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RADemics

AI-Enabled Decision Support Frameworks for Real-Time Industrial Process Automation and Operational Optimization

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C. Harriet Linda, Swati Bula Patil,
Sreekanth Ramasamy

SRM University, Vishwakarma Institute of
Technology, St. Joseph's College of
Engineering

AI-Enabled Decision Support Frameworks for Real-Time Industrial Process Automation and Operational Optimization

¹C.Harriet Linda, Assistant Professor ,Computing Technologies ,SRM University, Kattankulathur – 603203. Mail id: harrietc@srmist.edu.in

²Swati Bula Patil, Assistant Professor, Information Technology, Vishwakarma Institute Of Technology, Kondhwa, Pune. Mail ID: swati.patil@vit.edu

³Sreekanth Ramasamy, Assistant Professor, Electrical & Electronics Engineering, St. Joseph's College of Engineering, OMR, Chennai – 119. Mail id: sreekanthr@stjosephs.ac.in

Abstract

The accelerating evolution of industrial automation has driven the emergence of Artificial Intelligence (AI)-enabled Decision Support Systems (DSS) as a transformative force in real-time process optimization and intelligent control. Industrial ecosystems are increasingly defined by interconnected machines, complex data environments, and adaptive decision architectures that demand rapid, data-driven reasoning. This chapter explores the theoretical, architectural, and analytical foundations of AI-enabled DSS, focusing on the integration of advanced computational intelligence within modern industrial frameworks. The study emphasizes the convergence of machine learning, reinforcement learning, fuzzy logic, and cognitive computing as the core enablers of predictive and prescriptive decision-making. It investigates the transition from traditional rule-based systems to autonomous, self-learning platforms that continuously refine operational efficiency and resilience. The proposed framework highlights the strategic role of cloud–edge–fog collaboration, data fusion, and Industrial Internet of Things (IIoT) integration in creating scalable and adaptive decision environments. Emphasis is placed on data acquisition pipelines, feature engineering techniques, and real-time analytics that convert sensor-driven information into actionable intelligence. The chapter presents an architectural synthesis encompassing modularity, interoperability, and distributed intelligence—key characteristics that ensure seamless coordination between human operators and automated control systems. Through this perspective, the research underscores how AI-driven decision systems redefine industrial performance by enabling dynamic optimization, predictive maintenance, and intelligent resource allocation. The discussion concludes by identifying critical research gaps, including interoperability constraints, real-time model adaptation, and security challenges in distributed AI-driven infrastructures. Addressing these challenges through standardized communication protocols and hybrid intelligence mechanisms establishes the pathway toward autonomous, resilient, and context-aware industrial decision ecosystems. The insights presented serve as a comprehensive foundation for advancing next-generation industrial automation, where cognitive intelligence and data-driven analytics converge to deliver sustainable efficiency and strategic foresight.

Keywords: Artificial Intelligence, Decision Support Systems, Industrial Automation, Predictive Analytics, Real-Time Optimization, Industrial Internet of Things (IIoT)

Introduction

The emergence of Artificial Intelligence (AI) has revolutionized industrial process automation by transforming traditional control systems into intelligent, adaptive, and data-driven decision platforms [1]. Industrial sectors now operate in a hyperconnected environment where machines, sensors, and computing systems continuously exchange vast amounts of data [2]. The complexity of this data surpasses the analytical capacity of conventional systems, creating the need for AI-enabled Decision Support Systems (AI-DSS) [3]. These systems integrate computational intelligence with industrial control mechanisms to provide real-time insights, predictive diagnostics, and optimal decision recommendations [4]. The transformation from reactive to proactive management has enhanced operational efficiency, safety, and cost-effectiveness across multiple industrial domains, including manufacturing, energy, logistics, and process engineering. By embedding AI algorithms within industrial ecosystems, industries gain the ability to adapt to uncertainties and maintain resilience in rapidly changing production environments [5].

The foundation of AI-enabled DSS lies in the convergence of machine learning, predictive analytics, and optimization algorithms, enabling industries to transform raw sensor data into actionable intelligence [6]. Through continuous learning and model refinement, AI systems can anticipate operational deviations, suggest corrective measures, and ensure process stability without human intervention [7]. This intelligence-driven decision-making environment enhances precision, minimizes risks, and fosters a culture of innovation across industrial enterprises [8]. The growing integration of Industrial Internet of Things (IIoT) frameworks with AI-DSS allows seamless connectivity among distributed devices and control systems, providing a unified data infrastructure for monitoring and optimization [9]. As industries evolve toward digital transformation, AI-DSS emerges as the critical enabler of smart manufacturing, aligning operational processes with strategic objectives [10].

The incorporation of AI into decision support systems has redefined industrial analytics through the use of advanced computational models and hybrid intelligence [11]. Reinforcement learning, fuzzy logic, and cognitive computing techniques empower AI-DSS to operate effectively in dynamic and uncertain environments [12]. These systems can evaluate multiple decision scenarios, weigh trade-offs, and deliver context-aware recommendations in real time [13]. The inclusion of cognitive and hybrid intelligence enables systems to mimic human reasoning while maintaining computational precision, leading to adaptive and transparent decision processes [14]. Industrial applications such as predictive maintenance, anomaly detection, and resource optimization rely on these intelligent frameworks to reduce downtime and improve overall equipment effectiveness. The adaptability of AI-DSS fosters a self-learning ecosystem that continuously enhances process performance through data-driven feedback loops [15].