Horizon 2020
European Union Funding
for Research & Innovation

WP2: AI for Rail Safety & Automation
Report on case studies and analysis of transferability from other sectors

Elena Napoletano, Stefania Santini, Francesco Flammini

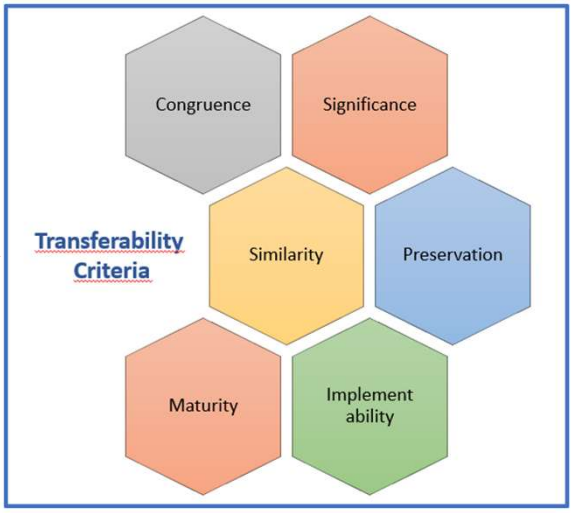
Outline

- *Research Process Overview*
- *Preliminary Results:*
  - *State of the art of AI in other Transport Sectors*
  - *Definition of a Framework for Transferability*
  - *Transferability Analysis*
- *Next Steps and Case Studies:*
  - *Railway Obstacle Detection and Collision Avoidance*
  - *Cooperative Driving for Virtual Coupling of Autonomous Trains*
  - *Future directions and roadmapping*

Research Process Overview

State of the Art of AI in other Transport Sectors

Definition of Transferability Criteria to Railways



Case Studies Identification

Transferability Analysis

Proofs-of-Concept Development

Roadmaps Identification

Unmanned Vehicles

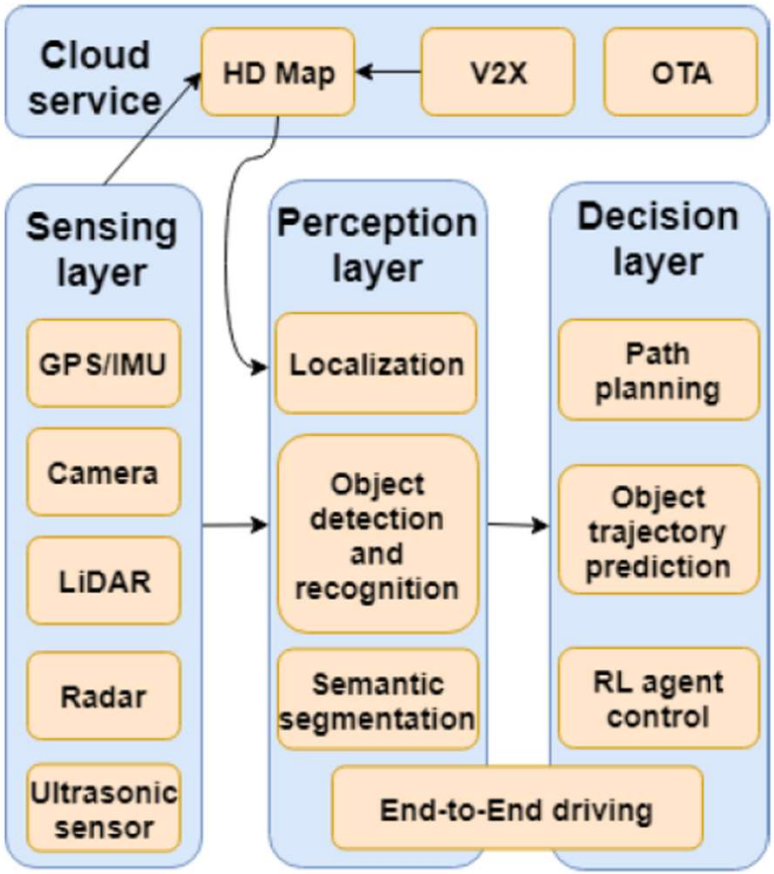
Automotive

Transport Sectors

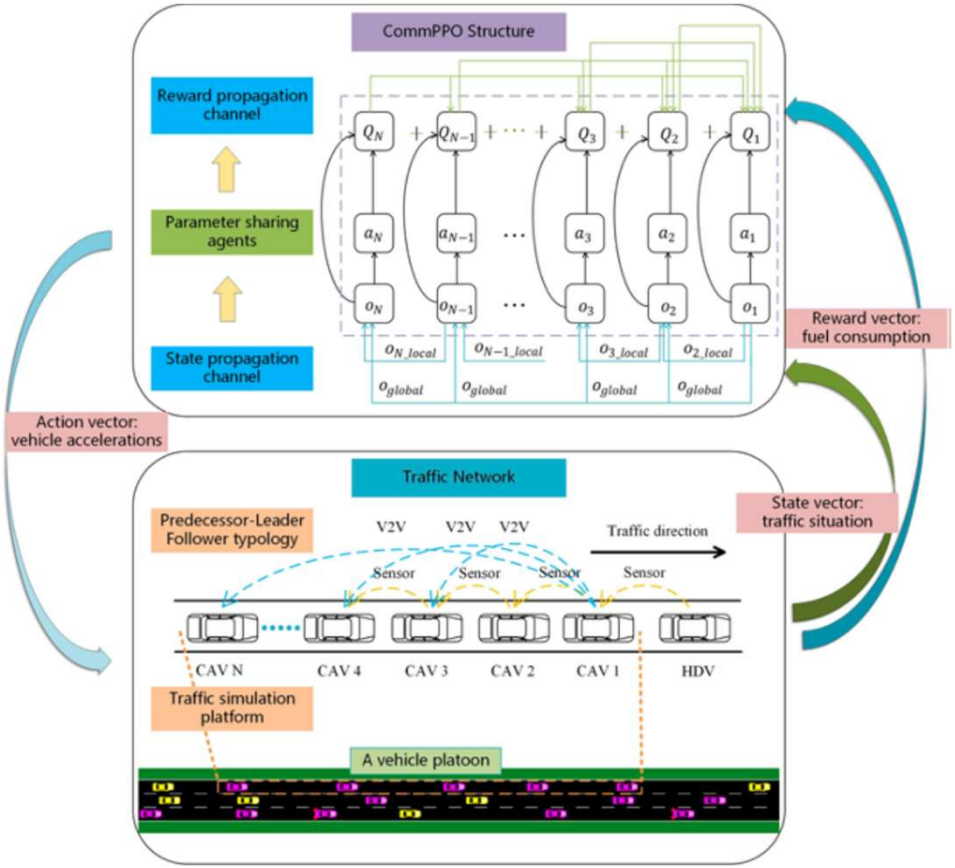
Clusters of Promising Applications:

- Obstacle detection
- Collision Avoidance
- Virtual Coupling
- Automatic Train Operation
- Autonomous Driving GAO4

Autonomous Driving System Achitecture



Vehicle Platooning using Multi-Agent Reinforcement Learning

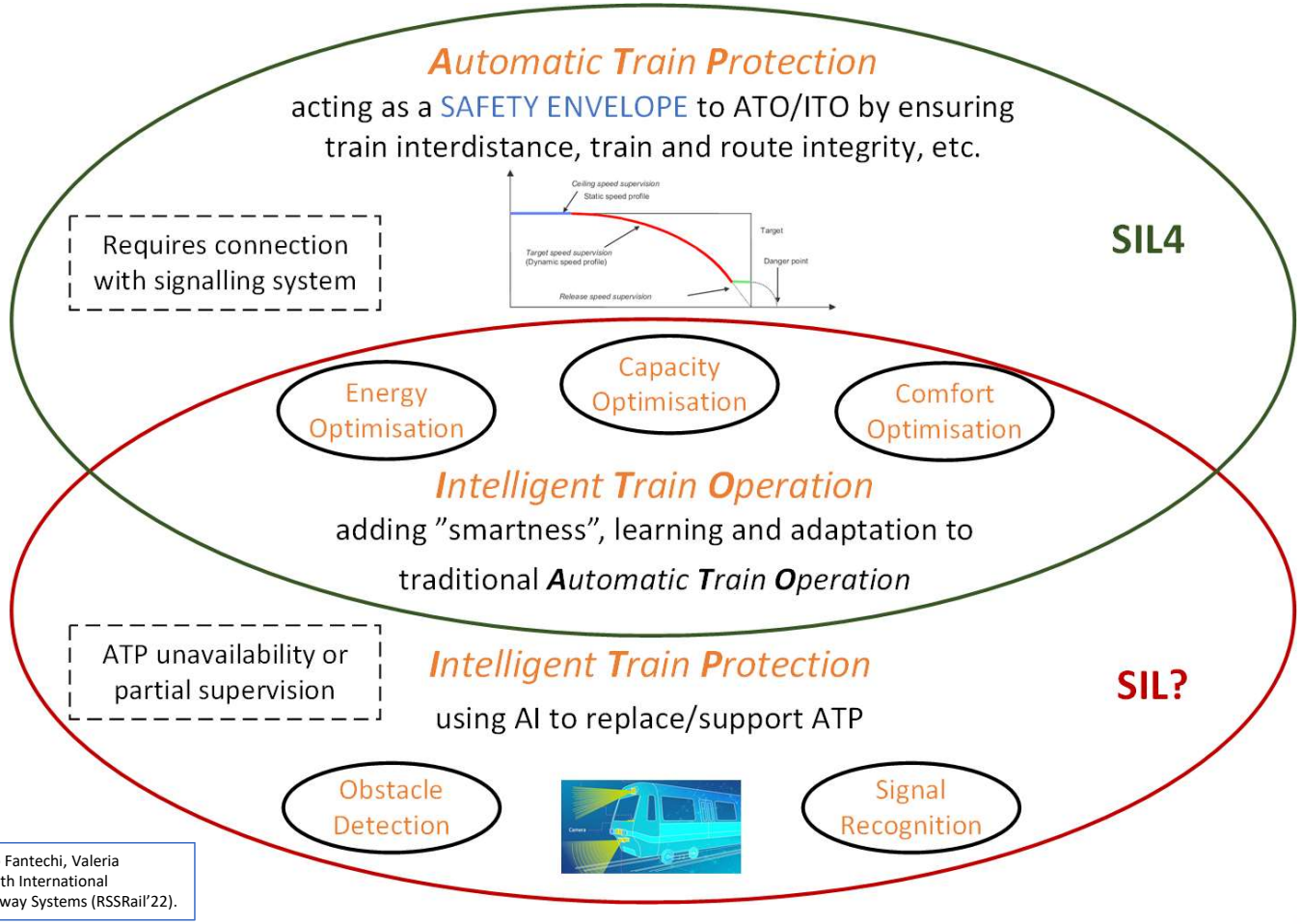


Current automatic train management functions and grades of automation

Automatic Train Operation	**ATO**	Used to automatically drive the train and stop at stations when needed.
Automatic Train Protection	**ATP**	Used to automatically protect the train by applying brakes when needed.
Automatic Train Control	**ATC**	Both ATP and ATO are in place to ensure full control of the train.
Automatic Train Supervision	**ATS**	Used to manage train schedule and coordinate routes along whole tracks.

GoA 0	Train operations are manually supervised by the driver, no automation.
GoA 1	Train operations are manually supervised by the driver supported by ATP.
GoA 2	Semi-automatic train operation. ATO and ATP systems automatically manage train operations and protection while supervised by the driver.
GoA 3	Driverless train operation with on-board staff handling possible emergencies.
GoA 4	Unattended train operation, neither the driver nor the staff are required.

Towards a Vision of Intelligent Train Control

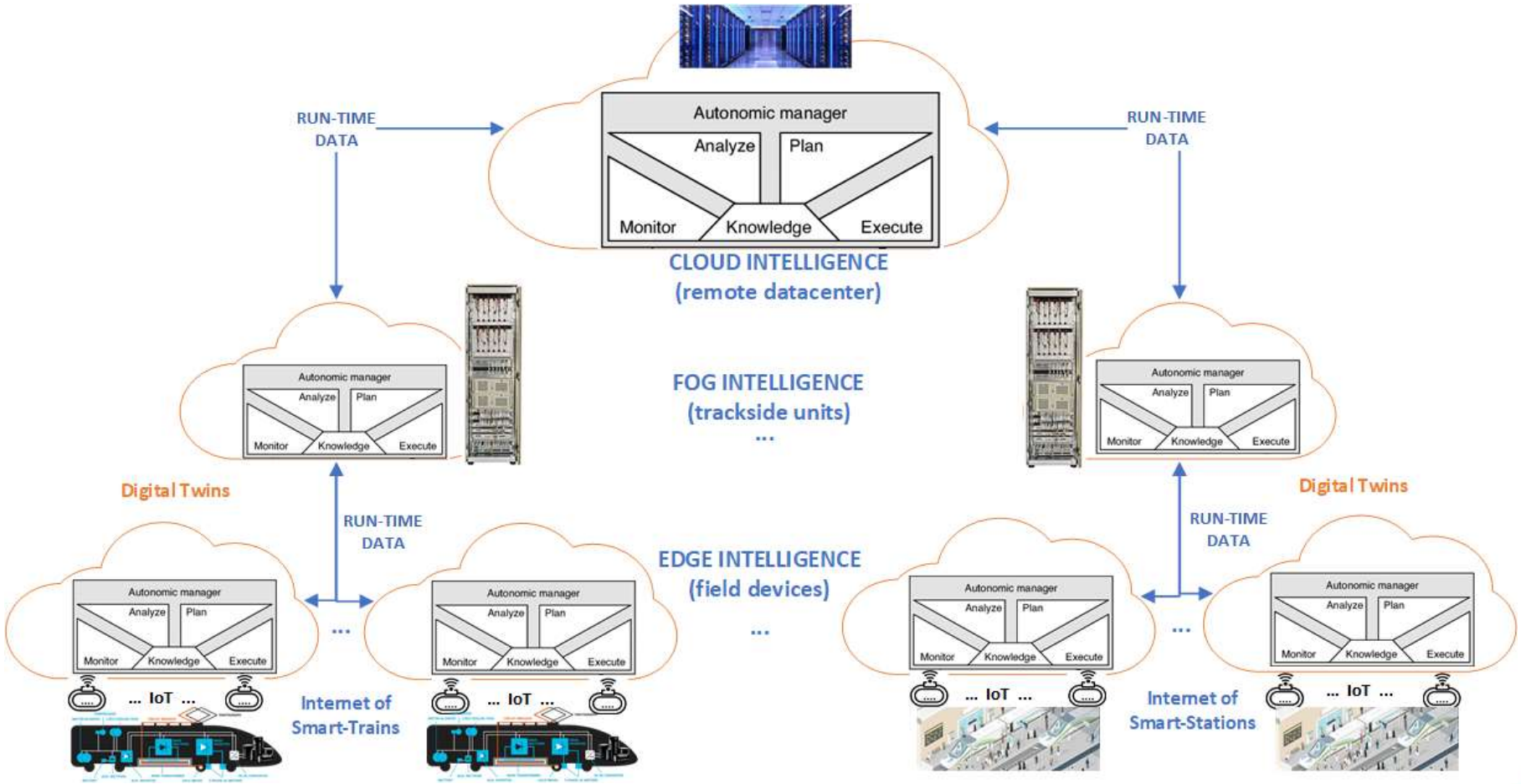


Francesco Flammini, Lorenzo De Donato, Alessandro Fantechi, Valeria Vittorini. A Vision of Intelligent Train Control. Proc. 4th International Conference on Reliability, Safety and Security of Railway Systems (RSSRail'22).

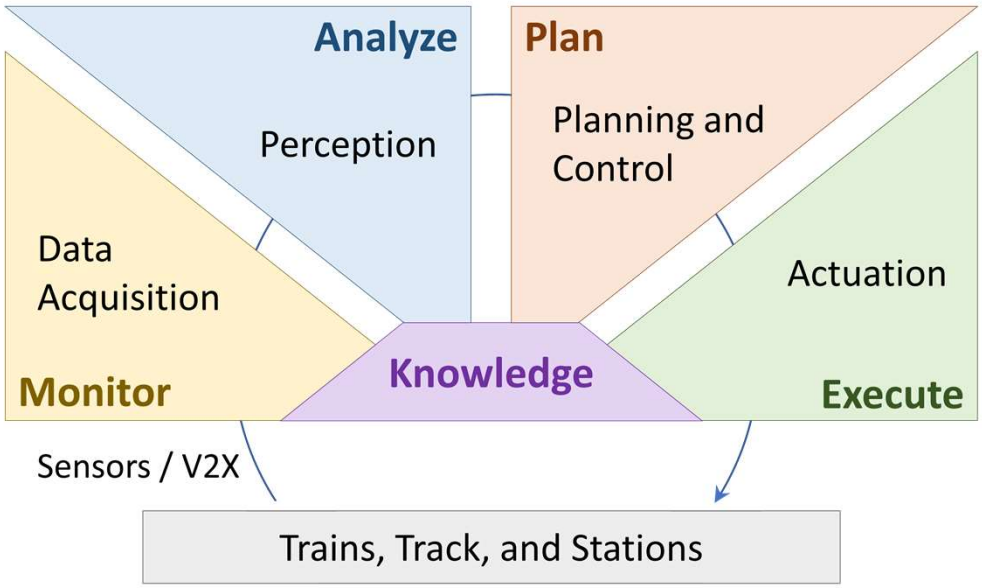
Grades of Intelligent Train Control

- **GoI 1**: This level includes all ATC implementations where AI is not used or it is used for limited functions such as optimisation within ATS. That means limited or no autonomy is normally possible in open environments.
- **GoI 2**: This level supports partial autonomy in open environments, by including only ITO as an adaptive ATO with energy, capacity and/or comfort optimisation capabilities, or only ITP for driving assistance and/or as a low-speed backup system in case of ATP unavailability or limited supervision.
- **GoI 3**: This level includes both ITO and ITP, allowing for full autonomy even in open environments, although with no advanced learning and adaptation capabilities. For instance, at GoI3, the artificial vision algorithms of ITP can be trained only once, e.g. to detect on-track obstacles, and never updated.
- **GoI 4**: This level includes both ITO and ITP, allowing for full autonomy in all environments, with advanced learning and adaptation capabilities, such as unsupervised and reinforcement learning. The system is typically fully connected, dynamically updated, and supported by higher levels of fog/cloud intelligence by using external AI models for big data analytics, such as those enabled by digital twins.

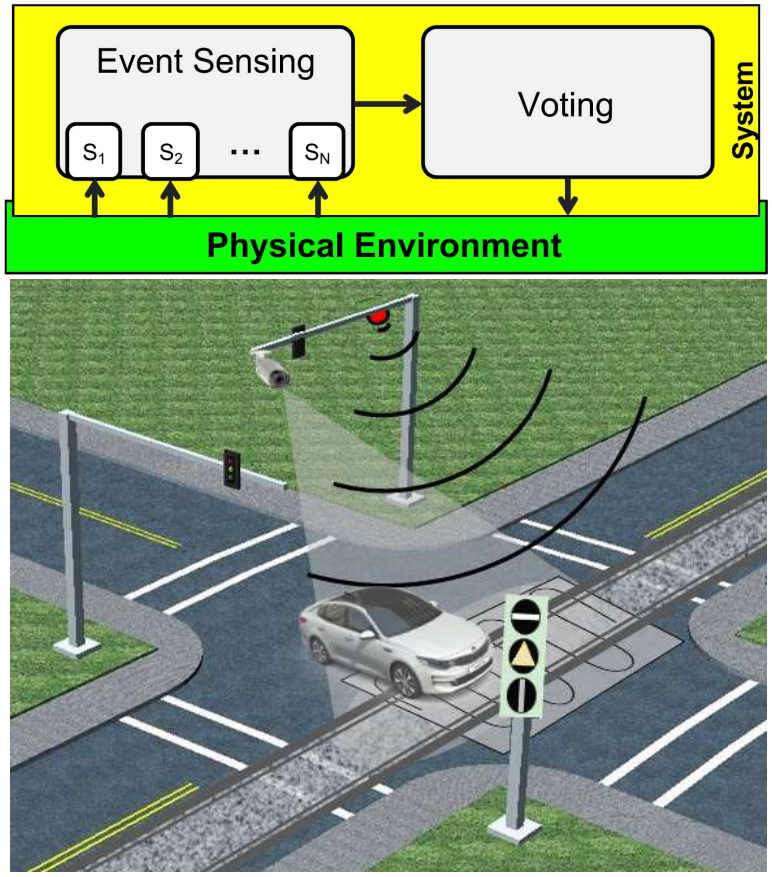
Levels of intelligence in railway control and supervision

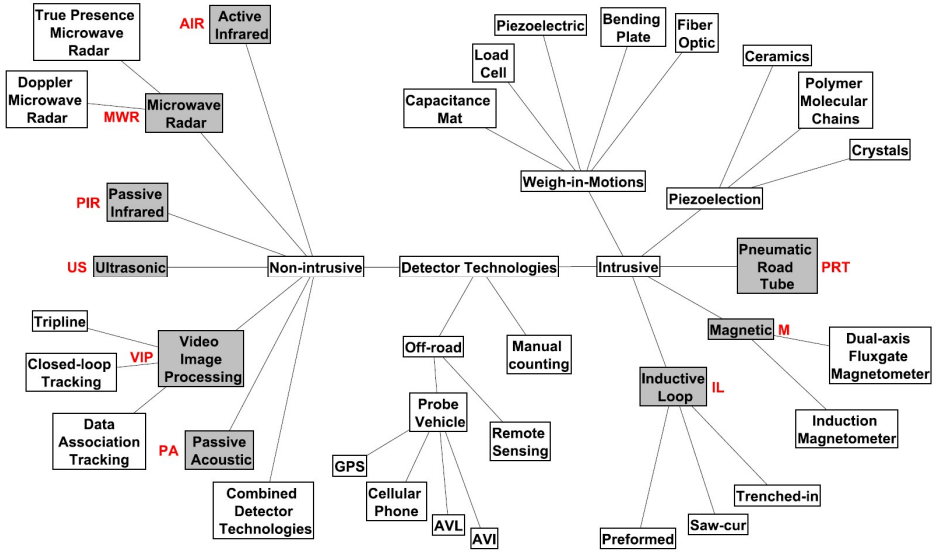


MAPE-K Loop for Intelligent Train Control



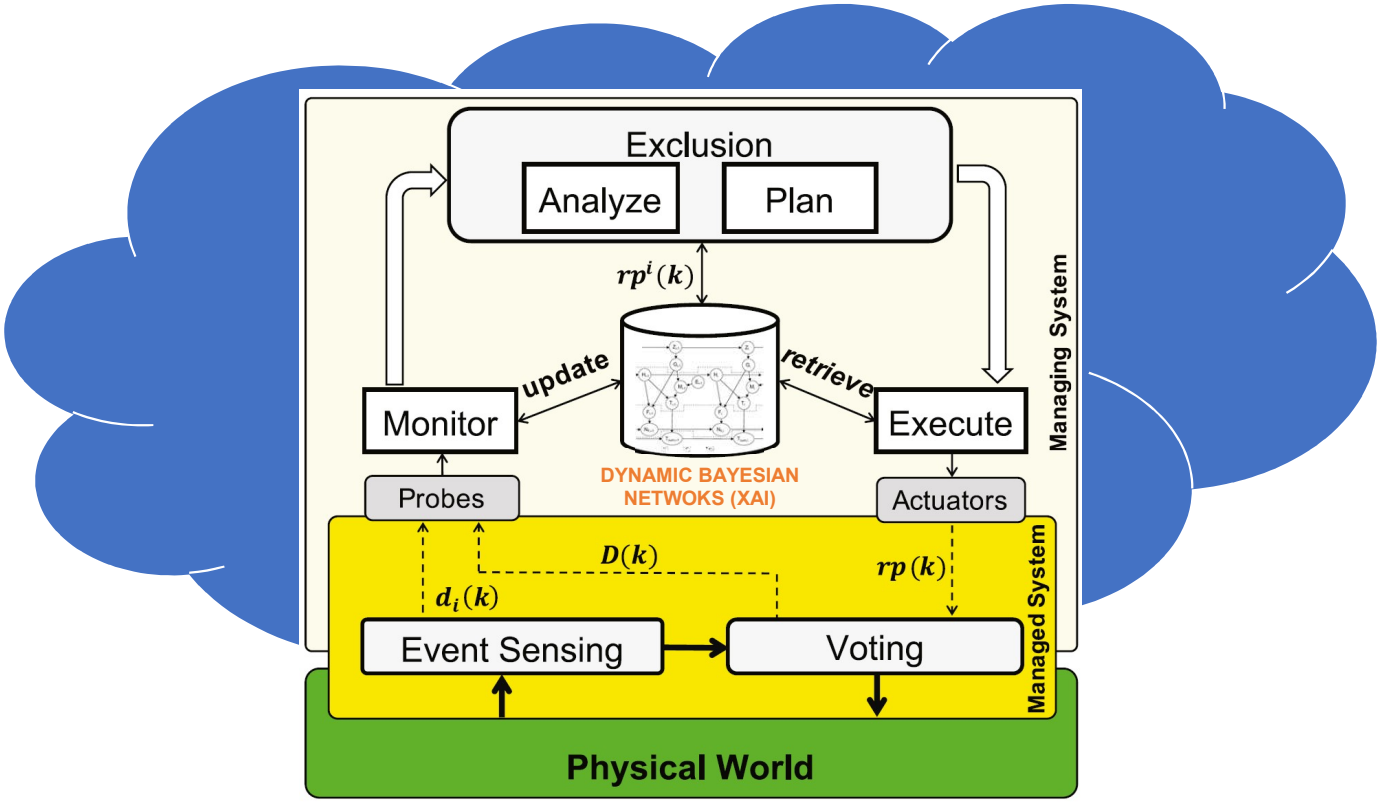
Vehicle detection example





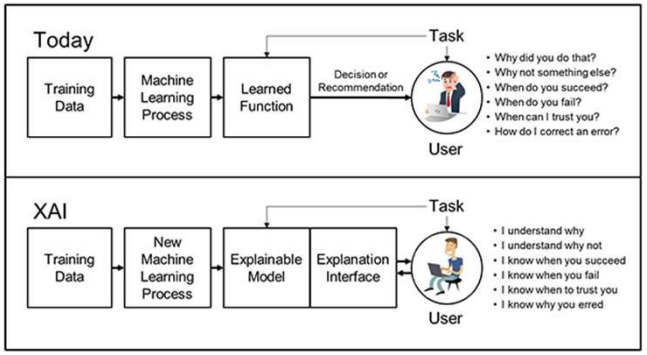
Francesco Flammini, Stefano Marrone, Roberto Nardone, Mauro Caporuscio, Mirko D'Angelo, Safety integrity through self-adaptation for multi-sensor event detection: Methodology and case-study, Future Generation Computer Systems, Volume 112, 2020, Pages 965-981, ISSN 0167-739X, https://doi.org/10.1016/j.future.2020.06.036.

Custom MAPE-K for multi-sensor event detection

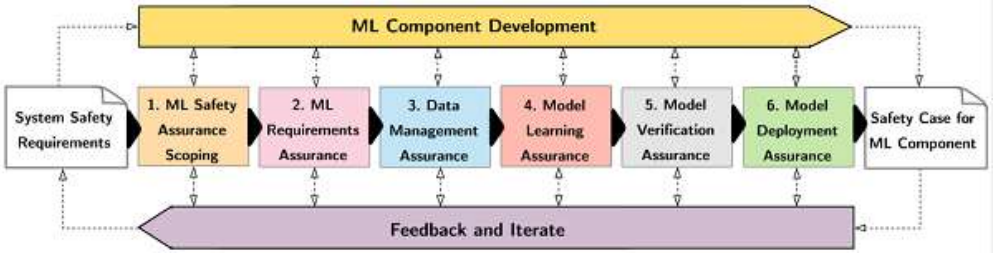


Exclusion mechanism: at every step k, the raw data di(k) captured by each sensor i, and the decision D(k) taken from Voting are used to analyze the system and compute the new sensor reputation rpi(k).

Several approaches needed to enable safe autonomous trains

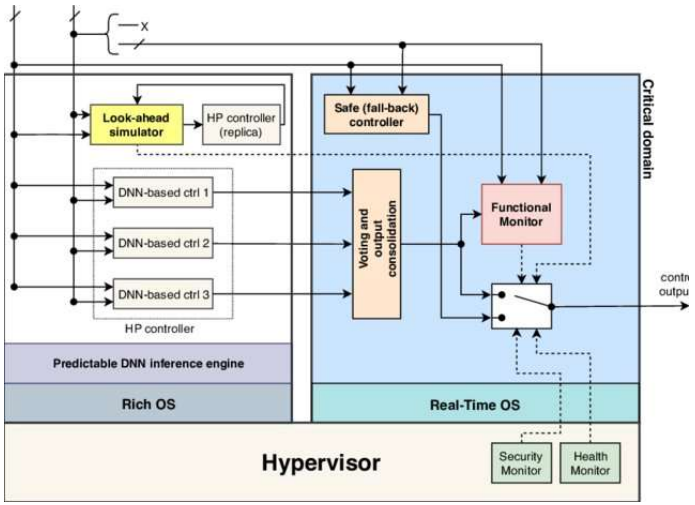


https://www.darpa.mil/program/explainable-artificial-intelligence



https://www.assuringautonomy.com/amlas

Methodology for the Assurance of Machine Learning for use in Autonomous Systems (AMLAS). AMLAS has six stages, which complement the machine learning (ML) development process.



https://ieeexplore.ieee.org/document/8897630

A Safe, Secure, and Predictable Software Architecture for Deep Learning in Safety-Critical Systems

N. Rajabli, F. Flammini, R. Nardone and V. Vittorini, "Software Verification and Validation of Safe Autonomous Cars: A Systematic Literature Review," in IEEE Access, vol. 9, pp. 4797-4819, 2021, doi: 10.1109/ACCESS.2020.3048047.

Case Study 1: Railway Obstacle Detection and Collision Avoidance

Railway accidents, in which trains collide with obstacles, often occur because of human error or fatigue. Problems can also arise due to intrusion of foreign objects, or illegal entry of pedestrians.

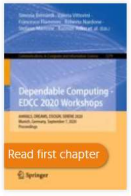
It is therefore necessary to detect traffic objects in front of the trains in order to automatically react or inform the driver to take timely action (in the case of human-driven trains).

Obstacle Detection and Collision Avoidance:

It is a safety-critical function that refers to the ability of an Autonomous Vehicle to collect information and extract relevant knowledge from its surrounding using data from sensors (e.g., on-board smart-cameras installed on front of the train) and V2X messages.

2020 | OriginalPaper | Chapter

Artificial Intelligence for Obstacle Detection in Railways: Project SMART and Beyond



Authors: Danijela Ristić-Durrant, Muhammad Abdul Haseeb, Marten Franke, Milan Banić, Miloš Simonović, Dušan Stamenković

Publisher: Springer International Publishing

Case Study 2: Cooperative Driving for Virtual Coupling of Autonomous Trains

Recently, the **Shift2rail** program proposed a novel paradigm in train control systems based on the concept of Virtual Coupling. One of the main advantages of this driving paradigm is the increasing in the capacity of the existing railway lines.

Virtual Coupling for Autonomous Trains:

It is one of the most challenging functionalities of cooperative driving since it strongly is based on the ability to share information with neighbours (T2T) and receiving the reference signals coming from the infrastructure (T2I). On the basis of the information received from its neighbours within the convoy, each Autonomous Train autonomously regulates its motion.

C. Di Meo, M. Di Vaio, F. Flammini, R. Nardone, S. Santini and V. Vittorini, "ERTMS/ETCS Virtual Coupling: Proof of Concept and Numerical Analysis," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 21, no. 6, pp. 2545-2556, June 2020, doi: 10.1109/TITS.2019.2920290.

Thank you for your attention!