Sustainable Mobility: Increase of Capacity and Digitisation of Railway Transport

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Researchers from the Formal Methods and Tools (FMT) lab of CNR–ISTI work on the increase of capacity and digitisation of railway transport. The research is conducted in the context of the NextGenerationEU-funded project on "Railway Transportation" (Spoke 4), which is part of the National Centre for Sustainable Mobility (MOST).

Railway transportation by train, metro, or tram is among the most energy-efficient and environmentally friendly means of transportation. In the near future, the railway domain is expected to contribute significantly to the European Green Deal by improved digitalisation and big data analytics [L1]. The NextGenerationEU project on "Rail Transportation" (Spoke 4) of the National Centre for Sustainable Mobility (MOST) [L2] aims, among others, to increase railway capacity and digitisation in order to improve railway safety, efficiency of railway maintenance, and railway asset management. The FMT lab of CNR–ISTI is involved in two work packages: WP1 and WP3.

WP1 "Increase of capacity of railway transport" aims to increase the capacity through the innovation of railway signalling systems (ERTMS/ETCS Level 3) and the development of robust quantitative methods for the assessment of capacity of railway lines. In Task 1.3 "Resilient and sustainable railway infrastructure", we have so far investigated the combination of an academic formal verification tool with an industrial semi-formal model-based development tool to develop a railway interface, namely the RBC/RBC handover protocol (UNISIG Subset 039 and Subset 098 standard interface) of the ERTMS/ETCS signalling system [1]. The use of advanced formal verification techniques integrated with model-based development, reflects significant technological innovation and contributes to achieve the Sustainable Development Goals (SDG), specifically to safe, resilient and sustainable mobility (SDG 11).

WP3 "Digitisation of railway transport", coordinated by Maurice ter Beek, aims to promote digital products and processes to foster smart management, monitoring and predictive maintenance in order to reduce fatalities, reduce operating cost, and increase the overall mobility safety level. In Task 3.1 "Learning Formal Models for Predictive Maintenance", we have so far investigated possible efficient predictive maintenance solutions based on big data analytics for safe and sustainable infrastructure maintenance in the railway domain. Detecting and preventing failures in domains with high operational risks and costs, like the railway industry, is paramount to improve utilisation and reliability of equipment and to increase operational efficiency by minimising downtime and reducing costs. One essential approach to achieve this is the deployment of effective and efficient maintenance strategies. In particular, predictive maintenance aims to detect failures before they actually occur.

The development of effective and efficient predictive maintenance solutions for the railway domain is a challenging and emerging research field. In the literature [2], one distinguishes several classes of predictive maintenance on the basis of how the data is collected and exploited to implement the prognostics application, i.e. (physical) model-based, data-driven-based, knowledge-based, and digital twin-based. To produce the actual predictions, model-based approaches use the provided input data on a previously defined physical or mathematical model; data-driven approaches use a statistical model inferred from the data that was available at the time of the training of the prognostics application; knowledge-based approaches use domain knowledge (e.g. ontologies) or expertise of the system; and digital twin-based approaches use a real-time digital representation of the physical system to generate data imitating the real events.

While data-driven approaches require huge amounts of data to correctly infer a statistical model, model-based approaches are less dependent on data. Yet model-based solutions can become quite complex if the modelled system is complex, whereas the domain-agnostic nature of data-driven solutions guarantees instant applicability on the data – without the need of a model or detailed knowledge of the system. We are currently developing a data-driven approach to define cost-effective predictive maintenance strategies for on-board equipment. Efficient pre-

Figure 1: Trenord's Fiorenza maintenance facility, the largest railway maintenance facility in Italy with a maintenance and cleaning capacity of up to 140 full trains every week, and a train driver control screen displaying diagnostic information on rolling stock assets.

dictive maintenance allows the optimisation of energy consumption and reduction of emissions associated with railway operations, contributing to limiting and adapting to climate change (SDG 13).

For now, we focus on predictive maintenance solutions for the railway Traction Control Unit (TCU) and the Door Control Unit (DCU) of local commuter trains. The goal is to identify operational anomalies and potential defects in the data logs of these on-board units, enabling the scheduling of maintenance ahead of time [3]. The traction system is important since it enables adherence to acceleration and deceleration values mandated by the regulations, whereas the door system is related to the safety, security and efficiency of railway operations, implying that its failure can lead to operational disruptions or delays that may propagate through the railway network, thus causing economic loss and bad social reputation. Surprisingly, the door system is responsible for 30% to 60% of the total failures in railway vehicles [L3] (see Fig. 1). This high failure rate is due to the complexity of the system's mechatronic structure, as well as to the high stress during its lifecycle (e.g. frequent opening and closing due to high passenger flow, in particular on local commuter trains).

Spoke 4 received funding from the European Union – NextGenerationEU. The project will run until August 2025 and is coordinated by Marco Bocciolone from the Polytechnic University of Milan. Further partners in T1.3 and T3.1 include the universities of Florence, Naples, Parma, and Roma "Sapienza", as well as the industrial partners Accenture, Almaviva, Ferrovie Nord Milano (FNM), Hitachi, Intesa Sanpaolo, Lutech, Rete Ferroviaria Italiana (RFI), and Trenord.

Links:
[L1] https://kwz.me/hAQ
[L2] https://www.centronazionalemost.it/
[L3] http://www.railway-technical.com/trains/train-maintenance/

References:
[1] D. Basile, F. Mazzanti, and A. Ferrari, "Experimenting with formal verification and model-based development in railways: the case of UMC and Sparx Enterprise Architect," in Proc. of the 18th Int. Conf. on Formal Methods for Industrial Critical Systems (FMICS'23), LNCS vol. 14290, Springer, 2023, pp. 1–21. https://doi.org/10.1007/978-3-031-43681-9_1
[2] M.A. Fidma, et al., "Predictive maintenance approaches in Industry 4.0: a systematic literature review," in Proceedings of the 31st IEEE Int. Conf. on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE'23), IEEE, 2023, pp. 1–6. https://doi.org/10.1109/WETICE57085.2023.10477802
[3] R. Ferdous, A. Ferrari, et al., "Identifying maintenance needs with machine learning: a case study in railways," in Proc. of the 32nd Int. Requirements Engineering Conf. Workshops (REW'24), IEEE, 2024, pp. 22–25. https://doi.org/10.1109/REW61692.2024.00008.

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Human-centred Smart Mobility: Shaping the Future of Urban Transport

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Exploring the fusion of advanced technology and urban planning, the HUMOVE project is pioneering diverse smart mobility solutions, each designed with a human-centred approach. From enhancing pedestrian pathways to optimising e-scooter and electric vehicle infrastructures, discover how these case studies are actively redefining sustainable urban transport for a variety of city residents.

As the world urbanises at an unprecedented rate, the pressure on urban transportation infrastructure has never been more intense. The HUMOVE (Human-centred Smart Mobility) project [L1], led by experts from ITIS Software [L2] at the University of Málaga, focuses on rethinking urban mobility from a human-centred perspective, offering solutions that address both social and environmental needs.

HUMOVE is committed to creating intelligent mobility solutions that anticipate the needs of a growing and diverse urban population. The project takes a comprehensive approach, integrating advanced technologies and inclusive design to improve the mobility experience for pedestrians, cyclists, electric vehicle drivers, and public transport users. In this project, we have developed multiple intelligent systems to improve mobility from the citizen's point of view. In the this article, we will detail two use cases as representative examples of the project's results.

Our first example is a plan to smoothly integrate e-scooters into the city environment. This task aims to improve the current road infrastructure to make e-scooters a practical part of the city's multi-modal transport system [1]. The main objective is to enhance the connectivity and extend the coverage of bike lanes designed specifically for e-scooter use while keeping the implementation costs as low as possible.

We are taking a holistic approach to urban mobility by redesigning roadways to accommodate e-scooters and bicycles. Our goal is to create a more inclusive and efficient transport network. Introducing dedicated lanes will provide safer and faster travel for e-scooter users and help reduce congestion in urban centres.

Moreover, the strategic placement of these new infrastructures is guided by a comprehensive analysis that balances the benefits of improved travel times against the financial implications of road modifications. Through careful planning and the use of multi-criteria optimisation techniques, it has successfully identified key areas within Málaga city (Spain) where interventions would yield the most significant impacts. This methodical placement ensures that investments are made where they can provide maximum benefits in terms of accessibility and user satisfaction.

The outcomes from this service highlight a promising reduction in travel times for e-scooter users, which is instrumental in pro-