Socio-Technical Systems in the Fifth Industrial Revolution

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The Fifth Industrial Revolution (5IR) redefines the relationship between humans and technology, emphasizing collaboration, ethical innovation, and sustainability beyond the automation-focused paradigm of Industry 4.0. Within this context, the Socio-Technical System (STS) approach extends the principles of Human-System Integration (HSI) to address the coordination, synchronization, and resilience challenges of complex systems. The goal is to ensure that human–machine partnerships remain effective, adaptable, and sustainable across changing conditions.

This research introduces a framework for operational sustainability, defined as the capacity of socio-technical systems to maintain effective, safe, and reliable performance under both expected and unexpected conditions. Drawing on case studies from aviation, nuclear, and industrial operations, the study identifies recurrent patterns of failure stemming from coordination gaps, poor decision support, and limited anomaly detection. These operational deficiencies erode sustainability by increasing errors, resource use, and system degradation over time.

To address these challenges, the study proposes rule-based and model-based operation design methods supported by Large Language Models (LLMs). These tools can accelerate learning from near misses and unnoticed incidents by formalizing basic models of system failure, identifying exceptions, and developing generic, adaptable rules. Building on the antifragility concept, the approach treats failure as a source of insight, enabling continuous improvement and resilience.

The paper introduces sustainability-oriented architecture featuring a generic, adaptable Universal Interaction Control (UIC) module that supports coordination, synchronization, decision-making, and troubleshooting proactively, by exception prevention, and reactively, by exception detection, through scenario-based modeling. This architecture enables cost-effective sustainability development by customized rule-templates.

Findings suggest that LLM-assisted STS design can transform error management from reactive correction to proactive prevention, achieving cost-effective sustainability. By integrating adaptive rule-based control with learning mechanisms, developers can enhance resilience, improve operational safety, and extend system life cycles. The study

concludes that in the 5IR, operational sustainability may develop by LLM tools for tracing and analyzing unnoticed incidents.