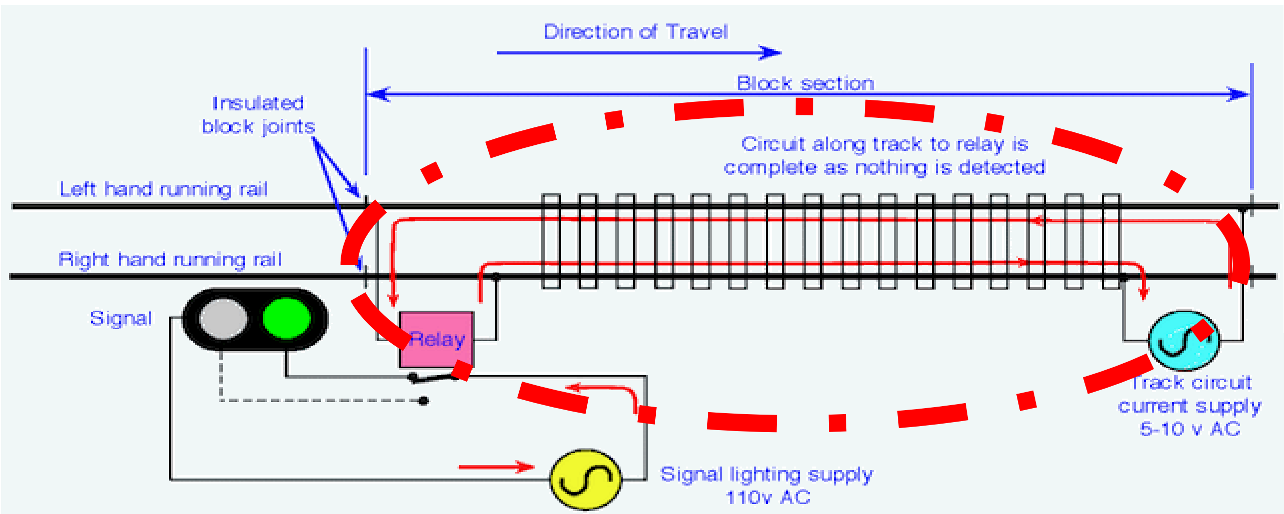
# GNSS-based Positioning Scheme & Application in Safety-critical Systems of Rail Transport

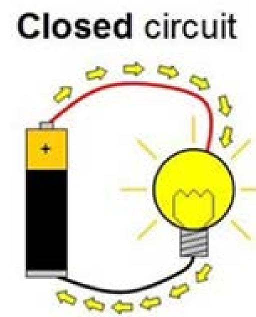
# CONTENT

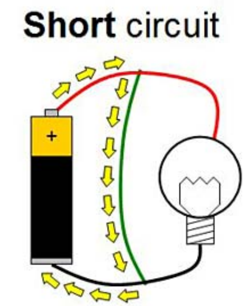
# Introduction

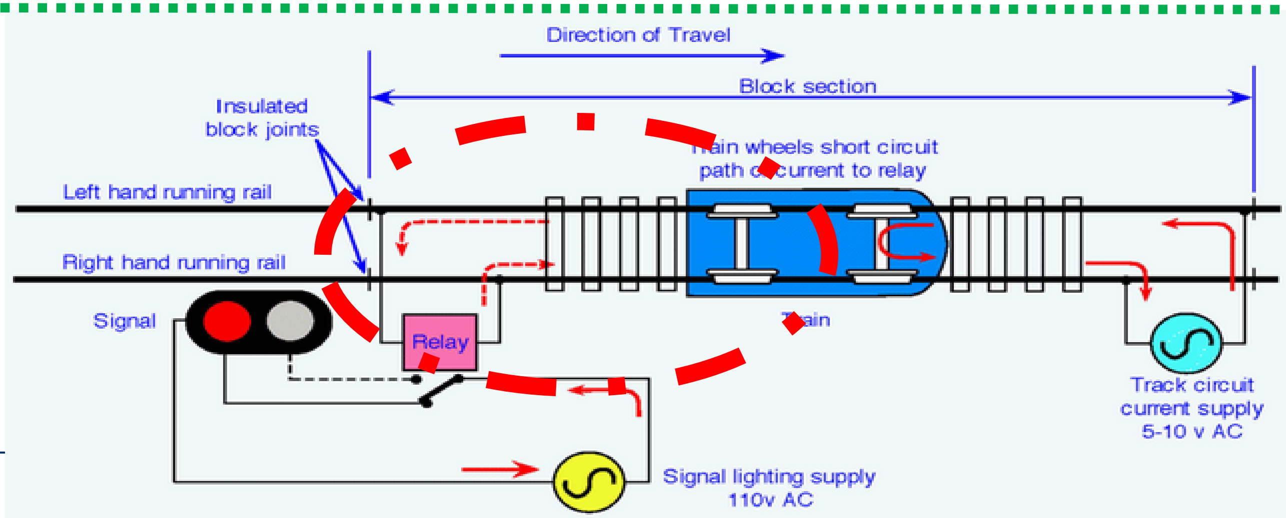
## ❑ How Modern Railway Signal Works?

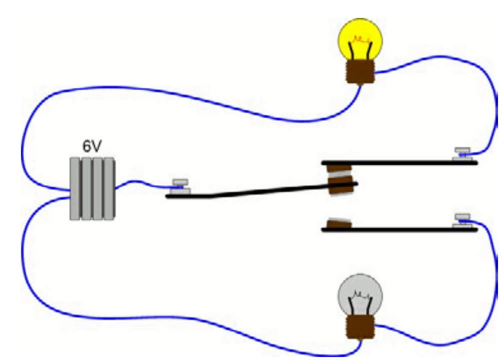
## ❑ Signalling System: Track Circuit



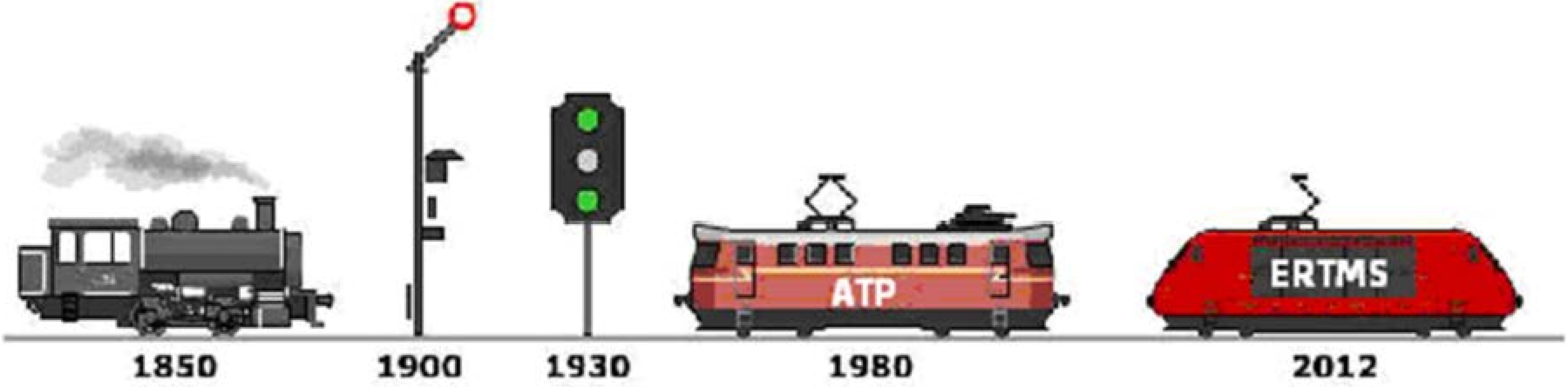



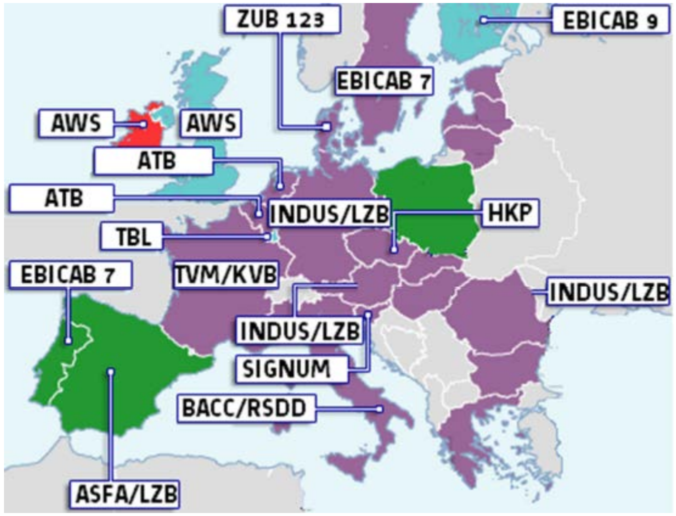



# Introduction

## ❑ History of Signalling Systems



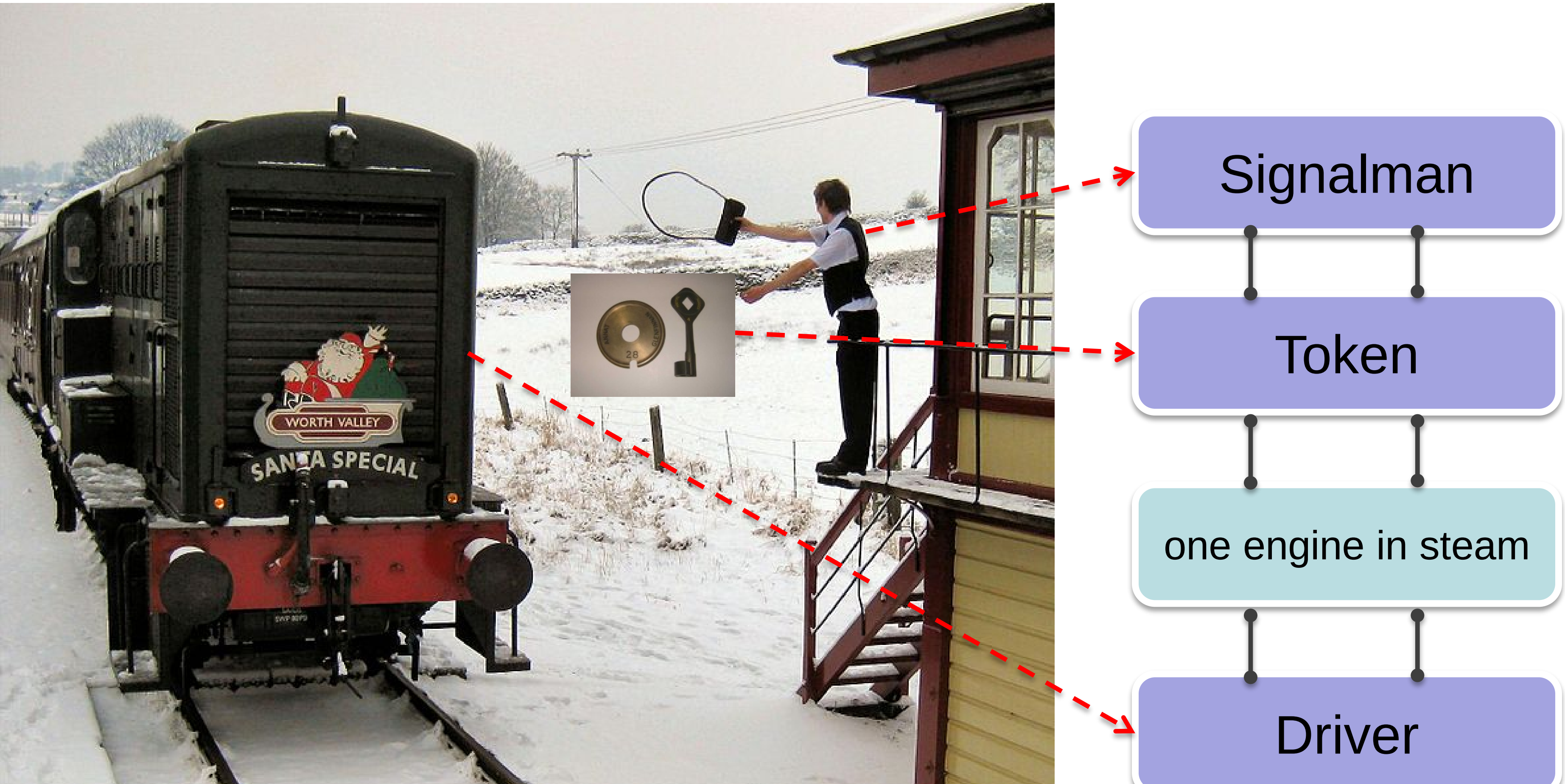




Diversity of European ATP systems

ETRMS/ETCS Cockpit

# Introduction

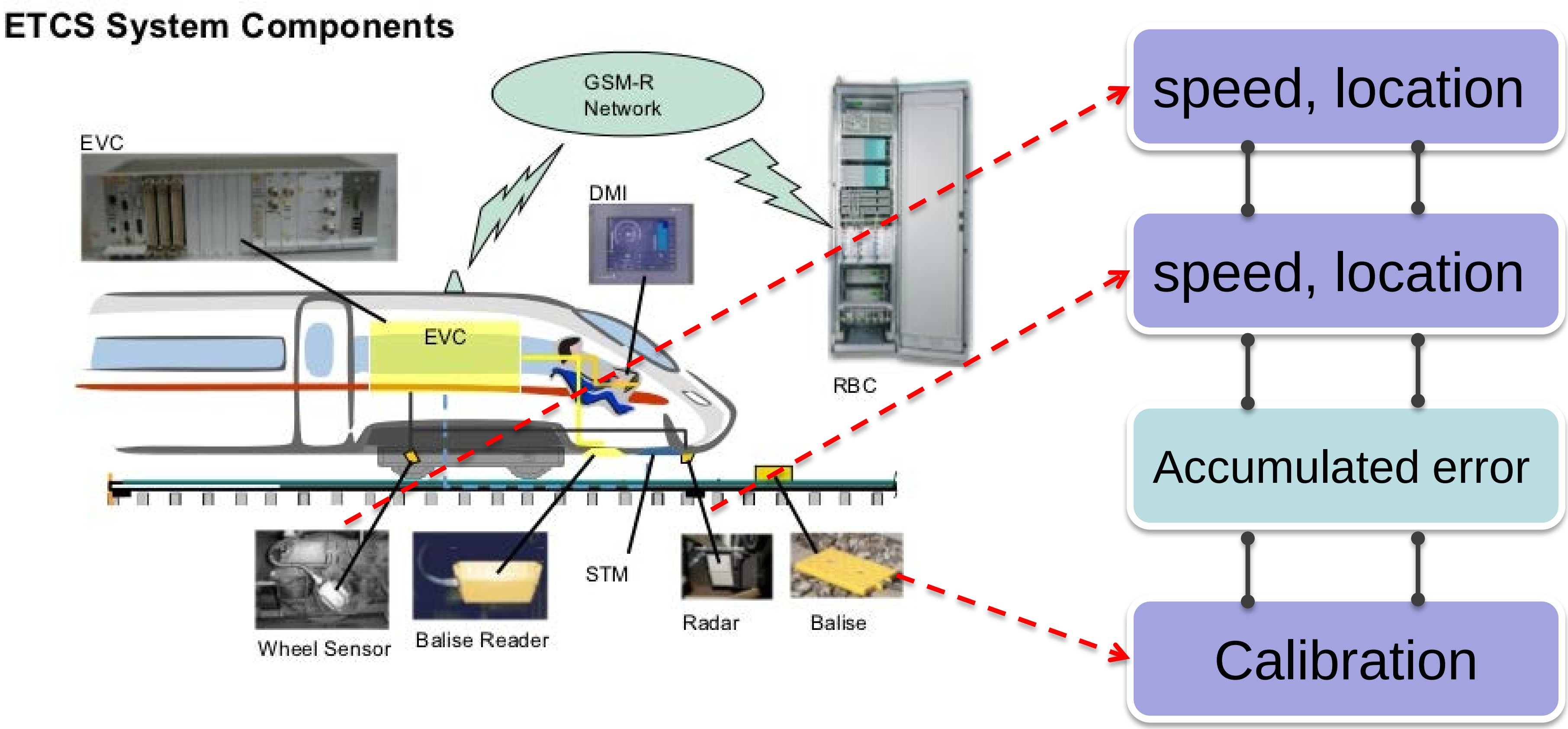
## ❑ Train Control Systems: Positioning Scheme




A token being offered by a signalman on the Keighley and Worth Valley Railway (from Wikipedia)

# Introduction

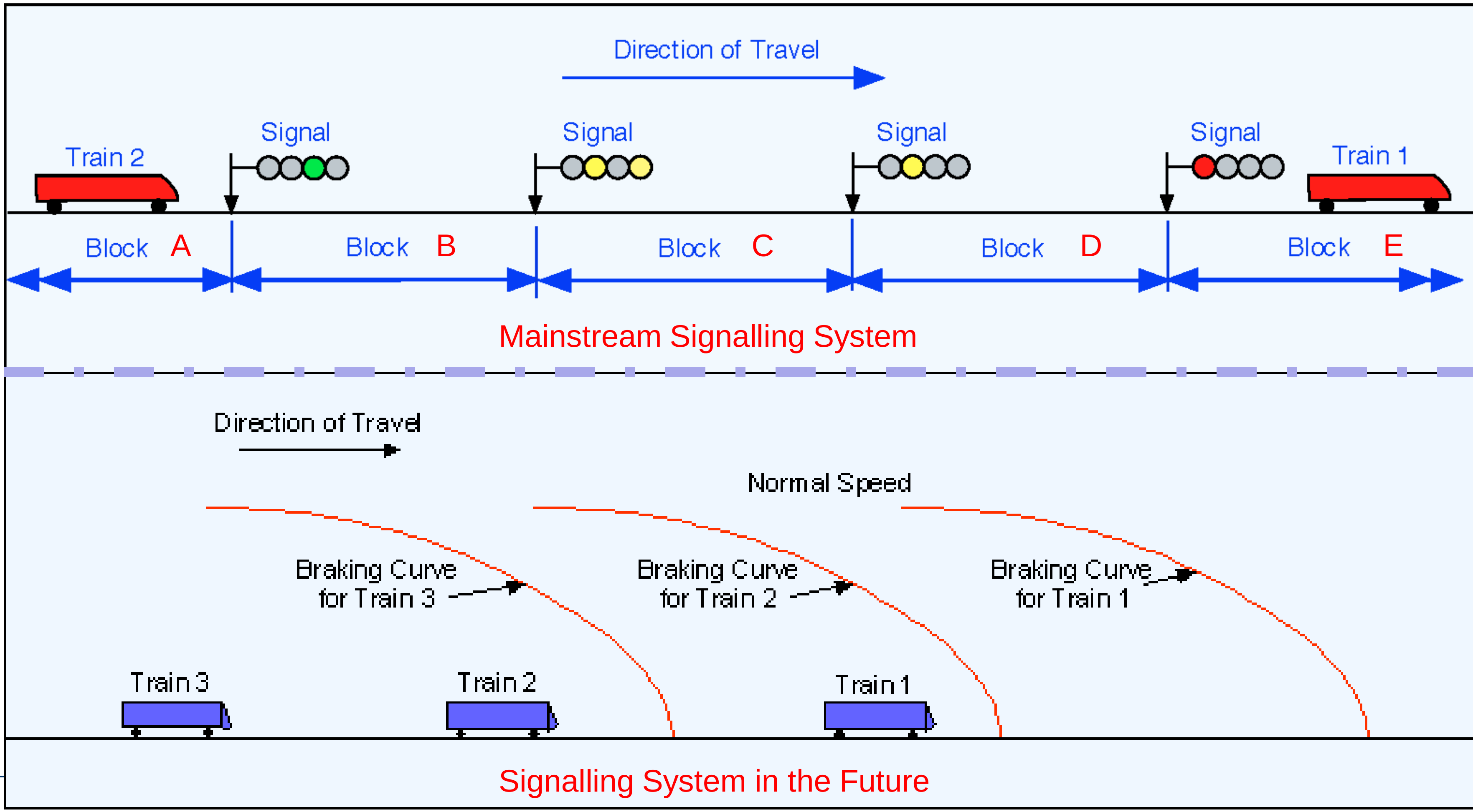
## ❑ Train Control Systems: Positioning Scheme



## ❑ Train control systems: Balise

- 2.5 km
- More in station
- Expensive
- difficult to maintain

## ❑ Signalling System: Fixed Block & Moving Block




*THE DEVELOPMENT AND PRINCIPLES OF UK SIGNALLING

# Introduction

## ❑ Next-Generation Train Control System

No track circuit

Ability to determine train integrity on board

No or less balise

Trains find their position themselves

Full radio-based train spacing

Moving Block

# Introduction

## ❑ GNSS

- Location info.
- Time info.
- Short messages(BDS)

- with high accuracy
- in all weather conditions
- anywhere on or near the Earth
- Cost-efficient
- available 24/7/365

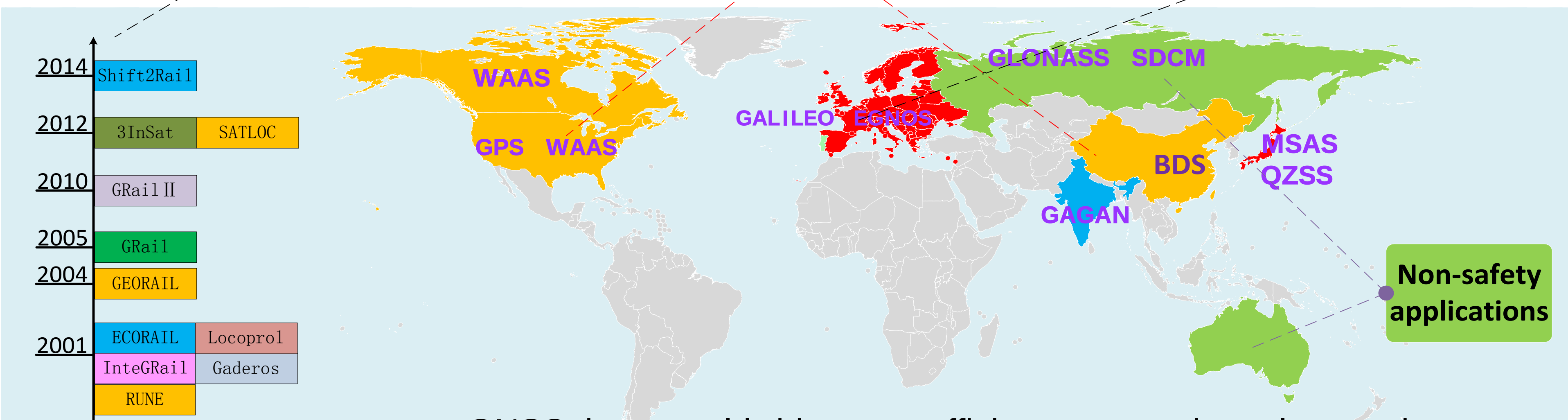
# Introduction

## ❑ GNSS-based train control systems

EC and European Railway Agency (ERA) launched many projects to promote the progress of GNSS-based railway applications

GPS-based PTC (Positive Train Control) had been equipped in the US and China (Qinghai-Tibet Line)

ATLAS 400, an European GPS-based train control system




Europe GNSS-based railway applications projects

GNSS is a worldwide, cost-efficient approach to locate the target, which makes GNSS-based positioning become one of the most promising positioning solutions for the next-generation train control system.

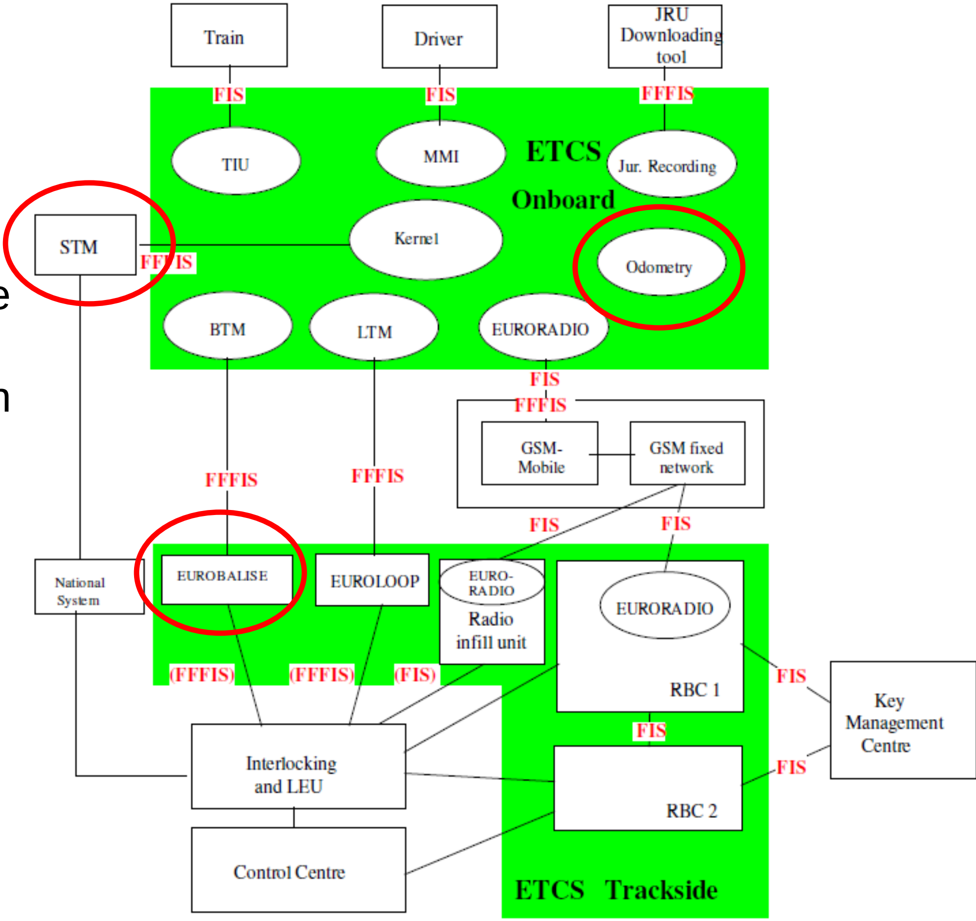
# CONTENT

# Challenges

## ❑ GNSS was refused by railway:

**Policy issue**

- ETCS (European Train Control System)、CTCS (Chinese Train Control System) have been standardized in the last two decades.
- Balise and STM (Specific Transmission Module) are necessary in ETCS-1,2.


*SUBSET-026 ERTMS/ETCS System Requirements Specification issue:3.0.0

ERTMS/ETCS reference architecture*

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# Challenges

## ❑ GNSS was refused by railway:

**Accuracy**

- Accuracy of distances measured on-board:

  $\pm(5m + 5\%S)$

- Accuracy of distinguishing parallel tracks: 1.5m




ERTMS/ETCS reference architecture*

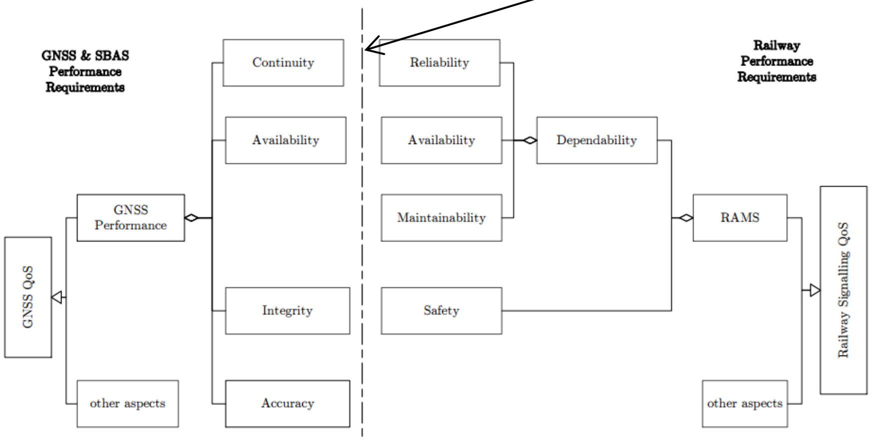
*SUBSET-026 ERTMS/ETCS System Requirements Specification issue:3.0.0

# Challenges

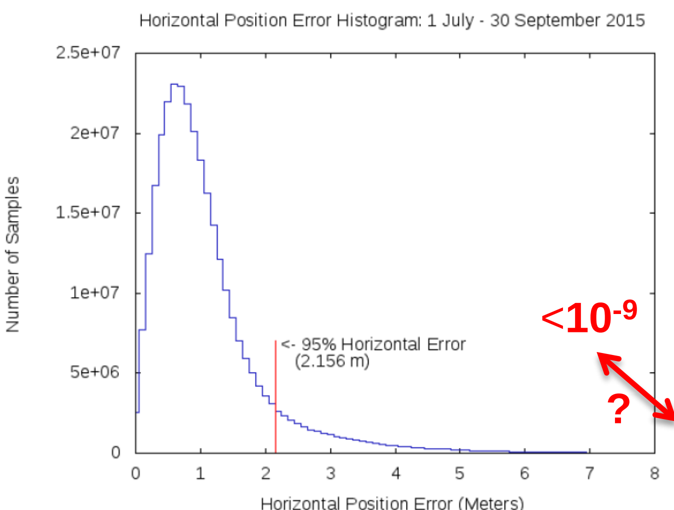
## ❑ GNSS was refused by railway: There is a wall!!

RAMS

- Railway applications must meet the requirements for Reliability, Availability, Maintainability, and Safety
- GNSS performance parameters, which are derived from aviation, are SIS **Availability, Integrity, Continuity**
- Safety: According to CCS TSI 2012/88/EU, for the **hazard** `exceeding speed and/or distance limits advised to ERTMS/ETCS' the **tolerable rate** (THR) is **$10^{-9}$/h** for random failure, for on-board ERTMS/ETCS and for track-side, and positioning unit is just one of many subsystems.




Relation between GNSS and Railway Signalling QoS Properties*




*Debiao Lu, "GNSS for Train Localisation Performance Evaluation and Verification", Dissertation, 2014.

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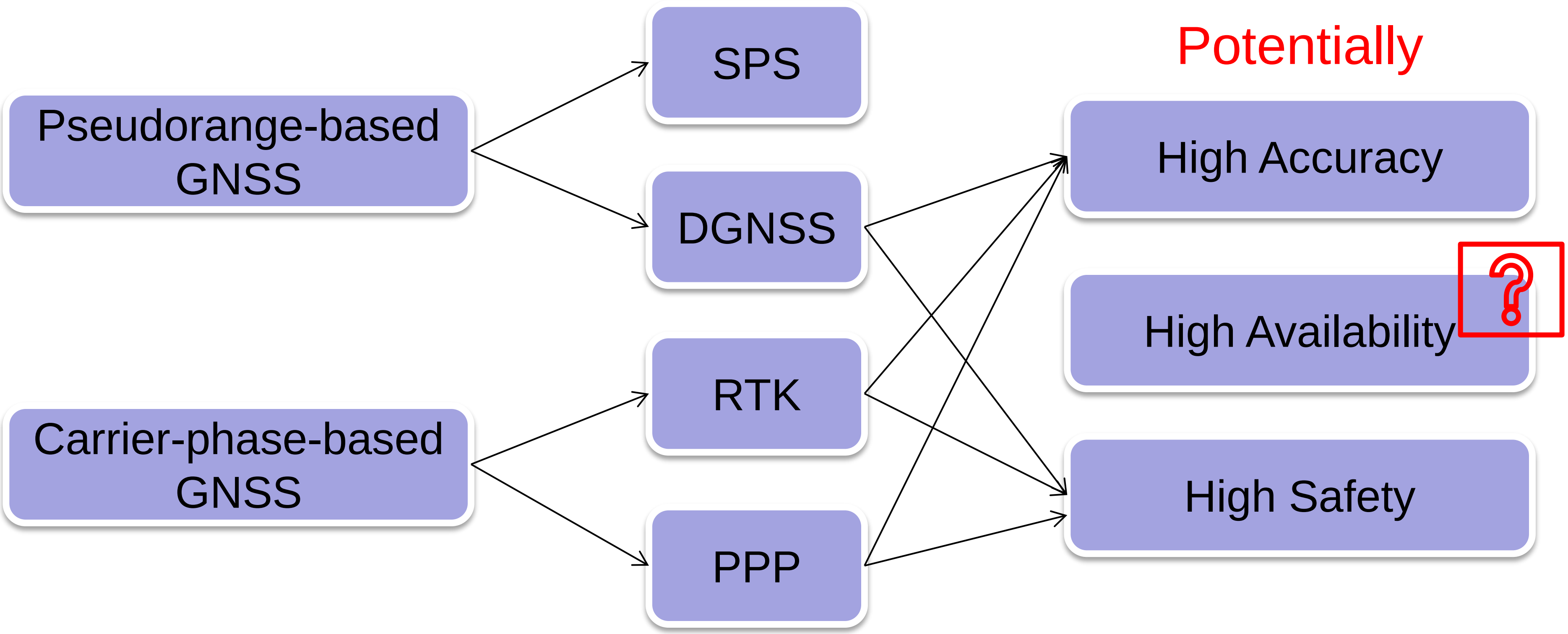
# Solutions

## ❑ Solutions:




SPS: Standard Positioning Service   DGNSS: Differential GNSS   RTK: Real Time Kinematic   PPP: Precise Point Positioning

# ❑ Solutions: Why PPP?

Differential solutions

$$\varphi_i = \rho_i + \varepsilon_i$$

$$-\varphi_j = -\rho_j - \varepsilon_j$$

PPP solutions

$$\varphi_k = \rho_k + \varepsilon_k$$

Station movements that result from geophysical phenomena such as tectonic plate motion, Earth tides and ocean loading enter the PPP solution in full, as do observation errors resulting from the troposphere and ionosphere.

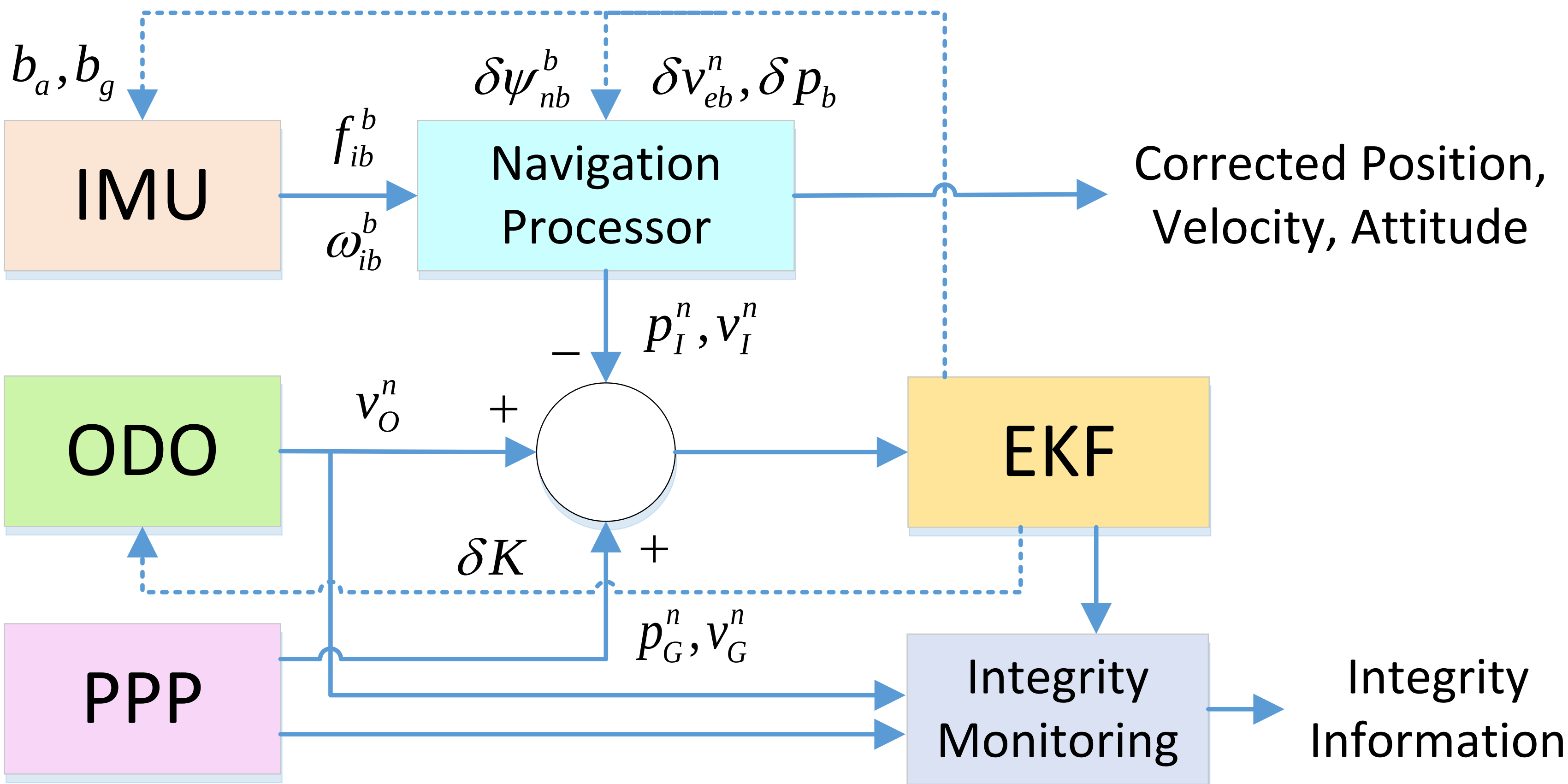
Relevant satellite specific errors are satellite clocks, satellite antenna phase center offset, group delay differential, relativity and satellite antenna phase wind-up error.

Receiver specific errors are receiver antenna phase center offset and receiver antenna phase wind-up.

- In comparison with DGNSS, PPP has higher accuracy(centimetre to decimetre level*)
- Compared with RTK, PPP requires fewer reference stations globally distributed. PPP gives a highly redundant and robust position solution

* M.D. Laínez Samper et al, Multisystem real time precise-point-positioning, Coordinates, Volume VII, Issue 2, February 2011

## ❑ Solutions: PPP-based multi-sensor fusion




IMU: Inertial Measurement Unit    ODO: odometer
EKF: Extended Kalman Filter

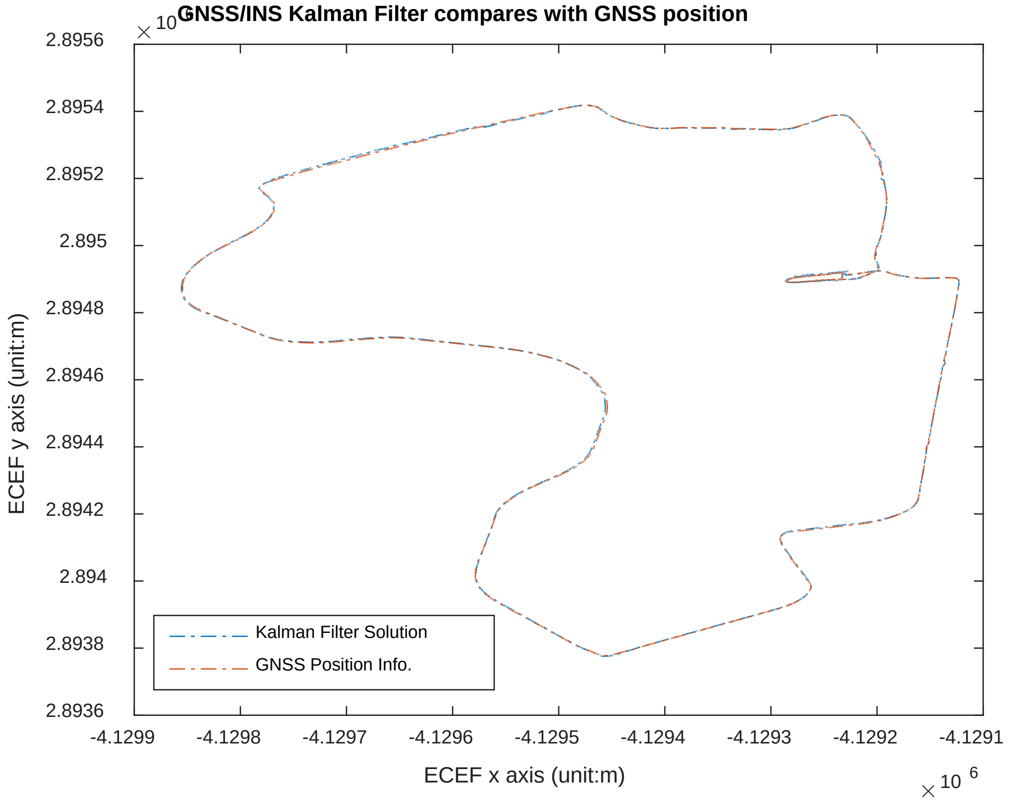
# Solutions

## ❑ Scenarios

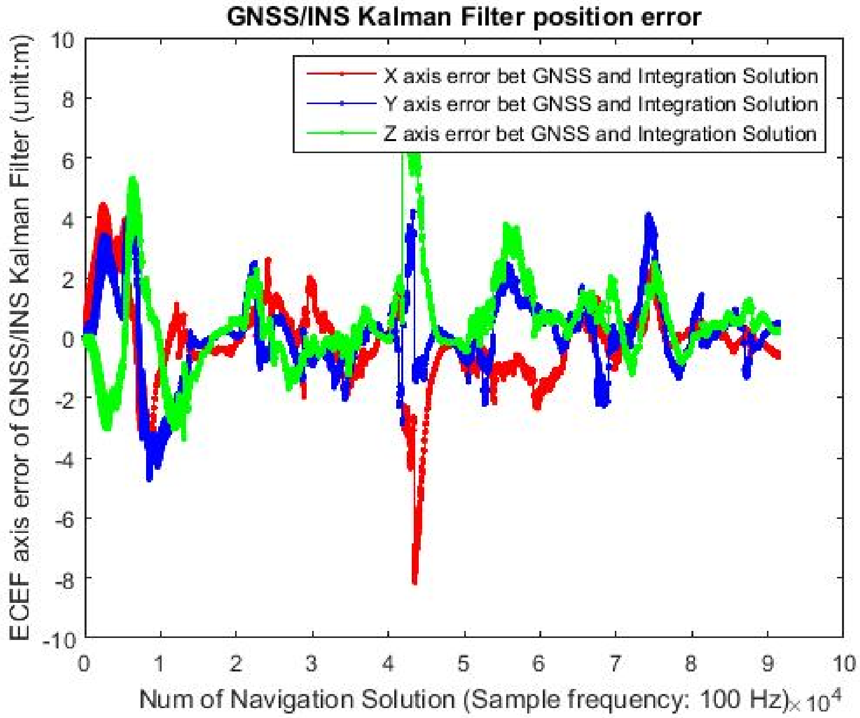
| | GNSS/PPP | | IMU | ODO |
|---|---|---|---|---|
| Scenario 1 | available | not converged | available | available |
| Scenario 2 | available | converged | available | available |
| Scenario 3 | unavailable | | available | available |

# Solutions

## ❑ On-site test




Trajectory of On-site Test

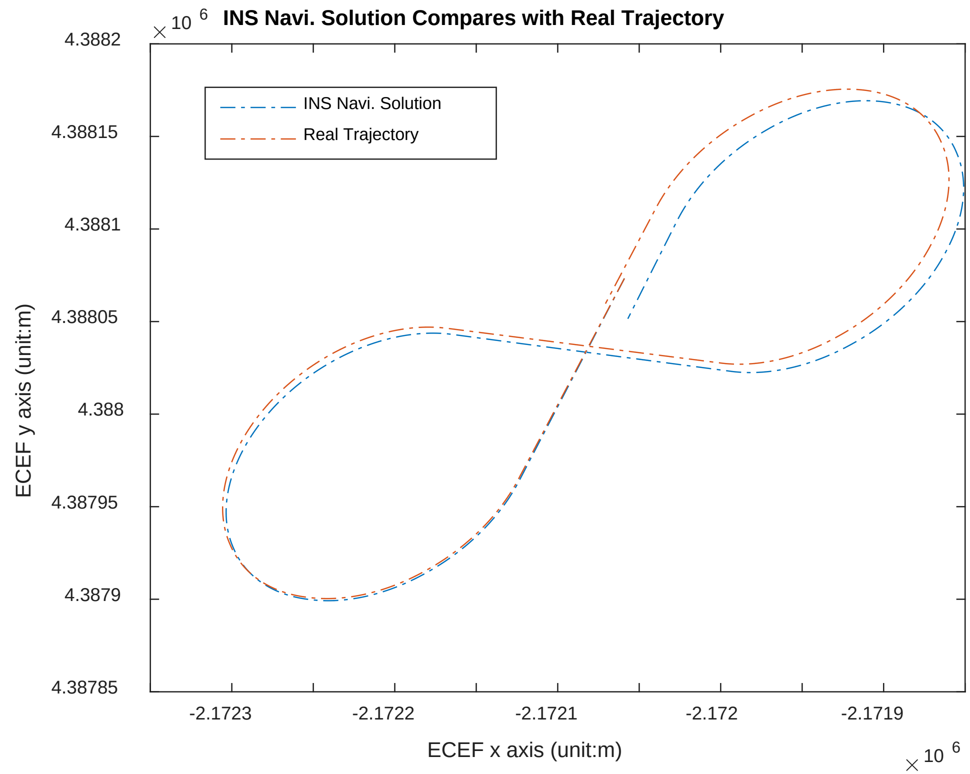



Position Error

# Solutions

## ❑ Simulation test

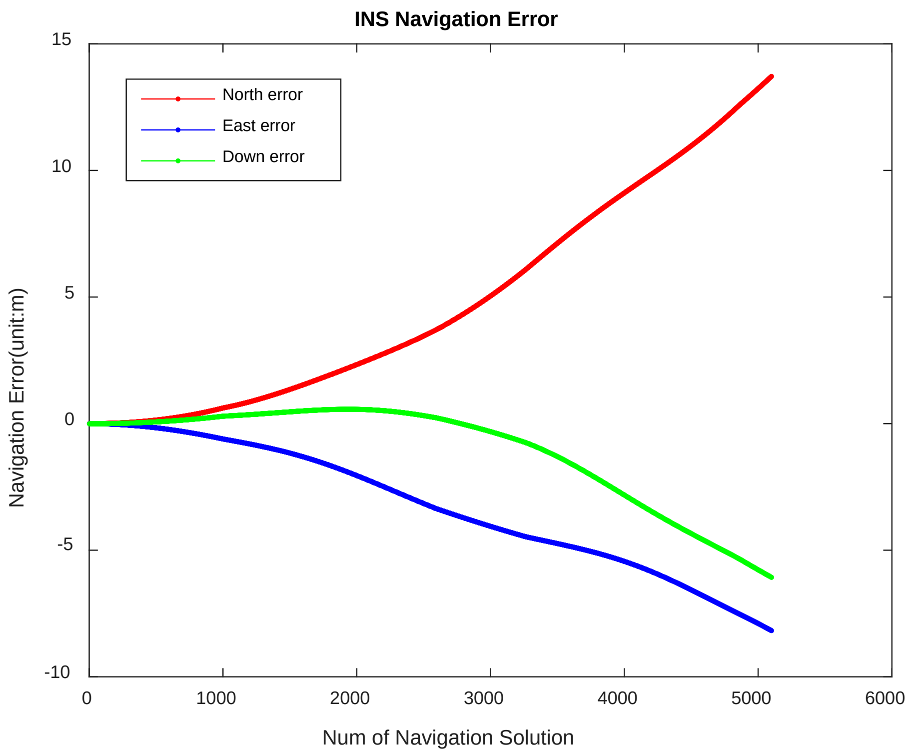

SPIRENT Simulator




Navigation Trajectory

# ❑ Solutions: PPP-based multi-sensor fusion

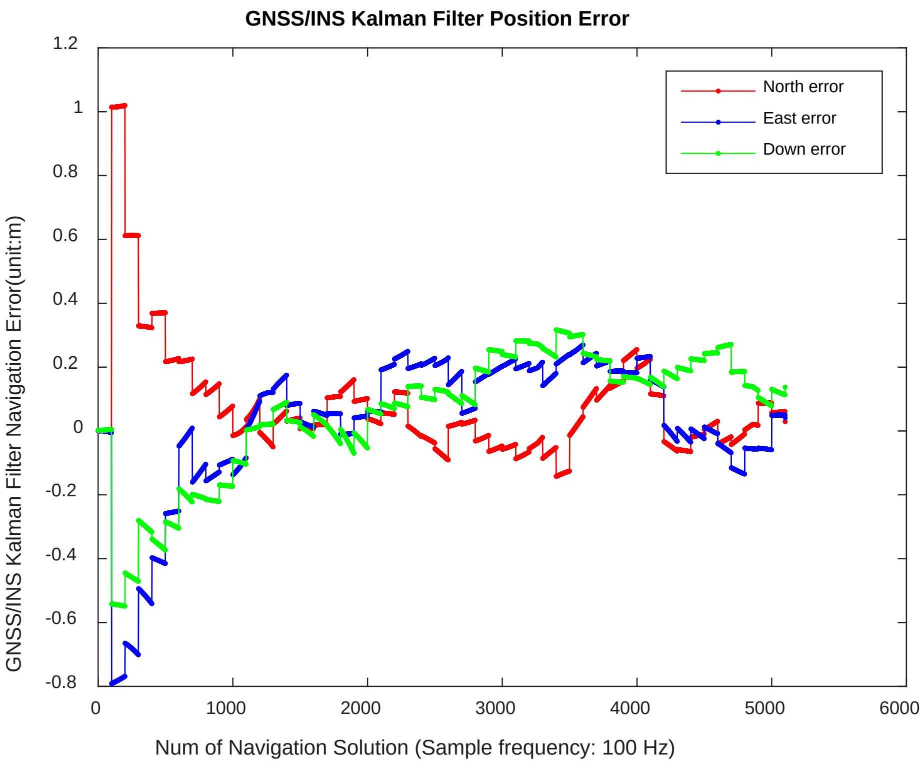

INS/ODO Kalman Filter Navigation Error



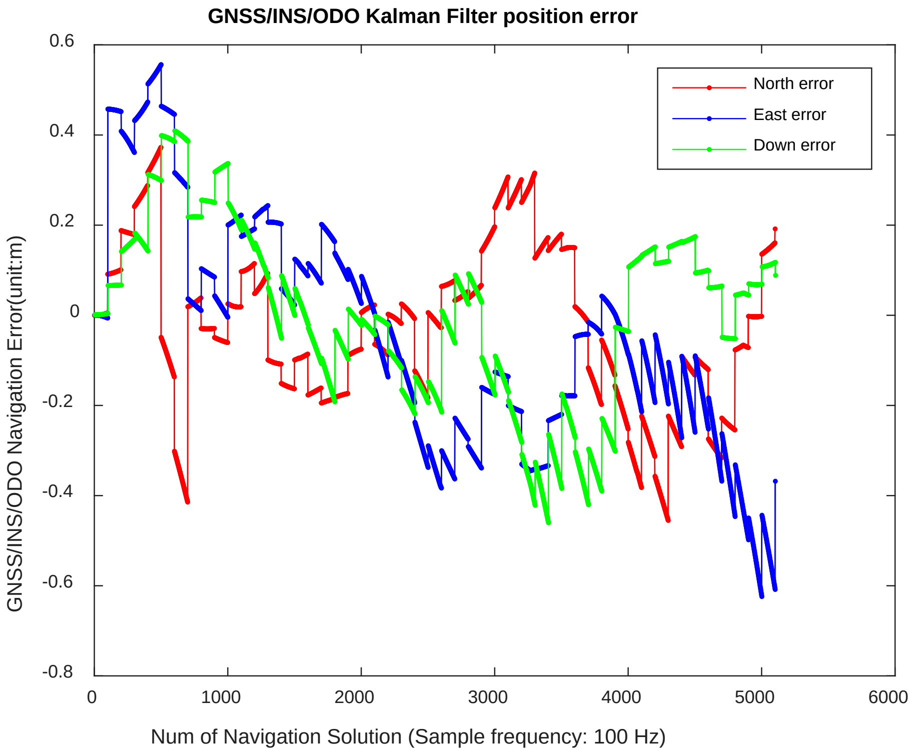

INS Navigation Error

*GNSS position error ~ N(0,1); GNSS velocity error ~ N(0,0.01); ODO velocity error ~ N(0,0.01)

# ❑ Solutions: PPP-based multi-sensor fusion




GNSS/INS Kalman Filter Navigation Error

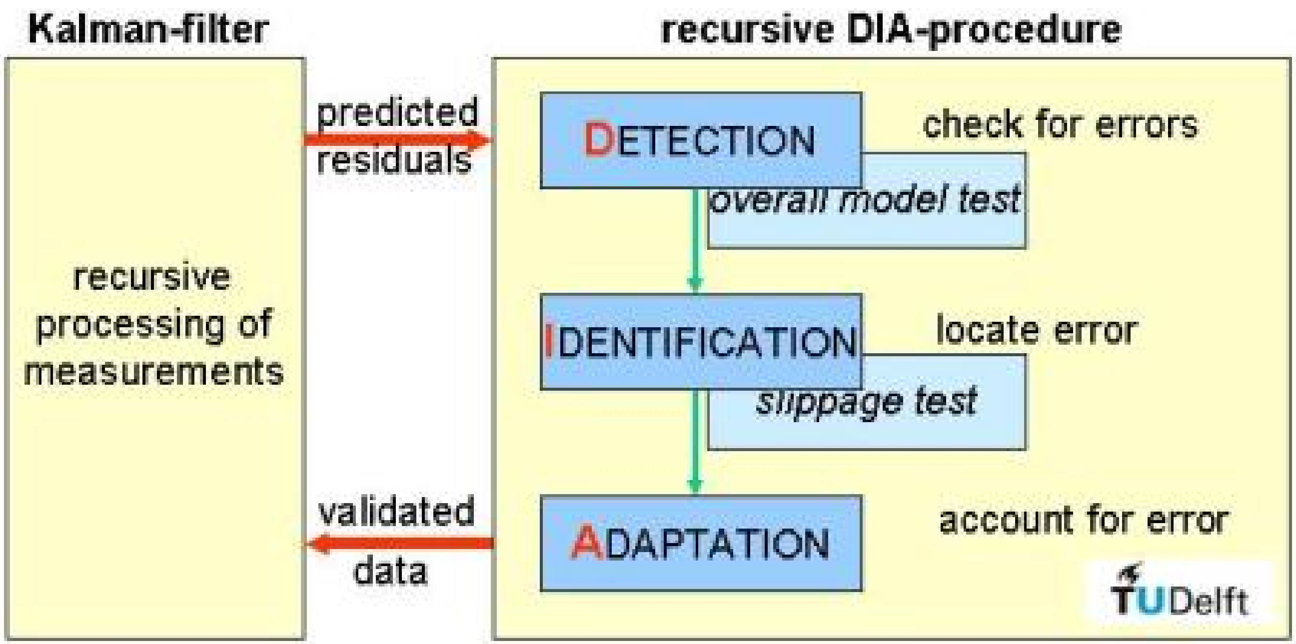



GNSS/INS/ODO Kalman Filter Navigation Error

*GNSS position error ~ N(0,1); GNSS velocity error ~ N(0,0.01); ODO velocity error ~ N(0,0.01)

# Solutions

- Quality Control: Detection, Identification and Adaptation(DIA)




- Based on consistency check of innovations $t_k = \dfrac{v_k^T Q_{v_k}^{-1} v_k}{m_k}$

*Quality control and integrity, Delft school

# Solutions

## ❑ Quality Control: Detection, Identification and Adaptation(DIA)

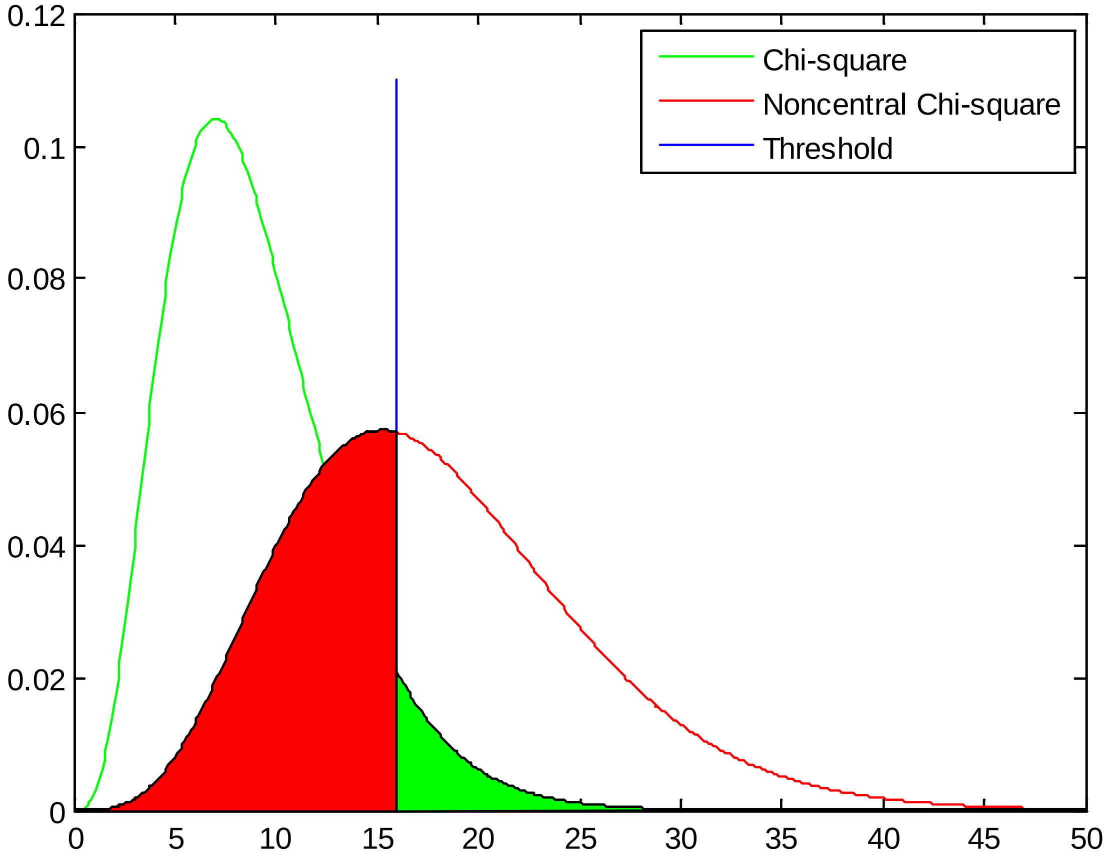
| Bias (unit: m/s) | Detected | Missed Detection | Success Rate |
|---|---|---|---|
| 0 | 1000 | 20 | 98.04% |
| 0.1 | 134 | 886 | 13.13% |
| 0.5 | 1000 | 20 | 98.04% |
| 1 | 1020 | 0 | 100% |

| Bias (unit: degree) | Detected | Missed Detection | Success Rate |
|---|---|---|---|
| 0 | 1000 | 20 | 98.04% |
| 0.0000001 | 77 | 943 | 7.54% |
| 0.000001 | 1000 | 20 | 98.04% |
| 0.1 | 1000 | 20 | 98.04% |
| 0.5 | 1000 | 20 | 98.04% |
| 10 | 1020 | 0 | 100% |

# Solutions

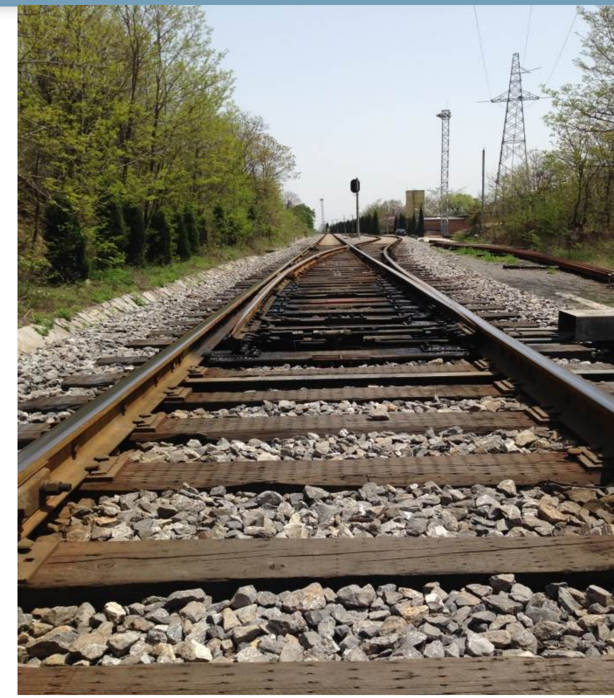
## Threshold

THR <= **$10^{-9}$/h**



# Solutions

## ❑ Further Research



DIA global test

Track maps aided

PPP integrity monitoring scheme


Thank You
Lhasa