A Vision of Intelligent Train Control

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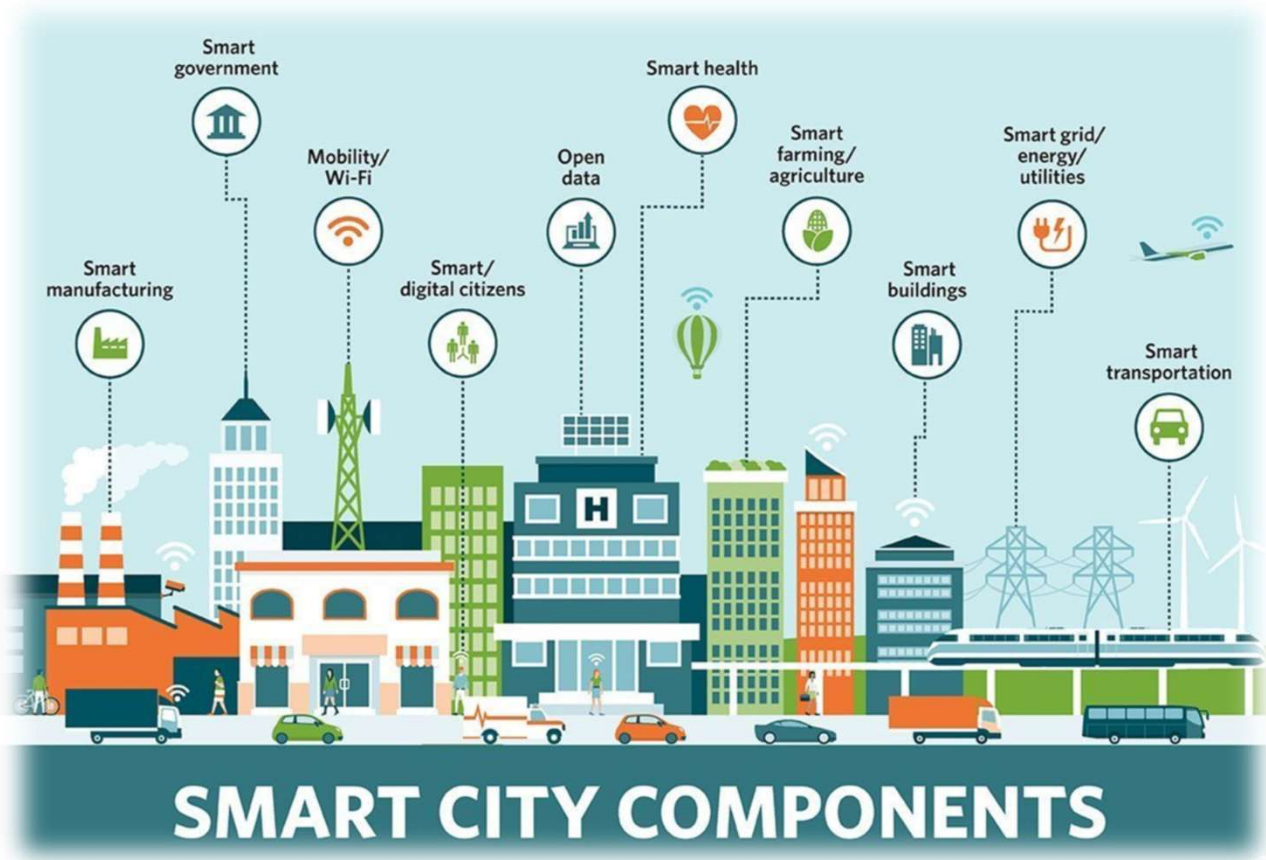
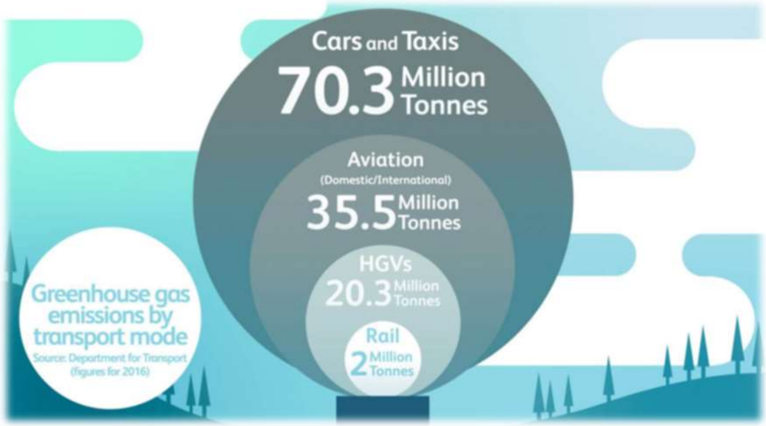
Smarter transportation for smarter and greener cities





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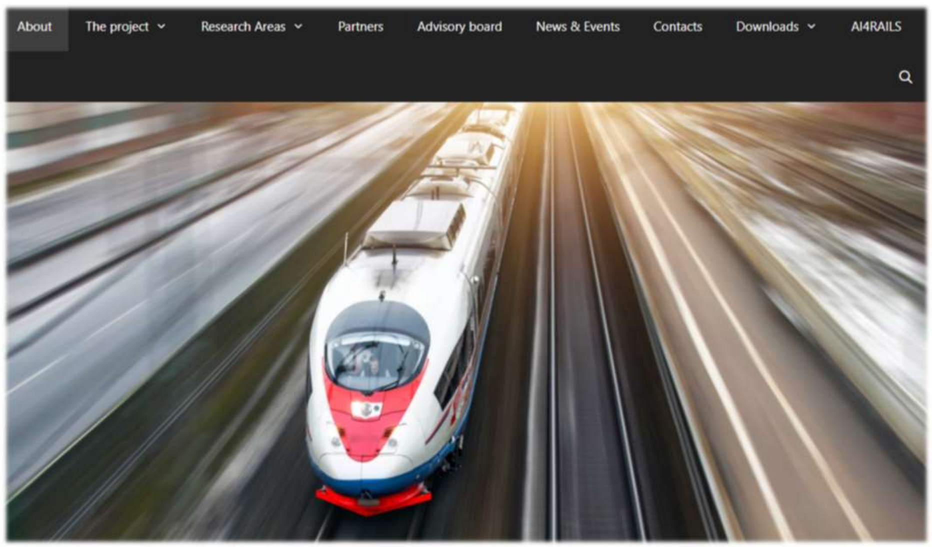
RAILS

Roadmaps for AI integration in the raiL Sector

Horizon 2020
European Union Funding
for Research & Innovation

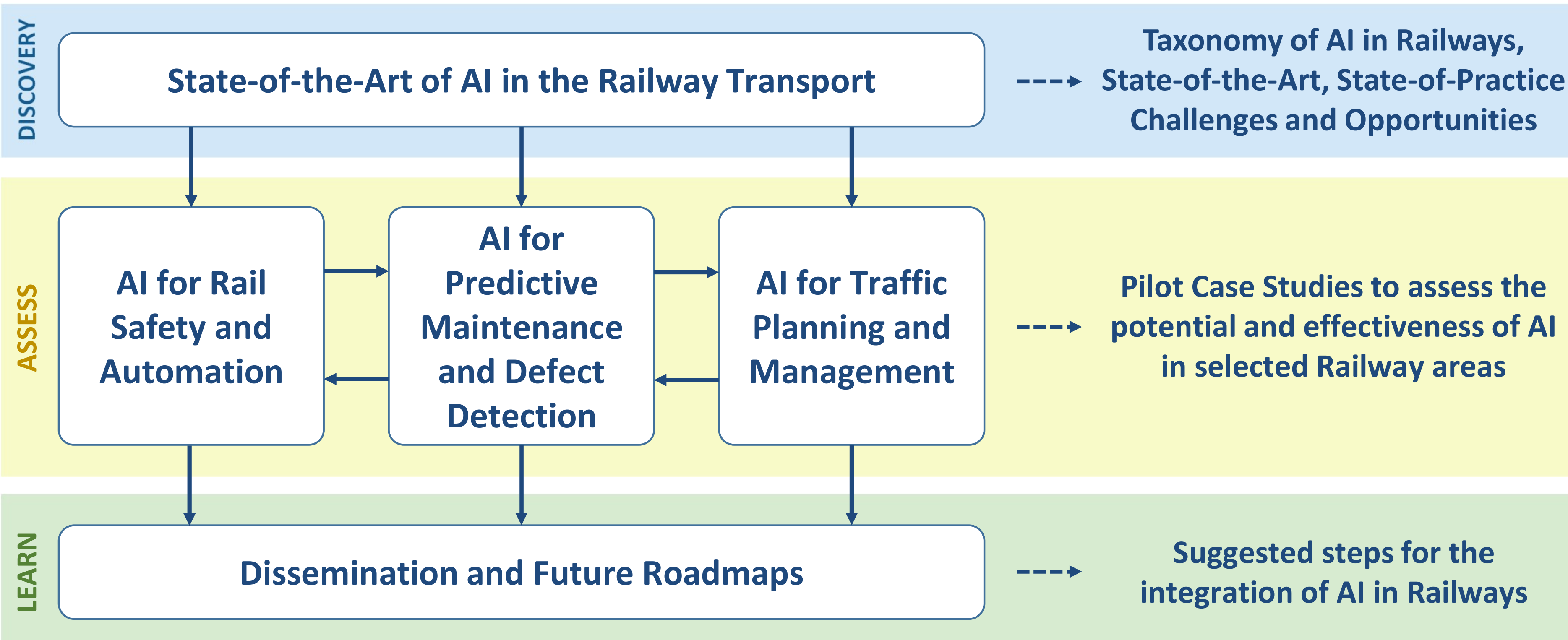


RAILS S2R Project

@project_rails

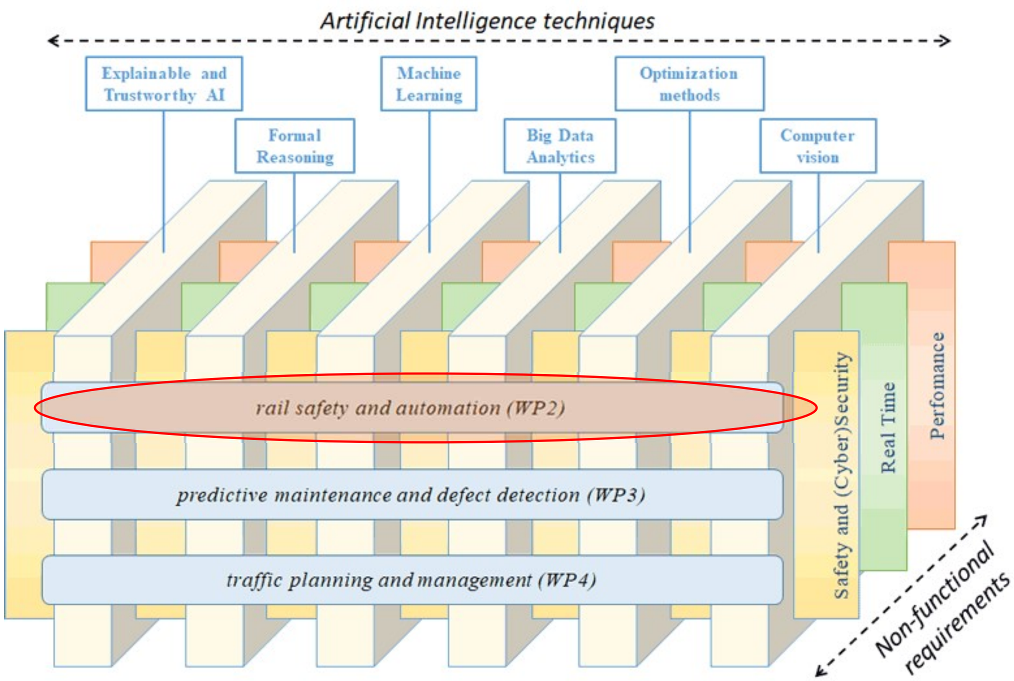
https://rails-project.eu/

Structure of the RAILS project



N. Bešinović et al., "Artificial Intelligence in Railway Transport: Taxonomy, Regulations, and Applications," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 9, pp. 14011-14024, Sept. 2022, doi: 10.1109/TITS.2021.3131637

Ruifan Tang, Lorenzo De Donato, Nikola Bešinović, Francesco Flammini, Rob M.P. Goverde, Zhiyuan Lin, Ronghui Liu, Tianli Tang, Valeria Vittorini, Ziyulong Wang, A literature review of Artificial Intelligence applications in railway systems, Transportation Research Part C: Emerging Technologies, Volume 140, 2022, 103679, ISSN 0968-090X, https://doi.org/10.1016/j.trc.2022.103679

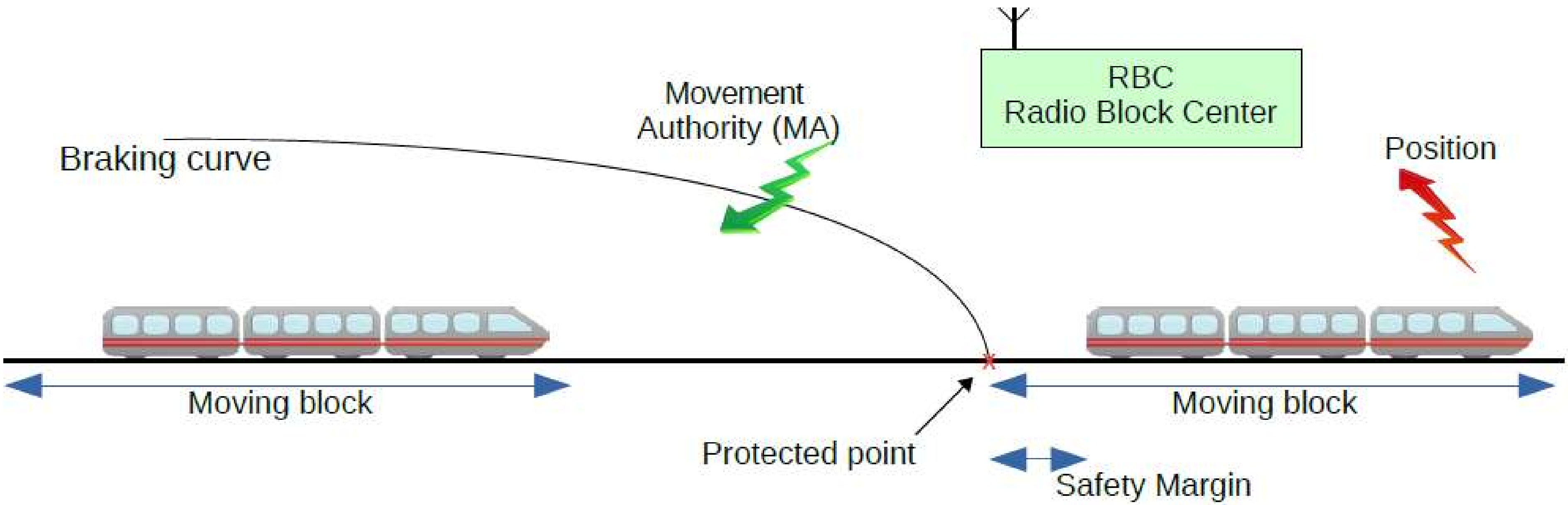


Focus on WP2:
AI for Rail Safety & Automation

Current automatic train management functions

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.

Moving block railway signalling



Flammini, Ind Eng Manage 2013, 2:5 DOI: 10.4172/2169-0316.1000120

Grades of automation in railways

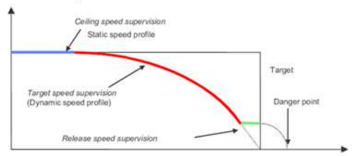
GoA 0	Train operations are manually supervised by the driver, no automation.
GoA 1	Train operations are manually supervised by the driver supported by ATP.
GoA 2	Semi-automatic train operation. ATO and ATP systems automatically manage train operations and protection while supervised by the driver.
GoA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

Intelligent Train Control

***A**utomatic **T**rain **P**rotection*

acting as a SAFETY ENVELOPE to ATO/ITO by ensuring train interdistance, train and route integrity, etc.

Requires connection with signalling system



SIL4

Energy Optimisation

Capacity Optimisation

Comfort Optimisation

***I**ntelligent **T**rain **O**peration*

adding ”smartness”, learning and adaptation to traditional ***A**utomatic **T**rain **O**peration*

ATP unavailability or partial supervision

***I**ntelligent **T**rain **P**rotection*

using AI to replace/support ATP

SIL?

Obstacle Detection

Signal Recognition

Flammini, F., De Donato, L., Fantechi, A., Vittorini, V. (2022). A Vision of Intelligent Train Control. In: Collart-Dutilleul, S., Haxthausen, A.E., Lecomte, T. (eds) Reliability, Safety, and Security of Railway Systems. Modelling, Analysis, Verification, and Certification. RSSRail 2022. Lecture Notes in Computer Science, vol 13294. Springer, Cham. https://doi.org/10.1007/978-3-031-05814-1_14

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AI4RAILS 2020: first studies on AI for Obstacle Detection in railways

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

Published in: Dependable Computing - EDCC 2020 Workshops

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Abstract

In this paper an AI-based system for detection and distance estimation of obstacles on rail tracks ahead of a moving train is presented, as developed within the H2020 Shift2Rail project SMART. The system software includes a novel machine learning-based method that is applicable to long range obstacle detection, the distinguishing challenge of railway applications. The development of this method used a novel long-range railway dataset, which was generated during the project lifetime as described in the paper. Evaluation results of reliable obstacle detection using SMART onboard cameras are presented. The paper also discusses the possible use of SMART software for obstacle detection in images taken by drone camera, for future extension of the SMART onboard system to a holistic system for obstacle detection in railways, as planned for SMART2, the follow-up project to SMART.

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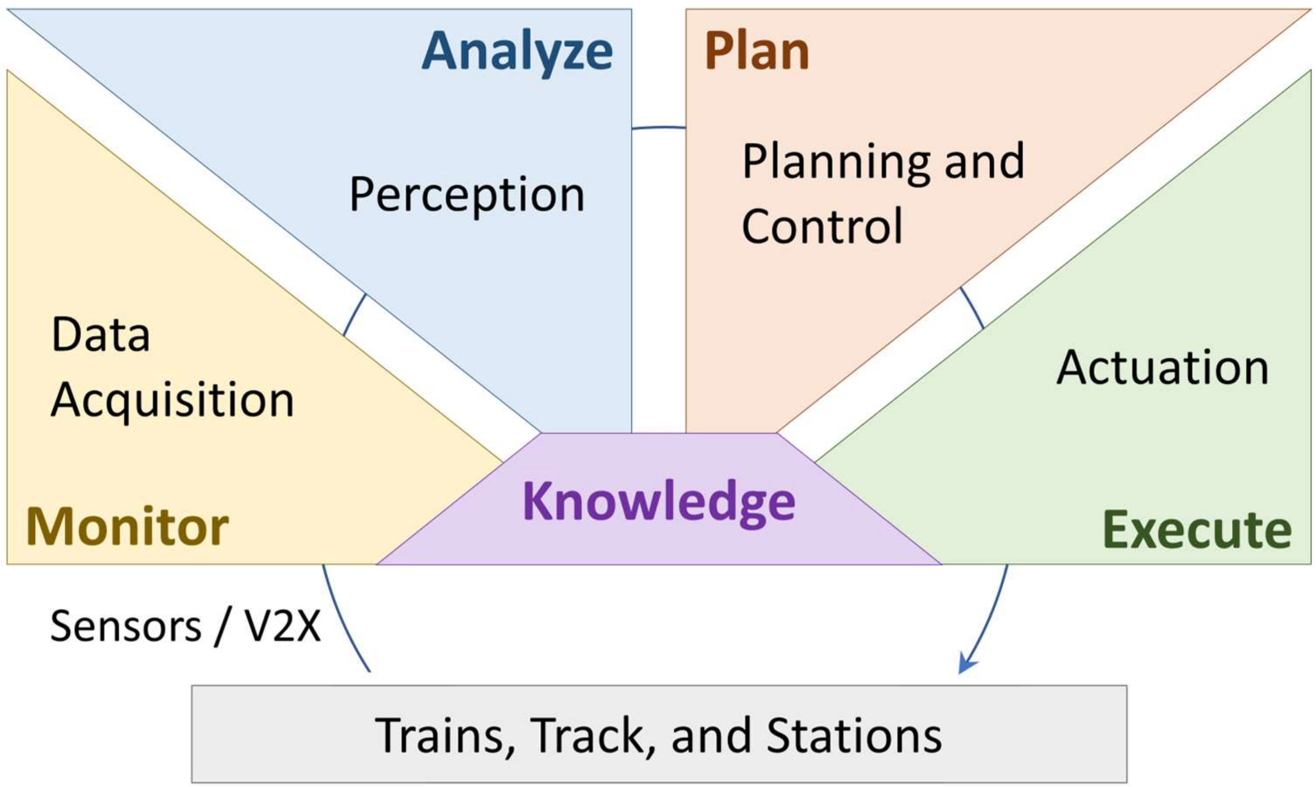
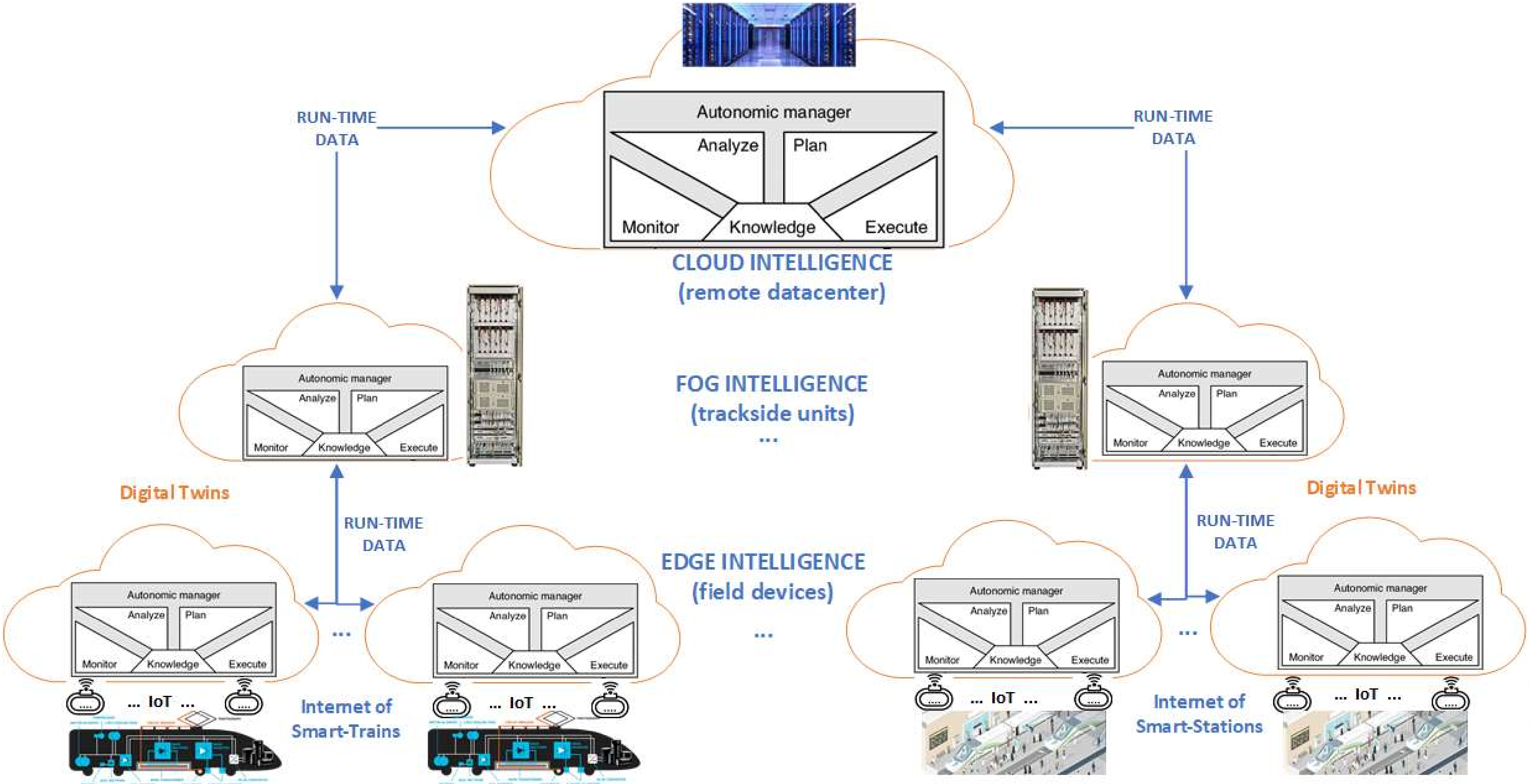
Grades of Intelligent Train Control

- **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.

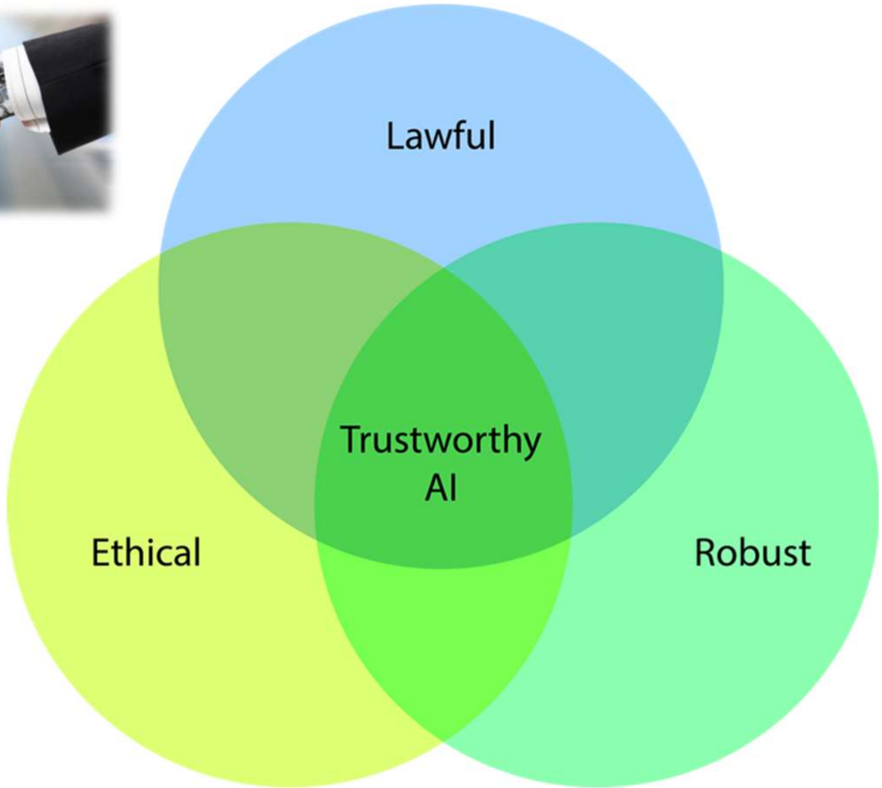
MAPE-K Loop for Intelligent Train Control

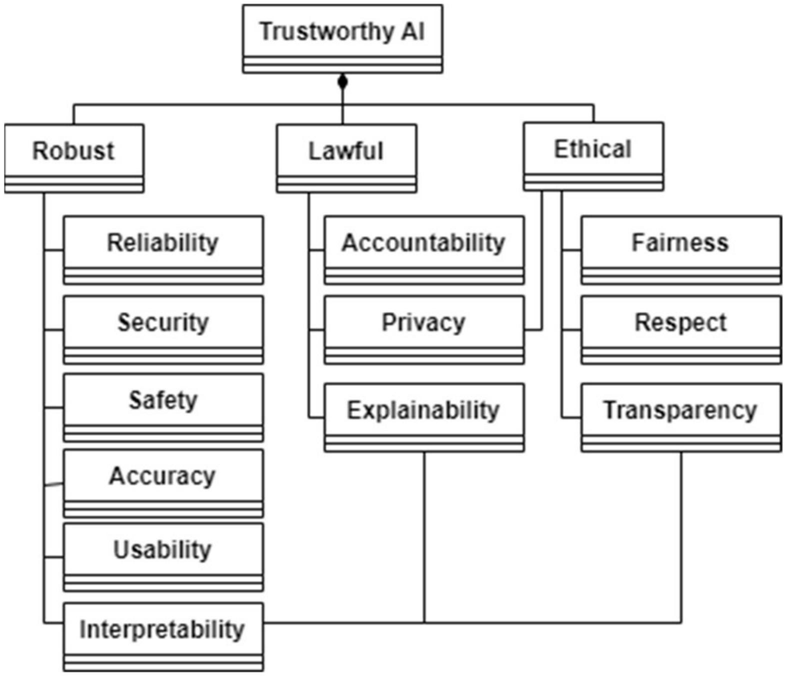


Levels of intelligence in railway control and supervision



Trustworthy artificial intelligence





F. Flammini, C. Alcaraz, E. Bellini, S. Marrone, J. Lopez and A. Bondavalli, "Towards Trustworthy Autonomous Systems: Taxonomies and Future Perspectives," in *IEEE Transactions on Emerging Topics in Computing*, doi: 10.1109/TETC.2022.3227113.

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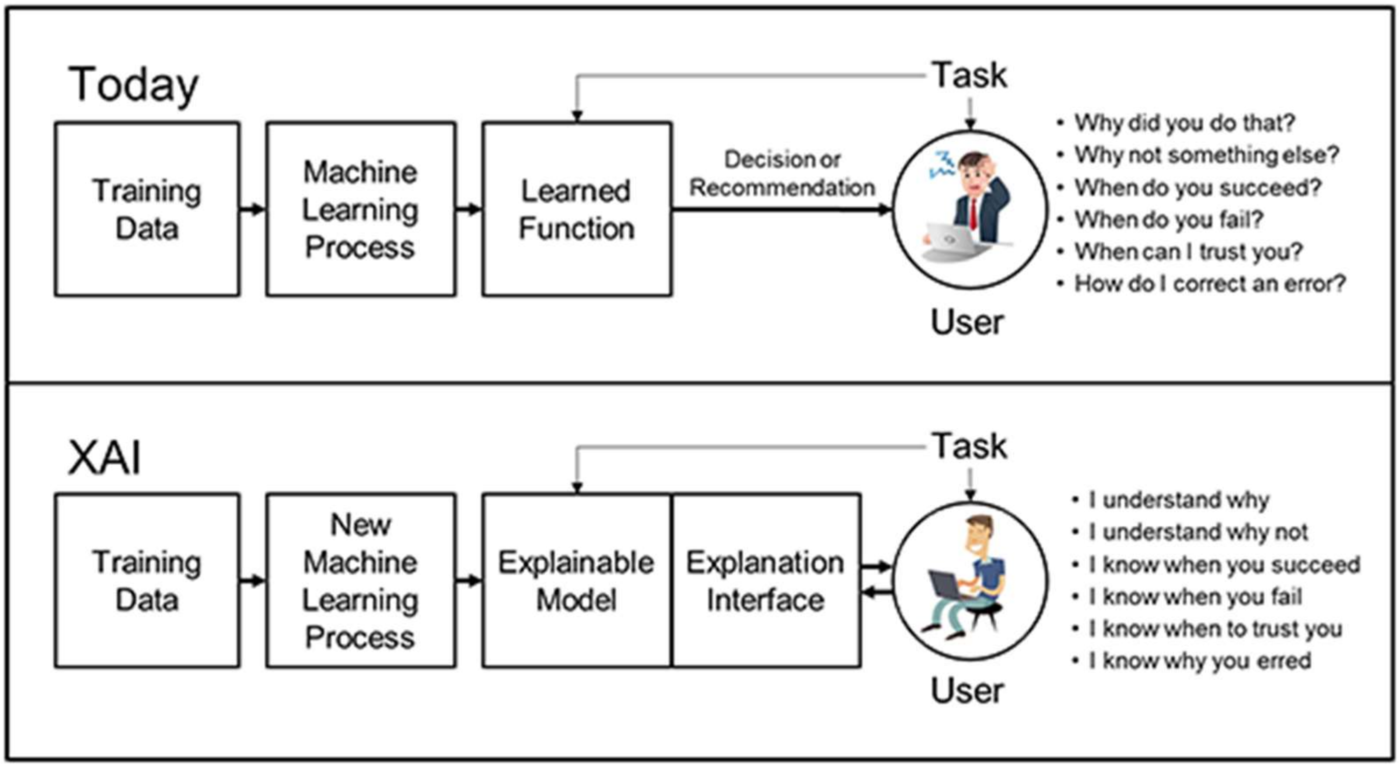
https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai

Explainable artificial intelligence



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

AI for safety critical systems

Growing concerns about safety-critical settings with AI

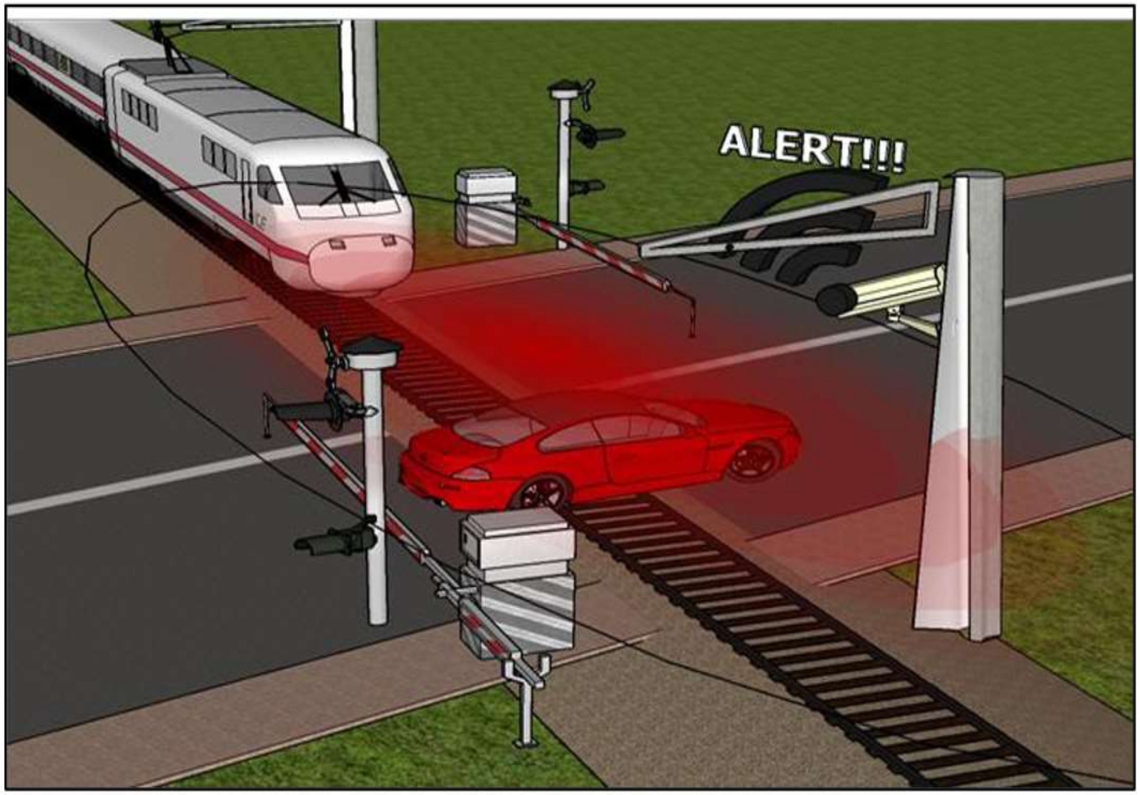
Autonomous cars that deploy AI model for traffic signs recognition

But with adversarial examples...

- https://www.eetimes.eu/2019/02/20/ai-tradeoff-accuracy-or-robustness/
- https://dorsa.fyi/cs521/

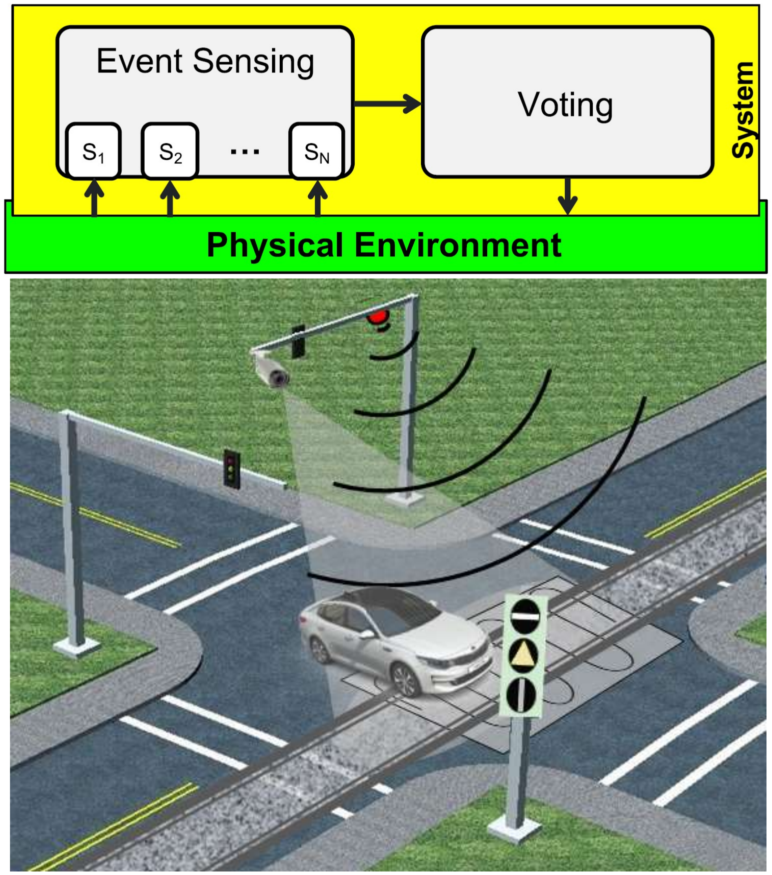
(IBM Research)

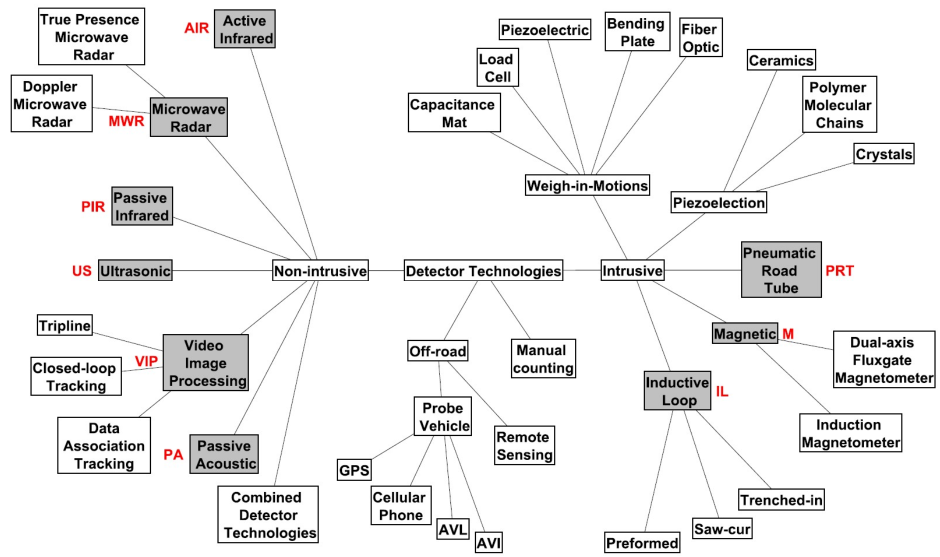
Applications of explainable AI



Vehicle stopped at a level crossing

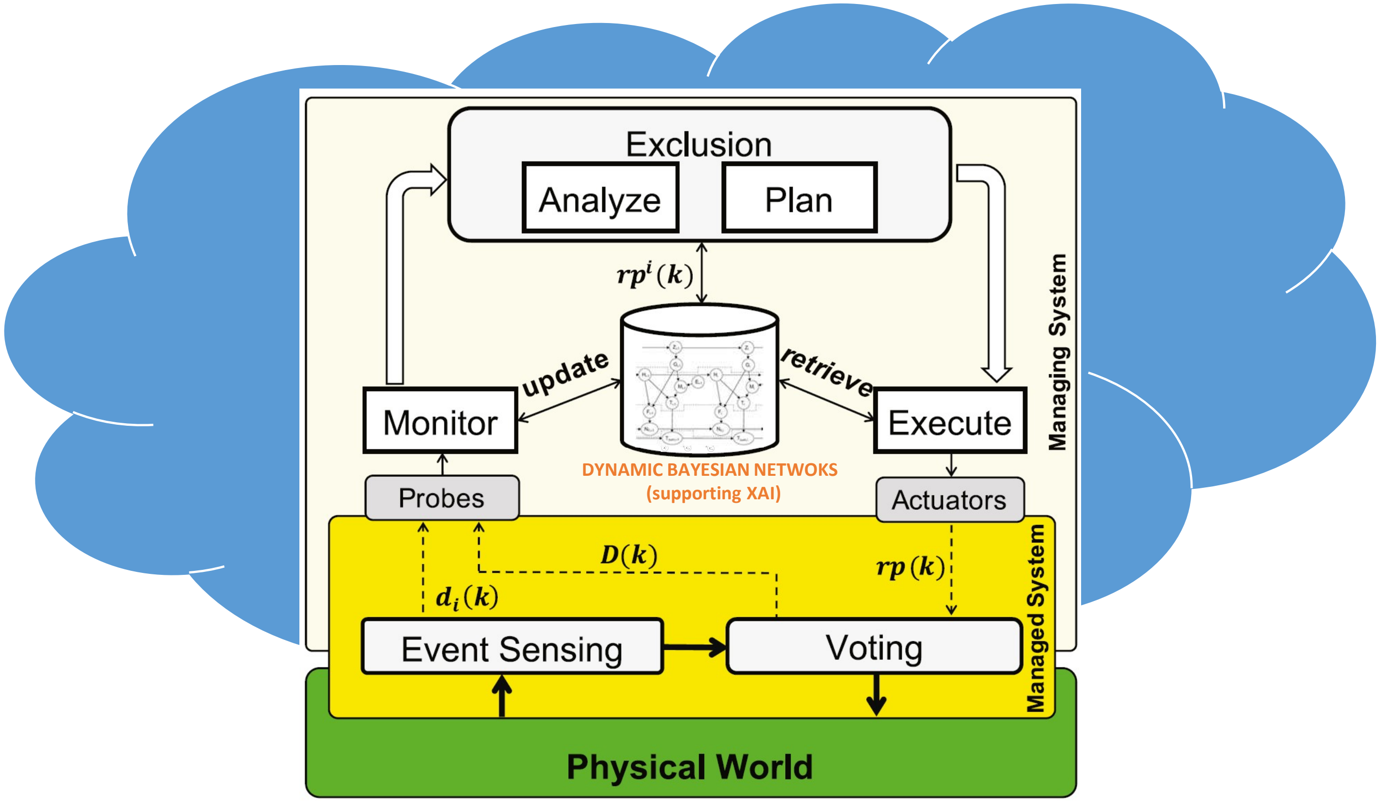
A real-world example





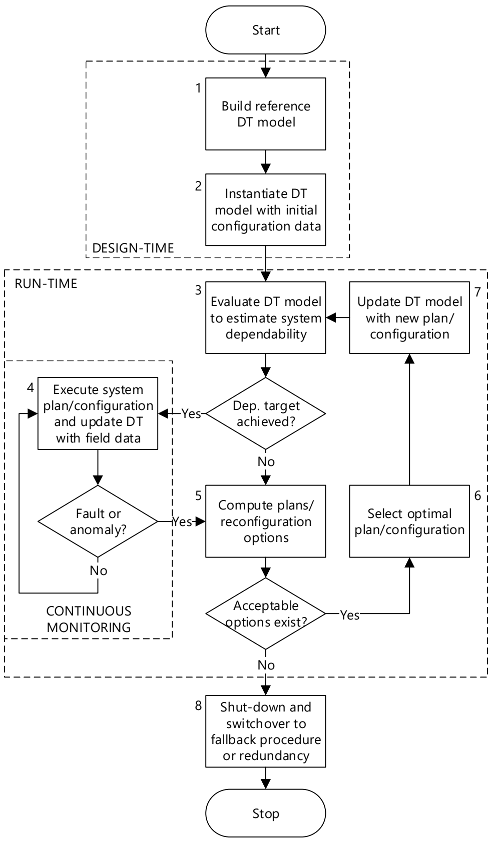
Francesco Flammini, Stefano Marrone, Roberto Nardone, Mauro Caporuscio, Mirko D'Angelo, Safety integrity through self-adaptation for multi-sensor event detection: Methodology and case-study, Future Generation Computer Systems, Volume 112, 2020, Pages 965-981, ISSN 0167-739X, https://doi.org/10.1016/j.future.2020.06.036.

Custom MAPE-K for multi-sensor event detection

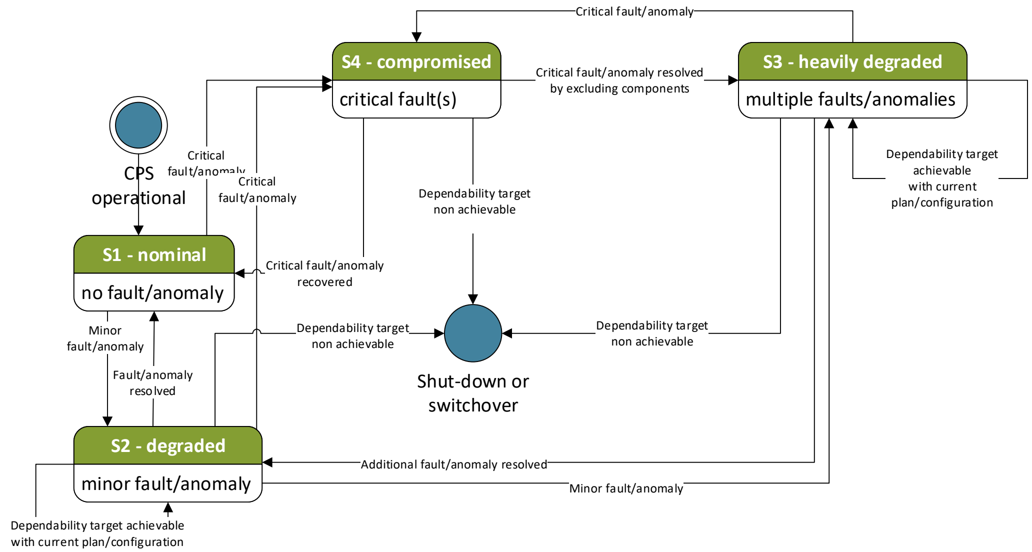


Exclusion mechanism: at every step k, the raw data di(k) captured by each sensor i, and the decision D(k) taken from Voting are used to analyze the system and compute the new sensor reputation rpi(k).

Digital Twins as Run-Time Predictive Models



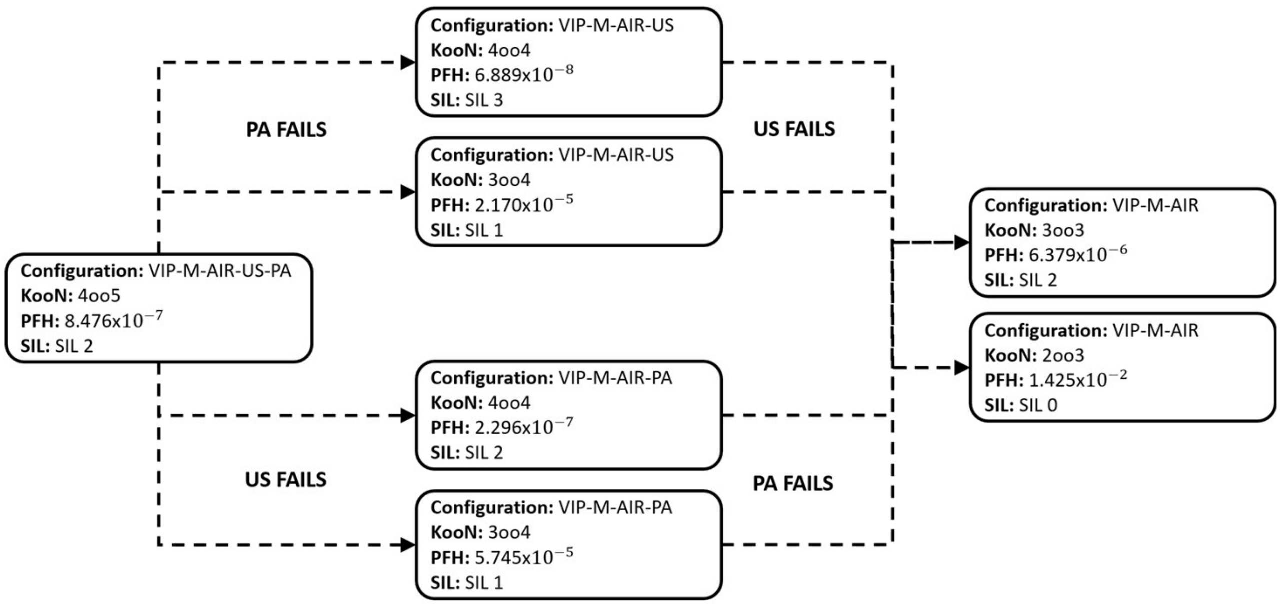
Continuous monitoring and planning and reconfiguration through DT run-time models.



State-chart describing the transitions among nominal, degraded and compromised states in self-healing CPS.

De Donato, L., Dirnfeld, R., Somma, A. *et al.* Towards AI-assisted digital twins for smart railways: preliminary guideline and reference architecture. *J Reliable Intell Environ* (2023). https://doi.org/10.1007/s40860-023-00208-6

Safety integrity levels depending on reconfiguration

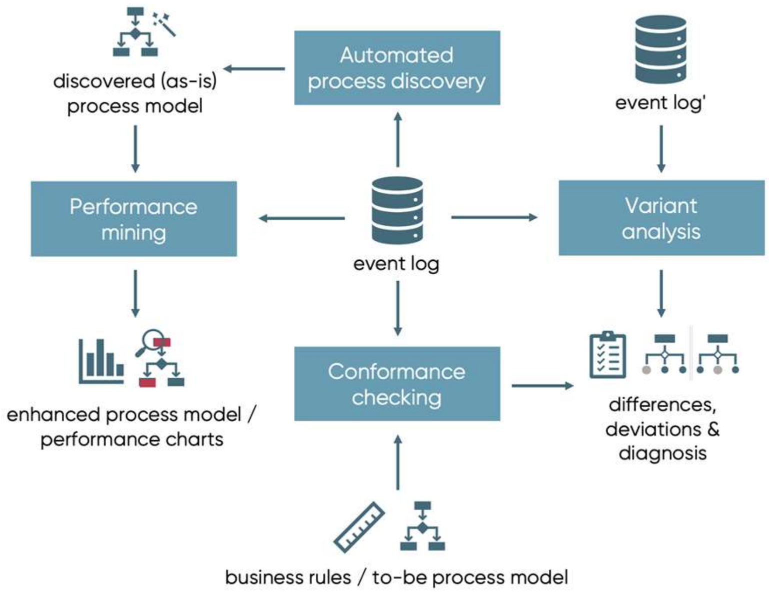


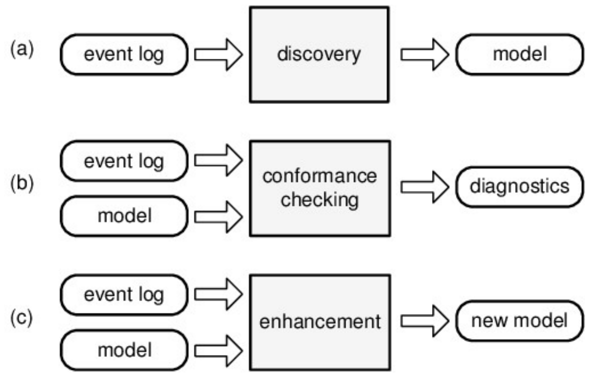
Francesco Flammini, Stefano Marrone, Roberto Nardone, Mauro Caporuscio, Mirko D'Angelo, Safety integrity through self-adaptation for multi-sensor event detection: Methodology and case-study, Future Generation Computer Systems, Volume 112, 2020, Pages 965-981, ISSN 0167-739X, https://doi.org/10.1016/j.future.2020.06.036.

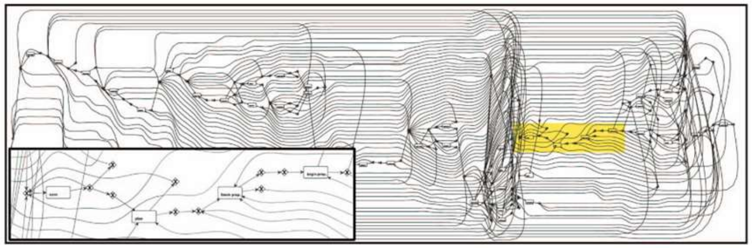
SIL	Probability of Failure per Hour (PFH)	PFH (power)	Risk Reduction Factor (RRF)
1	0.00001–0.000001	10^{-5}–10^{-6}	100,000–1, 000, 000
2	0.000001–0.0000001	10^{-6}–10^{-7}	1, 000, 000–10, 000, 000
3	0.0000001–0.00000001	10^{-7}–10^{-8}	10, 000, 000–100, 000, 000
4	0.00000001–0.000000001	10^{-8}–10^{-9}	100, 000, 000–1, 000, 000, 000

SIL requirements for continuous operation in IEC 61508

Process mining







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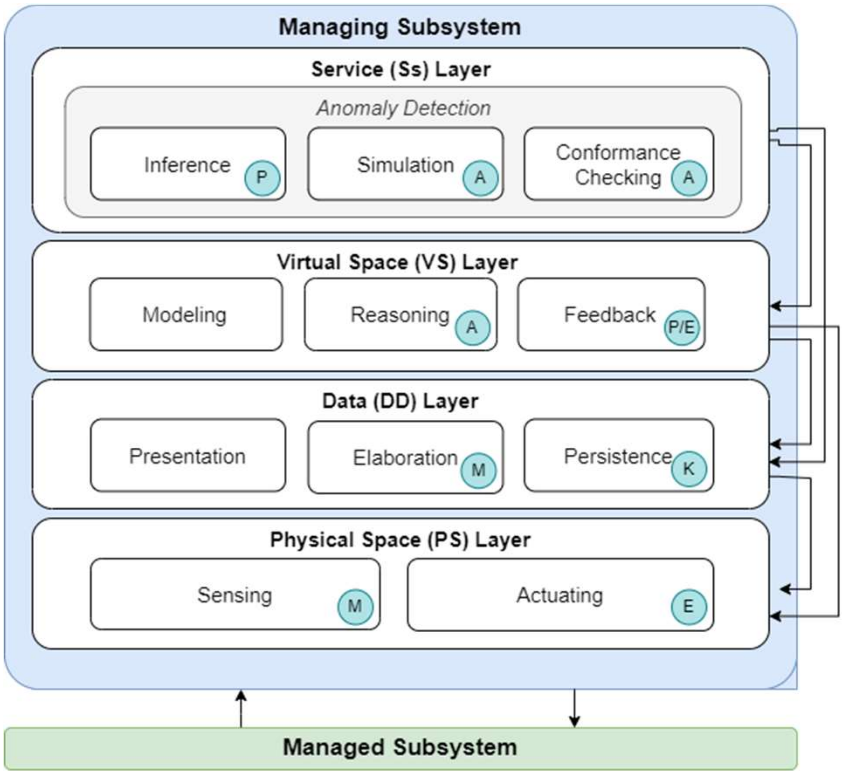
Singh PJ, Flammini F, Caporuscio M, Saman Azari M, Thornadtsson J (2020). Towards Self-Healing in the Internet of Things by Log Analytics and Process Mining. In Proc. ESREL2020 - PSAM15, 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference, Venice, Italy, June 21-26 2020

DT architecture for anomaly detection

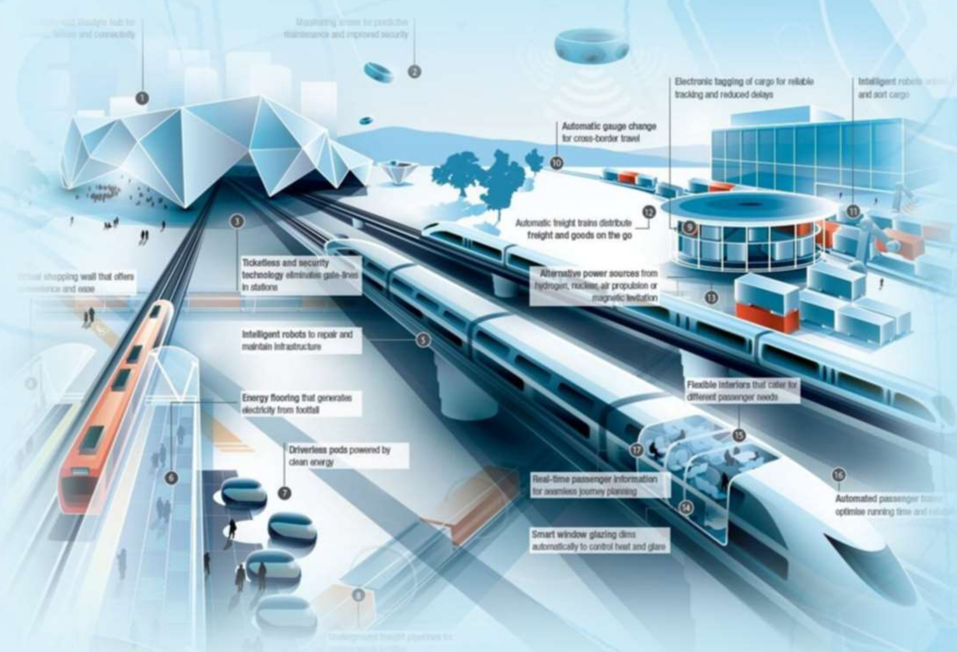


A. D. Benedictis, F. Flammini, N. Mazzocca, A. Somma and F. Vitale, "Digital Twins for Anomaly Detection in the Industrial Internet of Things: Conceptual Architecture and Proof-of-Concept," in *IEEE Transactions on Industrial Informatics*, doi: 10.1109/TII.2023.3246983.

DT-in-the-loop for mixed-reality testing of ML systems

Summary of key technical recommendations

- Work on **common dataset generation and sharing** to train and/or benchmark novel data-driven technologies, as well as data augmentation, automatic labelling, and new paradigms as **deep transfer learning** to support domain adaptation
- Combine **Cognitive Digital Twins**, autonomic computing through self-adaptation (**MAPE-K**) and distributed levels of intelligence (**edge-fog-cloud**) to enable on-line predictive analyses and pro-active safety
- Develop **mixed-reality simulators** to improve effectiveness and efficiency of AI testing
- Research on **trustworthy artificial intelligence** (e.g., robustness through ML redundancy and diversity, transparency and explainability to manage ethical and legal implications, etc.) as a key paradigm to enable autonomous train operation



Thank you for your kind attention!

Questions?

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