EVALUATING TECHNOLOGICAL INTERRELATIONS USING THIO FRAMEWORK AND MICMAC ANALYSIS: DEPLOYING INDUSTRY 4.0 IN THE SRI LANKAN APPAREL INDUSTRY

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The apparel industry of Sri Lanka is undergoing a significant transformation through the integration of Industry 4.0 (I4.0) technologies, which encompass cyber-physical systems, Internet of Things (IoT), artificial intelligence, big data analytics, cloud computing, and additive manufacturing, due to the potential benefits of these advanced technologies. However, their successful implementation requires a comprehensive understanding of the complex interrelationships between key technological components. This research examines the interrelationship of technological components in implementing Industry 4.0 technologies within the Sri Lankan apparel industry, utilising the THIO Framework, which categorises these components into four groups: Technoware, Humanware, Inforware, and Orgware.
The study employed a mixed-methods approach, combining qualitative semi-structured interviews with twelve industry experts and quantitative questionnaire surveys with seven respondents to gather comprehensive insights. Thematic analysis was conducted on interview responses to identify current applications and challenges of I4.0 technologies, while MICMAC (Cross-Impact Matrix Multiplication Applied to Classification) analysis was used to examine the driving and dependence power of thirty-six sub-components across the four technological categories.
The research findings reveal that the Sri Lankan apparel industry has adopted various I4.0 technologies, including industrial robots, automation systems, IoT-RFID integration, smart manufacturing systems, computer vision, and business intelligence tools. However, implementation faces challenges due to high initial investment costs, a shortage of skilled workforce, integration difficulties with legacy systems, and employee resistance to change. MICMAC analysis identified four distinct clusters of components: autonomous components with minimal influence, dependent components with strong dependence but weak driving power, linkage components with both strong driving and dependence power, and independent components with strong driving power but minimal dependence. Technical and operational skills, leadership skills, teamwork, responsibility and discipline are found to be critical factors with high driving power, while IoT, AI, cloud computing, and cyber-physical systems show high dependence on other components. Further, it is found that successful I4.0 implementation within the industry requires coordinated management of all four technological components, with specific attention to developing human capabilities and organisational readiness along with technological infrastructure.

Keywords: Industry 4.0, Apparel Industry, Technological Components, THIO Framework, MICMAC Analysis, Digital Transformation

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INTRODUCTION

The apparel industry is undergoing a significant transformation through the integration of Industry 4.0 (I4.0) technologies, including cyber-physical systems, the Internet of Things (IoT), cloud computing, big data analytics, autonomous robots, additive manufacturing, and augmented and virtual reality. These technologies offer substantial benefits, including enhanced efficiency, customisation capabilities, sustainability improvements through real-time data collection, predictive analytics, and automated manufacturing processes. However, despite the promising potential of I4.0 technologies, their adoption in the apparel industry faces critical challenges, including high investment costs, complex system integration, and workforce skill gaps (Wijewardhana et al, 2021).

The primary research problem arises out of the certitude that within the industry, there is lack of comprehensive understanding regarding the interrelationships between the four key technological components essential for successful I4.0 implementation. The study employs the THIO Framework developed by Smith and Sharif (2007), which categorises these technological components into four interconnected groups: Technoware (advanced manufacturing equipment and hardware), Humanware (skilled workforce and human capabilities), Inforware (information systems and data management technologies), and Orgaware (organisational structures and management frameworks). Understanding how these components interact and influence each other is crucial for successful I4.0 implementation, as each component plays a complementary role in achieving operational excellence.

This research specifically examines the Sri Lankan apparel industry to analyse how these four technological components interact and influence each other during I4.0 implementation. The study addresses the critical knowledge gap in understanding these interdependencies, which currently hinders effective technology adoption and optimisation in the sector. The research objectives include investigating I4.0 technologies and their technological component effects, examining current I4.0 applications in the Sri Lankan apparel industry, analysing the implementation status of I4.0 technologies in Sri Lankan apparel manufacturing, and identifying the interrelationships and influences between technological components for successful I4.0 adoption. This research aims to provide practical insights and guidelines for apparel manufacturers to navigate digital transformation complexities, optimise technology integration strategies, and leverage I4.0's transformative potential by understanding the dynamic interactions between technological components.

METHODOLOGY

The research adopted a mixed-methods approach combining qualitative and quantitative data collection and analysis techniques:
Phase 1 - Qualitative Data Collection: The research methodology employed semi-structured interviews with twelve (12) industry experts from leading Sri Lankan apparel organisations, selected through purposive sampling based on their technological expertise and direct involvement in digital transformation initiatives. This sampling approach ensured that participants possessed relevant knowledge and experience in implementing Industry 4.0 technologies within the apparel sector. Details regarding the current technological status of Sri Lankan apparel industry were collected through these interviews, and the validation of technological sub-components was achieved through comprehensive expert feedback, allowing for refinement and verification of the research framework and ensuring the accuracy and relevance of the identified technological components within the specific context of the Sri Lankan apparel industry.
Phase 2 - Quantitative Data Collection: The second phase of the research involved conducting an online questionnaire survey with seven (7) industry experts, who comprised a subset of participants from Phase 1, ensuring continuity and consistency in expert knowledge. The questionnaire facilitated the development of pairwise comparison matrices to systematically analyse the relationships between technological components. The four technological components and their respective sub-components are presented in Table 1. Through this structured approach, a Structural Self-Interaction Matrix (SSIM) was created using a majority voting, enabling the identification and quantification of interdependencies among the four technological components within the context of Industry 4.0 implementation in the Sri Lankan apparel industry.

Table 1: Technological components and their sub-components

Humanware	Leadership skills (1)	Change management (2)	Teamwork (3)	Ability to take risks (4)
	Responsibility and discipline (5)	Technical and operational skill (6)	Workforce diversity (7)	
Inforware	Company databases (8)	Connectedness (9)	Data processing systems (10)	Operational procedures (11)
	Speed and ease of information access (12)	Data collection process (13)	Process workflows (14)	Performance metrics (15)
	Quality assurance protocols (16)			
Orgaware	Revenue (17)	Capabilities and capacities (18)	Customer relationships (19)	Supplier relationships (20)

	Autonomy of work (21)	Organisational involvement (22)	Innovation climate in organisation (23)	Hierarchies, roles and decision-making frameworks (24)
	Partnerships (25)	KPIs (26)	Environmental sustainability practices (27)	Governance (28)
	Manufacturing practices (29)			
Technoware	Cyber physical systems (30)	Internet of Things (31)	Artificial Intelligence (32)	Big data analysis (33)
	Cloud computing (34)	Additive manufacturing (35)	Augmented reality and virtual reality (36)	

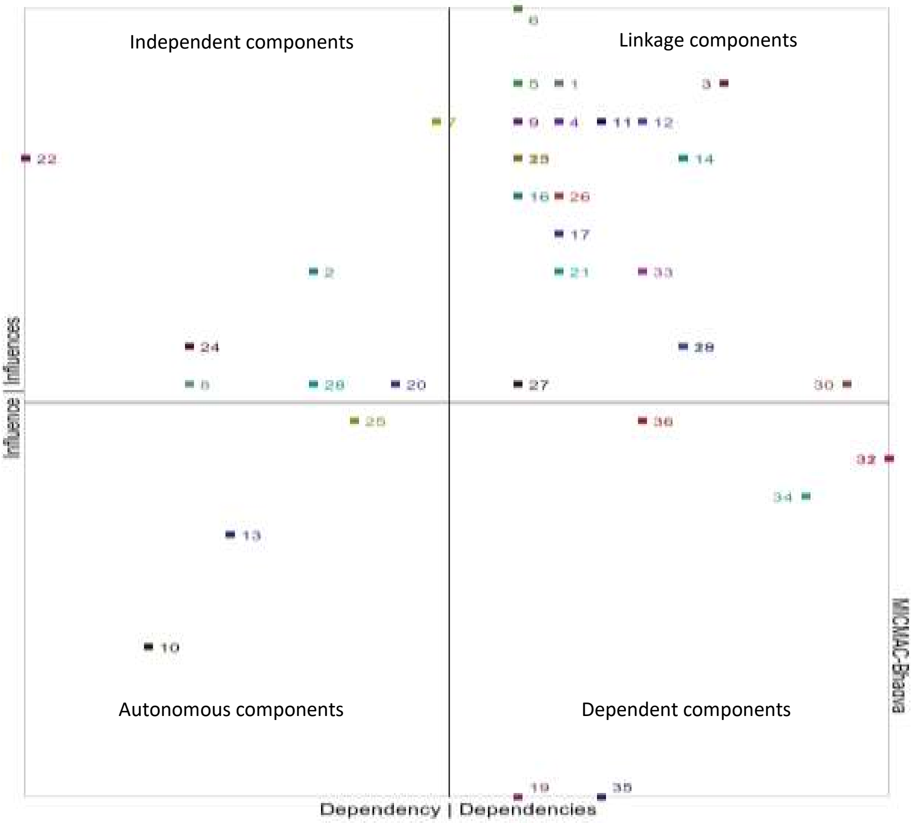
Phase 3 - Data Analysis: The data analysis process used thematic analysis of interview transcripts to systematically identify current Industry 4.0 applications and implementation challenges within the Sri Lankan apparel sector. Subsequently, MICMAC (Cross-Impact Matrix Multiplication Applied to Classification) analysis, which is used to categorise and rank the elements according to their driving and reliance power (Sreenivasan et al, 2023), was conducted to provide quantitative insights into their relative influence and interconnectedness. This methodology facilitates the structural analysis process, enabling the classification of variables based on their driving and dependence power. The analysis results in a hierarchical model that groups the components into four distinct clusters: autonomous, dependent, linkage, and independent (Akash et al, 2025), thereby revealing the hierarchical structure and strategic importance of each component in the successful implementation of Industry 4.0 technologies in apparel manufacturing.

RESULTS AND DISCUSSION

The thematic analysis revealed that the Sri Lankan apparel industry has successfully adopted several I4.0 technologies including industrial robots for reducing cycle time and automating transportation, building automation systems for energy management and security, IoT and RFID technologies for machine monitoring and inventory tracking, smart manufacturing systems for real-time production tracking, computer vision for quality inspection and automated operations, additive manufacturing for prototyping, business intelligence tools like Power BI integrated with ERP systems, and emerging applications of AR/VR for training and product development. These implementations have resulted in significant benefits, including increased productivity through real-time monitoring, improved product quality and consistency, enhanced inventory management, and reduced waste and production costs.

However, implementation of many other technological components faces considerable challenges including high initial investment costs exacerbated by the fast-changing nature of fashion, lack of industry-specific knowledge among technology providers leading to project delays, shortage of skilled workforce particularly among older generations who struggle with technology adaptation, integration difficulties with legacy systems, employee resistance to change often intensified by concerns about job security, and maintenance issues during initial implementation phases.
The MICMAC analysis of thirty-six technological components revealed four distinct clusters. These are illustrated in Figure 1. The numbers within the clusters refer to the sub-components as given in Table 1.

Figure 1: Classification of sub-components through MICMAC analysis



Autonomous components with weak driving and dependence power include data processing systems, data collection processes and partnerships. These standalone elements exhibited limited system integration and required activation by other components to generate a transformative impact, suggesting that internal capability development should precede external partnerships.
The dependent quadrant of components with weak driving but strong dependence power includes several elements that challenge conventional assumptions by revealing that technology adoption is not the primary driver of transformation but

rather depends on supporting organisational capabilities and infrastructure development.
The linkage quadrant with strong driving and strong dependence power demonstrates the interconnected nature of I4.0 implementation, highlighting the critical role of human capital and the bidirectional relationship between financial performance and organisational competencies in digital transformation.
Finally, the independent components with strong driving but weak dependence power, such as change management, workforce diversity, company databases, organisational involvement, governance and supplier relationships, are foundational elements that serve as optimal entry points for transformation initiatives, with change management and internal data infrastructure identified as particularly strategic drivers. This classification provides strategic insights for prioritising component development and understanding their interconnected influence on successful I4.0 implementation in the apparel industry.

CONCLUSION

The study demonstrates that successful I4.0 implementation in the apparel industry is not merely about adopting individual technologies but requires a holistic understanding of component interrelationships. The MICMAC analysis reveals that human-centric components, information systems and organisational factors serve as primary drivers of technological success, while specific I4.0 technologies tend to be dependent variables influenced by these foundational elements. The findings provide a foundation for industry practitioners to develop more effective digital transformation strategies by prioritising the development of driving components while ensuring adequate support for dependent technologies. This approach can help overcome common implementation barriers and maximise the transformative potential of Industry 4.0 in the apparel sector.

REFERENCES

Mehedi Hasan Akash, Ridwan Al Aziz, Chitra Lekha Karmaker, Mainul Bari, A.B.M., Ariful Kabir, K. M., Abu Reza Md.Towfiqul Islam. (2025). Investigating the attributes for implementing circular economy in the textile manufacturing supply chain: Implications for the triple bottom line of sustainability. *Sustainable Horizons*, Vol. 14, 2772-7378. DOI: https://doi.org/10.1016/j.horiz.2024.100129

Aswathy Sreenivasan, Suresh Ma, Ateekh Ur Rehman, Shanthi Muthuswamy. (2023). Assessment of Factors Influencing Agility in Start-Ups Industry 4.0. *Sustainability*, 7564. DOI: https://doi.org/10.3390/su15097564

Smith, R., & Sharif, N. (2007). Understanding and acquiring technology assets for global competition. *Technovation*, 27(11), 643-649 DOI:http://dx.doi.org/10.1016/j.technovation.2007.04.001

Wijewardhana, G.E.H., Weerabahu, S.K., Nanayakkara, J.L.D. and Samaranayake, P. (2021), "New product development process in apparel industry using Industry 4.0 technologies", *International Journal of Productivity and*

Performance Management, Vol. 70 No. 8, pp. 2352-2373. DOI: https://doi.org/10.1108/IJPPM-02-2020-0058