Railway Infrastructure Administration

Galileo as an instrument of unification of the European railway transport

by

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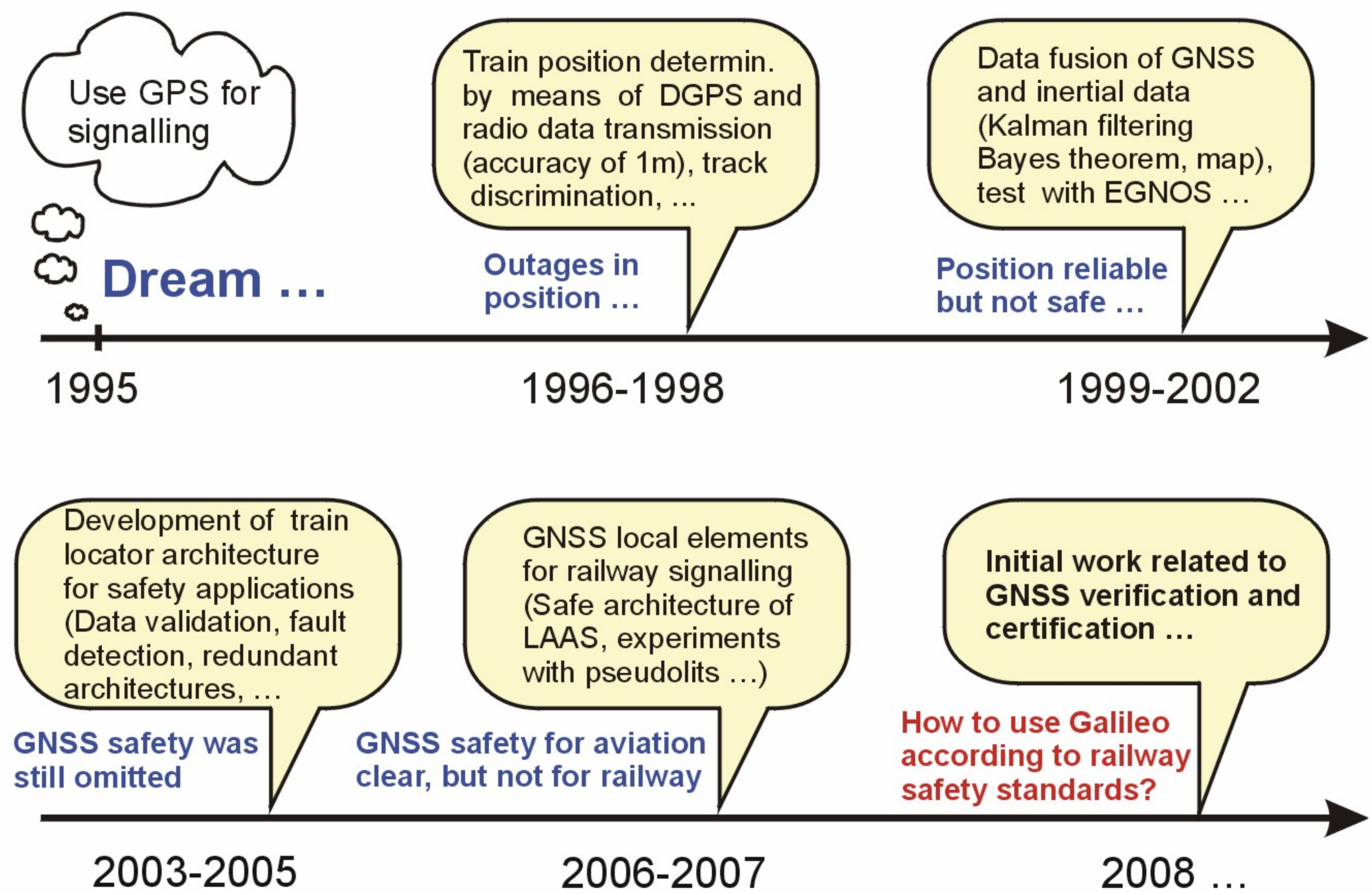
Content:

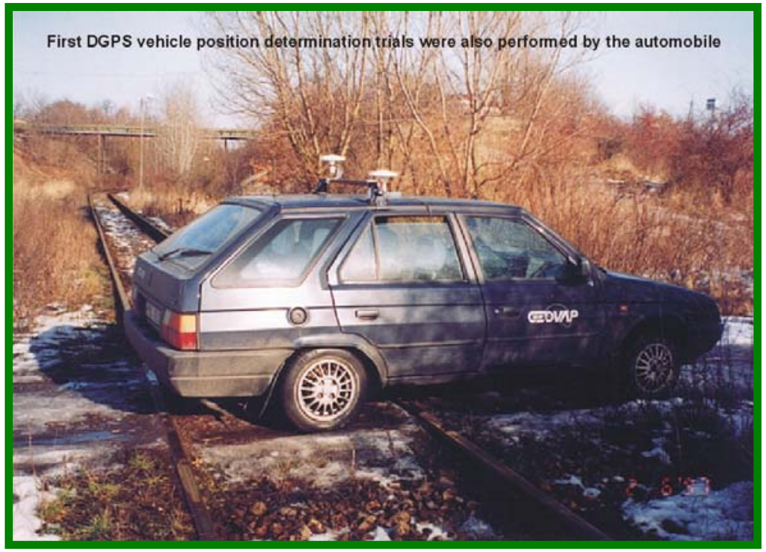
- Overview of R&D work related to GNSS applications done at SŽDC LIS within period 1996-2008
- Motivation: Railway needs for GNSS based train position determination
- Origin of GNSS quality measures
- Description of Galileo SoL service by means of failure modes
- Probabilistic description of failure modes by Venn diagrams
- Relation among GNSS quality measures and railway RAMS
- Train Position Locator based on Galileo

GNSS Route at SŽDC LIS (1996-2008)

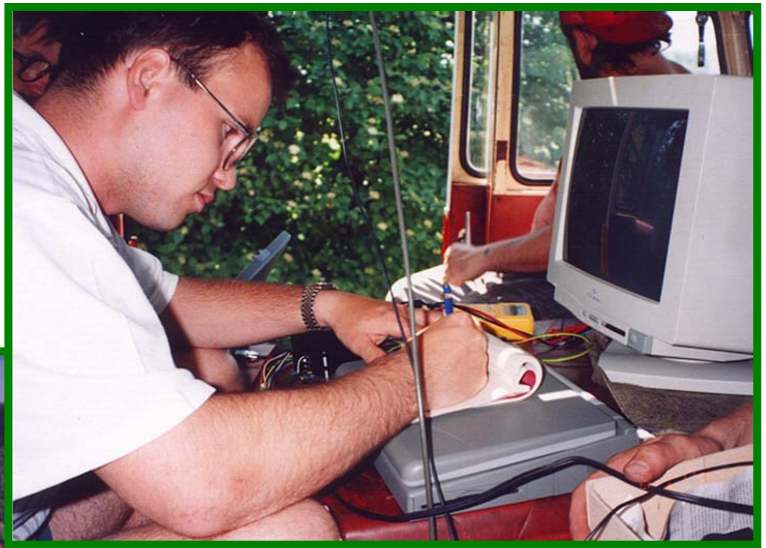


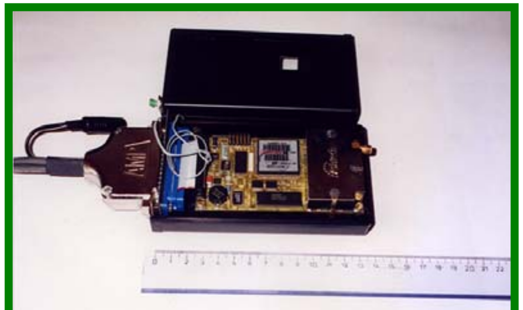
GNSS Route at SŽDC LIS (1996-2008)

The first experiments (1996) focused on validation of accuracy of DGPS method have been performed by a car and Diesel track motor car on industrial line in Pardubice.



Year 1996



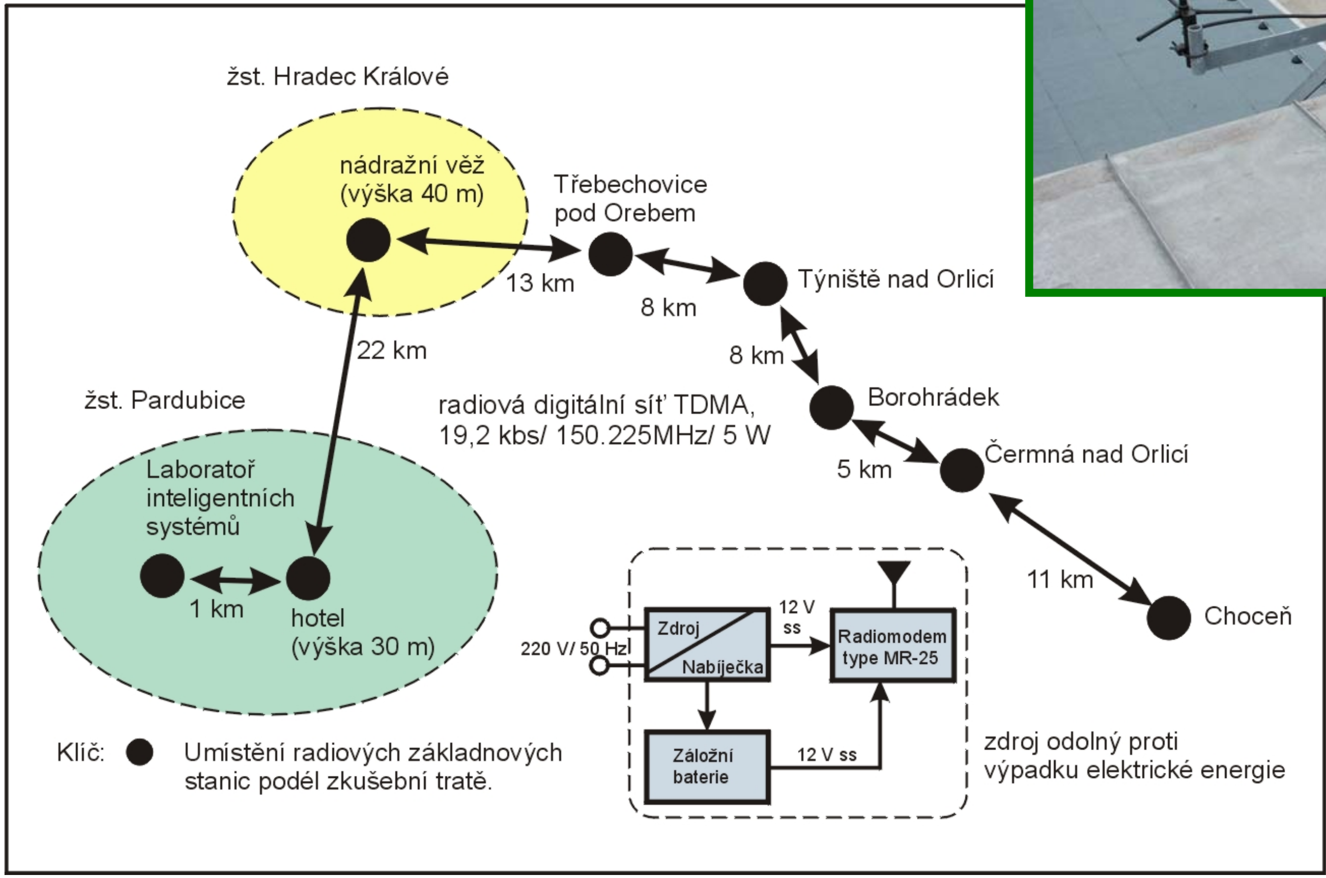


DGPS receiver

GNSS Route at SŽDC LIS (1996-2008)

Digital radio network and DGPS reference station in trial area

Radio signal covers about 100 km of tracks

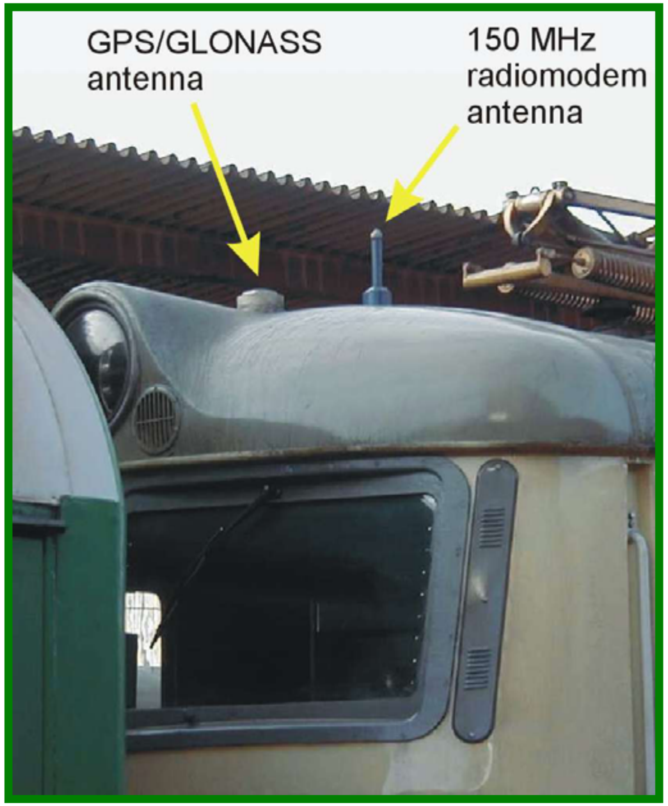


Year 1998

GNSS Route at SŽDC LIS (1996-2008)

European Commission's APOLO Project

Project objectives: Develop and verify train localization unit based on GNSS-1 (GPS+EGNOS) receiver + INS (odometer+gyro)



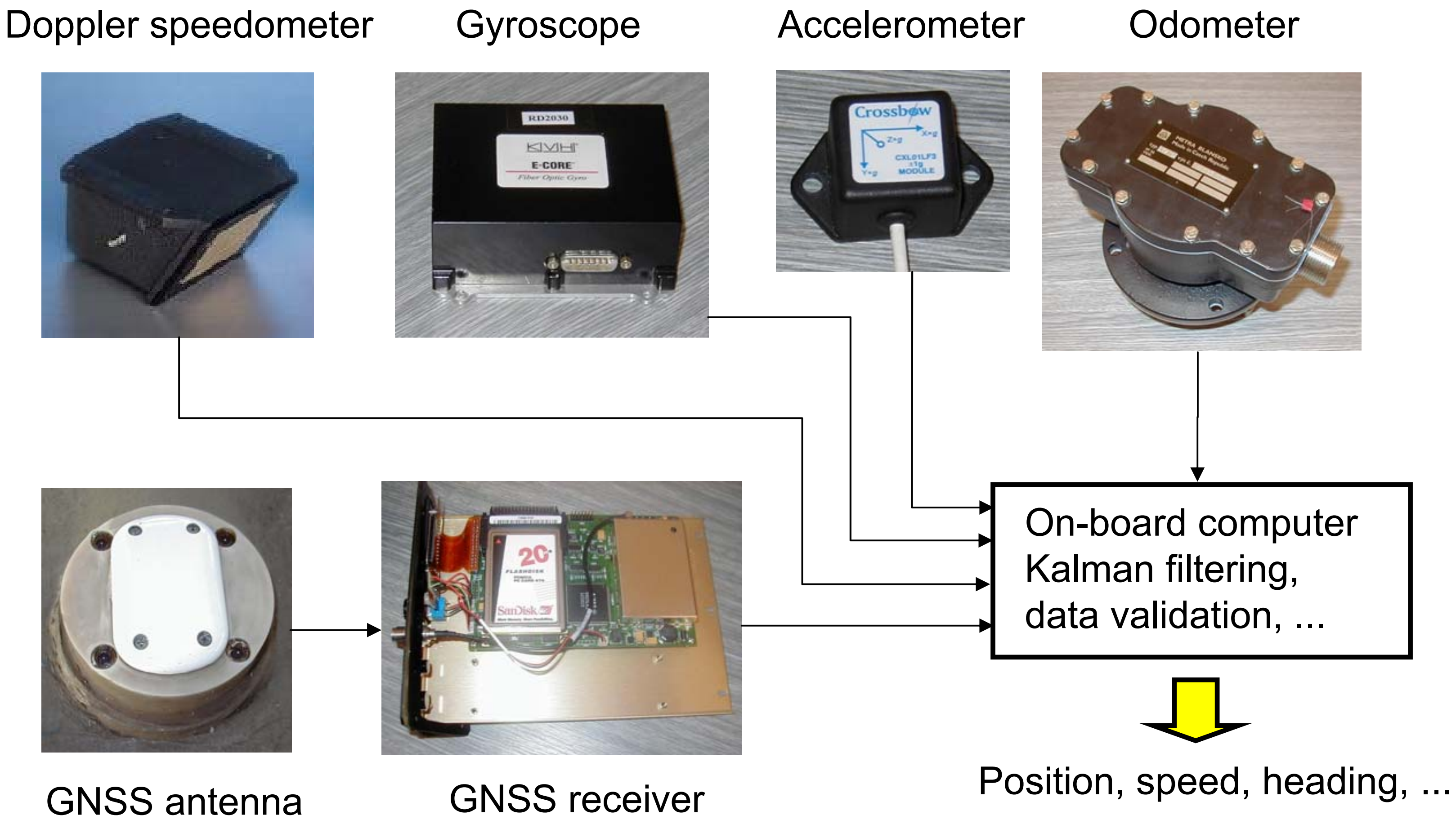
GPS/GLONASS/EGNOS and radio modem antennas on the roof of the 3kV DC locomotive, type 130 023-5.

Year 2000

GNSS/ INS based train position locator in the locomotive cabin.

GNSS Route at SŽDC LIS (1996-2008)

Sensors of the on-board Train Position Locator



Year 2001

GNSS Route at SŽDC LIS (1996-2008)

Tools and equipment for trial

Computer controlled self moving vehicle.

2.4 GHz CDMA repeater. The wireless LAN installed along the trial track enables remote control of the mobile robots on the 4 km long trial track in Pardubice station.

Year 2002

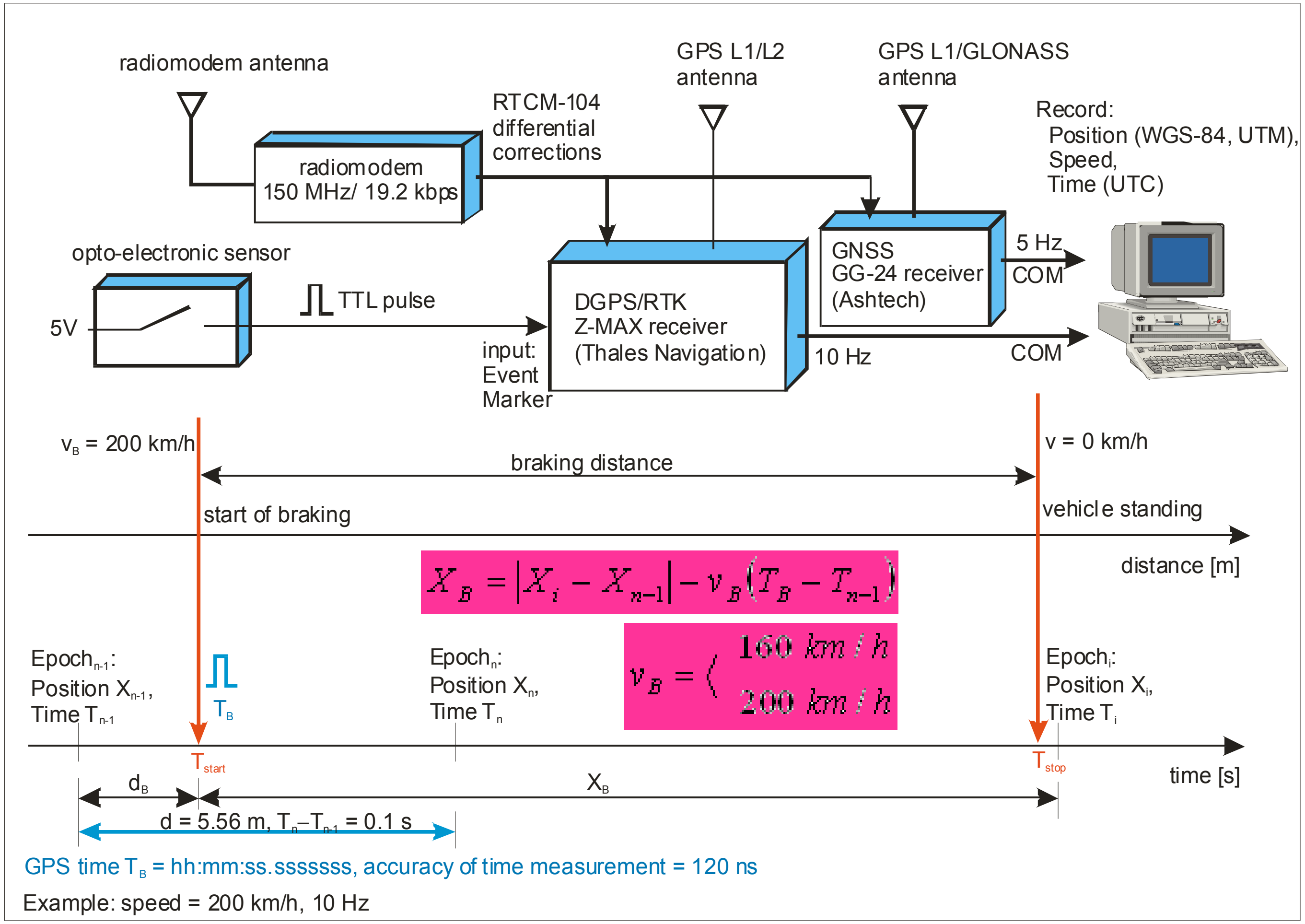
Practical use of R&D results at SŽDC LIS

Technical and Safety Tests of 7 Pendolino trains with use of DGPS RTK

GPS antennas (L1+L2) on roof

Year 2005

Braking distance measurement – vehicle part



Event Marker – record of time when braking process starts.

Initiated by TTL pulse from opto-electronic sensor.

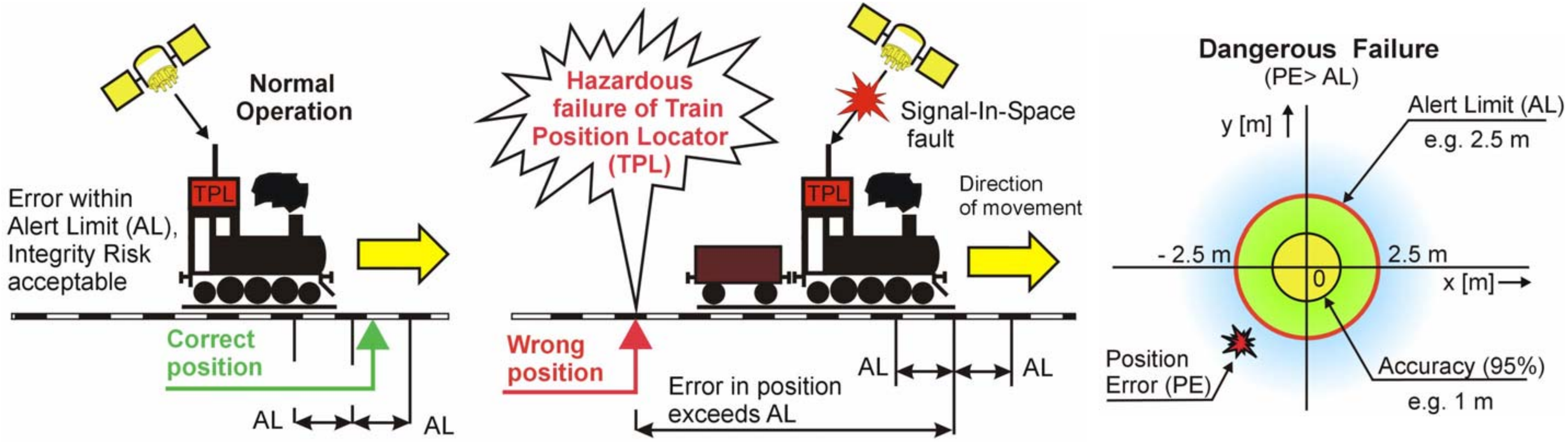
Technical and Safety Test of Pendolino trains

- Higher accuracy,
- Independence on daylight and weather conditions,
- Automatic data recording (possibility of further evaluation),
- On line and “in protocol” measured data output in the driver cabin:

- ♦ Speed & time & acceleration
- ♦ Braking distance,
  event time of braking start,
  duration of braking
- ♦ Instantaneous UTC time,
  position status, digital map,
  total traveled distance
- ♦ Maximal absolute and relative
  errors of measurements

Motivation: Needs for GNSS based signalling

- **Safe train position determination** Example: Head of Train Determination



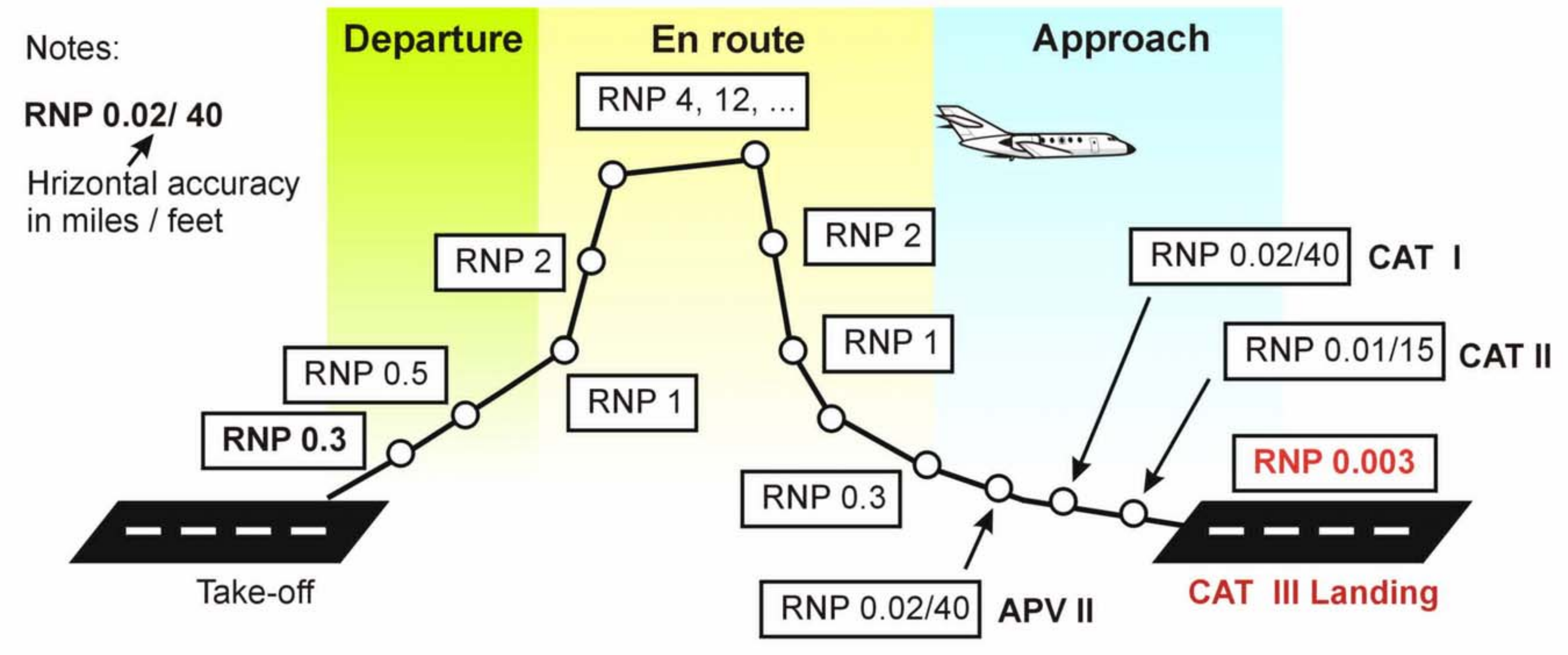
- **Railway requirements for GNSS Train Position Locator (2000)**

Application/ Lines	Horizontal Accuracy [m]	Integrity Alert Limit [m] - HAL	Integrity Time-To-Alarm [s]	Continuity of Service [%]	Interruption of Service [s]	Availability of Service [% of time]	Fix Rate [s]
ATC Corridors Station tracks	1	2,5	< 1.0	> 99.98	< 5	> 99.98	1
Middle density	10	20	< 1.0	> 99.98	< 5	> 99.98	1
Low density	25	50	< 1.0	> 99.98	< 5	> 99.98	N/A

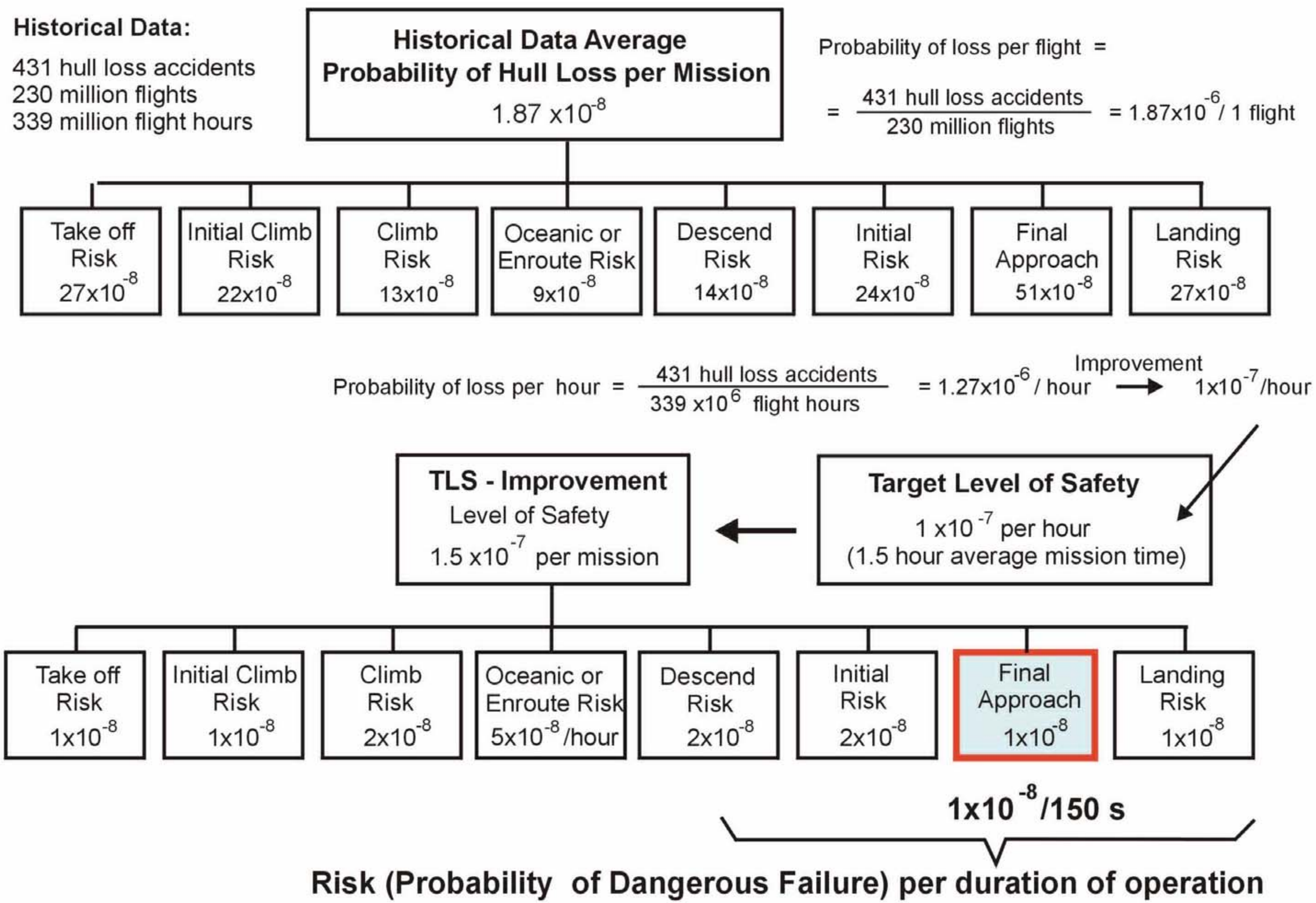
Ref: GNSS Rail Advisory Forum – Requirements of Rail Applications, 2000.

Origin of GNSS Quality Measures

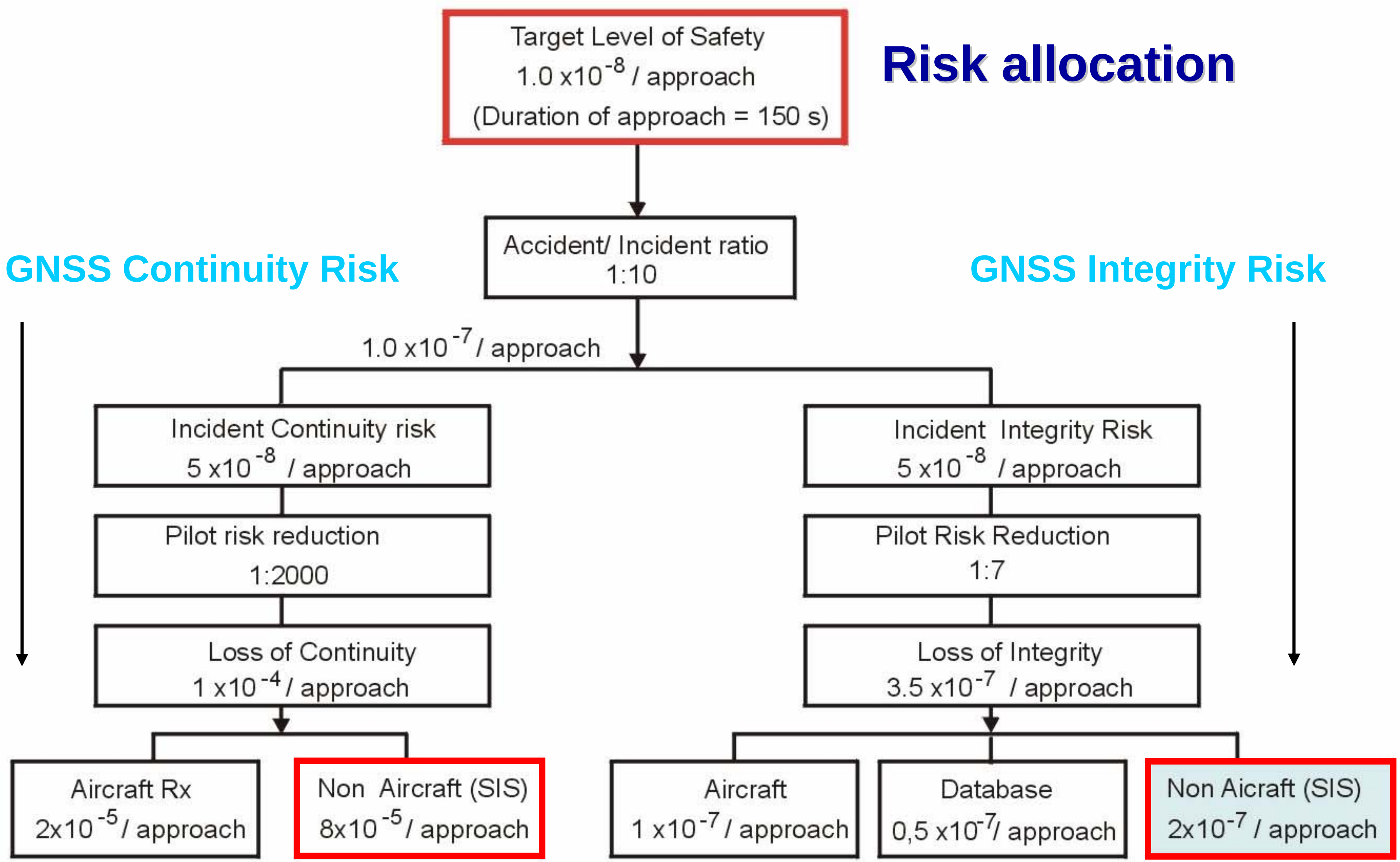
- **Derived from needs of Civil Aviation - ICAO**
  - RNP Concept (Required Navigation Performance) - since 1993
  - RNP specifies accuracy with reference to safety
  - **RNP (minima): Accuracy, Integrity, Continuity and Availability**



Target Level of Safety (TLS) for GNSS in Aviation



Target Level of Safety for GNSS in Aviation



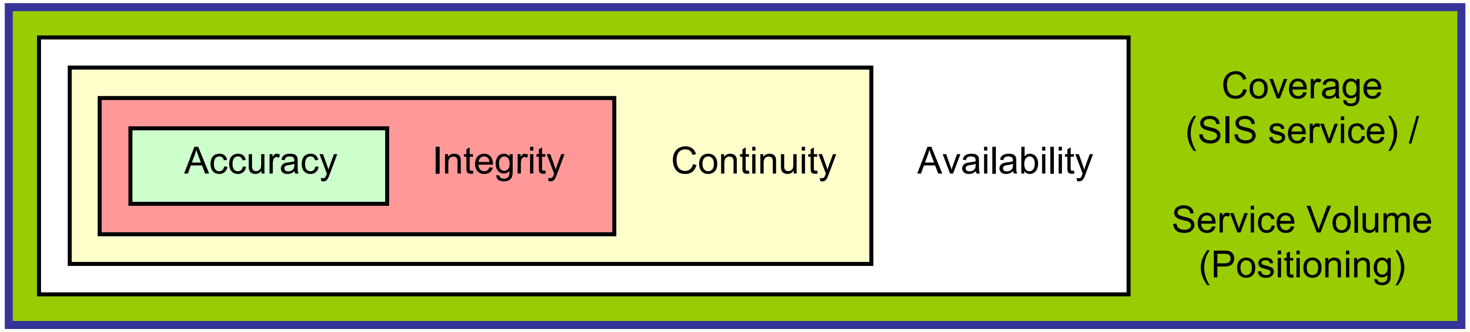
Mission level SoL requirements for Galileo SIS

- **Galileo SIS high level requirements were mainly derived according to the aeronautical requirements.**
- **Railway requirements for Galileo SIS are missing.**
- **Due to different aeronautical and railway safety concepts there is necessary to understand, what railways can get from Galileo in railway safety and dependability terms (EN 50126, EN 50129, ...).**

	Level A (critical) requirements Aviation - APV II	**Railway requirements**	**Level B (non-critical) requirements** Aviation - to NPA	**Level C requirements** Maritime
SIS Integrity Risk	2e-7 in any 150 s		1.0e-7/ 1 h	1.0e-5/ 3 h
Continuity Risk	8.0e-6 in any 15 s		1.0e-4 to 1.0e-8 / 1h	3.0e-4 / 3 h
Availability of Service	99.50%		99.50%	99.50%
TTA	6 s		10 s	10 s
Accuracy (95%) H / V	4 m / 8 m		H:220 m	H: 10 m
HAL / VAL	40 m / 20 m		HAL=556 m	25 m / NA
Dual Frequency E5+L1 or E5b+L1	YES		YES	YES
Single Frequency L1 or E5b	NO		YES	YES
Coverage	Global		Global	Global

Quality measures of GNSS

- **Accuracy** - difference between the estimated and true position, under fault free conditions, 95% of time (2σ).
- **Integrity** - ability of the system to provide timely warnings to users of when the system should not be used for navigation (Correctness of position).
- **Continuity** - probability of maintaining navigation guidance without interruption during a certain period of time (Guarantee of positioning when it is very needed). It is the most demanding GNSS requirement.
- **Availability** - percentage of time that the system services are within the required performance limit (Accuracy + Integrity + Continuity fulfilled).



- **Coverage** – is function of factors that affect signal availability: satellite-user geometry, signal power level, receiver sensitivity, …
- **Service Volume** – a region in which GNSS system meets accuracy, integrity, continuity and availability.

Railway safety concept – EN 50126, EN 50129,...

- **Quality attributes of railway systems**: Reliability, Availability, Maintainability and Safety (RAMS) – EN 50126.

- **Functional Safety** – proper performance of all required safety functions in expected working environment under absence of failures.

- **Technical Safety** – prescribed behaviour of system in case of failures.

- **Basic principles of railway Technical Safety (EN 50129):**
  It includes integrity requirements against systematic and random failures.

  (1) No failure can endanger ride of train ...
  (2) Any failure must be detected promptly enough ...

  ....

- **Definition of railway safety integrity (CENELEC EN 50129)**
  - The ability of a safety-related system to perform the **required safety functions** under all the stated conditions within a stated operational environment and within **a stated period of time**.
  - SIL is reliability of performing of safety functions

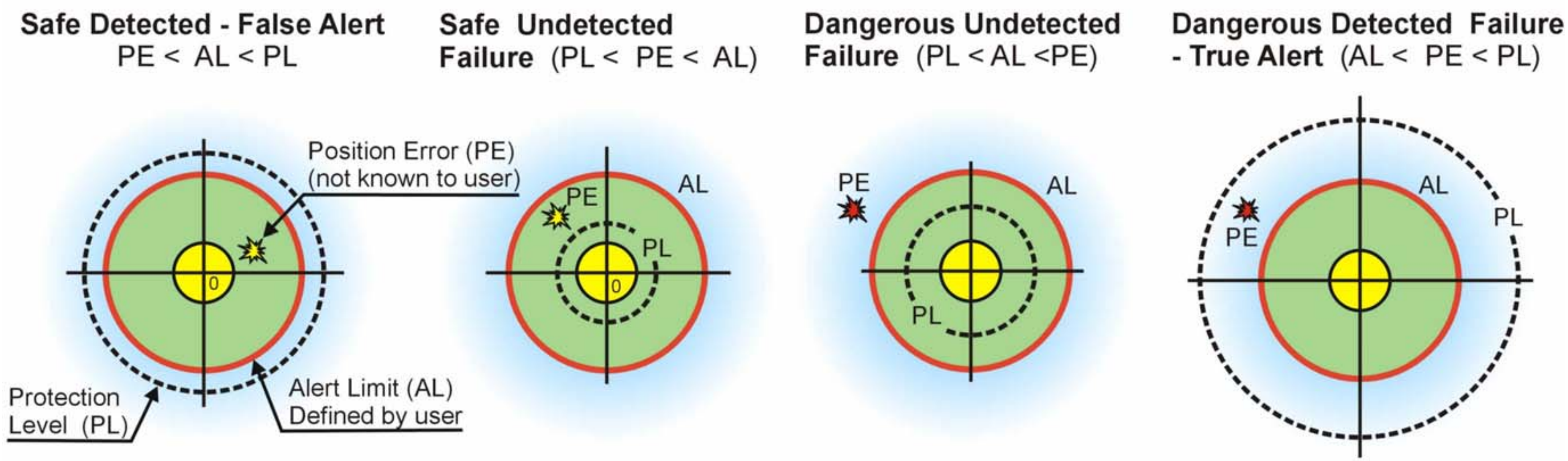
Classification of GNSS SIS failure modes / Safe or Dangerous?

- **Dangerous failure - Position Error (PE) is outside of Alert Limit (AL)**
- **Safe Failure - Position Error is inside of Alert Limit**

- **Failure modes with diagnostics**
  - **Dangerous Undetected (DU) – Integrity Event**
  - **Dangerous Detected (DD) – True Alert**
  - **Safe Detected (SD) – False Alert**
  - **Safe Undetected (SU)**

- **GNSS failure modes (SD, SU, DU, DD)**

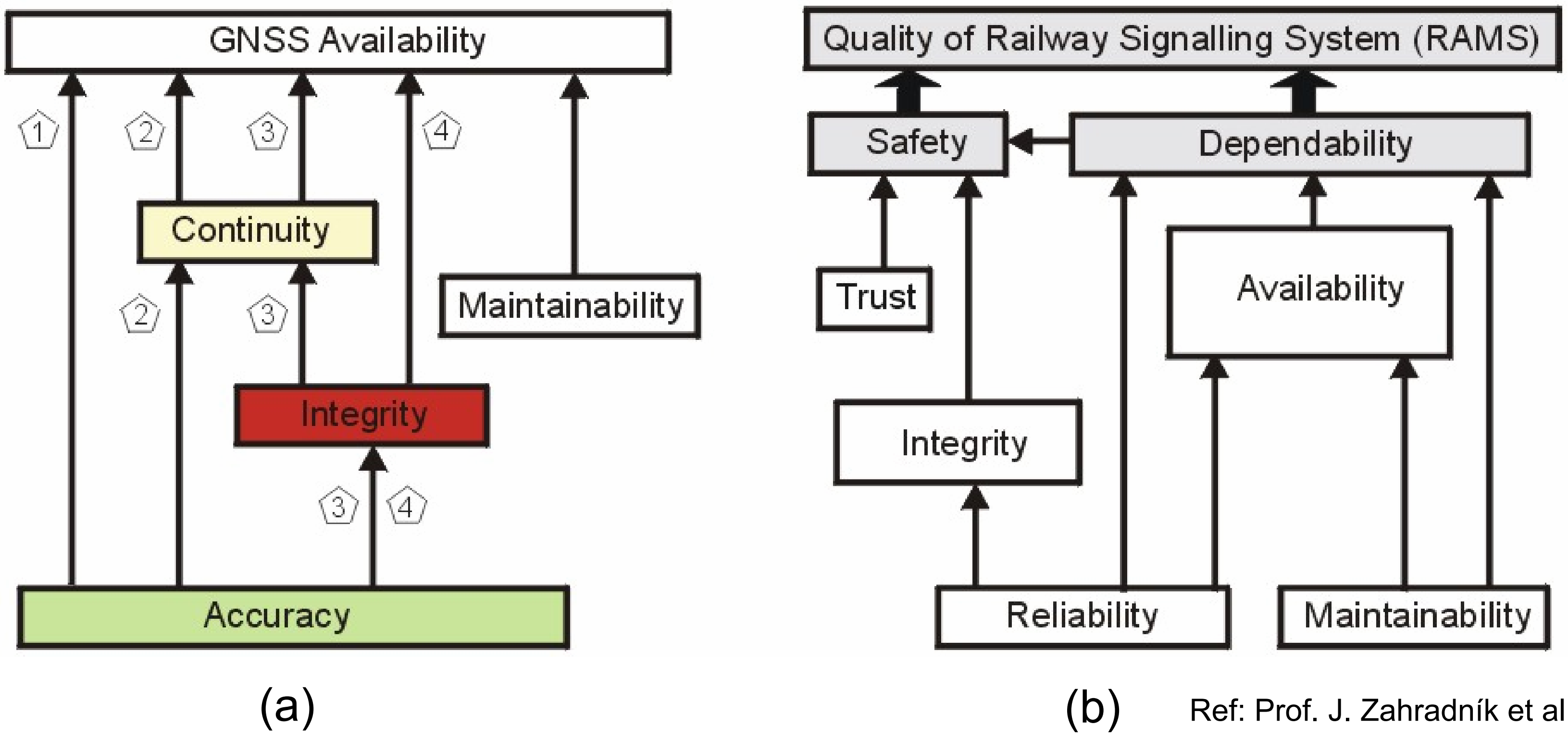
  Failure modes classified on the basis of relation among Position Error (PE), Protection Level (PL) and Alert Limit (AL)



Relation among GNSS quality measures and railway RAMS

- **GNSS system is available, if services of the system are within required limits. That is requirements for accuracy, integrity and continuity of service/ function are met.**

Goal in Aviation - Dependability **Goal in Railway Signalling - Safety**

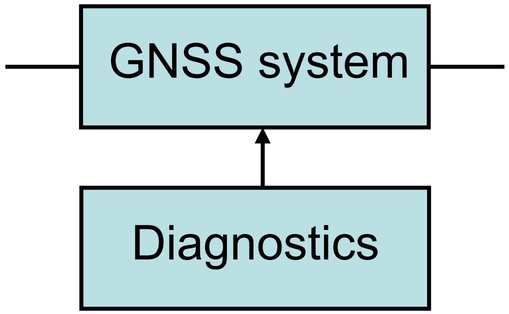


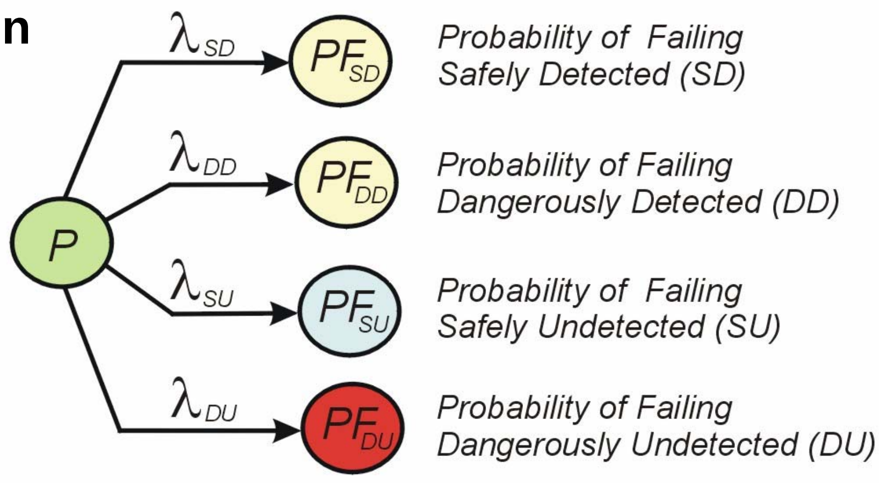
Ref: Prof. J. Zahradník et al.

The relation among: (a) GNSS availability, continuity, integrity, and accuracy,
(b) Quality attributes of railway signalling system.

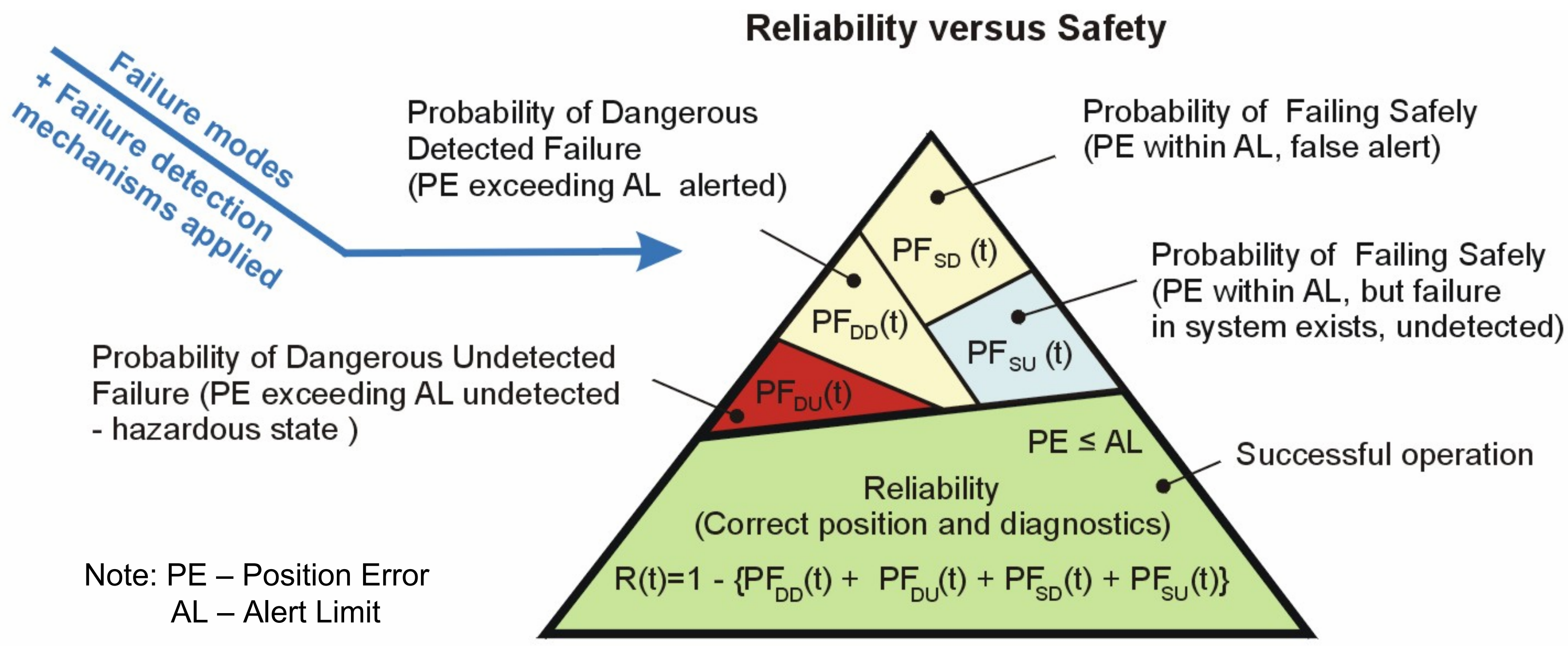
Relation among GNSS quality measures and railway RAMS

- **Failure modes and failure detection**



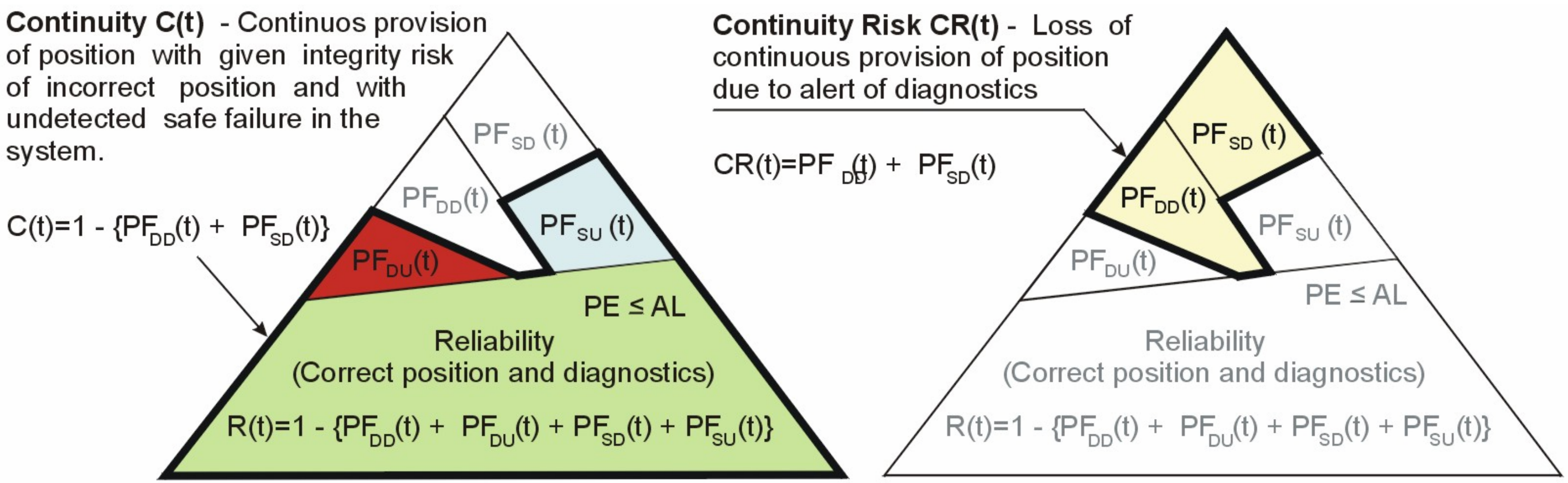


- **Venn diagrams of system states**

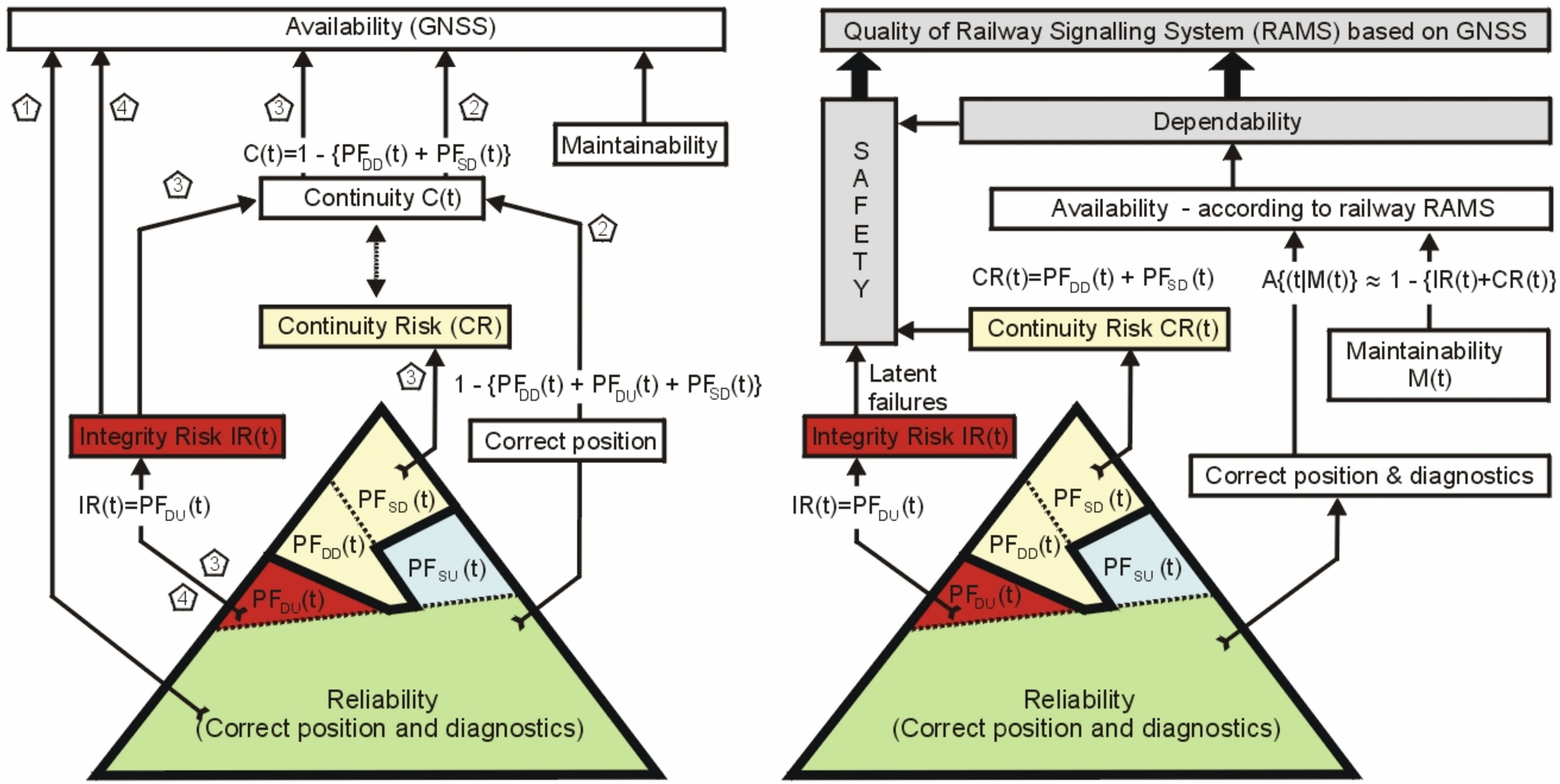


Relation among GNSS quality measures and railway RAMS

- **GNSS Continuity and Continuity Risk – Probabilistic description**
  - **Loss of continuity (CR) is related to unscheduled interruptions**
  - **CR is a failure since system has already started safety function**
  - **Loss of SIS due to obstacles along track is not Loss of Continuity**



Relation among GNSS quality measures and railway RAMS



- **There are discrepancies among GNSS measures and railway RAMS**
  - **Continuity doesn‘t exactly correspond to reliability**
  - **Availability (EN 50126) doesn‘t include integrity and continuity**
  - **Railway RAMS doesn‘t know terms Integrity and Continuity Risks …**

Galileo SIS Integrity Risk (IR) as Hazard Rate / Hour

- **Probability of Failure on Demand (PFD)**

$$PFD(T) = \int_0^{3600s} \frac{P_f}{150s} dt = P_f \frac{3600s}{150s} = 24 \cdot P_f = 24 \cdot 2 \cdot 10^{-7} = 4.8x10^{-6}$$

where P_f is probability of dangerous failure at any time interval of 150 s and IR (Integrity Risk) corresponds to probability density of failure $f(t)$.

- **Why cumulative probability principle is used for derivation of failure rate?**

Galileo SIS IR is determined by number of independent hazardous events that could occur during a critical operation, i.e. during interval of 150 s. Correlation time between independent hazardous events is higher than 150 s for most of hazardous events in the Galileo system. Therefore only one independent integrity check is considered for the interval of 150 s.

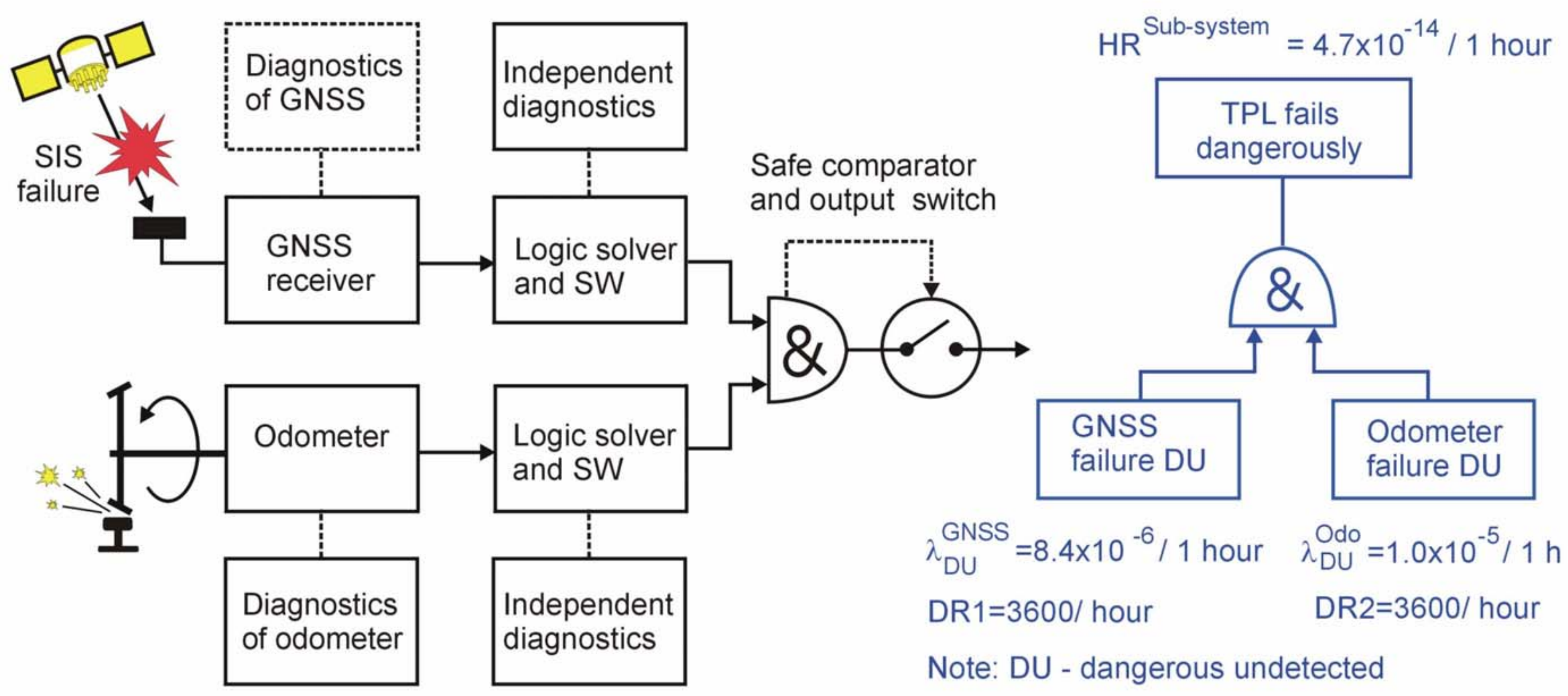
- **Probability of Dangerous Failure per Hour (PFH)**

$$PFH = \frac{PFD(T)}{T} = 4.8x10^{-6} / hour$$

- **Hazard Rate (HR)**

$$PFH \approx HR(T = 1\,hour) = \lambda_{DU}^{SIS}(T = 1\,hour) = 4.8x10^{-6} / 1\,hour$$

Example: 1oo2D (with diagnostics) TPL based on Galileo



$$HR^{System} \approx \frac{\lambda_{DU}^{GNSS}}{DR^{GNSS}} \times \frac{\lambda_{DU}^{Odo}}{DR^{Odo}} \times (DR^{GNSS} + DR^{Odo})$$

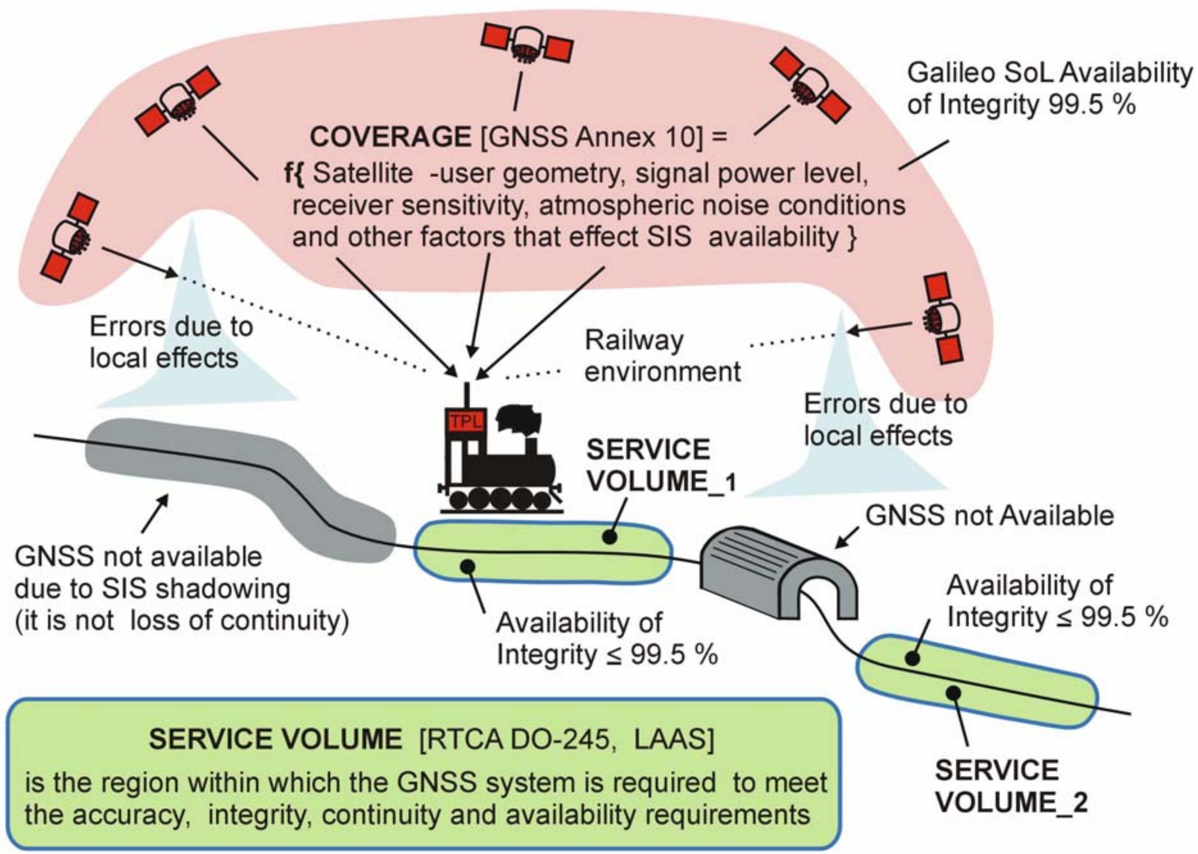
$$HR^{System} \approx \frac{8.4x10^{-6}}{3600} \times \frac{1x10^{-5}}{3600} \times (3600 + 3600)$$

Example: GNSS + Odo system

$$HR^{System} \approx 4.7x10^{-14} / hour$$

1oo2D has high integrity, high availability in respect to 1oo2 system

Availability at GNSS Service Volume



- **Service Volume determination will be part of signalling system design. Tools for design of Service Volume are needed (simulators, …)**
- **Tasks: Improvement of availability from 99.5 (Galileo) to 99.99999 and reduction of Integrity Risk from 3.5×10^{-7}/150 s to THR of < 10^{-10}/ hour**

Conclusions

- **Different definitions and notions used for description of the GNSS quality measures and railway RAMS (EN 50126).**
- **The relationship between the GNSS quality measures and railway RAMS can be described by means of failure modes of GNSS.**
- **Correct interpretation of the Galileo High Level SoL aeronautical requirements by means of railway RAMS (EN 50126) represents fundamental step towards GNSS based railway safety applications.**
- **Application Method of Galileo Integrity Concept for railway safety related systems should be clearly described - consensus of railway specialists is needed. It should be part of certification process.**

Ref: Galileo Integrity Concept

The assessment of the navigation service performance requirements (in terms of integrity, continuity and availability) will be finally achieved by verifying (through ***Service Volume simulation*** *and* ***RAMS analysis****).*

Acknowledgement

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Thank you!

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