Digital Technologies for Resource Optimization, Product Quality, and Process Automation in the Food Industry

Marcello Bozzini[a], Marco Menegon[b], Alberto di Loreto[b], Gaia Lunari[a], Silvia Mariani[a], Mattia Vallerio[a], Laura Piazza[b] and Flavio Manenti[a,*]

[a]CMIC Department "Giulio Natta", Politecnico di Milano, Piazza Leonardo da Vinci 32, Milan 20133, Italy
[b]Department of Environmental Science and Policy, Università degli Studi di Milano, Via Mangiagalli 25, Milan, 20133, Italy

Digital technologies are playing an increasingly strategic role in the transformation of food manufacturing, offering new opportunities to improve energy efficiency, enhance product quality, and reduce resource consumption. This study presents a methodological approach for the implementation of a digital twin in a real food production process, with a focus on the preparation and thermal treatment of vegetable broth. The proposed workflow includes the structured collection of process data, its refinement through data reconciliation techniques, and the construction of a dynamic simulation model. The methodology was applied to a sterilization line using shell-and-tube heat exchangers and UHT treatment, with particular attention to the monitoring and control of thermal energy use. Results show that integrating digital tools, such as reconciled data and dynamic models, can significantly enhance process awareness and operational robustness, enabling real-time optimization and informed decision-making. Beyond the specific case study, this approach is designed to be scalable and applicable to a wide range of food industry contexts, particularly where energy-intensive operations are involved. The work supports the broader goals of sustainability in the agri-food sector by fostering the intelligent use of resources, reducing waste, and contributing to the achievement of environmental targets defined by international standards and policies. The integration of digital solutions in traditional food processes marks a key step toward a more resilient, efficient, and environmentally responsible manufacturing paradigm.

Keywords: Digital technologies, Food production process, Product quality, Process Optimization, Digital Twin