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Development of Statistical and Predictive Models for Anomaly Detection and Quality Control Improvement Based on Heterogeneous Industrial Data in Medical Device Manufacturing

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This postdoctoral research is conducted within the Laboratory of Computer Science, Modeling and Optimization of Systems (LIMOS) and falls within one of its research themes, Data, Services and Intelligence (DSI), in close alignment with the activities of the Department of Mathematical and Industrial Engineering. It focuses on the optimization of quality control processes in medical textile manufacturing through the analysis of large-scale, heterogeneous industrial data generated by increasingly digitalized production systems. The project is carried out in collaboration with the company Thuasne and the École des Mines de Saint-Étienne, within the Institut Henri Fayol.

The main objective of the project is the identification of anomalies and their root causes in order to better understand performance deviations, defect propagation across production stages, and interactions that influence the final quality of medical devices. By addressing defects such as appearance flaws and dimensional nonconformities, this work seeks to reduce losses related to non-quality, including waste of finished products, chemicals, and water, while improving the efficiency of quality control procedures and reducing the environmental impact of manufacturing processes, in line with sustainable development principles.

The first results obtained in this work correspond to an initial phase of the project, following the collection and analysis of a subset of the available production data. This preliminary study is based on annual production data from circular knitting machines used to manufacture compression socks for the treatment of chronic venous insufficiency. From indicators such as defect rate, machine event rate, and defect rate per event, a quadrant-based analysis was developed to provide an initial classification of machine performance and risk levels. This intuitive approach offers a first, interpretable framework for anomaly detection and establishes the foundation for more comprehensive analyses as additional data are progressively integrated.

To further enhance this initial analysis, multivariate data analysis techniques were applied. Principal Component Analysis (PCA) captured more than 96% of the total variance, revealing latent structures related to operational load and event severity. The combination of PCA with K-means clustering enabled a robust, data-driven classification of machine behavior, clearly isolating anomalous machines while identifying those with stable and near-optimal performance.

The machine classifications and performance indicators will be used to track defect propagation across production stages, to investigate relationships between different quality control processes, and to identify interactions that may contribute to the emergence of specific defects.

Overall, this work represents a first step toward advanced predictive quality control strategies and defect-specific monitoring. It highlights the potential of performance indicators, data-driven modeling, and artificial intelligence approaches to address concrete industrial challenges, while contributing to the digital and sustainable transition of the medical device manufacturing industry.

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