EUROPEAN SPACE WEEK

ONLINE EDITION

#EUSpaceWeek

Horizon 2020
European Union Funding
for Research & Innovation

European
Global Navigation
Satellite Systems
Agency

HELMET

High Integrity EGNSS Layer for Multimodal Eco-friendly Transportation

GNSS and Copernicus in Rail – state of art

Alessandro NERI

RadioLabs

Organised by:

European
Global Navigation
Satellite Systems
Agency

European Commission

Under the auspices of:

eu2020.de

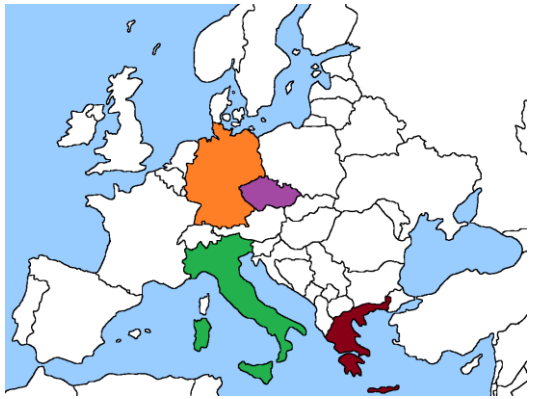
EU Space Programme:

Copernicus

EGNOS

GALILEO

HELMET



Horizon 2020
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Main objective: development of innovative EGNSS based applications for the most impacting eco-friendly and green TRANSPORTATIONS MEANS as

- automated and driverless CARS,
- connected CARS,
- TRAINS (mostly signaling and control systems),
- UAV (Unmanned Aerial Vehicles) for surveillance and integrated information management of roads and railways.

HELMET

Enabling Safety critical applications on road and rails

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Automotive and Railway Synergie

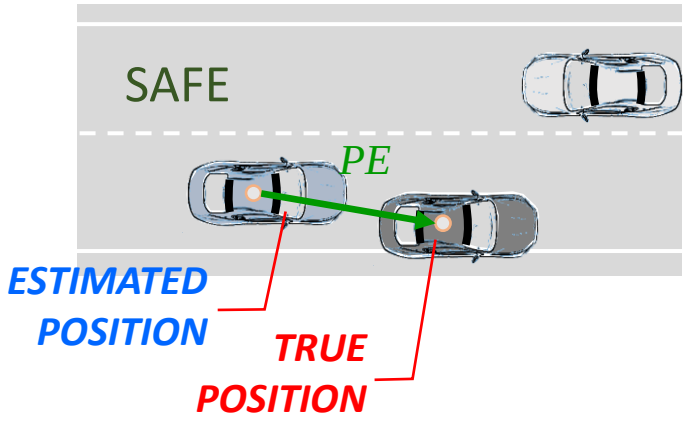
Railways and Highways are very often close to each other and share the same EM environment and similar requirements

Largest distance between road and railway [m]	Road/rail length [km]
<50 m	1,500 km
<100 m	2,200 km
<500 m	6,000 km
< 1,000 m	10,000 km

Application	Scenario User Requirement / Use case	Integrity	Accuracy 95%		Alert Limit		Time to alert	Availability	Continuity	Security
			Lateral	Long.	Lateral	Long.				
RAIL Localization System	Track Identification	<1e-9/h	0.70 m		1.7 m		10 s – 30 s	High	N/A	Very High
	Odometry Calibration	<1e-9/h		0.70 m		1.7 m	< 1 s	High	N/A	Very High
	Cold Movement Detection	<1e-9/h		2 m		5 m	< 10 s	High	N/A	Very High
Road Localization System	Automated Driving on Highway	<1e-7/h	0.27 m	4.50 m	0.67 m	11 m	1 s	> 99.5%	High	Very High
	Automated Driving on Local Roads	<1e-7/h	0.17 m	0.40 m	0.42 m	1 m	1 s	> 99.5%	High	Very High
	Automated Driving on Narrow and Curved Roads	<1e-7/h	0.07 m	0.11 m	0.17 m	0.30 m	1 s	> 99.5%	High	Very High

INTEGRITY in Automotive

INTEGRITY CONCEPT



Starting point:
Road Traffic Fatality Rate (TFR) =

17.4 fatalities per 100,000 population and year globally

→ Public survey on estimation of safety level for self-driving car (SDC)

→ Result of survey:
Self-driving car should be safe as travel by train or airplane

→ Target for SDC safety performance measured by fatal car crashes

3e-8 / hr

← Real safety performance of travel by

Rail: 3e-8 fatalities / hr
Air: 3.08e-8 fatalities / hr

← Ratio: $\frac{\text{No. of fatalities}}{\text{No. of fatal car crashes}} = \frac{1}{1.09} \doteq 1$

← Ratio: $\frac{\text{No. of fatal crashes}}{\text{No. of all crashes}} = \frac{1}{172} \doteq 1\text{e-}2$

→ Target for SDC safety performance measured by hazardous failure rate of car systems

3e-6 / hr

→ **Result:**
Harmonised Design Target for self-driving car

PF = 1e-7 failures / hr
(for 1 fatality - car)

Application of harmonised RAP and RAC taken from railway CSM Designed Targets approach

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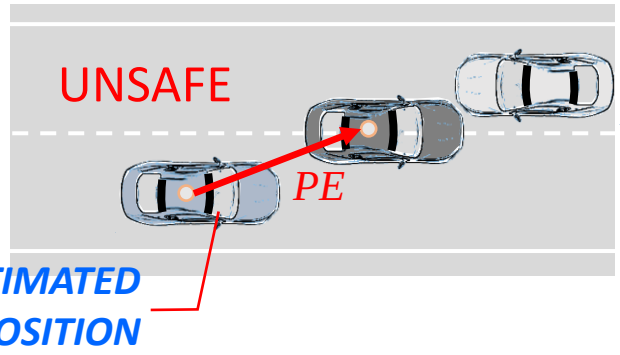

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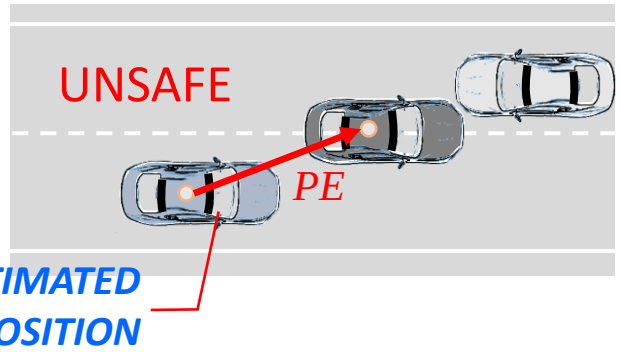
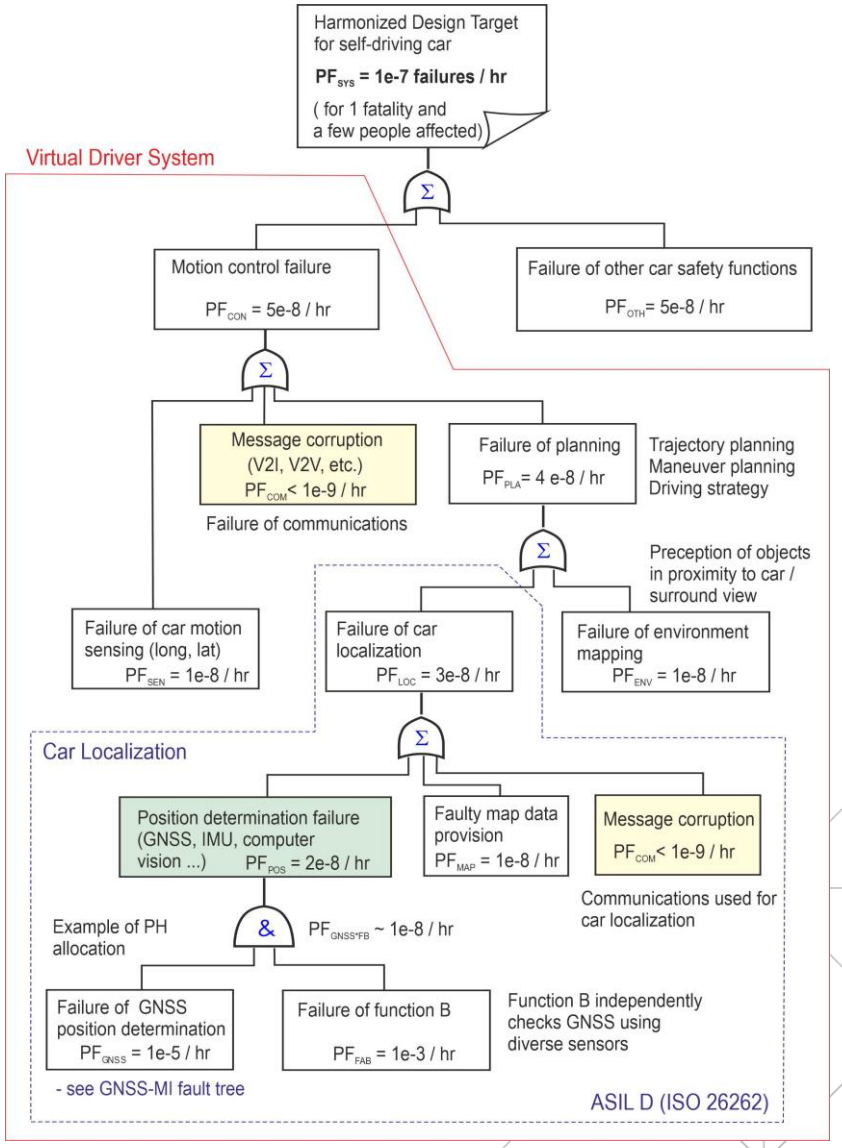
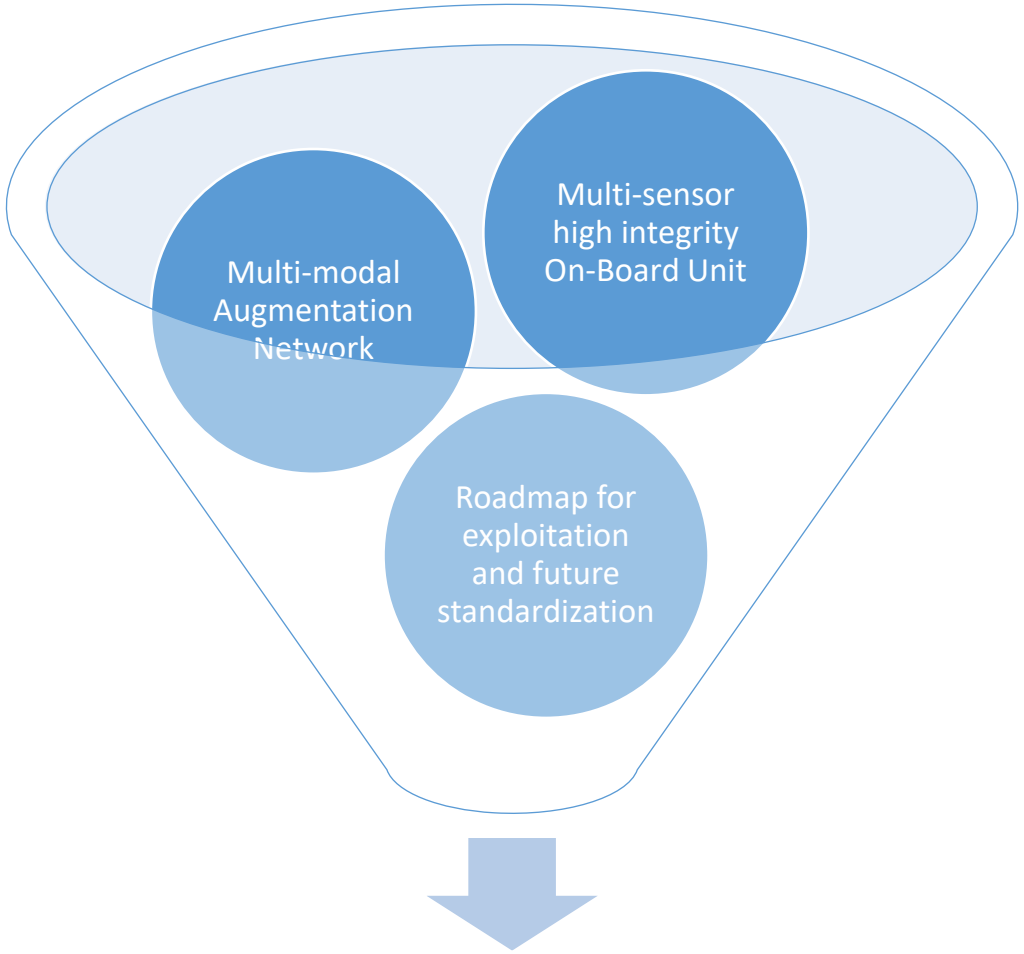


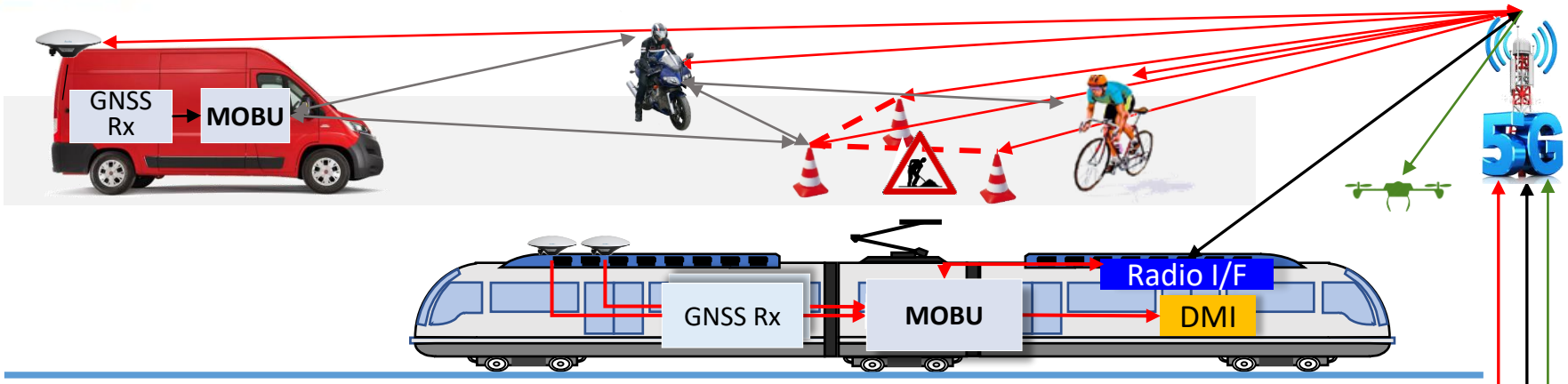


HELMET pillars and ambition



- leverage of expertise, experience and cutting-edge technologies available in state-of-the art for designing high integrity and **high accuracy multimodal AIMN** for land transportation and UAV
- design of high integrity and high accuracy **multi-sensor** algorithms based on **COTS** devices
- contribution to draw an advanced **roadmap** for exploitation and future commercialisation of EGNSS solutions for land transportations;
- contribution to the GNSS **certification** and authorization process into the ETCS/ERTMS and connected and semi-autonomous sectors
- working collaboration methodology **Industry 4.0**.

HELMET Multi-modal architecture



SMART TRANSPORTATION INFRASTRUCTURE

AUTOMOTIVE Adaptation Layer → ITS Cloud → TLC I/F

RBC

RAIL Adaptation Layer → Core RBC Functions → TLC I/F

UAV REMOTE CONTROL CENTER

UAV Adaptation Layer → UTM → TLC I/F

GNSS MULTIMODAL AUGMENTATION 2nd Tier

High QoS – High Security Communication Network

SBAS Ground Services

GPS & GALILEO Ground Services

GNSS MULTIMODAL AUGMENTATION 1rst Tier

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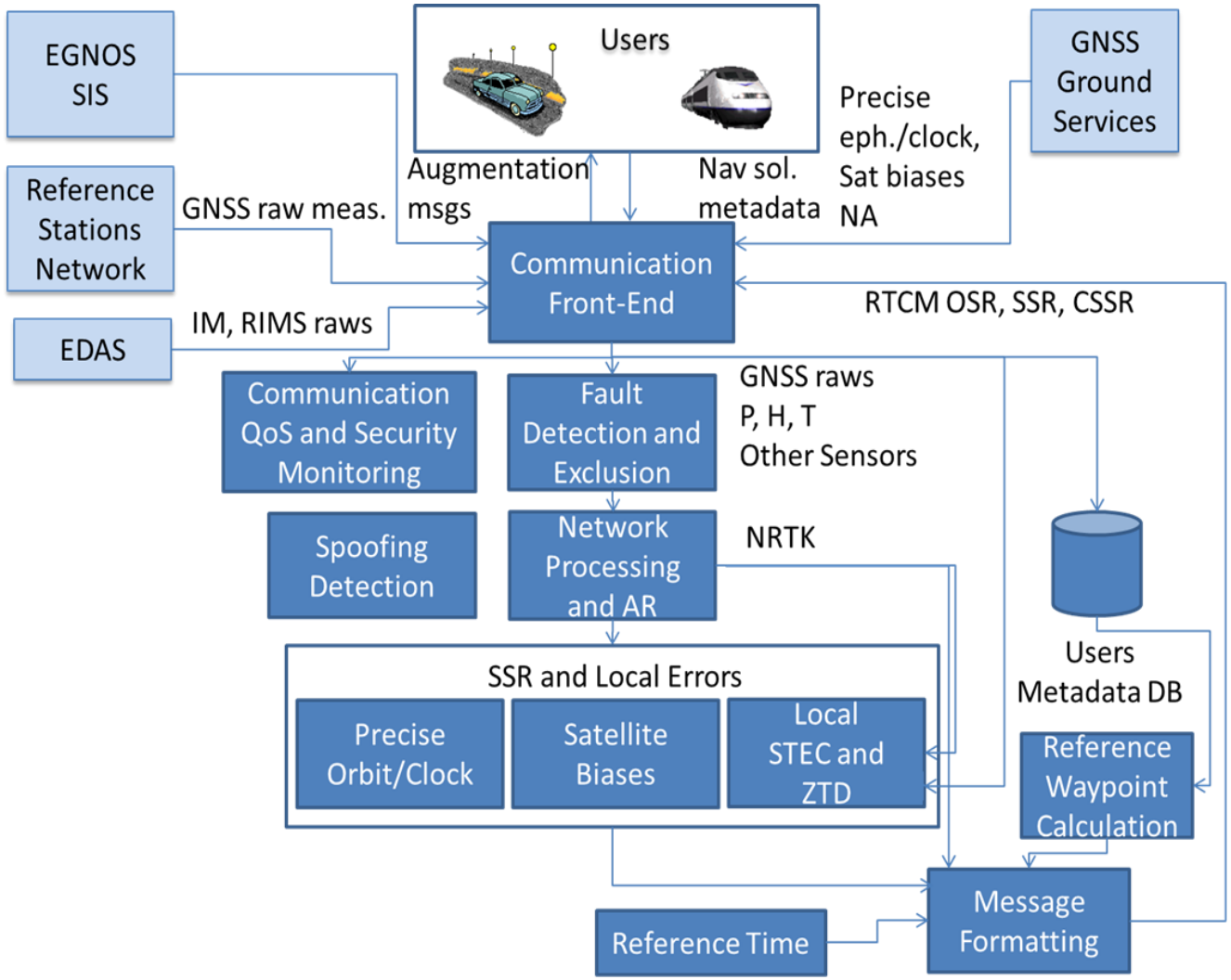
2nd Tier Multimodal AIMN



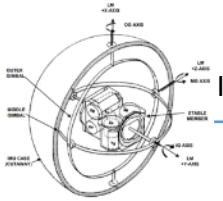
HELMET Multisensor Platform

GNSS Receiver

GNSS CORRECTIONS

Communication Subsystem

Augmentation & Integrity Data Digital Maps

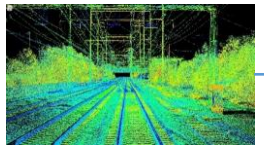


IMU

Kinematic Sensors

GNSS FDE

Track Digital Map



Perception Sensors

ESTIMATION COMPUTER

MULTI-SENSOR Fault Detection & Exclusion

INTEGRITY MONITORING

PVT & Confidence Interval

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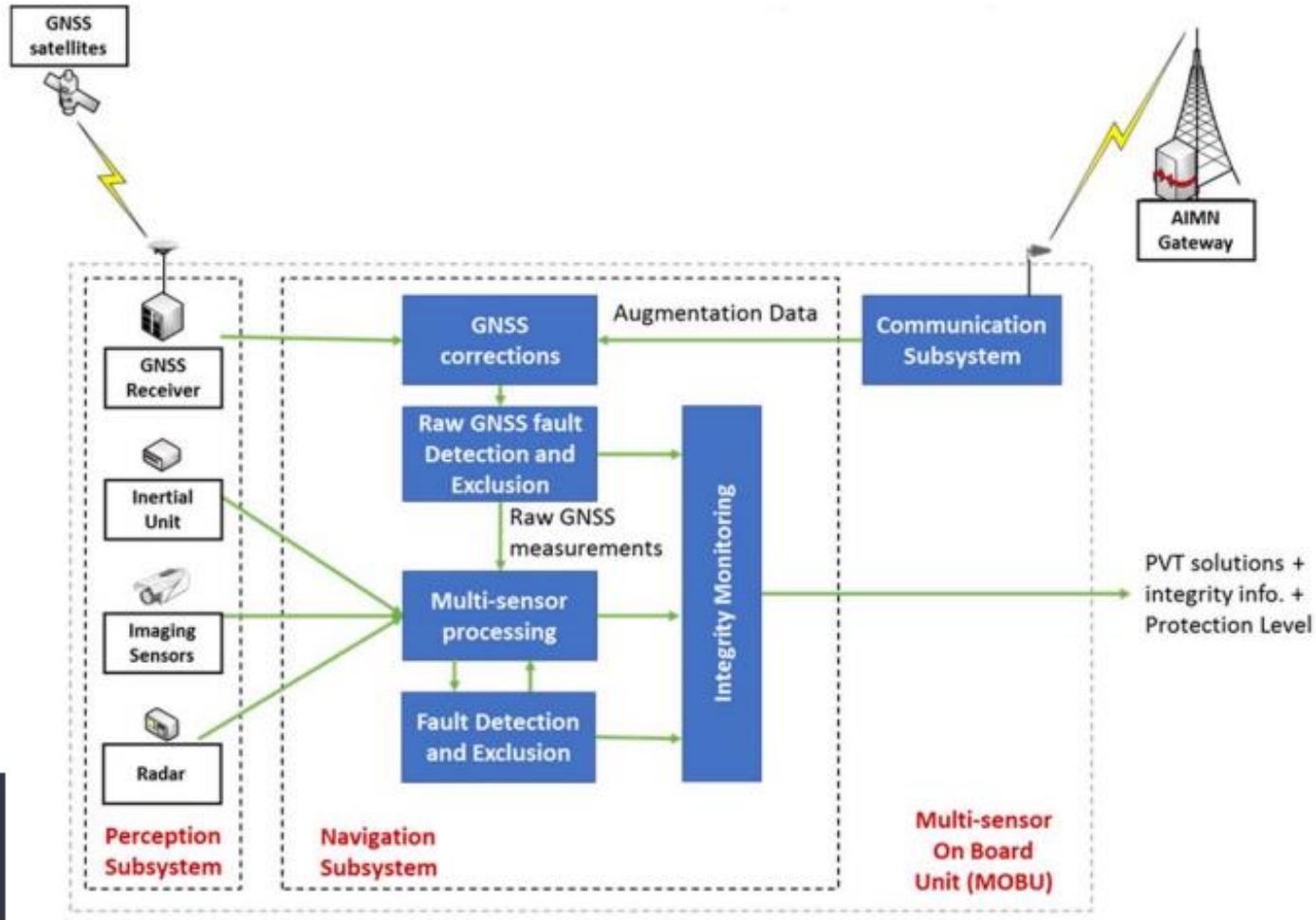
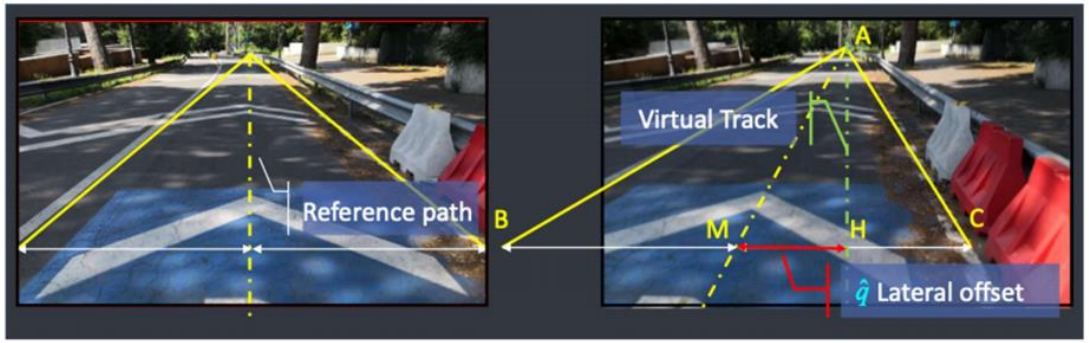
HELMET Multi-sensor platform

- The high integrity multi-sensor unit will deal with a set of sensors that constitutes the perception subsystem.
- The output of these sensors will be elaborated in the navigation subsystem along with the data retrieved by the augmentation network.
- An integrity monitoring procedure will estimate the Protection Levels and ensure the system integrity
- A communication subsystem will ensure the interaction among the ground segment and the on-board unit





Cameras can be used to create a Virtual lane and then exploit the track/lane constraint estimation.

Ref.: S. Baldoni, F. Battisti, M. Brizzi, A. Neri **Virtual Track: A Vision-based Integrity Enhancement,** IEEE/ION PLANS 2020.

The Urban EM scenario

Global Hazards

sufficiently high spatial correlation so that Augmentation Techniques are effective

- *Ephemerides and satellite clock errors*
- *Ionospheric and tropospheric incremental delay*
- *Inter-frequency bias, wind-up effect, solid tides, …*

Local Hazards

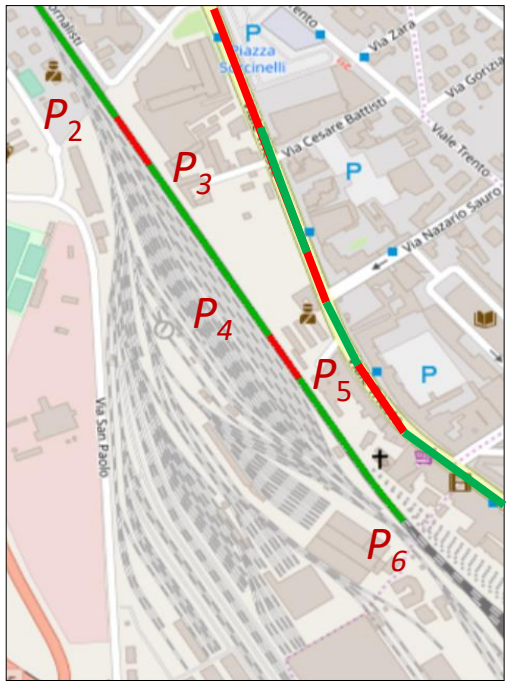
error sources with very low spatial correlation, so that only a statistical, space variant, description of their behavior can be reliably given.

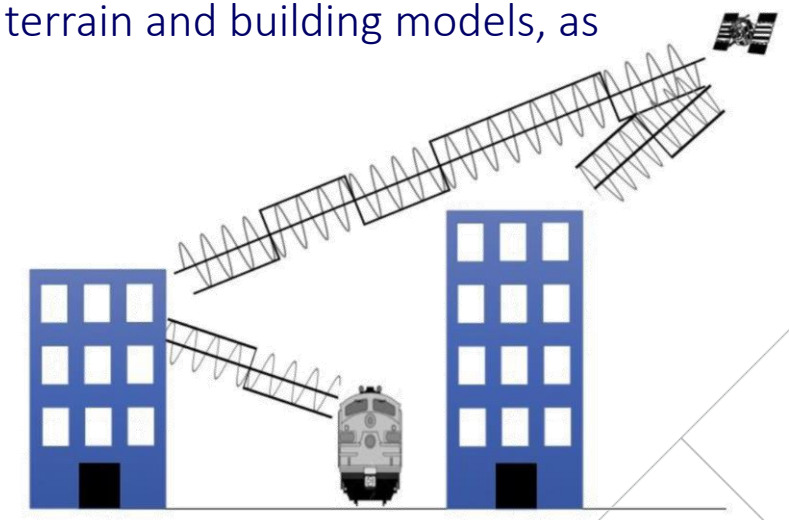
- *Multipath, Shadowing*
- *Intentional and unintentional EMI (ElectroMagnetic Interferences)*
- *Digital map errors*

Satellite Visibility Map

- To circumvent the performance losses originated by NLoS signals, a SATELLITE VISIBILITY MAP associated to the Rail/Road Digital Map is introduced.
- For each point of a track/road the map provides the list of satellites whose SIS contains a LoS component good enough so that it can be used for High Accuracy fixing during a given time interval.
- The Visibility Map can be obtained by means of predictive tools based on 3D terrain and building models, as well as by skyward video cameras as experimented in RHINOS [ROB17].

SATELLITE #n VISIBILITY MAP
As list of visibility segments defined by the end points' coordinates (e.g. mileage)





[ROB17] S. Roberts, L. Bonenberg, X. Meng, T. Moore e C. Hill, «Predictive Intelligence for a Rail Traffic Management System,» in Proceedings of the 30th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2017), Portland, Oregon, 2017.

MULTIPATH HAZARD MAP

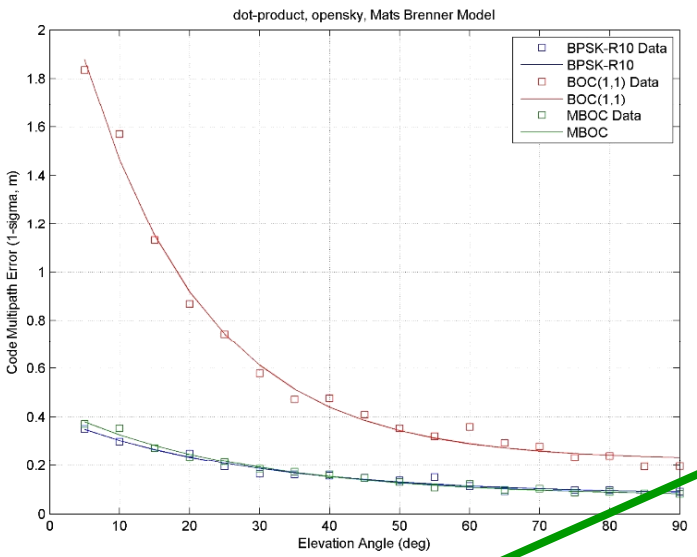
- *LoS Multipath described by parametric models*

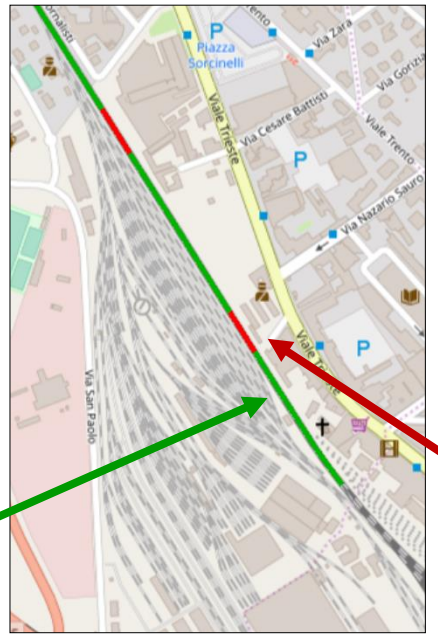
The **Multipath Hazard Map** associated at a given track is constituted by a list of segments. For each segment the map contains

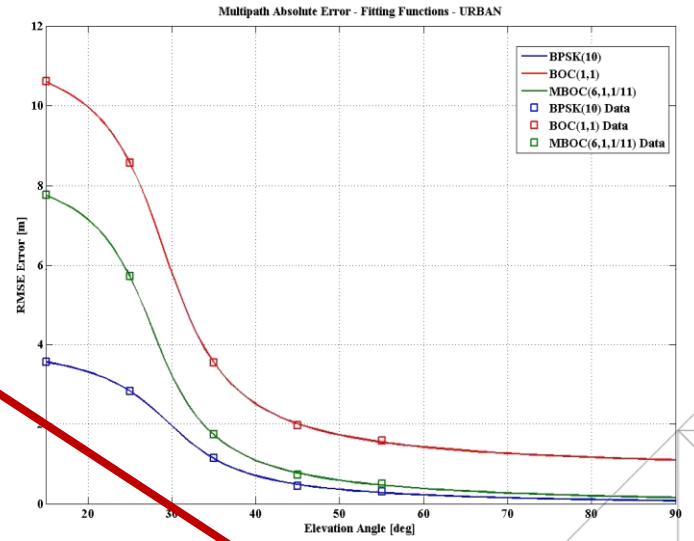
- The **coordinates** of the two **end points**
- The **identifier** of the first order distribution of the pseudorange error
- The **(attribute,value) pairs** of the distribution
- The **spatial** and **temporal constants** of the first order Markov approximations

Mats Brenner model

$\sigma = a + b \cdot \exp[cE]$







	BOC(1,1)	MBOC	BPSK(10)
a	0.22176	0.070391	0.077988
b	2.2128	0.37408	0.32624
c	-0.057807	-0.037694	-0.036692

	BOC(1,1)	MBOC	BPSK(10)
a	6.3784	4.4144	2.0338
b	-3.5782	-2.871	-1.3428
c	0.1725	0.1846	0.1462
d	29.075	27.6112	29.565

Interference Hazards

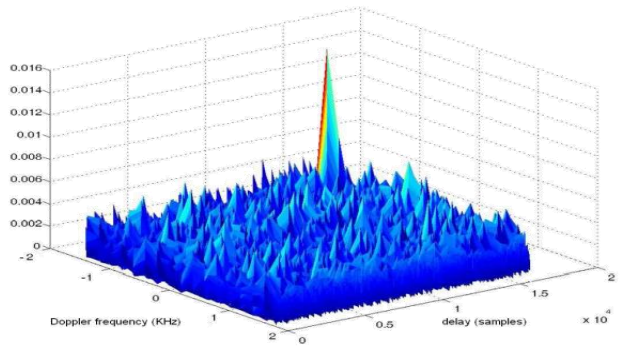
Intentional and unintentional interferences may have impacts on

- Signal acquisition,
- Signal tracking
- PVT computation.

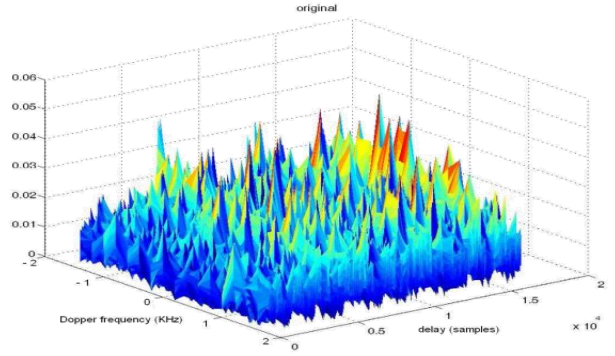
Impacts and Mitigations strictly depend on Interference Power Spectral Density specific Hazard

Therefore several EMI classes are considered specific Hazard Maps are considered

- *Narrowband*
- *Matched-Spectrum*
- *Bandlimited White Gaussian Noise*



Single SIS PSD

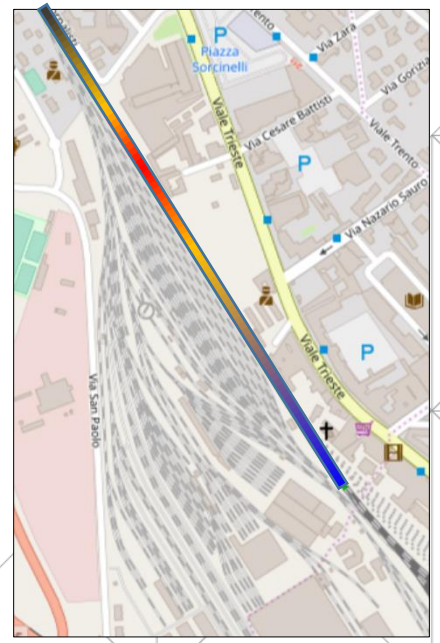


Single SIS+CW interference PSD

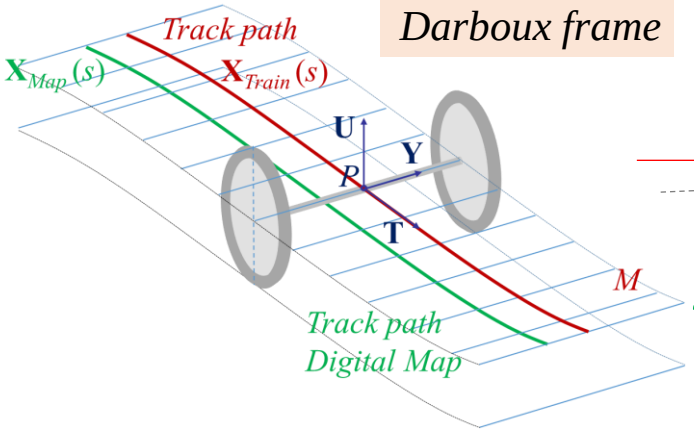
The **EMI Hazard Map** associated at a given track is constituted by a list of segments for which the EMI strength of each EMI class is almost constant.

For each segment, tha map contains

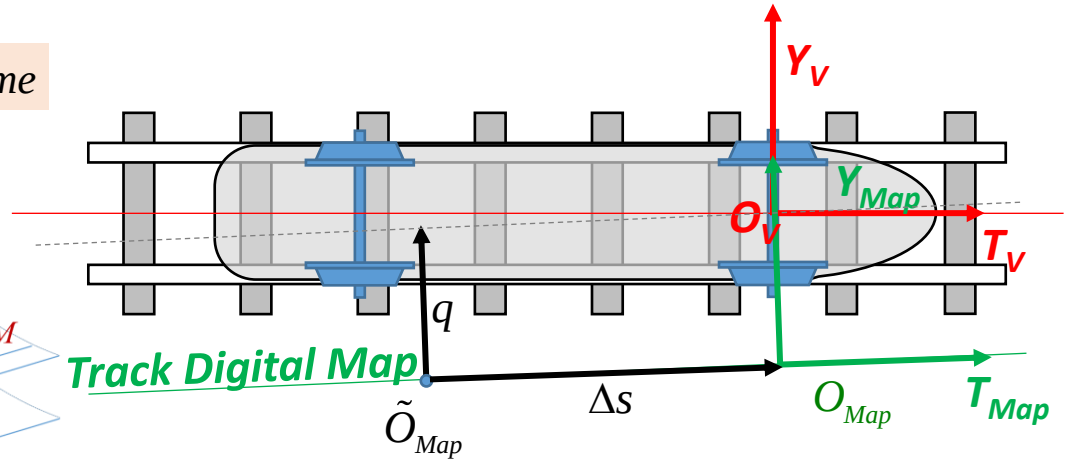
- the **coordinates** of the two **end points,**
- The **identifier** of the prevaling EMI class the **Interference-to-Noise ratio** of the prevaling EMI class



Track Constrained PVT



Darboux frame



Let $\hat{\mathbf{z}}_{3D}$ be the unconstrained Maximum Likelihood Estimate of the train location with respect to the Darboux frame. Then, the constrained solution $\hat{\mathbf{z}}_{1D}$ can be computed as follows

$$\hat{\mathbf{z}}_{1D} = \hat{\mathbf{z}}_{3D} + \mathbf{K}_{Map}(\mathbf{0}_{2x1} - \mathbf{H}_{Map}\hat{\mathbf{z}}_{3D})$$

Survey error Covariance Matrix

$$\mathbf{K}_{Map} = \mathbf{R}_{\mathbf{z}_{3D}}\mathbf{H}_{Map}^{T}\left[\mathbf{H}_{Map}\mathbf{R}_{\mathbf{z}_{3D}}\mathbf{H}_{Map}^{T} + \mathbf{R}_{Map}\right]^{-1}$$

$$\mathbf{H}_{Map} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

For the covariance matrix $\mathbf{R}_{\mathbf{z}_{1D}}$ of the constrained solution we have

$$\mathbf{R}_{\mathbf{z}_{1D}} = \left[\mathbf{I} - \mathbf{K}_{Map}\mathbf{H}_{Map}\right]\mathbf{R}_{\mathbf{z}_{3D}}$$

CONCLUSIONS

HELMET's Takeaways

- a bold new step, on the roadmap of H2020 RHINOS project, to implement EGNSS localization means on land transport domain
- Design and in-field verification of the capabilities of a MULTI-MODAL LOCALISATION PLATFORM supporting High Integrity High Accuracy Positioning services for cars, trains and UAVs
- PROOF OF CONCEPT of high integrity and high accuracy innovative algorithms with multi-sensors architectures
- EXPLOITATION of EGNSS DIFFERENTIATORS to fight back against common hazards of the land mobile scenarios
- Consortium of Research institutions, SMEs and a Large company representing the whole value chain
- Interactions with RTCM SC 134 on GNSS High Accuracy Applications standardisation and representative users to define a roadmap up to the full exploitation of the system.
- KNOWLEDGE TRANSFER from academia to industry
  - Autonomous vehicles community can get know-how from ERTMS+GNSS, especially regarding safety and certification
  - Car multi-sensor high-resolution platforms can further improve the ERTMS economical sustainability

Linking space to user needs

Organised by:

European GNSS Agency

European Commission

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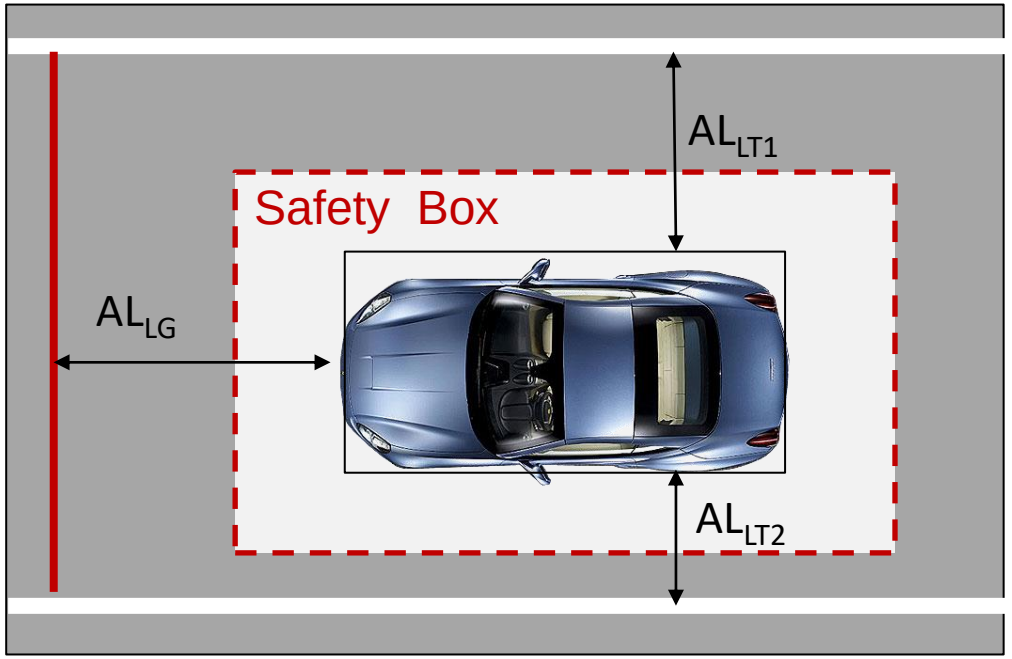
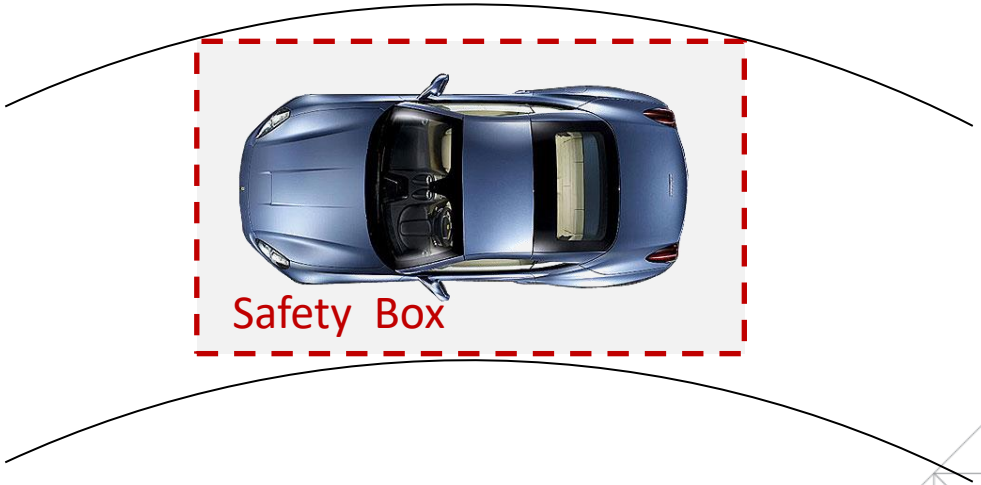
DEFINITIONS





Alert Limit: Maximum error for which driving can still be considered safe w.r.t. a given ASIL

AL lateral: $AL_{LT}=\min(AL_{LT1},AL_{LT2})$

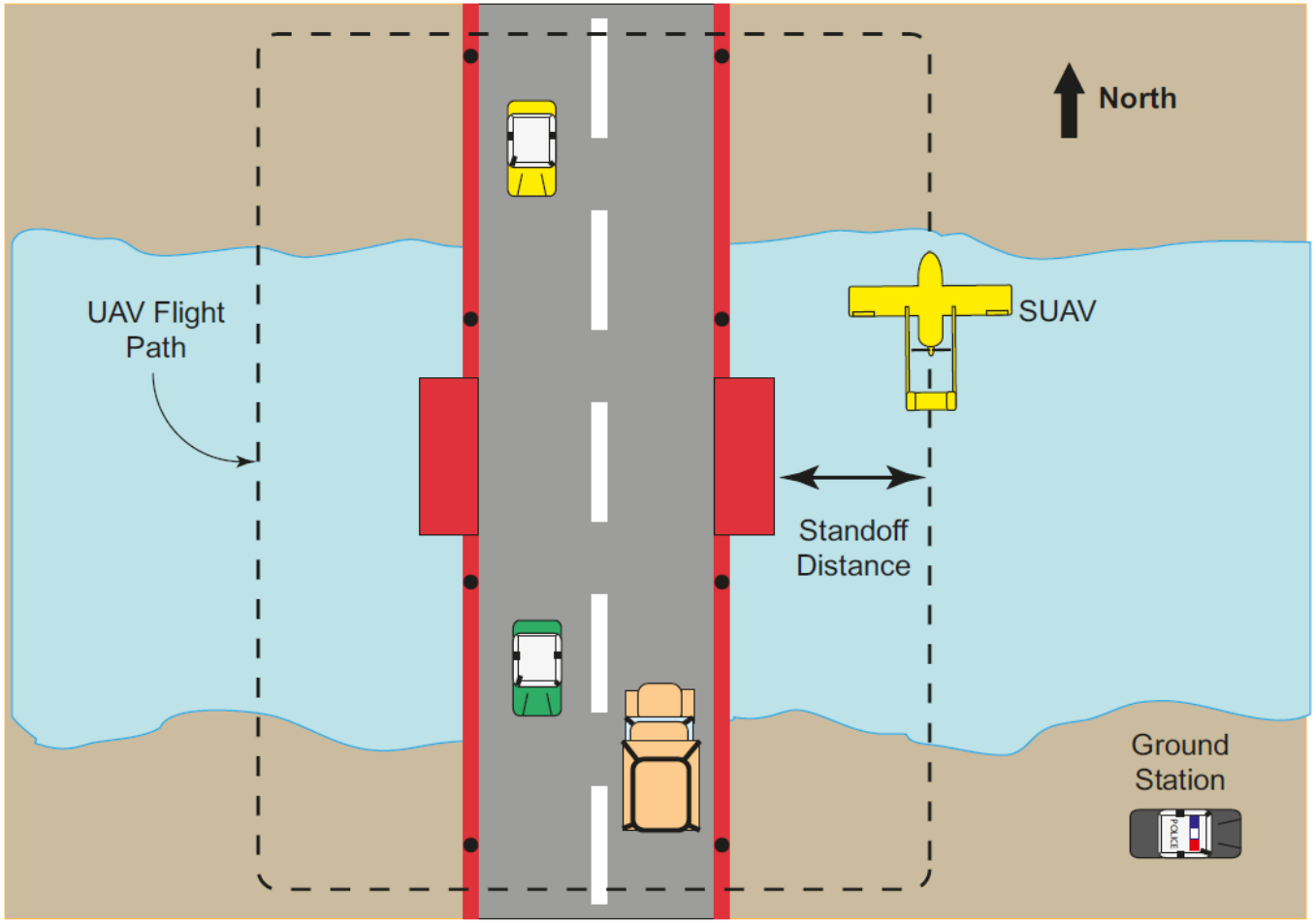
AL longitudinal: AL_{LG}

Safety Box: Position Confidence Interval corresponding to a given Probability equal to a $1\text{-}P_{HMI}$

Protection Levels (Longitudinal and Lateral): half amplitudes of the safety box

COLLISION RISK

UAV Infrastructure Inspection Use Case: Engine failure mitigation



Source: Demoz Gebre-Egziabher Zhiqiang Xing, *Analysis of Unmanned Aerial Vehicles Concept of Operations in ITS Applications*

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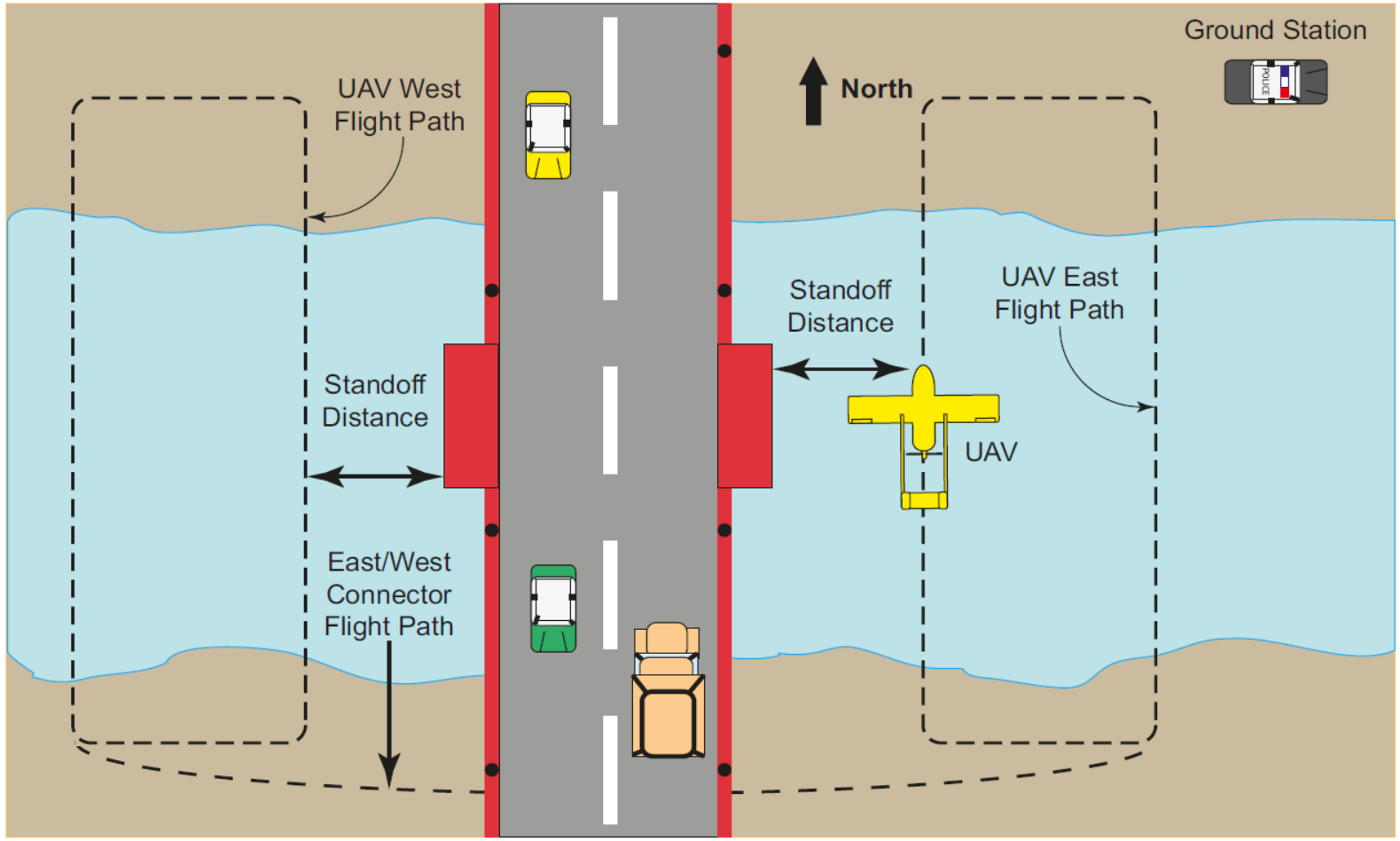

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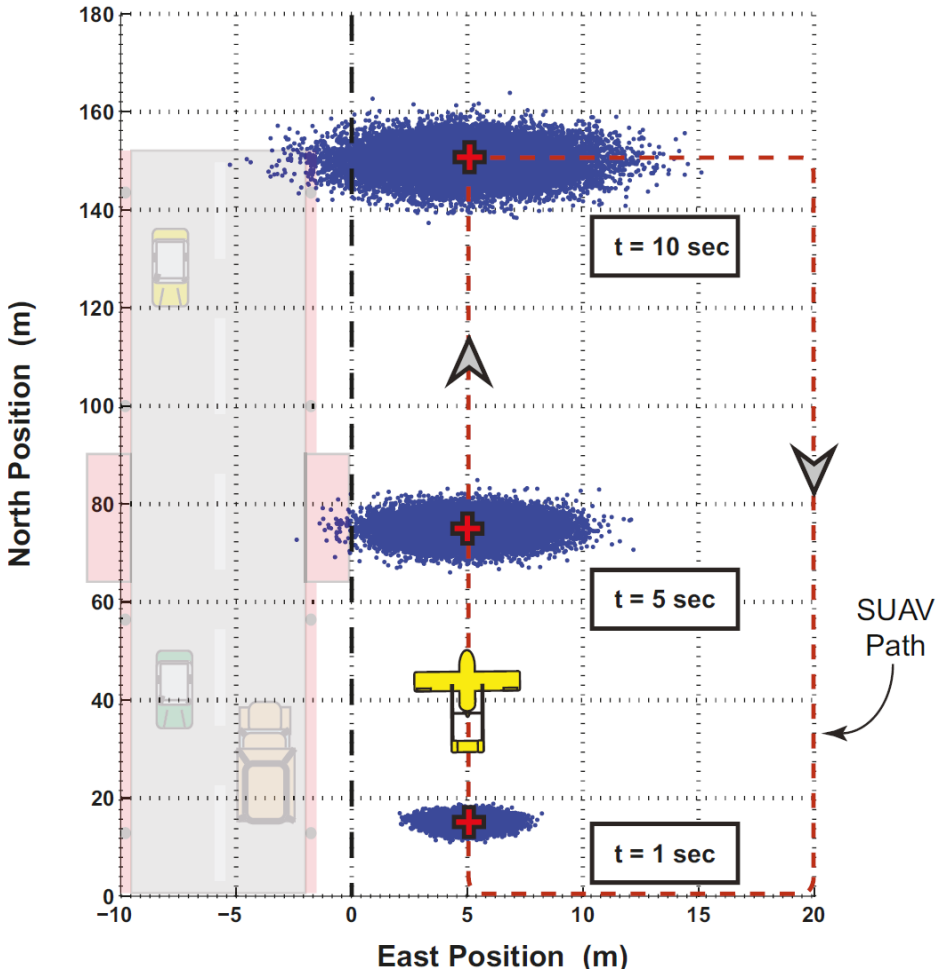

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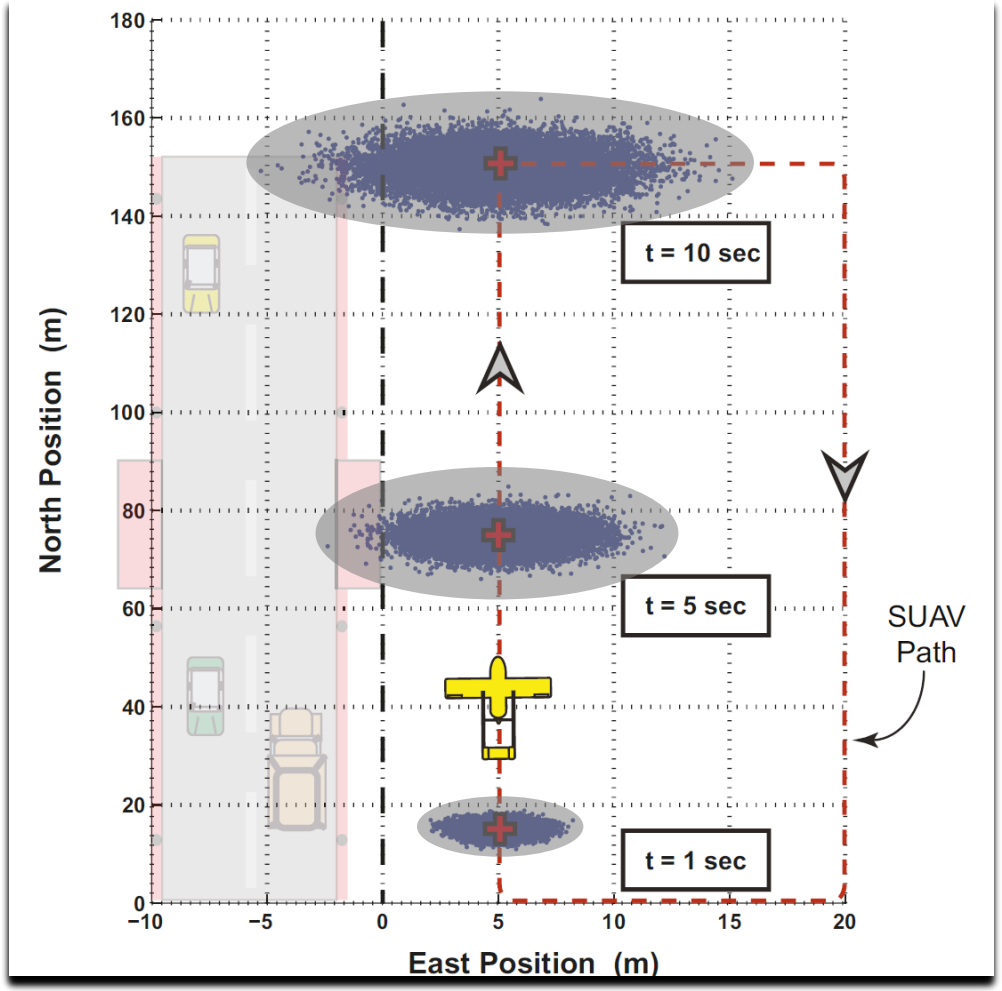

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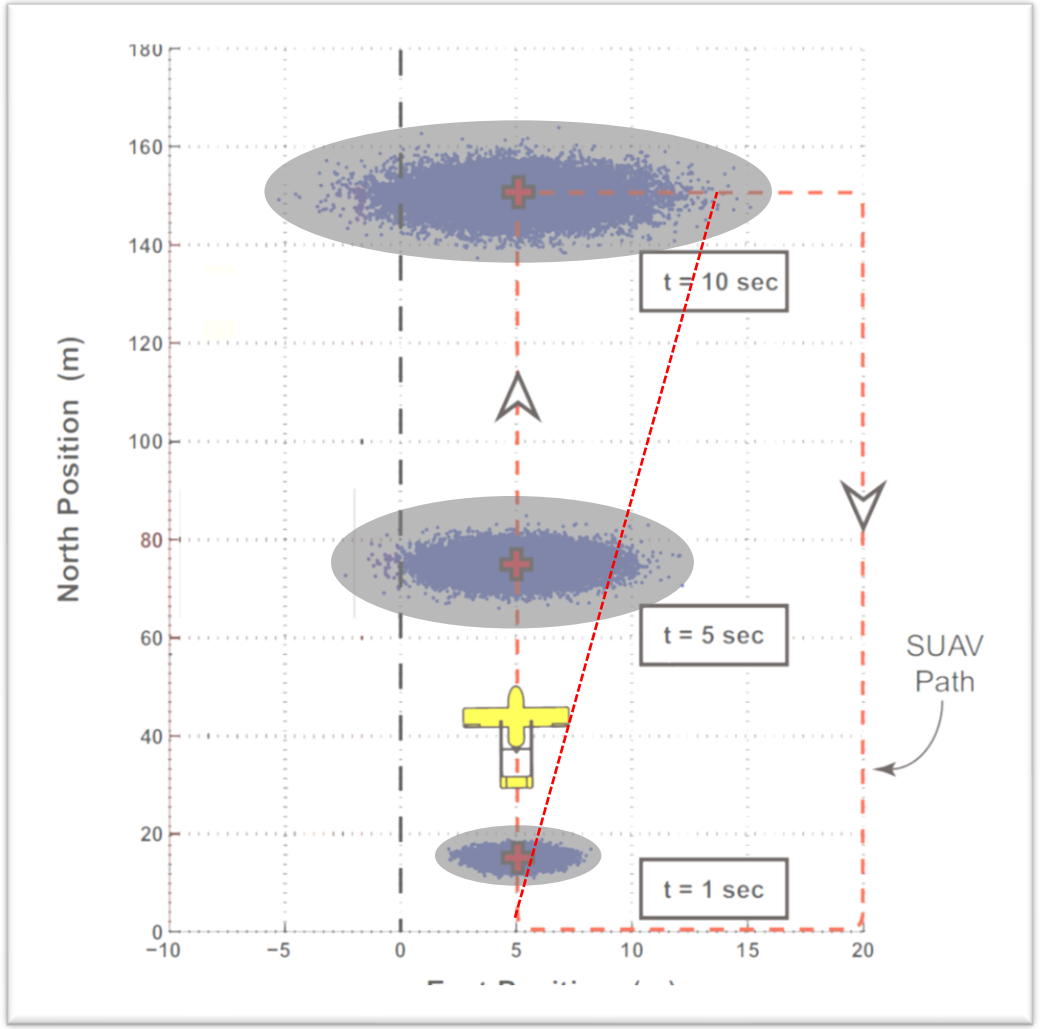

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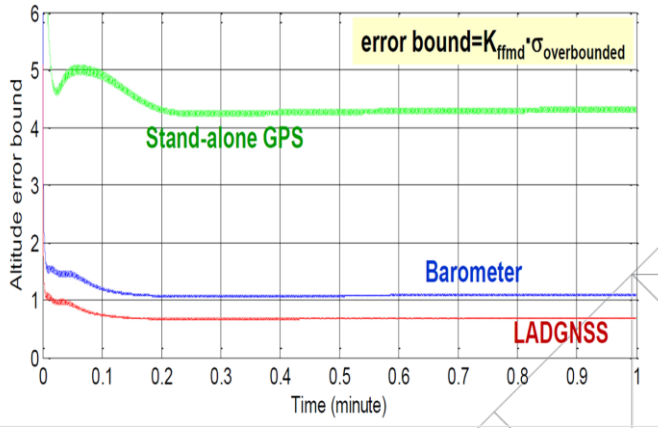

Source: J. Lee, J. Lee, S. Pullen, SCPNT 2015