

Digital Transformation in the Textile Cutting Sector: An Industry 4.0 Approach to Operational Excellence

Márcia Barroso¹, Sónia Longras², Vânia Dias², Miguel Ângelo Pereira¹ and António Rocha^{23*}

¹School of Technology, Polytechnic University of Cávado and Ave, 4750-810 Barcelos, Portugal

²2Ai – Applied Artificial Intelligence Laboratory, School of Technology, Polytechnic University of Cávado and Ave, 4750-810 Barcelos, Portugal

ORCID: 0009-0006-6235-5845

Email: slongras@ipca.pt

ORCID: 0009-0000-5503-9824

Email: vdias@ipca.pt

³ LASI – Associate Laboratory of Intelligent Systems, 4800-058 Guimarães, Portugal

ORCID: 0000-0003-0863-6567

*Email: arocha@ipca.pt

Abstract

Purpose – This study investigates how the integration of Industry 4.0 monitoring technologies with structured change management and employee involvement can improve FCI system adoption, operational data quality, and warehouse efficiency in the cutting department of a Portuguese textile SME.

Design/methodology/approach – Action research methodology was employed across four iterative phases – problem identification, action planning, implementation, and reflection – at ATêxteis S.A., a knitwear manufacturer. Data collection triangulated direct observation, FCI/ERP system logs, anonymous employee questionnaires, and supervisor interviews. Theoretical grounding draws on the Technology Acceptance Model (TAM) and Kotter's eight-step change model.

Findings – FCI system registrations increased nearly three-fold (300 to 1,000 per month) between November 2022 and July 2023, with registrations per 1,000 pieces cut rising from 3.5 to 12.2. Remnant warehouse occupancy decreased from 28.35% to approximately 15% of total capacity. ERP integration enabled automatic detection of material consumption discrepancies, and quality non-conformance detection increased from an estimated 5–8 to 23 cases per period. Results confirm that change management and participatory training are the proximate drivers of digital tool adoption, even when system use is formally mandated.

Originality – The study provides rare empirical evidence on Industry 4.0 implementation in textile SME cutting operations, extending TAM and Kotter's model to a manufacturing digitalization context. It introduces a production-normalized utilization metric (registrations per 1,000 pieces) and demonstrates the complementarity of Lean principles with digital monitoring for operational excellence in traditional manufacturing.

Keywords: Digital Transformation; Industry 4.0; Textile Industry; Lean Manufacturing; System Integration; Technology Acceptance; Change Management

1. Introduction

The textile and clothing industry represents one of humanity's oldest manufacturing activities, having played a crucial role in the initial phases of industrialization (Yang & Zhong, 1998; Berde et al., 2025). Despite its historical significance, the sector faces unprecedented challenges stemming from globalization, rapid technological advancement, and evolving consumer demands (Adhikari & Yamamoto, 2007). The emergence of Industry 4.0 technologies has created both opportunities and imperatives for textile manufacturers to enhance competitiveness through digital transformation (Duarte et al., 2018).

In Portugal, the textile and clothing industry has demonstrated remarkable resilience. The sector represented approximately 18% of industrial production in 1995 with revenues of €10.6 billion (Amador & Opromolla, 2009), declining to 10% by 2014 while successfully repositioning towards quality, innovation, and niche markets (Truett & Truett, 2019). Sustaining this competitiveness increasingly requires investments in digital technologies and process optimization.

The Fourth Industrial Revolution, Industry 4.0, offers transformative potential through cyber-physical systems, IoT, cloud computing, and data analytics (Schwab, 2016; Zhou et al., 2015), enabling real-time monitoring, enhanced decision-making, and improved operational efficiency (Rüßmann et al., 2015). However, successful implementation requires not only technological infrastructure but also organizational change, employee development, and strategic planning (Wichmann et al.,

2019). A critical enabler is employee acceptance of new technologies, as described by the Technology Acceptance Model (TAM) (Davis, 1989), which posits that perceived usefulness and ease of use determine adoption. Kotter's (1996) eight-step change model further emphasizes that structured change management is essential to sustain digital transformation. The cutting sector in textile manufacturing presents particular digitalization challenges due to its complexity, material variability, and critical role in quality and material utilization efficiency. Current literature reveals a gap in empirical studies examining practical Industry 4.0 implementation in textile cutting operations, particularly regarding system integration and participatory change management (Saleeshya & Raghuram, 2012). This research addresses this gap by investigating a comprehensive digital transformation initiative in a Portuguese textile SME.

The central research question guiding this study is:

RQ1: How can the integration of Industry 4.0 monitoring technologies with structured change management and employee involvement improve FCI system adoption and operational data quality in the cutting department of a textile SME?

Two secondary research questions complement this:

RQ2: To what extent does ERP integration with the FCI monitoring system improve material traceability and inventory accuracy?
RQ3: How does a structured remnant management system contribute to reducing warehouse space utilization and material waste?

The objectives include: (1) analyzing the current state of cutting operations and identifying digitalization opportunities; (2) implementing and evaluating the FCI monitoring system; (3) integrating the monitoring system with the company's ERP platform; (4) developing a comprehensive remnant management system; and (5) assessing the impact of these interventions on operational data quality and warehouse efficiency. The article proceeds as follows: Section 2 reviews relevant literature; Section 3 describes methodology; Section 4 details the initiatives; Section 5 presents results; Section 6 discusses findings; Section 7 concludes.

2. Literature Review

2.1. Textile industry and digital transformation

The textile and clothing industry remains economically significant despite substantial challenges from globalization and technological disruption (Adhikari & Yamamoto, 2007). In developed economies, textile manufacturers have increasingly focused on quality, customization, and rapid response rather than competing primarily on cost (Truett & Truett, 2019). The Portuguese textile sector exemplifies this strategic reorientation: after pressure from low-wage competitors, Portuguese manufacturers carved out competitive positions through quality, innovation, and specialized segments (Thiel *et al.*, 2000). Recent empirical studies indicate that the textile industry is undergoing a fundamental transformation driven by digitalization (Duarte *et al.*, 2018). Saleeshya and Raghuram (2012) demonstrated in a textile manufacturing case study that lean practices combined with digital monitoring led to measurable reductions in production lead times and defect rates. Yet complete integration of Industry 4.0 tools remains limited in many textile operations, creating both challenges and opportunities (Asadollahi-Yazdi *et al.*, 2020).

2.2. Industry 4.0: conceptual framework and implementation

Industry 4.0 represents the fourth major industrial revolution, characterized by the fusion of physical and digital technologies to create smart, interconnected manufacturing systems (Schwab, 2016). The conceptual framework rests on nine foundational pillars: Industrial IoT, system integration, additive manufacturing, autonomous robots, cloud computing, big data analytics, augmented reality, simulation, and cybersecurity (Rüßmann *et al.*, 2015). Dalenogare *et al.* (2018) identified significant expected benefits including improvements in production efficiency, quality control, resource utilization, and cost reduction across a survey of 92 Brazilian manufacturers. Frank *et al.* (2019) found that firms in early stages of Industry 4.0 adoption primarily benefit from operational improvements, while more advanced adopters gain strategic advantages through mass customization. Implementation challenges are nonetheless substantial: Wichmann *et al.* (2019) identified data security concerns, technological complexity, integration challenges, cultural resistance, workforce skill gaps, and capital requirements as critical obstacles.

2.3. *Technology adoption and change management in manufacturing*

The Technology Acceptance Model (TAM), originally proposed by Davis (1989) and extended by Venkatesh and Bala (2008), provides a robust theoretical lens for understanding employee adoption of digital systems. TAM posits that perceived usefulness and perceived ease of use determine adoption intention. In manufacturing contexts, Bhattacharjee and Hikmet (2007) demonstrated that resistance to technology adoption is often rooted in insufficient training rather than technological deficiencies – a finding directly relevant to this study.

Kotter's (1996) eight-step change model complements TAM by emphasizing urgency creation, coalition building, short-term wins, and cultural anchoring of new practices. Oreg (2003) further demonstrated that individual differences in resistance to change significantly predict technology adoption outcomes in organizational settings. Participatory action research approaches in industrial technology implementation increase employee ownership and reduce resistance (Kemmis *et al.*, 2014).

2.4. *Lean manufacturing and integration with industry 4.0*

Lean manufacturing, originating from the Toyota Production System, provides a complementary framework for operational excellence aligning well with Industry 4.0 (Liker, 2004). Lean identifies eight categories of waste (muda): overproduction, waiting, transportation, excess inventory, overprocessing, unnecessary motion, defects, and underutilized talent (Melton, 2005). The integration of Lean with digital technologies – termed „Lean Industry 4.0” (Sanders *et al.*, 2016) – enables evidence-based continuous improvement through real-time data. Digital monitoring systems facilitate the PDCA cycle (Deming, 1982) and make OEE calculation more actionable (Irhirane *et al.*, 2017).

2.5. *Inventory management and warehouse operations*

Effective inventory management is critical for manufacturing competitiveness, directly impacting costs, customer service, and operational efficiency (Piasecki, 2009). In textile manufacturing, material costs represent a substantial portion of product costs, making inventory optimization particularly important. ABC analysis – classifying materials by consumption value – is a fundamental tool for rationalizing inventory strategies (Bowersox *et al.*, 2008). Integration of warehouse management with ERP platforms ensures inventory records accurately reflect material flows, reducing planning errors (Ketikidis *et al.*, 2008).

3. **Research methodology**

3.1. *Action research design*

This study employed action research methodology, which emphasizes collaborative problem-solving through iterative cycles of planning, action, evaluation, and reflection (Altrichter *et al.*, 2002). Action research is particularly appropriate for investigating organizational change and technology implementation because it engages practitioners as active participants while generating both practical solutions and theoretical insights (Kemmis *et al.*, 2014). The approach followed four phases: (1) Problem identification through direct observation, workflow mapping, and stakeholder consultation; (2) Action planning involving goal setting and intervention strategy development; (3) Action implementation with data collection; and (4) Reflection leading to further improvement cycles.

To ensure research rigor and reduce bias, multiple data sources were triangulated: direct observation field notes, system-generated quantitative data (FCI logs, ERP records), anonymous employee questionnaires, and semi-structured interviews with department supervisors. The researchers acted as facilitative collaborators: assisting in diagnosing problems, designing interventions, and facilitating training, while operational decisions remained with company personnel. Findings were validated through member checking with supervisors and operators.

Regarding mandatory versus voluntary system use: the FCI system was designated as mandatory by company management. However, prior to the intervention, compliance was minimal due to technical barriers, lack of understanding of system benefits, and insufficient training. The training programme therefore addressed both capability gaps and motivational factors, consistent with TAM predictions that perceived usefulness influences adoption even when use is formally required (Davis, 1989).

3.2. *Company context*

The research was conducted at ATéxteis S.A., a textile company specializing in knitted outer garment production. Founded in 1987, the company evolved from a small subcontractor with 30 employees to a Group encompassing more than 25 companies.

It maintains flexible production capacity of approximately 25,000 pieces per day, with T-shirts and sweatshirts constituting approximately 70% of production volume. The cutting department, the focus of this study, employs approximately 45 operators across three shifts and handles materials with significant variability in weight, stretch, and defect characteristics. At the outset, the FCI monitoring system had been partially implemented but with minimal utilization – a common intermediate state in SME digital transformation journeys.

4. Digital transformation initiatives

4.1. Current state analysis

The initial phase involved comprehensive analysis of the cutting department's current operations, workflow, information systems, and performance challenges. The cutting process comprised three main stages: material spreading, cutting, and lot separation and quality control. The FCI monitoring system had been implemented in spreading and cutting stages but utilization remained minimal.

Investigation revealed several contributing factors: equipment reliability problems (scanner malfunctions during peak production), inadequate employee training, lack of understanding of system benefits, and insufficient employee involvement in system development. Consequently, actual material consumption data were not being captured, creating inventory discrepancies and hindering production planning. Warehouse analysis revealed that remnant materials occupied approximately 28.35% of total capacity (79 carts out of 276 storage slots).

4.2. FCI system enhancement and training programme

Based on current state analysis, a structured training programme was developed consistent with TAM principles (Davis, 1989), aimed at increasing perceived usefulness and ease of use. Programme objectives included: FCI system operational competency; process optimization through key performance indicators; understanding of the FCI system's strategic purpose; motivating adoption through demonstration of benefits; and fostering a continuous improvement culture aligned with Kaizen (Imai, 1986). Sessions were structured following Kotter's (1996) change model: initial sessions established urgency and vision; intermediate sessions built capability; follow-up sessions consolidated wins and anchored new practices. Anonymous feedback was collected after each session to enable adaptive improvement of subsequent modules.

4.3. ERP integration

A critical component involved integrating the FCI monitoring system with the SIMTextil ERP platform to enable seamless data flow and eliminate manual data entry. The FCI system captures actual material consumption through several data points: number of fabric layers spread per marker, fabric length per roll used, and extra consumption due to defects identified during spreading. Actual consumption data flow automatically from FCI to SIMTextil, updating material stock records in real time. This integration makes discrepancies between theoretical and actual consumption automatically visible, supporting investigation of root causes.

4.4. Quality management integration

Six primary fabric defect types were systematically classified: holes, needle defects, contamination, stains, creases, and barre defects. All defect information recorded in FCI automatically transfers to SIMTextil ERP. A threshold was established such that when defects exceed 2% of pieces in a production order, a non-conformance is automatically generated in the Quality Management System (QMS), ensuring significant quality issues receive timely attention.

4.5. Remnant management system

A standardized process was established for handling remnants returning from cutting: the warehouse supervisor collects and weighs remnants using a calibrated scale, with weight data entered through a mobile device running the SIMTextil mobile application. An ABC analysis of material purchasing data (Figure 1) revealed that four material types accounted for the vast majority of usage: interlock (41%), jersey (28%), fleece (19%), and rib (10%). This informed the space allocation strategy for the remnant storage area, concentrating high-turnover materials in the most accessible locations.

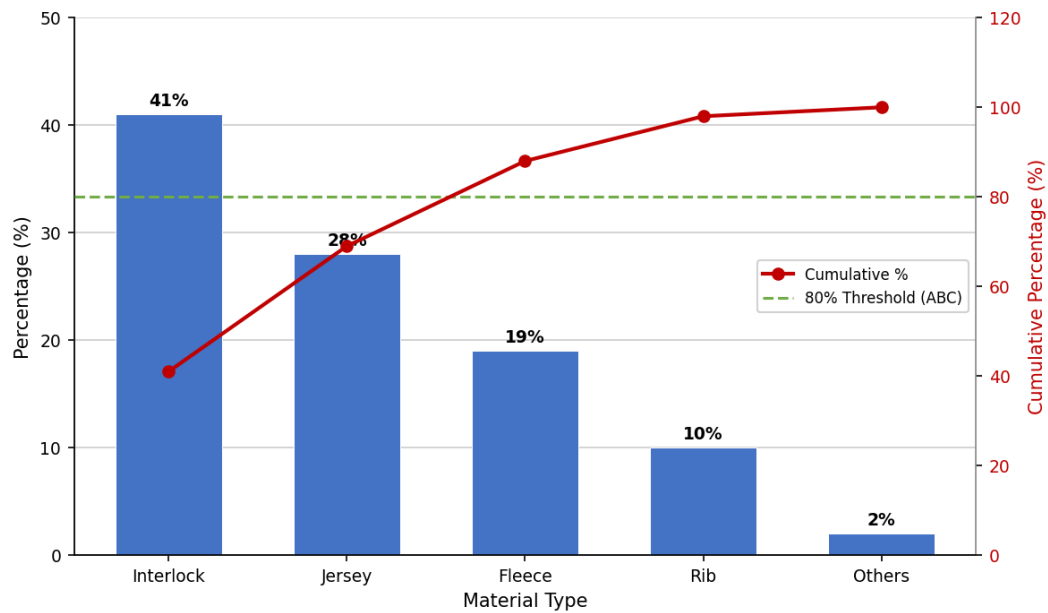


Figure 1: ABC Analysis of Material Types by Purchase Volume

5. Results

5.1. FCI system adoption

FCI system utilization increased dramatically following the training programme. Monthly registrations rose from approximately 300 in November 2022 to nearly 1,000 by July 2023 – a nearly three-fold increase (Figure 2). Linear regression analysis of the post-training period (January–July 2023) confirms a sustained average increase of approximately 77 registrations per month ($R^2 = 0.91$), indicating a robust positive trend rather than a temporary improvement.

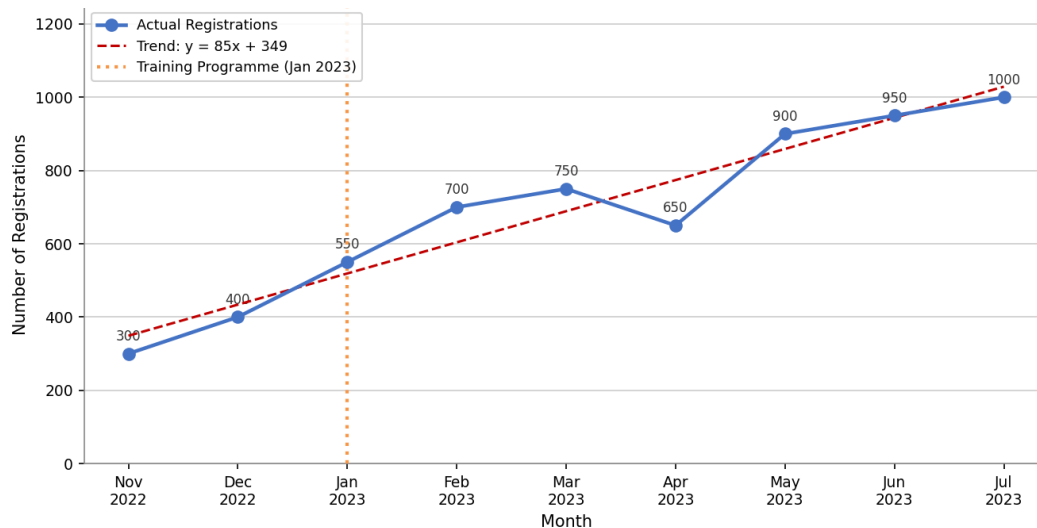


Figure 2: Number of FCI Registrations per Month

Figure 3 presents the number of pieces cut each month to contextualize registration trends. Production volumes varied substantially across the study period, with December 2022 showing a seasonal peak (177,200 pieces). The April 2023 dip in registrations (650) corresponds to a production decrease (47,450 pieces), confirming that registration trends reflect genuine operational activity rather than artefactual variation.

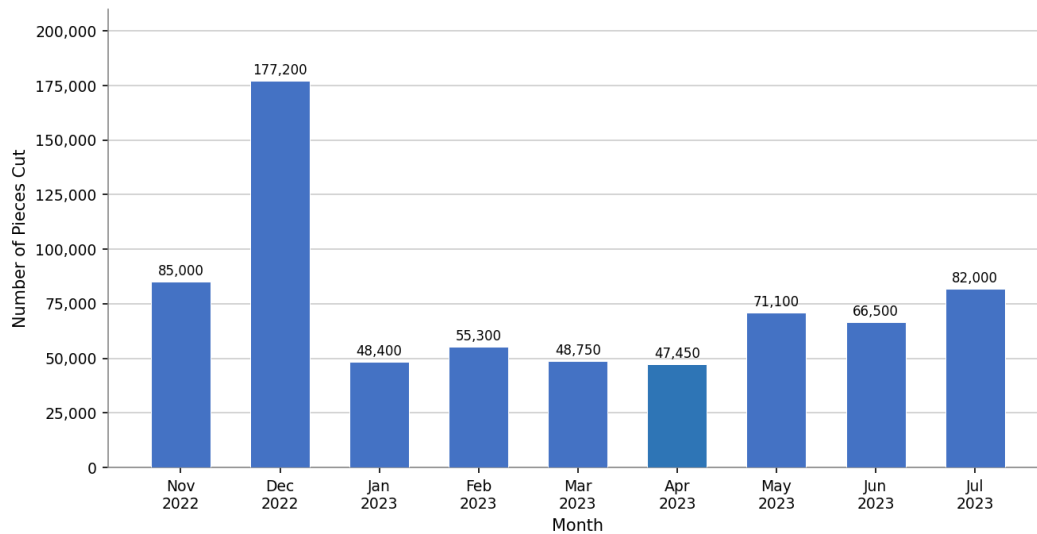


Figure 3: Number of Pieces Cut per Month

5.2. System utilization relative to production volume

Figure 4 presents registrations per 1,000 pieces cut – a production-normalized indicator providing more intuitive assessment of data capture completeness. This metric increased from 3.5 in November 2022 to 12.2 in July 2023, representing a 3.5-fold improvement. Post-training stabilization in the range of 10–14 registrations per 1,000 pieces indicates consistent behavioral change rather than temporary compliance.

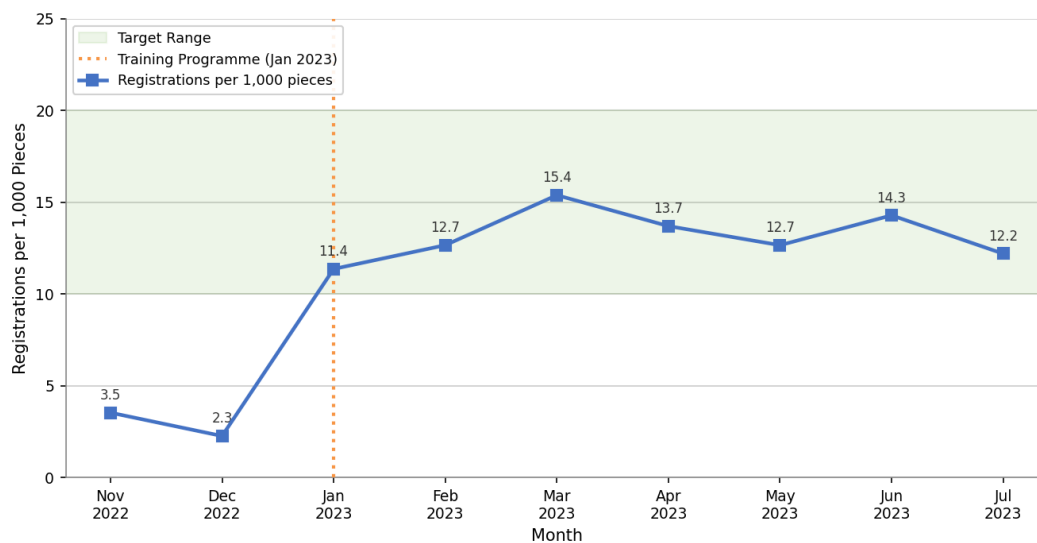


Figure 4: Registrations per 1,000 Pieces Cut

5.3. Inventory and material management outcomes

Remnant materials, which previously occupied 28.35% of warehouse capacity (79 out of 276 storage slots), were reduced to approximately 15% through standardized remnant processing, ABC-based space allocation, and real-time weight recording in SIMTextil – recovering approximately 36 storage slots for productive use. Following FCI–SIMTextil integration, the operations team identified and corrected five systematic consumption discrepancy patterns attributable to fabric defect recording omissions and roll-end waste estimates, improving overall inventory accuracy.

5.4. *Quality management outcomes*

The automatic defect recording and non-conformance generation system substantially increased quality issue visibility. During the study period, 23 non-conformances were automatically generated through the 2% defect threshold trigger, compared to an estimated 5–8 that would have been manually raised under the previous system. This improvement supports earlier intervention and supplier feedback.

5.5. *Organizational and cultural changes*

Beyond quantifiable improvements, the initiative generated important organizational changes. Operators reported that their knowledge and opinions were valued, as captured through anonymous post-training questionnaires. Supervisors began using FCI dashboard data in daily briefings – a practice not observed prior to the intervention. These behavioral changes align with the organizational learning outcomes predicted by action research theory (Kemmis *et al.*, 2014).

6. Discussion

6.1. *Theoretical contributions*

This study contributes to Industry 4.0 implementation literature in several ways. First, it provides empirical evidence on digitalization in textile SMEs, extending the predominantly large-enterprise focus of existing studies (Dalenogare *et al.*, 2018; Frank *et al.*, 2019). The finding that utilization increased dramatically following participatory training – despite the system being technically available for months beforehand – confirms TAM propositions that perceived usefulness and ease of use are the proximate determinants of adoption, even when system use is formally mandated (Davis, 1989; Bhattacharjee & Hikmet, 2007).

Second, the study demonstrates the complementarity of Lean manufacturing with Industry 4.0: the remnant management system eliminates inventory waste while the monitoring infrastructure makes Lean interventions evidence-based, extending the „Lean Industry 4.0” framework (Sanders *et al.*, 2016) to textile cutting operations. Third, the study provides empirical support for Kotter’s (1996) change model in a manufacturing digitalization context – the structured sequencing of urgency creation, capability development, and win consolidation preceded the sustained behavioral changes observed.

6.2. *Practical implications*

The research generates several practical implications for textile companies and other traditional manufacturers pursuing digital transformation:

- Prioritize system integration: enabling seamless FCI–ERP data flow eliminated manual entry errors and made inventory discrepancies visible, reinforcing employee motivation to use the system correctly.
- Invest in change management: technology implementation is fundamentally an organizational change process; participatory design and structured communication of benefits are essential alongside training.
- Use production-normalized metrics: registrations per 1,000 pieces provides a more accurate assessment of data capture quality than absolute counts, and is recommended for benchmarking in similar implementations.
- Apply ABC-based warehouse reorganization: targeted space optimization informed by consumption data analysis can substantially reduce warehouse inefficiencies without capital investment.
- Build internal capabilities: sustaining digital transformation requires developing internal champions and routinizing data use in daily operational decisions.

6.3. *Limitations*

Several limitations must be acknowledged. First, the single-company design limits generalizability; future research should examine digital transformation across multiple textile companies to identify boundary conditions and moderating factors. Second, while system utilization and warehouse space utilization improved measurably, comprehensive economic data (cost savings, productivity gains, lead time reductions) were not systematically collected; future research should incorporate

rigorous cost–benefit analysis. Third, several components of the digital transformation vision – including full lot separation coverage and formal OEE reporting – remained incomplete at conclusion, pointing to a natural agenda for follow-up action research cycles.

7. Conclusions and recommendations

This research investigated Industry 4.0 implementation in the cutting department of a Portuguese textile SME, addressing how integrated monitoring technologies and structured change management improve operational performance. The key finding is that technological availability alone is insufficient: the FCI system existed but was minimally utilized prior to structured, participatory training grounded in TAM and Kotter's change model.

Quantitative outcomes include: a 3-fold increase in monthly FCI registrations; a 3.5-fold improvement in registrations per 1,000 pieces cut; remnant storage reduced from 28.35% to approximately 15% of warehouse capacity; and a 3–4x increase in quality non-conformances generated, reflecting improved defect visibility. These results demonstrate that strategic digitalization, combined with proper change management, can significantly enhance operational data quality and warehouse efficiency in textile manufacturing SMEs.

Based on this research, the following recommendations are offered:

- Develop clear digital transformation strategies aligned with business objectives and communicate rationale to all affected employees.
- Prioritize ERP-level system integration to enable automatic data flows and make performance discrepancies visible.
- Design training programmes addressing both technical skills and the motivational dimensions of technology acceptance.
- Employ participatory approaches involving operational personnel in problem diagnosis, solution design, and continuous improvement.
- Use production-normalized performance metrics to assess data quality improvements independently of production volume fluctuations.
- Conduct ABC analysis of materials before implementing remnant management systems.
- Plan for iterative implementation with pilot testing, phased expansion, and regular review cycles.

The Portuguese textile industry has demonstrated remarkable resilience over decades of change. The integration of Industry 4.0 capabilities with its traditional strengths in quality and craftsmanship – as evidenced by this research – positions the sector for continued competitiveness in an increasingly digital global marketplace.

Funding

This paper was funded by national funds and FCT/MCTES (PIDDAC), through the Foundation for Science and Technology, I. P. (FCT) under the scope of the projects UID/PRR/05549/2025 and 2023.13382.PEX.

Author Contributions

Conceptualization: A.R. and M.A.P.; Methodology: A.R., M.B. and S.L.; Investigation: M.B., S.L. and V.D.; Data curation: M.B. and S.L.; Formal analysis: M.B. and A.R.; Writing – original draft: M.B.; Writing – review and editing: A.R. and M.A.P.; Supervision: A.R. and M.A.P. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- Adhikari, R., & Yamamoto, Y. (2007). The textile and clothing industry: Adjusting to the post-quota world. *Industrial Development for the 21st Century: Sustainable Development Perspectives*, 183–234. <https://doi.org/10.18356/9c7e6821-en>
- Altrichter, H., Kemmis, S., McTaggart, R., & Zuber-Skerritt, O. (2002). The concept of action research. *The Learning Organization*, 9(3/4), 125–131. <https://doi.org/10.1108/09696470210428840>
- Amador, J., & Opromolla, L. D. (2009). Textiles and clothing exporting sectors in Portugal – recent trends. *Banco de Portugal Economic Bulletin Spring*, 145–166.
- Asadollahi-Yazdi, E., Couzon, P., Nguyen, N. Q., Ouazene, Y., & Yalaoui, F. (2020). Industry 4.0: Revolution or evolution? *American Journal of Operations Research*, 10(6), 241–268. <https://doi.org/10.4236/ajor.2020.106015>
- Bartodziej, C. J. (2017). *The concept Industry 4.0: An empirical analysis of technologies and applications in production logistics*. Springer. <https://doi.org/10.1007/978-3-658-16502-4>
- Berde, É., Szabó-Bakos, E., Németh, P., Remsei, S., & Kuncz, I. (2025). GDP per Capita and Human Capital Investment in Five Countries after Exhaustion of the First Demographic Dividend. *REGIONAL STATISTICS*, 15(5), 908–929. <http://doi.org/10.15196/RS150504>
- Bhattacharjee, A., & Hikmet, N. (2007). Physicians' resistance toward healthcare information technology: A theoretical model and empirical test. *European Journal of Information Systems*, 16(6), 725–737. <https://doi.org/10.1057/palgrave.ejis.3000717>
- Bowersox, D. J., Cooper, M. B., & Closs, D. J. (2008). *Supply chain logistics management* (3rd ed.). McGraw-Hill Education.
- Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, 204, 383–394. <https://doi.org/10.1016/j.ijpe.2018.08.019>
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. <https://doi.org/10.2307/249008>
- Deming, W. E. (1982). *Out of the crisis*. MIT Press.
- Duarte, A. Y., Sanches, R. A., & Dedini, F. G. (2018). Assessment and technological forecasting in the textile industry. *Strategic Design Research Journal*, 11(3), 193–202. <https://doi.org/10.4013/sdrj.2018.113.02>
- Farahani, R. Z., Rezapour, S., & Kardar, L. (2011). *Logistics operations and management: Concepts and models*. Elsevier. <https://doi.org/10.1016/B978-0-12-385202-1.00001-1>
- Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, 210, 15–26. <https://doi.org/10.1016/j.ijpe.2019.01.004>
- Imai, M. (1986). *Kaizen: The key to Japan's competitive success*. McGraw-Hill.
- Irhirane, E., Bounit, A., & Dakkak, B. (2017). Estimate of OEE (Overall Equipment Effectiveness) objective from classical OEE. *International Journal of Innovation and Applied Studies*, 19(3), 799–803.
- Kemmis, S., McTaggart, R., & Nixon, R. (2014). *The action research planner: Doing critical participatory action research*. Springer. <https://doi.org/10.1007/978-981-4560-67-2>
- Ketikidis, P. H., Koh, S. C. L., Dimitriadis, N., Gunasekaran, A., & Kehajova, M. (2008). The use of information systems for logistics and supply chain management in South East Europe. *Omega*, 36(4), 592–599. <https://doi.org/10.1016/j.omega.2006.11.010>
- Kotter, J. P. (1996). *Leading change*. Harvard Business School Press.
- Liker, J. K. (2004). *The Toyota Way: 14 management principles from the world's greatest manufacturer*. McGraw-Hill.
- Melton, T. (2005). The benefits of lean manufacturing: What lean thinking has to offer the process industries. *Chemical*

- Engineering Research and Design*, 83(6), 662–673. <https://doi.org/10.1205/cherd.04351>
- Moura, B. (2006). Logística: Conceitos e tendências. *Centro Atlântico*.
- Oreg, S. (2003). Resistance to change: Developing an individual differences measure. *Journal of Applied Psychology*, 88(4), 680–693. <https://doi.org/10.1037/0021-9010.88.4.680>
- Piasecki, D. J. (2009). *Inventory management explained: A focus on forecasting, lot sizing, safety stock, and ordering systems*. OPS Publishing.
- Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The future of productivity and growth in manufacturing industries*. Boston Consulting Group.
- Saleeshya, P. G., & Raghuram, P. (2012). Lean manufacturing practices in textile industries – a case study. *International Journal of Collaborative Enterprise*, 3(1), 18–37. <https://doi.org/10.1504/IJCEN.2012.046875>
- Sanders, A., Elangeswaran, C., & Wulfsberg, J. P. (2016). Industry 4.0 implies lean manufacturing: Research activities in Industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management*, 9(3), 811–833. <https://doi.org/10.3926/jiem.1940>
- Schwab, K. (2016). *The Fourth Industrial Revolution*. World Economic Forum.
- Thiel, J., Pires, I., & Dudleston, A. (2000). *Globalisation and the Portuguese textiles and clothing filière in the post-GATT climate*. In Restructuring industry and territory (pp. 109–130). Routledge.
- Truett, L. J., & Truett, D. B. (2019). Challenges in the Portuguese textile and clothing industry. *Applied Economics*, 51(27), 2842–2854. <https://doi.org/10.1080/00036846.2018.1558351>
- Tsenga, M. L., Tan, R. R., Chiu, A. S., Chien, C. F., & Kuo, T. C. (2018). Circular economy meets Industry 4.0: Can big data drive industrial symbiosis? *Resources, Conservation and Recycling*, 131, 146–147. <https://doi.org/10.1016/j.resconrec.2017.12.028>
- Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences*, 39(2), 273–315. <https://doi.org/10.1111/j.1540-5915.2008.00192.x>
- Wichmann, R. L., Eisenbart, B., & Gericke, K. (2019). The direction of industry: A literature review on Industry 4.0. *Proceedings of the Design Society*, 1(1), 2129–2138. <https://doi.org/10.1017/dsi.2019.219>
- Womack, J. P., & Jones, D. T. (2003). *Lean thinking: Banish waste and create wealth in your corporation* (2nd ed.). Simon & Schuster.
- Yang, Y., & Zhong, C. (1998). China's textile and clothing exports in a changing world economy. *The Developing Economies*, 36(1), 3–23. <https://doi.org/10.1111/j.1746-1049.1998.tb00996.x>
- Zhou, K., Liu, T., & Zhou, L. (2015). Industry 4.0: Towards future industrial opportunities and challenges. In 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (pp. 2147–2152). IEEE. <https://doi.org/10.1109/FSKD.2015.7382284>



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