

# Industrial IoT-Enabled Modeling and Optimization for the Process Industry

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The process industry is undergoing a profound transformation driven by the rapid development of the Industrial Internet of Things (IIoT). Through pervasive sensing, real-time connectivity, and continuous data acquisition, IIoT supports advanced modeling, prediction, and optimization of complex industrial processes. These capabilities are particularly important in steel manufacturing, thermal power generation, energy conversion, materials processing, and warehousing, where operational safety, energy efficiency, equipment reliability, and environmental performance must be maintained under uncertain operating conditions.

Against this background, this Special Issue explores how IIoT-enabled modeling and optimization can support the transition from industrial sensing and predictive analytics to intelligent decision-making and autonomous operations. The contributions collectively highlight an emerging shift toward integrated, adaptive, and sustainable industrial systems.

The first group of studies advances secure and predictive industrial analytics. Qin et al. developed MAS-LSTM, a decentralized anomaly-detection framework that combined multi-agent systems (MASs) with long short-term memory (LSTM) networks to enhance the security and reliability of heterogeneous IIoT networks. Zhang et al. addressed power-load forecasting in iron and steel enterprises by proposing a joint learning method based on deep kernel learning (DKL) and multiple kernel learning (MKL), thereby improving the modeling of nonlinear and time-varying electricity demand patterns and supporting production planning, power purchasing, and energy cost reduction.

The second group addresses process and energy optimization across different system scales. Yu et al. proposed a rapid online combustion optimization framework for utility boilers based on an adaptive hybrid case library. The framework integrated data filtering, case-based reasoning, extreme gradient boosting (XGBoost), and multi-objective optimization to improve combustion efficiency and reduce nitrogen oxides (NOx) emissions. Amini-Rankouhi et al. extended the optimization perspective from individual units to process networks through a thermodynamic-model-based methodology for synthesizing heat-integrated work exchanger networks, thereby enabling the coordinated recovery of thermal and mechanical energy while reducing the total annualized cost.

The third group focuses on intelligent condition monitoring, fault diagnosis, and alarm management. Guo et al. combined depthwise separable convolution with bidirectional LSTM (Bi-LSTM) to diagnose distribution-box faults in hot rolling, extracting both spatial and temporal features from vibration signals while maintaining a lightweight model structure. Yu et al. addressed rotating machinery fault diagnosis under time-varying speed conditions through the adaptive identification of order structures, improving nonstationary fault-feature extraction without requiring additional speed measurements. Zhang et al.



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proposed a data-driven intelligent alarm method for ultra-supercritical thermal power units, improving threshold selection and reducing missed and nuisance alarms.

The final group broadens the application of IIoT-enabled modeling and optimization to autonomous operations, intelligent logistics, production decision-making, and sustainability assessment. Ou et al. improved mobile-robot local path planning by incorporating predicted future obstacle positions, while Ren et al. investigated switched control for modular reconfigurable flight arrays under actuator faults. Yan et al. developed a binocular-vision-based measurement method for unmanned bar warehouses, supporting three-dimensional perception for automated crane-hoisting operations. Within steel manufacturing, Wang et al. proposed an online partition-cooling system for hot-rolled electrical steel to regulate the thermal roll profile and improve strip-shape control, while Zhang et al. developed a multi-criteria group decision-making method based on Group analytic hierarchy process (AHP) and cloud-model-enhanced technique for order preference by similarity to ideal solution (TOPSIS) for evaluating production scheduling schemes. In addition, Jian et al. refined Deng's grey relational analysis model for panel data and applied it to assess the water environment of Poyang Lake, illustrating the broader relevance of industrial data-analysis methods to sustainability evaluation.

Taken together, the contributions to this Special Issue highlight three emerging research trends:

- (1) Hybrid industrial modeling: Industrial modeling is increasingly integrating data-driven learning with domain knowledge, adaptive mechanisms, and distributed intelligence to address complex and nonstationary processes.
- (2) Online and deployable optimization: Modeling and optimization methods are moving toward online implementation under practical constraints, supporting closer integration among process control, condition monitoring, energy management, logistics, and operational decision-making.
- (3) Engineering-oriented validation: Greater emphasis is being placed on validating new methods using real industrial data, representative operating scenarios, pilot platforms, and field applications, thereby strengthening their practical relevance and deployment potential.

Building on these advances, future research should focus on translating increasingly sophisticated models and optimization methods into reliable, trustworthy, and adaptive solutions for real-world industrial operations. Key challenges remain in robust learning from limited labeled data, uncertainty-aware optimization, interpretable and deployable industrial AI, secure distributed analytics, and adaptation to changing operating conditions.

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