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SUSTAINABLE ENERGY MANAGEMENT AND ECO-DRIVING STRATEGIES IN AUTONOMOUS RAIL SYSTEMS

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Summary: Recent technological advancements and the growing push for sustainability in transportation demand innovative strategies to reduce energy consumption and carbon emissions in rail systems. This article explores algorithms for both onboard and trackside automation, focusing on train control methods—such as optimal driving strategies, brake/traction regulation, coasting, and regenerative braking—and dynamic timetabling that incorporates train-to-track feedback, conflict detection, and traffic prediction optimization. The potential integration of renewable energy sources is also highlighted, with a particular focus on leveraging systems critical to rail automation in the European context, including Automatic Train Operation (ATO) running over the European Train Control System (ETCS).

A key element of this research is the use of a detailed digital infrastructure model coupled with real-time feedback among involved components. For instance, the railway vehicle itself continuously supplies sensor data to the onboard control system, while train-to-track communication facilitates precision regulation of speed, coasting intervals, and braking profiles. Such an integrated environment unlocks advanced operational strategies that optimize energy efficiency by tailoring speed profiles to the specific characteristics of the surrounding railway infrastructure.

Dynamic timetabling further enhances efficiency and coordination—not only among multiple trains but also with other modes of transport—enabling seamless multimodal systems. With trains continuously reporting accurate positions and projected arrival times to the Track Management System (TMS), traffic control centers can predict and manage flows hours in advance, helping minimize delays and reduce bottlenecks.

To validate these energy-optimization approaches, simulations and field tests are conducted across different train types, ranging from regional and suburban commuter services to long-distance high-speed trains. These trials account for varying traffic levels, traction systems, route curvature, gradients, and maximum speed profiles, allowing for a comprehensive assessment of energy savings under diverse operational conditions.

The evolution of rail automation does not simply improve operational efficiency and lower costs—it also has the potential to enhance safety and reliability. By integrating real-time feedback loops, data-driven decision-making, and next-generation automation, railway operations become more resilient and robust. This article provides a wide-ranging analysis of energy optimization methods and underscores the essential role of automation in achieving a more sustainable, high-performance European railway network.