



FROM AUTOMATION TO INTELLIGENT TRAIN CONTROL: AI, DIGITAL TWINS AND TRUSTWORTHY AUTONOMY FOR FUTURE RAILWAYS

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Abstract – Railway transport is entering a new phase of digital transformation in which automation, artificial intelligence and advanced communications are expected to support higher capacity, improved energy efficiency, more flexible operations and enhanced safety. Current railway control architectures already provide a mature foundation through Automatic Train Protection, Automatic Train Operation and traffic supervision, with the certified signalling and train-protection layer defining the safety envelope within which trains are allowed to operate. Moving from conventional automation to higher levels of autonomy, however, requires additional intelligence: trains and infrastructure must perceive operational contexts, detect anomalies, support human operators and adapt to degraded or unexpected situations without compromising safety integrity. This keynote presents a vision of Intelligent Train Control as the progressive evolution of automatic train management towards trustworthy autonomous railway systems. The core idea is not to replace the proven principles of railway safety with opaque AI, but to integrate AI-enabled functions around and within existing control paradigms in a way that remains explainable, verifiable and certifiable. Examples include AI-based driving assistance, obstacle and intrusion detection, artificial vision for railway signal recognition, predictive maintenance of railway assets, anomaly detection at level crossings, and decision-support functions for traffic management and supervision. Such functions can enrich the operational picture available to drivers and control centres while supporting the gradual transition towards autonomous and resilient railway operations. A central part of this vision is the combination of trustworthy artificial intelligence with digital twins and autonomic computing. Digital twins can act as run-time predictive models, continuously synchronised with the physical world through sensor data and operational information. Coupled with MAPE-K loops — monitoring, analysis, planning, and execution over a shared knowledge — they can support online diagnosis, prediction, reconfiguration and self-healing strategies. In safety-critical railway contexts, this requires robust sensor fusion, redundancy and diversity, explicit management of uncertainty, and explainable reasoning mechanisms such as probabilistic models and Bayesian networks, so that AI outputs remain understandable to human operators and assessable by safety engineers. The keynote will also discuss open research and engineering challenges that must be addressed before intelligent train control can be widely deployed. These include the availability and sharing of high-quality datasets, the generation of rare and adverse operating conditions, mixed-reality simulation for testing machine-learning components, assurance cases for AI-enabled functions, and the integration of distributed intelligence across edge, fog and cloud layers. Particular emphasis will be placed on preserving human oversight, regulatory compliance and safety certification while exploiting AI to improve perception, prediction and operational decision-making. By framing AI as an enabling technology within a disciplined systems-engineering approach, Intelligent Train Control can contribute to future railways that are safer, more efficient and sustainable, and better prepared for autonomous operation.

Keywords - intelligent train control; autonomous railways; trustworthy AI; digital twins; safe perception; railway automation; safety-critical systems.

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