

A pilot study on strategic operations transformation in manufacturing: How circular economy and Industry 5.0 integration can shape managerial decision-making, process redesign and sustainable performance

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Abstract

This pilot study begins by providing a clear background on the current state of the manufacturing industry and how it is dealing with huge pressures of sustainability and resource management. Then, this study focuses on identifying gaps in how the integration of circular economy concepts and Industry 5.0 technologies might assist in improving the operation management of the current manufacturing industry. It then conducted a qualitative research study with a few important manufacturing managers from diverse industries. After conducting the interviews, the researcher examined the data using opinion-based thematic analysis and presented the findings. The researcher structured the findings in terms of theoretical contribution, managerial consequences, and strategic framework development. The researcher then focused on the potential problems of executing the contribution in the industry. At the conclusion of the pilot study, the researchers discussed the possibility of future research on the aforementioned topic. In the second part of the research, the researcher gave his reflections on how he went through the entire procedure, how he encountered challenges, and how he overcame them. Finally, the researcher discussed his findings from the entire investigation and how the research will go in the future.

Introduction

In the current scenario, manufacturing organisations around the world must balance fulfilling profit targets with addressing environmental and human concerns (Hassan and O.M, 2025). Older industrial practices extract resources from the earth, form them into products, and then discard those products after they are finished, rather than recycling materials. Rivers weaken, forests narrow, and mountains of trash accumulate as a result of these systems' infrequent plans for rejuvenation. When nothing is disassembled and rebuilt, waste accumulates quickly. As the strain increases, businesses are changing the manufacturing process and challenging outdated plans one by one.

Meanwhile, improved linkages between machines and digital tools within factories enable more precise, fluid workflows. Because of these changes, new ways of constructing things are emerging, ones that prioritise worker health while using high-tech advancements for speed and oversight (Shafique, Adelel, & Rashid, 2024). Those in charge of plants are currently faced with difficult decisions: implement greener techniques while not falling behind competitors. With shifting needs, balancing environmental goals, technological expenses, and everyday productivity remains a constant challenge (Serang, Wiranwata, and Syafei, 2025).

According to Sasso, Filho, and Ganga (2024), the circular economy is characterised by a trend away from straight-line manufacturing. Businesses discover more efficient operations, less of an impact on the environment, and improved community results when they combine those concepts with Industry 5.0, which involves machines learning alongside people (Cuevas-Pichardo et al., 2024). However, research indicates that gaps still exist in industries; plans frequently stall before being implemented daily.

Reusing resources, not discarding anything, and creating renewable products—a concept that was once limited to academic discussions—now influences how Europe and other regions manage their industries (Kovacic, Z., Strand, R. and Völker, T., 2020). What follows traditional digital factories is a shift toward machines working alongside people, more robust supply chains, and technology that serves society rather than just speed (Breque et al., 2021). The area where those pathways converge is hardly touched by in-depth research.

Empirical study on the combined impact of CE and Industry 5.0 on management decision-making, process transformation, and sustainability performance is still in its infancy, despite the growing corpus of literature on both topics separately. Without sufficiently addressing the strategic and cognitive aspects faced by operations managers navigating this dual integration, the majority of current research either concentrates on the technical aspects of digital adoption (Xu et al., 2021) or on the implementation of circular practices at the supply chain level (Govindan and Hasanagic, 2018).

This pilot research aims to fill that gap. Its central goal is to investigate, from the perspectives of practising manufacturing managers, how the integration of CE principles and Industry 5.0 technologies shapes strategic operations transformation, which includes managerial decision-making processes, operational workflow redesign, and the reconfiguration of sustainability performance frameworks. The study is specifically led by below research questions:

1. How can manufacturing enterprises integrate a circular economy and Industry 5.0 technology to ensure sustainable operations?
2. How can manufacturing Firms navigate from employing circular economy and Industry 5.0 technologies as a strategic framework to incorporating these principles into their organisational culture?
- 3.
4. How can technologies like artificial intelligence and digital twins, can be used to circular economy while simultaneously increasing worker safety, skill training, and job quality?
4. What types of initiatives and efforts are most helpful in motivating manufacturing firms to implement an integrated CE-I 5.0 approach?
5. How much influence does manufacturing have on the strategic CE-I5.0 integration and performance strategies?

Literature Review

Circular Economy Practices in Manufacturing

Rajić et al. (2024) claim that products can outlive the take-make-waste path by being made wisely and avoiding landfills. Plants are now building return channels, where outdated equipment is brought back in before it expires, rather than just producing complex machinery. According to Andrade et al. (2024), worn-out models are restored and resold in order to preserve their value over time rather than being thrown away. Real-world processes with tighter loops cut waste, lengthen raw inputs, and lower daily costs (Sajadieh and Noh, 2025). Instead of just introducing new technology or procedures, true success entails reframing what a firm considers essential. Although many businesses now acknowledge the concepts of the circular economy, only a small number integrate them into core objectives, sometimes passing them off as short-term fixes or strategies to save costs (Huang & Zhao, 2025).

Smarter resource management leads to less waste and supports circular aims (Sasso, Filbo, and Ganga, 2024). According to Tavares et al. (2025), progress is driven by significant modifications that improve efficiency and sustainability, rather than just mixing ideas. What about supply networks? They become crucial participants as modest changes spread outward, influencing purchasing patterns, improving supplier trust, and even sketching out what occurs after a product's life cycle. According to data from shipping routes across continents, businesses that link purchases to reuse plans are better able to avoid shortages, recover from disruptions more quickly, and progressively build stronger connections along the way (Van and L., 2025).

Industry 5.0 technologies in Manufacturing

Gaffley and Pelsner (2025) suggest a change from Industry 4.0 to a focus on people and societal results, rather than solely on technological advancements. I5.0 combines smart systems such as artificial intelligence, connected sensors, live simulations, and localised data processing with a focus on worker well-being, growth, and safety. It also aims to reduce emissions, reuse materials, and heal ecosystems over time (Rejeb et al., 2025). Consider digital twins, which are real-time mirror images of factories that make adjustments based on continuous feedback, anticipate problems before they arise, and fine-tune operations minute by minute while displaying developments to employees in a manner that is simpler to understand and engage with (Sajadieh and Noh, 2025).

According to real-world research on Industry 5.0, businesses that successfully integrate people and machines typically outperform those that solely rely on automation; this is evident in how smoothly operations function (Peruzzini, Prati, and Pellicciari, 2023). Smarter arrangements allow AI to assist workers rather than replace them; this kind of human-tech collaboration improves performance while taking on challenging jobs, adapting to change, or coming up with fresh ideas (Gomaa, 2025). By creating interactive learning environments, connecting remote teams, and even enhancing awareness during live operations, tools like virtual, augmented, and mixed reality are taking on crucial roles (Chu et al., 2024).

Managerial Decision-Making and Process Redesign

Combining CE with Industry 5.0 greatly increases the complexity of managerial decision-making. Managers must simultaneously oversee the trade-offs of digital investment, workforce reskilling, circular process redesign, and sustainability performance responsibilities (Li, L. and Duan, L., 2025). Lean-Green integration frameworks offer some support, even if they were not designed with the full complexity of Industry 5.0 in mind (Gomaa, A., 2026). This suggests that efficiency and environmental goals are often complementary rather than hostile.

Process redesign in CE–Industry 5.0 contexts usually entails human–AI collaborative decision-making for real-time optimisation, digital tracking of material provenance across extended product lifecycles, and modular production architectures enabling component recovery and reuse (Pourrahimian et al 2026). According to adaptive strategy frameworks (Angelis et al 2026), this kind of change necessitates dynamic capabilities, or the capacity to recognise changes in the environment, take advantage of digital and circular possibilities, and adjust operational resources appropriately.

The velocity of digital transformation in relation to the longer-term horizon of sustainable change is a recurrent source of conflict in the literature (Bai et al., 2023). In addition to investing in circular capabilities, whose rewards may be spread over longer time horizons and necessitate inter-organisational cooperation, managers regularly report feeling pressured to produce short-term digital ROI. The main goal of this pilot research is to comprehend how managers tactically and cognitively negotiate this conflict.

Integration of Circular Economy and Industry 5.0

When it comes to industrial transformation, the application of Industry 5.0 (I5.0) technology in conjunction with Circular Economy (CE) principles offers benefits that multiply rather than merely add up (Singh et al. 2025). Transparency, traceability, and even real-time monitoring—all essential components of closed-loop systems—are made possible by digital technologies, which aid in the implementation of CE. For example, blockchain can establish immutable records of a product's lifecycle to aid remanufacturing choices, IoT sensors enable real-time monitoring of materials throughout reverse logistics systems, and artificial intelligence helps streamline resource distribution in circular supply chains (Bhler, Schuster, and Pflaum, 2025). Still, CE principles guide how technologies are chosen. This means digital systems like I5.0 follow sustainability rules. These tech solutions aim to improve people's well-being, not harm it (Rejeb et al. 2025).

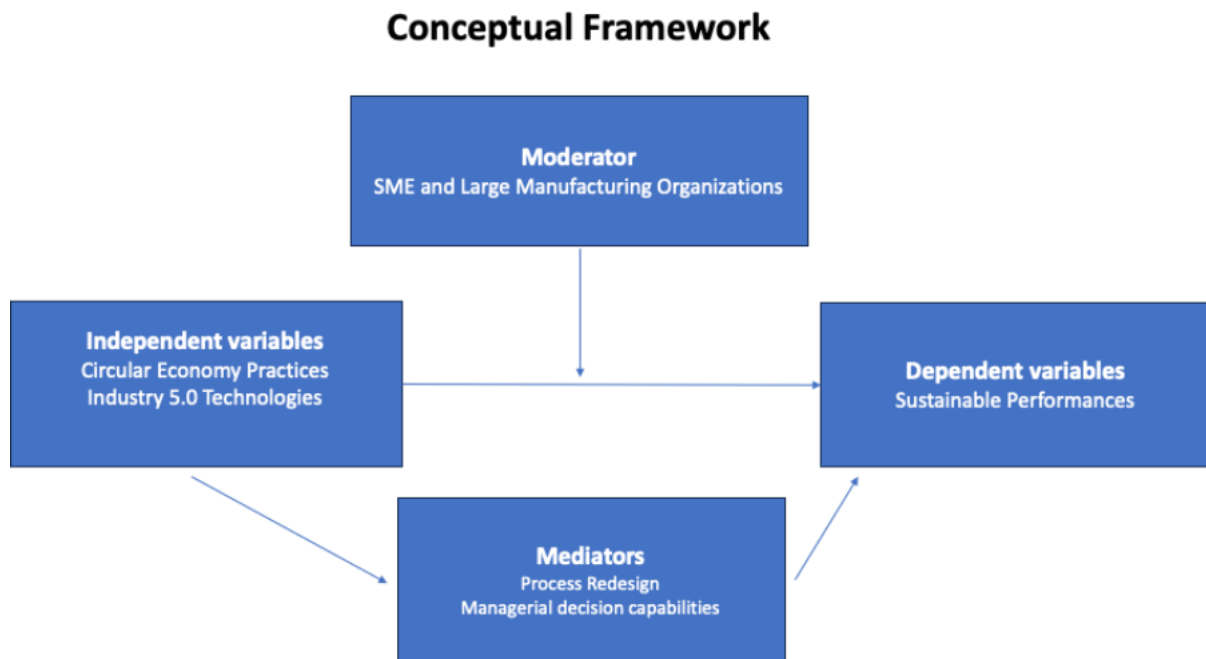
Organisational implementations demonstrate that simultaneous attention to technical, organisational, and cultural elements is necessary for a successful CE-I5.0 integration (Shahin, Maghanaki, and Chen, 2026). Even though change is needed, current business process reengineering (BPR) methods using PDCA cycles show only moderate progress. On average, just 44.70% of steps are carried out. This suggests there is still much room for improvement (Rajic et al. 2024). Examples from the car, electronics, and drug industries show that companies treating circular economy (CE) and Industry 5.0 (I5.0) as separate goals will gain little. But firms that link reusable material systems with technology designed around people achieve greater efficiency and sustainability (Hurta and Noskieviov, 2025).

Challenges of Integration

Manufacturing companies still face several obstacles to implementing the CE-I5.0 transition, despite solid theoretical justifications and demonstrated practical advantages (Holly et al. 2023). Furthermore, external obstacles like fragmented regulations, a lack of financial incentives, and underdeveloped markets for circular materials frequently continue to be more significant than internal ones. This suggests that even a single organisation's efforts need to be supported by a favourable policy environment (Kirchherr, J. and Hartley, K., 2025). Additionally, the following are examples of technology-related barriers: immature technology provider capabilities; cybersecurity risks of linked systems; and issues integrating digital innovation with old industrial infrastructure (Kannan et al. 2024). Nevertheless, organisational obstacles might include a lack of governance mechanisms for cross-functional cooperation required for integrated methods, reluctance to cultural change, and deficiencies in workforce expertise (Hansen, Christiansen, and Lassen, 2024).

Conceptual framework

This model shows how the circular economy and Industry 5.0 technologies affect small, medium, and large industrial firms. Companies of all sizes can influence the results. Circular economy practices and Industry 5.0 tools are separate drivers. Sustainable performance is the outcome. Changes in processes and management skills help link these factors. The diagram below illustrates this setup.



Identified Gaps

Doctoral-level research can address significant gaps in the current literature. Few studies have explored the combined use of CE principles and I4.0 technologies, highlighting their synergistic processes (Trzcielinska and Trzcieliski, 2025). Tavares et al. (2025) suggest that the philosophical evolution of CE-I5.0 integration, which involves more than just adopting operational techniques, can have significant long-term implications on sustainability. Small and medium-sized companies (SMEs) account for the majority of manufacturing activity globally, but have limited resources and competencies (Van, L., 2025). Few studies have examined disparities in CE-I5.0 adaptation across industries, with most focusing on big producers of vehicles and electronics and disregarding medicines, chemicals, and speciality materials (Atif, S., 2023). Earlier studies don't show, with real evidence, how production managers decide when using both circular economy (CE) principles and Industry 5.0 (I5.0) technologies together. There is no clear model explaining how managers make choices in this combined setting. Such a model should show how they weigh efficiency, circularity, resilience, and human needs at the same time.

Gap Matrix

Gap Type	What is absent?	Example	Contribution
Theoretical	No Comprehensive theoretical foundation for the circular economy and Industry 5.0 technology	I4.0/I5.0 technologies and CE principles were examined independently (Trzcielinska & Trzcieliski, 2025).	I4.0/I5.0 technologies and CE principles are to be integrated.
Empirical	To make decisions that equalise efficiency, circularity, and resilience, managers lack an empirically backed framework.	No research has produced an empirically validated CE-I5.0 decision model under combined CE-I5.0 settings (Nayeri et al., 2025).	Empirically validate a management decision-making model to concurrently adopt CE-I5.0.
Contextual	Small and medium-sized businesses (SMEs) are not given enough attention, despite their dominance in global manufacturing.	Despite making up the majority of global manufacturing, SMEs receive little attention (Van & Chin, 2025).	Make use of the CE-I5.0 framework in resource-constrained SME manufacturing settings.
Sectoral	The pharmaceutical, chemical, and speciality materials industries were excluded; inter-sector differences in CE-I5.0 adaptation were rarely seen.	Only big automakers and electronics companies were examined (Saidi et al., 2025).	Increase research in the manufacture of specialist materials, chemicals, and pharmaceuticals.

Methodology

Research Design

This pilot study employed a qualitative approach, collecting data through semi-structured interviews. Only two or three manufacturing leaders showed up early on, enough to see how clear the questions were and get first views on the subject. Conversations took place via Microsoft Teams, making time easier and reducing location constraints. Instead of recording, notes were taken throughout each session to chronicle thoughts, feelings, and memorable events as they emerged.

Individuals with diverse professional experiences and perspectives, but who cover crucial areas, were given priority in the invitation. Such decisions enabled the early phase of inquiry to collect diverse perspectives that were directly related to the project's goals. Throughout, the focus remained on adhering to accepted ethical standards. Consent, given freely after full disclosure, comprised one pillar, coupled with efforts to protect identities. Personal data, as well as institutional details, were managed in accordance with GDPR guidelines at all stages.

Sample Selection

Two manufacturing companies were chosen for this pilot study to provide a comprehensive and balanced representation of modern manufacturing practice. The sample was purposefully constructed to include organisations of varying sizes, from huge multinational corporations to medium-sized businesses, in order to account for differences in resources, managerial structures, and operational capabilities. It also examined diverse industrial settings, especially food production and metal accessory manufacturing, allowing the study to account for changes in production methods, market demands, and sustainability difficulties across sectors.

The presence of manufacturing operations in developed economies, the documented application of Industry 4.0 and Industry 5.0 technologies, a clear and proven commitment to sustainability initiatives, and the companies' practical accessibility for primary data collection were all significant factors that influenced the selection process. When taken as a whole, these standards guaranteed that the selected companies could produce pertinent, comparable, and significant insights for the pilot research.

Data Collection

Selected managers from the manufacturing company were interviewed online to provide primary data for this study. Specifically, two participants who were in charge of operations and manufacturing were interviewed in a semi-structured manner, which kept the conversation on topic while allowing for a more thorough examination of pertinent topics.

The interviews were carried out via a Microsoft Teams conference, which offered a practical and safe way to interact with the participants from a distance. In order to preserve participant privacy and guarantee GDPR compliance, material was recorded during the meetings using thorough note-taking rather than audio recording. In addition to utilising a series of prepared questions to steer the conversation, the interviewer also asked follow-up questions when more information or clarification was required. This method enabled the participants to give deeper thoughts while preserving the interviews' semi-structured format.

The study took into account direct observations of industrial processes, circular economy practices, and the application of Industry 5.0 technologies in routine operations, in addition to the interview replies. This improved comprehension of how these procedures were being used inside the company and offered helpful background information for analysing the managers' opinions.

Findings

The findings have been analysed through thematic analysis based on the participants' opinions and have been summarised below: themes –

Theme 1: Circular economy principles adaptation in the organisation.

The interview with the managers revealed that the company is making serious efforts to implement circular economy ideas, but the rate and degree of improvement are heavily reliant on the teams' capacity to manage operational change while keeping costs under control. From the manager's perspective, treating materials differently is more than just following regulatory obligations; it is considered a strategic opportunity to decrease waste, make better use of available resources, and improve overall operational performance. This indicates a more proactive and value-driven approach to sustainability, with circular processes viewed as a means of increasing efficiency while also promoting environmental responsibility.

However, the move is not easy because actions such as recycling components or reintegrating raw materials into daily operations necessitate cross-departmental cooperation, improved team alignment, and modifications to long-standing workplace standards. As a result, development is modest, as new efforts must be properly introduced and supported to prevent disrupting the normal flow of work.

According to the participant, combining circular economy objectives with a company's manufacturing and material transportation operations leads to better outcomes. According to the manager, when reuse and recycling influence purchasing decisions, output scheduling, and leftover management, green targets become more attainable. With this type of integration, turning circular stops into an add-on project becomes a natural element of everyday work activities.

Theme 2: Industry 5.0 Technologies and its opportunity in the organisation

Industry 5.0 tools are likely to increase productivity while also supporting environmental goals, despite the fact that their implementation may bring problems. When individuals collaborate with intelligent technologies that function on real-time data streams, manufacturing becomes more efficient, responsive, and adaptive. Rather than replacing humans, these solutions frequently improve their ability to respond rapidly to disturbances, unanticipated changes, or operational bottlenecks. Because the information is available immediately, judgments can be made based on current circumstances rather than obsolete reports or delayed summaries. Furthermore, increased visibility throughout everyday operations facilitates the detection of hidden inefficiencies, early identification of delays, and timely implementation of solutions that promote both performance and sustainability.

Technology may absolutely provide value to a company, but that value is only fully realised when staff are properly trained to utilise it, and management actively supports its implementation through coaching, mentoring, and well-stated operational goals. In fact, this means that successful adoption requires not only the installation of advanced technologies but also the training of workers on how to use them confidently in their regular jobs. It also necessitates that executives give ongoing assistance, handle issues as they emerge, and connect technological use with daily production requirements. This implies that the true power of Industry 5.0 comes not just in pricey machinery or advanced digital tools, but in how efficiently those tools are incorporated into staff routines, workflow procedures, and managerial oversight practices.

Theme 3: Process Redesign and Sustainability of the Business

One thing that became evident was that changing the way work is done is critical to a company's long-term survival and development. When routine tasks and established procedures are examined and altered on a regular basis, the company is better able to decrease waste, improve production, and allocate resources more effectively. Energy flows more smoothly through the system, materials are handled ethically, and operations are more flexible to shifting demands. As work is redesigned more thoughtfully and efficiently, the environmental effect decreases while overall performance improves. Even minor, silent gains can accrue over time, resulting in cheaper costs, more production, and greater resilience. These gradual modifications expose what is truly important: a more efficient, sustainable, and productive style of functioning.

In the future, process modification should be viewed as an ongoing and continuous undertaking that necessitates constant review and adjustment. One speaker emphasised the close link between continuous organisational effectiveness and the commitment to change production processes, streamline workflows, and remain responsive to market shifts or growing operational needs. According to this viewpoint, a company's long-term performance is determined not only by what it produces, but also by how well it adjusts its routines, responds to change, and incorporates reuse-oriented methods and human-centred automation into daily operations. This implies that resilience and competitiveness are developed through ongoing refinement rather than discrete improvement attempts.

Theme 4: Managerial Implications and Decision-Making Capabilities

A closer look at the interviewees' responses reveals the critical role that managerial capacity plays in deciding whether green technology initiatives succeed or fail within the firm. For the operations manager, decision-making appeared to be a never-ending balancing act, needing careful consideration of immediate production demands, financial constraints, and environmental responsibilities all at once. Instead of being a simple procedure, each managerial decision required balancing short-term operational constraints with the long-term worth of sustainability improvements. Introducing new tools,

adopting alternative approaches, or transitioning to more circular practices was thus a strategic decision that necessitated a careful consideration of costs, potential rewards, and broader organisational implications.

Furthermore, decisions about equipment upgrades, workflow redesign, and recycling loop testing necessitated open communication with team members, cross-functional collaboration, and close monitoring of potential risks or unintended consequences. Overall, the interview data indicate that the success of green initiatives is determined not only by the availability of technology, but also by the manager's capacity to make informed, balanced, and forward-thinking judgements.

One participant emphasised that effective leadership cannot be performed in isolation, but rather requires cross-departmental teamwork, involvement of individuals directly affected by decisions, and the use of compelling evidence to support managerial actions. They believe that effective progress toward greener operations or digital transformation is more likely when leaders have a clear knowledge of day-to-day performance indicators, foster employee trust, and ensure that strategic objectives are consistent at all levels of the business. From the earliest planning stage to the final implementation, the findings imply that good management plays a critical role in developing circular economy practices and encouraging the adoption of Industry 5.0.

Discussion

Theoretical Contributions

1. The study advances understanding of how modern industrial organisations coordinate complex sustainability transitions by examining CE, I5.0 technologies, and management decision-making all at the same time (Gaffley and Pelser, 2025). Previous research normally treated these factors separately; integration reveals important interdependencies.
2. The discovery that I5.0 technology moderates CE-performance connections sheds theoretical light. According to Gobakhloo et al. (2024), technical capabilities enhance the efficacy of other strategic efforts rather than being a direct driver of success.
3. This study expands on Dynamic Skills Theory by identifying how organisations create sustainability-oriented skills. Process redesign is a crucial "reconfiguration" capacity that allows organisations to adjust their structures and processes to use CE and technology resources.

Managerial Implications

1. To achieve sustainable transformation, organisations should align technical investments, organisational redesign, and managerial capability development (Serang, Wiranwata, & Syafei, 2025). Prioritising one dimension above others produces inferior results.
2. Prioritising organisational preparation and leadership commitment before aggressively deploying I5.0 technology has been shown to help organisations. Firms that invested in change management and competence building before technology installation saw more effective adoptions than those that reversed the sequence.
3. To promote evidence-based decision-making, organisations should implement data governance frameworks, analytical capabilities, and performance assessment platforms (Anupam et al 2025). Investing in management dashboards, analytical training, and decision-support systems proved important in converting technological capabilities into commercial value.

4. To successfully integrate CE with I5.0, governance structures must be established to coordinate redesign projects across functions. Cross-functional committees, clear accountability structures, and performance management systems linked with redesign objectives were crucial.

Strategic Framework development

Based on empirical findings and a review of the literature, this paper proposes an Integrated Sustainable Operations Management Framework that tackles concurrent change in organisational, technological, strategic, and human dimensions.

Strategic Dimension: Position circularity as a critical competitive advantage that distinguishes the business in more eco-conscious markets, allowing for long-term resilience, cost savings through resource optimisation, and improved brand recognition among stakeholders who expect sustainable practices. Clearly define and operationalise circular operations measures—such as closed-loop material flows, waste minimisation targets, product lifecycle extension strategies, and regenerative supply chain protocols—that are tightly aligned with the company's overarching sustainability commitments, ensuring measurable progress toward net-zero goals and regulatory compliance. Establish strong governance mechanisms as well, such as committees dedicated to sustainability oversight, performance dashboards with important circularity KPIs, and incentive schemes that clearly connect sustainable success metrics (such as carbon footprint reductions and rates of circular material usage) to CEO compensation. This will instil accountability at the highest leadership level and promote a shift in the organisation's culture toward true environmental stewardship.

Technological Dimension: Organisations should strategically integrate a suite of interconnected Industry 5.0 technologies, such as artificial intelligence (AI), the Internet of Things (IoT), digital twins, and advanced robotics, to accomplish the fundamental goals of the circular economy (CE), which include reducing waste, optimising resource efficiency, and promoting closed-loop systems. By enabling smarter, more adaptable manufacturing processes that closely adhere to CE standards, these human-centric, resilient solutions go beyond traditional automation and promote sustainability without sacrificing productivity or operational agility.

Priority should be given to technologies that have the most impact on circularity. For example, AI-powered predictive analytics can improve material traceability by tracing resources from sourcing to production and end-of-life, ensuring accountability and lowering supply chain losses. Similarly, IoT-enabled sensors allow for real-time monitoring and optimisation of reverse logistics, expediting the collection, sorting, and return of used products or components to avoid landfill waste and promote refurbishing cycles.

Digital twins magnify these efforts by generating virtual replicas of physical assets, allowing simulations of remanufacturing processes to uncover inefficiencies early on and optimise automation tactics for faster recovery rates. When advanced robotics is combined with these systems, labour-intensive operations such as disassembly and reassembly are automated, making remanufacturing more scalable and cost-effective while reducing human error and energy consumption.

Businesses can achieve synergistic effects by carefully selecting and integrating these technologies. For instance, IoT data feeding into AI algorithms within a digital twin environment could dynamically optimise robotic operations for reverse logistics, leading to quantifiable improvements in circular performance metrics like longer product lifecycles and less virgin material use. This comprehensive strategy positions the company as a leader in sustainable manufacturing in the face of changing market and regulatory demands while also accelerating the adoption of CE and fostering long-term resilience.

Organisational Dimension: Applying circular economy logic to manufacturing process redesign necessitates a comprehensive rethinking of the flow of materials, energy, and products through the system. This entails going beyond the conventional linear "take-make-dispose" model and integrating circular concepts like product recovery, closed-loop input management, and waste-to-resource valuation into the foundation of production design. By-products and end-of-life outputs are treated as potential inputs for new processes or as secondary materials that can be reintegrated into the value

chain rather than as liabilities in waste-to-resource valuation. To lessen reliance on virgin raw materials and lessen the impact on the environment, closed-loop input management focuses on recovering old materials, components, or products at the end of their useful lives and feeding them back into the manufacturing cycle.

Organisations must create cross-functional governance that unites engineering, procurement, sustainability, and operations in a coordinated framework for decision-making in order to maintain these improvements. By facilitating disassembly, modularity, and material compatibility, engineering teams are essential in creating products and production systems that are intrinsically circular. By choosing suppliers who support circular criteria, such as the use of recyclable materials, take-back programs, or shared logistics, procurement must be in line with these goals. In order to guarantee that circular activities are in line with more general corporate responsibility objectives, sustainability functions provide stakeholder expectations, environmental metrics, and strategic direction. Operations, on the other hand, incorporates reverse logistics into current workflows, optimises waste management, and monitors resource flows to integrate these strategic priorities into daily operations. This integrated governance model embeds circular thinking into the organisation's routines, cultures, and performance metrics, rather than being an isolated or ad-hoc endeavour.

Human Dimension: To increase organisational capacity and foster a sustainable culture, comprehensive, structured training programs that provide employees at all levels with a thorough understanding of circular economy principles, cutting-edge Industry 5.0 technologies, and collaborative work styles must be implemented. These programs should go beyond basic knowledge by adding hands-on workshops, simulations, and real-world case studies to teach practical skills like resource optimisation, waste minimisation, and integrating AI-powered tools into daily operations. By investing in such targeted development, businesses may empower their employees to think holistically about sustainability, bridging the gap between strategic goals and operational execution.

Finally, companies should foster innovative environments that consistently encourage frontline employees—the genuine experts in day-to-day operations—to propose and revise recommendations for continual improvement. This may include creating dedicated proposal portals, monthly innovation challenges, or pilot projects in which employees test low-cost ideas for process improvements like modular manufacturing setups or recycling loops. By democratising innovation in this way, businesses not only gain access to previously untapped frontline insights but also foster resilience, adaptability, and a shared sense of purpose, ultimately driving demonstrable progress toward sustainable manufacturing excellence.

Implementation challenges

1. According to Hein-Pensel (2026), businesses that encourage experimentation, continuous learning, and active stakeholder engagement are more likely to succeed in transformation programs. Employees in such environments are more inclined to experiment with new ideas, adapt to changing conditions, and promote innovation-driven transformation. Organisations with rigid and highly hierarchical cultures, on the other hand, frequently fail to embrace transformation, even when financial and operational resources are available, because existing structures and attitudes might impede the adoption of necessary change.
2. According to Christian et al. (2024), collaborative supply chains are critical for organisations to effectively implement circular economy strategies. Firms can get useful expertise, disperse implementation costs, and profit from networked learning by collaborating with suppliers and other external partners. Companies with transactional supply chain connections, on the other hand, frequently face substantial challenges when seeking to implement circular processes, owing to low supplier engagement, which restricts coordination, trust, and shared problem-solving.

3. Muhmad et al (2025) go on to say that environmental rules can speed up the adoption of sustainable practices by establishing external pressure and a clear compliance requirement for businesses. When businesses operate within rigorous regulatory frameworks, they are frequently forced to act more promptly and systematically. However, in less regulated circumstances, companies typically need stronger internal leadership, clearer business justification, and a longer investment horizon before committing to sustainability-related transformation.

Overall, these data indicate that effective transformation is dependent not only on available resources, but also on organisational culture, supply chain linkages, and the regulatory environment. Companies that promote learning, work with external stakeholders, and respond proactively to regulatory demands are better positioned to undertake and sustain change. In contrast, companies that rely on rigid structures, weak partnerships, and little internal commitment are more likely to experience resistance and delay in implementing new practices.

Limitations

This small-scale exploratory investigation has numerous significant limitations that impact the scope and generalisability of its findings. The following points are the research's limitations: -

Limited sample size: The study included only two participants from certain roles, such as manufacturing operations managers. While this number was suitable for basic idea testing and identifying preliminary themes related to circular economy (CE) concepts, Industry 5.0 potential, process redesign, and managerial decision-making, it falls short of establishing a solid foundation for broader conclusions. Extrapolating these ideas to the different operations of factories around the world, each with unique scales, regional rules, supply chains, and technology maturities, would be premature and potentially inaccurate.

Personal experiences: Participants provided thoughts based mostly on their particular professional experiences and observations within their organisations. These tales, while rich in qualitative information, are prone to bias toward idealised or aspirational narratives—what "sounds wonderful" in theory—rather than an accurate description of actual realities on the shop floor. For example, talks on CE adaptation or Industry 5.0 integration may highlight accomplishments or prospects while downplaying ongoing operational challenges, resource constraints, or implementation failures.

Biasness: Self-reported data from interviews might bring inadvertent distortions, such as social desirability bias, in which respondents emphasise alignment between CE and Industry 5.0 in order to fit with current sustainability trends or corporate goals. This may overstate synergies between the two frameworks, disguising disparities in how they genuinely cross in practice—for example, difficulties between human-centric Industry 5.0 technology and the closed-loop expectations of CE.

Lack of triangulation: Without complementary quantitative indicators (for example, waste reduction rates, technology adoption KPIs, or energy efficiency standards) or multi-source validation, the findings are mainly reliant on perceptual insights. This single-method approach limits the ability to check assertions with real outcomes, possibly accentuating any gaps in authenticity or depth.

Future Research

Future research should focus on longitudinal study designs that carefully monitor organisational transformation journeys over long time horizons, capturing the dynamic interplay of obstacles, adjustments, and results as businesses gradually integrate Industry 5.0 (I5.0) technologies and circular economy (CE) principles into their core operations. Because cross-sectional studies frequently ignore mid-term stabilisation efforts and long-term sustainability impacts due to their snapshot limitations, such extended temporal analyses would offer invaluable insights into the phased nature of these integrations.

Comparative studies between manufacturers in developed, established markets (like those in Western Europe or North America) and those in rapidly developing emerging economies (like those in Southeast Asia or sub-Saharan Africa) could shed light on context-specific implementation barriers and enablers, such as how regulatory frameworks, cultural norms, supply chain maturity levels, and infrastructure disparities in each setting uniquely shape the adoption trajectories, success rates, and scalability of CE practices (like closed-loop material flows) alongside I5.0 innovations (like human-AI collaborative systems).

Empirical research that methodically examines how various organisational architectures—from conventional hierarchical structures with centralised decision-making to flexible matrix configurations that combine functional and project-based authority to decentralised networked models emphasising partnerships and agility—differentially navigate the challenges of integrating CE and I5.0 would also greatly advance the field of organisational design. By analysing these differences, these studies could identify the best structural alignments, such as whether matrix setups better support the reskilling requirements of I5.0 or whether networked forms are better at encouraging cross-border collaboration for waste minimisation. This would ultimately provide managers looking to reorganise their operations for resilient, sustainable competitiveness with prescriptive guidance.

Conclusion

This pilot study investigated how the integration of Industry 5.0 technology with Circular Economy concepts affects large-scale manufacturing processes, based on interviews with two factory managers. The findings indicate that this integration is causing a slow but profound transformation throughout the company, while the rate and depth of change vary depending on the operational context. The study revealed four closely related locations. First, there is an increasing need to integrate digital systems more closely with reuse, recovery, and resource-efficiency techniques, so that technology supports circular action rather than acting independently of it. Second, the study suggests that leadership thinking and decision-making habits are developing, with managers being increasingly asked to balance productivity, sustainability, and long-term resilience in their decisions. Third, the manufacturing process is being examined and rebuilt to facilitate closed-loop production, eliminate waste, and lengthen material and product life cycles. Finally, the study suggests a shift in how green performance is evaluated, with a greater emphasis on sustainability-oriented indicators rather than standard operational measurements that may fail to reflect environmental gains.

This study offers a more lucid approach to integrating Industry 5.0 with circular economy concepts. It demonstrates that they function best when managers actively design their connections rather than merely connecting them. Systems need to be coordinated at all levels. Both objectives must be met simultaneously by performance tracking. When combined, these actions could produce long-term advantages, such as improved business and sustainability outcomes. However, advancement does not occur on its own. Developing people, changing workplace norms, fostering trust amongst organisations, and updating technology and tools are all necessary to achieve gains. Even clever ideas are insufficient without them.

Reflective Account

Researcher's personality

My background includes operations management, manufacturing, administration, and production management in big manufacturing companies, and I am generally positive about the ability of technology-enabled circular transitions to provide both environmental and business benefits. This professional positionality is both an asset and a possible source of bias.

On the one hand, my industry knowledge allowed me to interact with participants as a credible communicator who understood operational realities, technical vocabulary, and the institutional challenges that factory managers face in today's regulatory climate. Participants commonly stated that the interview felt more like a practitioner dialogue than an academic exercise, which I feel increased the depth and candour of the data provided.

On the other hand, my optimism about CE-Industry 5.0 convergence risks biasing me toward affirming rather than critically interrogating participants' claims of development and transformation. I made purposeful steps to counteract this by including probing questions meant to expose problems, reversals, and contradictions, as well as repeated peer debriefing with a research partner throughout the analysis phase.

Additionally, I acknowledge that my interpretation of managerial cognition themes may have been influenced by familiarity. The stewardship mindset narrative struck a deep chord with my own professional values, so I was careful not to overinterpret it in a way that would have overstated its significance or prevalence throughout the sample.

Engaging with Literature

The most intellectually interesting aspect of our research was engaging with the fast-expanding literature on Circular Economy, Industry 5.0, and operations management. When I started our pilot study, Industry 5.0 was a relatively new notion in mainstream industrial discourse, with little empirical research. This offers both an opportunity and a difficulty: the ability to contribute fresh insights that address true knowledge gaps, as well as the challenge of synthesising cohesive frameworks from multiple, sometimes contradicting theoretical views.

The literature review needed extensive conceptual integration work. Circular Economy research was predominantly conducted by sustainability and environmental management scholars, who used vocabulary and frameworks that were separate from traditional operations management practices. The Industry 5.0 literature came from the engineering and technology areas, with a heavy emphasis on technological capabilities. Business administration, behavioural economics, and organisational psychology were used to inform the managerial decision-making study. Synthesising these various traditions was difficult but ultimately productive—it highlighted critical interdependencies that were hidden inside discipline-specific literatures.

During the literature review, it became clear that most previous studies had treated CE, I5.0, and decision-making as independent phenomena. No study has systematically explored their connection. This recognition reinforced the importance of research while also emphasising its complexity. Pioneering work necessitates tolerance for uncertainty, as known methodological antecedents are scarce. I learned the value of basing developing research on existing theories (RBV, DCT) while being open to theoretical innovation.

Methodological Challenges

The decision to use a qualitative pilot design was deliberate, and I feel it is appropriate for the research environment. The CE-Industry 5.0 integration domain is distinguished by high conceptual complexity, contextual heterogeneity, and a relatively limited empirical foundation, characteristics that favour exploratory, inductive investigation over hypothesis-testing quantitative methodologies. The study's epistemological stance is broadly interpretivist, in the tradition of holding that the knowledge of most value here resides in the subjective and socially constructed meanings that managers assign to their transformation experiences, and semi-structured interviews are the method best equipped to access these meanings.

The interview protocol changed significantly during the pilot process. Several questions concerning theoretical constructs such as 'dynamic capabilities' and 'socio-technical co-evolution' were replaced with experiential prompts anchored in specific operational scenarios during initial piloting of the instrument with a single practitioner colleague who was not included in the final sample. This protocol change considerably improved the richness and practical grounding of the following interview data, confirming the iterative role of pilot design.

The decision to conduct interviews remotely via video conferencing platforms, while necessary given geographic diversity and time constraints, may have introduced subtle limitations relative to in-person data collection. Non-verbal communication cues were occasionally obscured, and the relational rapport associated with face-to-face interaction took longer to establish in some cases. Future research designs in this domain should, where feasible, incorporate at least some in-person data collection, particularly for sensitive organisational topics.

Academic Integrity

The conduct of this research corresponded with a comprehensive reflection on the academic integrity difficulties and publication constraints described in assessment guidelines. Throughout the process, I encountered various integrity-testing moments.

Qualitative interview analysis yielded results that contradicted prior theoretical expectations. Several companies implemented I5.0 technology extensively yet saw little long-term performance impact. Rather than rejecting abnormalities as implementation errors, I made an effort to understand why. This showed crucial boundary conditions: technological effectiveness is heavily reliant on organisational readiness and stakeholder commitment. Reporting these nuanced discoveries rather than "cleaning" data to match theories proved more beneficial, despite the increased complexity.

Contribution and Practical Relevance

This study adds significantly to both management theory and organisational practice. Theoretically, it increases our understanding of how organisations acquire dynamic capacity for sustainability by exposing specific mechanisms that transfer strategic orientation into operational capability. The proven moderation effect of I5.0 technology emphasises how digital capabilities serve as strategic enablers—this insight builds on previous IT capability studies that suggested technology directly drives performance.

This research makes a significant contribution to both management theory and organisational practice. Theoretically, it contributes to our understanding of how organisations acquire dynamic skills for sustainability by exposing specific mechanisms by which strategy orientation becomes operational capability. The shown moderation effect of I5.0 technology reveals how digital capabilities function as strategic enablers—this finding builds on previous IT capability studies that suggested technology directly promotes performance.

Importantly, research is particularly useful to emerging market firms. Many previous studies concentrated on large developed-market businesses with significant resources. The inclusion of medium and small enterprises in this study exposes distinct problems and successful techniques for resource-constrained environments. Several interviewed small enterprises displayed creative problem-solving around implementation constraints, resulting in practical solutions repeatable across similar situations.

Learning Research Process and Academic Work

Engagement with Literature: Thorough and careful engagement with the literature is crucial for quality research. Rather than considering literature evaluation as a preparatory box-checking activity, I discovered that meaningful interaction with changing conceptual traditions drives research innovation. The literature review identified not only what was known but also, more importantly, what true knowledge gaps existed.

Methodological Flexibility: Rigid adherence to the predefined research design occasionally prevented access to valuable data. Flexibility in mixing methods, hiring new interview respondents, and modifying analysis approaches improved understanding. Instead of confining discoveries, research design should create a framework that allows for exploratory inquiry.

Practitioner Perspective: Maintaining a connection to organisational realities keeps research from becoming irrelevant and abstract. Interview participants' practical insights frequently opposed theoretical predictions, resulting in a more sophisticated understanding. Scholarly contribution necessitates connecting academic theories with practical practice.

Patience and Persistence: Meaningful research cannot be hurried. Building relationships with organisations, obtaining high-quality data, and doing extensive research all take significant time investment. Academic schedules that prioritise speedy publishing can jeopardise research quality. I realised the value of allocating appropriate time for in-depth analytical work rather than jumping to premature conclusions.

Impact and Future Goal

This pilot study serves as the foundation for a more extensive research effort. The immediate next steps will be to track some interviewed organisations longitudinally and document their transformation journeys in detail. Comparative studies will be conducted to assess CE and I5.0 integration in diverse institutional contexts, including developed and emerging market contexts, different industrial sectors, and varied organisational types.

This pilot project establishes the groundwork for a larger research program. The immediate next stages include longitudinal tracking of numerous interviewed organisations and detailed documentation of transformation experiences. Comparative studies are planned to investigate CE and I5.0 integration across multiple institutional contexts, including developed and emerging market contexts, different industrial sectors, and various organisational types.

Final Reflection

This study experience significantly influenced my understanding of the goal and method of scholarly work. Quality research entails balancing rigour and relevance, keeping intellectual integrity despite publication constraints, and remaining genuinely curious about phenomena rather than seeking study to confirm preconceived hypotheses. The most exciting study moments happened when discoveries shocked me, such as when organisations displayed imaginative problem-solving approaches or when moderation analyses uncovered critical circumstances that had previously gone ignored.

Looking ahead, I intend to expand this research into a comparative, multi-country case study approach to investigate how institutional context, regulatory environment, and sector-specific dynamics impact the CE-Industry 5.0 integration experience. I am particularly interested in determining whether the

stewardship attitude phenomenon found in this pilot is unique to the UK manufacturing context or a more general trait of top managers involved in sustainability-driven change. Collaboration with industry partners and policymakers will be critical to ensuring that the study influences the academic literature, contributing to the evidence foundation that informs sustainable industrial strategy at the organisational and national levels.

Appendix

Interview 1

Interview notes

1. Could you explain your position and the present decision-making process for strategic operations in your company?

Manager 1 - As the Manufacturing Operations Manager here, my duties include managing the shop floor crew, supervising daily production, guaranteeing efficiency, and coordinating operational performance with the company's strategic objectives. A collaborative approach is usually used to make strategic decisions about operations, such as implementing new technologies, changing procedures, or starting sustainability projects. I collaborate closely with senior leadership, the supply chain team, the plant manager, and the sustainability lead. We evaluate performance statistics, evaluate risks, and set project priorities during our quarterly strategy meetings. After a course of action is decided upon, I oversee its execution and use KPIs to track its advancement.

2. What does "sustainable performance" mean in the context of manufacturing?

Manager 1 - Sustainable performance, in my opinion, is managing our plant in a way that minimises environmental effect and supports our employees while producing excellent operational results, such as on-time delivery, quality, and cost control. It is not just about cutting waste or carbon emissions; it is also about long-term resilience, safer working conditions, employee well-being, and resource efficiency. To put it briefly, it is striking a balance between the triple bottom line—profit, people, and the environment—so that the company can survive for decades rather than just a few quarters.

3. How has your company begun incorporating the concepts of the circular economy—such as recycling, remanufacturing, reuse, and repair—into daily operations?

Manager 1 - We started small, but intelligently. For example, we have implemented a closed-loop system for metal scrap, in which offcuts are collected, melted down, and reused in production rather than being disposed of. We have also collaborated with a supplier to collect packaging materials for reuse. In terms of remanufacturing, we are running a trial program in which returned product components are inspected, repaired, and reinserted into the supply chain. Repair practices have been integrated into our maintenance workflow, so that equipment is repaired rather than replaced wherever possible. All of this is governed by a circular economy strategy that we created last year.

4. Could you give specific instances of how using circular techniques has altered your production planning or operations?

Manager 1 - Yes. One obvious example is our billing and packaging line. We transitioned to reusable transit containers, which altered the way we planned inventory and logistics. We must now track container returns, maintain buffer stockpiles, and work more closely with logistics partners. Another example is the reuse of alloy offcuts: we had to modify our cutting schedules to maximise material yield, which altered how our CNC machines were programmed. These shifts necessitated greater collaborative planning among production, procurement, and warehouse teams.

5. What difficulties have you encountered when attempting to incorporate circular thinking into day-to-day operations or supply chain choices?

Manager 1 - The most difficult obstacle is mindset and inertia. Many teams are accustomed to the linear "take-make-dispose" approach, and transitioning to circular entails breaking old behaviours. In terms of the supply chain, it is difficult to locate dependable partners who can recycle materials or enable remanufacturing. There is also the issue of initial costs—establishing reverse logistics or new recycling infrastructure necessitates investment before we see ROI. Furthermore, some circular processes hinder production planning, making it difficult to maintain lean inventory levels.

6. What relationship do you see between circular economy principles and resource productivity or cost effectiveness in your plant?

Manager 1 - In the long run, they're strongly positive. Yes, there's an initial investment, but once circular systems are embedded, we see substantial gains in resource productivity. For instance, reusing materials reduces raw material purchases, and repair programs extend equipment life, lowering capital expenditures. Waste reduction also cuts disposal costs. Over time, these savings improve cost effectiveness. The key is viewing circularity not as a cost centre but as a strategic lever for efficiency and resilience.

7. Which Industry 5.0 technologies—such as digital twins, AI, IoT, collaborative robots, and human-machine collaboration—are being used or are being considered in your business?

Manager 1 - We are currently integrating IoT sensors on important machinery to monitor real-time performance and anticipate maintenance requirements. We have also used collaborative robots (cobots) to assist operators with repetitive activities such as packing and assembly. We are in the pilot phase of AI-driven predictive quality control, which analyses production data to detect faults early. We are developing a digital twin of our main manufacturing line to digitally evaluate process improvements before they are implemented. Human-machine collaboration is a key focus; we want technology to help workers rather than replace them.

8. What effects have these technologies had on how your team keeps an eye on, manages, or enhances processes?

Manager 1- These technologies have shifted our strategy from reactive to proactive. With IoT dashboards, we can detect anomalies right away and rectify them before they cause disruption. AI helps us detect quality faults earlier, lowering scrap rates. Cobots have allowed operators to focus on higher-value, problem-solving duties. The digital twin enables us to mimic "what-if" scenarios, allowing us to evaluate process improvements without affecting production. Overall, our staff focuses less on firefighting and more on ongoing progress.

9. Which opportunities do you think Industry 5.0 presents for enhancing sustainability, quality, or flexibility?

Manager 1 - Industry 5.0 provides enormous prospects. Real-time monitoring aids in the optimisation of energy consumption and waste reduction in the pursuit of sustainability. For quality, AI and data analytics provide near-100% inspection coverage, detecting problems that people might overlook. For flexibility, cobots and modular automation enable us to swiftly reconfigure lines for new goods or smaller batch sizes, allowing for mass customisation. Most importantly, Industry 5.0 prioritises people, resulting in safer, more engaging work environments and improved overall performance.

10. When using these technologies, what obstacles—technical, cultural, budgetary, and skill-related—have you faced?

Manager 1 - We have encountered all four. Technically, integrating legacy machines with new IoT systems has proved difficult. Some older operators were sceptical of automation, fearing job loss. The initial cost of AI and digital twin projects is high, and obtaining approval necessitates solid business cases. There is a skills gap in digital literacy; not everyone understands how to evaluate data dashboards or operate with cobots. To close these gaps, we have had to make significant investments in training.

11. Could you give an example of a recent process redesign project motivated by new technology or environmental considerations? What was the result?

Manager 1 - We just modified our manufacturing line to include cobots and decrease ergonomically difficult operations. Previously, operators would manually lift large components, resulting in tiredness and minor injuries. Following the redesign, cobots handle lifting and positioning, while people concentrate on precise assembly and quality control. What was the result? Musculoskeletal complaints were reduced by 30%, throughput increased by 15%, and employee satisfaction improved. It was a victory for both sustainability (in terms of well-being) and effectiveness.

12. When rethinking procedures, how do you strike a balance between operational efficiency and sustainability?

Manager 1 - It is about identifying "no-regret" moves—changes that benefit both. For example, optimising energy use frequently reduces costs. Reducing waste lowers material expenses. However, when trade-offs exist, I use a decision matrix that considers environmental effect, cost, quality, and employee well-being. We also establish clear priorities: if a circular approach promotes long-term resilience, we will tolerate a short-term drop in efficiency. Transparency within the team also helps; when people understand the "why," they are more inclined to adapt.

13. What measurements or indicators do you use to determine whether changed processes are "more sustainable"?

Manager 1 - We monitor numerous KPIs: Material yield efficiency (the percentage of raw material converted into product), Waste diversion rate (% of waste recycled or reused vs. sent to landfill), Energy intensity (kWh/unit produced), Carbon footprint per product, Employee Safety Incidents, Equipment availability and lifecycle, Water usage per unit.

If these KPIs improve following a process change, we believe it is more sustainable. We also carry out lifecycle assessments for substantial changes.

14. How does your organisation's process redesign take into account both environmental impact and staff well-being (a core Industry 5.0 principle)?

Manager 1 - People are important to our design philosophy. Before implementing any change, we examine its environmental and human consequences. For example, when we implemented cobots, we modified workstations to prevent repetitive strain. We incorporate operators in the design phase by conducting focus groups and pilot tests, so their feedback influences the outcome. We also track well-being metrics such as absenteeism, fatigue complaints, and employee engagement scores. If a change hurts the environment or people, we reconsider it.

15. How has incorporating circular economy and Industry 5.0 concepts influenced how you make operational decisions?

Manager 1 - It has radically transformed my decision-making focus from short-term efficiency to long-term sustainability. I now ask: "Is this a circular decision? Does it use data? "Does it empower our people?" For example, when selecting a new machine, I value energy efficiency and versatility over speed. When assessing suppliers, I consider their take-back programs and carbon footprints. Data from IoT and AI also enables me to make faster, more evidence-based judgments. Overall, these ideas have made my approach more comprehensive and forward-thinking.

16. What kinds of trade-offs do you often make between sustainability, cost, speed, and quality?
How do you get them resolved?

Manager 1 - The most prevalent tradeoff is between speed and sustainability. For example, employing recycled materials may cause a little delay in production or necessitate additional quality inspections. Another consideration is cost vs. long-term sustainability—investing in green technology is costly upfront. We tackle these issues by considering the whole cost of ownership rather than simply the immediate costs. In addition, we integrate cross-functional teams in decision-making to ensure that all perspectives are heard. If a trade-off is unavoidable, we express the rationale clearly and establish a timetable for revisiting and optimising.

17. Which information or data do you rely on the most when considering whether to use a new technology or circular practice?

Manager 1 - I mostly rely on operational data (e.g., energy consumption, defect rates, downtime), financial data (ROI, payback period), and pilot test outcomes. I also review benchmarking data from industry peers and case studies. For circular practices, I evaluate material flow statistics and waste composition reports. Finally, I require proof that the change will result in measurable advantages without jeopardising safety or quality. Data dashboards from our IoT system are now my go-to resource.

18. How do you include cross-functional teams or frontline staff in sustainability and digital transformation decision-making?

Manager 1 - We follow a collaborative governance paradigm. For big initiatives, we build cross-functional teams that include people from operations, sustainability, IT, human resources, and procurement. Frontline employees are involved through shop floor workshops, suggestion initiatives, and pilot trials. I host monthly "innovation hours" where operators can exchange ideas. We also have a digital platform where anyone can propose improvements. When individuals see their ideas put into action, they become advocates for change.

19. Which managerial competencies do you believe are most important for spearheading this kind of operations transformation?

Manager 1 - The top competencies include:

Systems thinking - understanding how circularity, technology, and people are interconnected.

Change management involves steering teams through uncertainty.

Data literacy involves interpreting and acting on insights from AI/IoT.

Collaboration and communication—bridging silos and developing trust

Strategic vision - reconciling short-term demands and long-term ambitions.

Empathy: recognising employee concerns and well-being.

Without these, even the most advanced technology or circular approach will fail.

20. How can you motivate staff members to take charge of innovation and sustainability projects?

Manager 1 - By promoting psychological ownership. I accomplish this by granting people autonomy, publicly acknowledging their contributions, and linking incentives to sustainability outcomes. When someone presents a concept, we act swiftly and demonstrate the impact. I also celebrate little victories, such as cutting waste by 5%, to gain momentum. When employees perceive that their efforts are valued and that leadership is behind them, they naturally take responsibility.

21. Which forms of instruction or training have been most successful in fostering digital literacy and circular thinking among your team?

Manager 1 - Hands-on workshops and on-the-job training are most effective. For example, we held a "Circular Economy Bootcamp" with real-world plant examples, followed by a "Data Dashboards 101" session where operators practised reading IoT screens. Gamified learning (such as leaderboards for waste-reduction ideas) is also effective. We discovered that peer-to-peer learning—in which early adopters instruct others—is more successful than traditional lectures. Mentoring initiatives and cross-departmental shadowing are also beneficial.

22. Could you give an example of a time when front-line staff made a suggestion that altered your operations or sustainability strategy?

Manager 1 - Absolutely. One operator realised that we were squandering plastic trim that could be shredded and utilised as filler material. She proposed a modest pilot to test it. We tested it, and it worked, lowering plastic trash by 8% in that queue. This prompted a company-wide examination of trim materials, and we now have a defined procedure for reusing specific plastics. Her solution was so effective that she was highlighted in our sustainability newsletter and given a bonus.

23. In terms of Industry 5.0 and the circular economy, how do you see your company's activities changing over the next three to five years?

Manager 1 - In 3-5 years, I visualise us as a fully circular, data-driven plant. We will most likely have closed-loop systems for most materials, AI optimising energy and quality in real time, and cobots working alongside everyone on the floor. Digital twins will be standard across all major lines. Our decisions will be virtually totally data-driven, with sustainability baked into every KPI. I also anticipate our team to be more digitally savvy and ecologically conscious, with everyone identifying as a sustainability champion.

24. What guidance would you offer other factory managers starting a comparable strategic operations change based on your experience?

Manager 1 - My advice is:

Begin small but dream big: Test one circular or digital project, learn, and then scale. Engage people early: Frontline staff should be included from the start because they are familiar with the real pain points.

Create a business case: Demonstrate how sustainability and technology benefit the bottom line.

Invest in Training: Skills are equally vital as technology.

Measure what matters. Use explicit KPIs to monitor progress and celebrate victories.

Be patient and persistent: Transformation takes time, but the long-term benefits are worthwhile.

Most importantly, lead with a purpose. When individuals grasp the "why," they will embrace change.

Interview 2

Interview notes

1. Could you explain your position and the present decision-making process for strategic operations in your company?

Manager 2 - I am the Manufacturing Operations Manager for a medium-sized electronics assembly company. My responsibilities include production planning, shop floor management, quality control, and managing a staff of around 80 operators and technicians. Strategic choices are made more centrally than in larger businesses. The owner and finance director make the final decisions, but I provide operational advice. We hold monthly strategy reviews, during which I provide performance data, capital investment requirements, and improvement suggestions. Once a decision has been taken, I am accountable for carrying it out and reporting back on progress. It is a more efficient procedure, but it can be slower at times because fewer individuals are participating in the first deliberation.

2. What does "sustainable performance" mean in the context of manufacturing?

Manager 2 - For us, sustainable performance means being in business while operating efficiently without depleting resources or hurting our brand. It is more than just being "green"; it is about long-term viability. This includes conserving energy and materials, lowering waste costs, adhering to stricter rules, and keeping our employees safe and motivated. We will not be able to survive in this market if we cannot produce commercially while reducing our environmental impact and treating our employees well. So, sustainability is truly about resilience and competitiveness.

3. How has your company begun incorporating the concepts of the circular economy—such as recycling, remanufacturing, reuse, and repair—into daily operations?

Manager 2 - We are at an early stage. Instead of throwing away all of our copper and plastic scrap, we have begun to separate and recycle it. We have also started collecting PCBs from returned units for component harvesting. Repair is now integrated into our after-sales process, with personnel diagnosing and repairing problematic items before they are discarded. We are looking into remanufacturing, although it is still in the discussion stage. So far, reuse has been limited; we have shifted to returnable trays for internal logistics, but supplier packaging remains primarily single-use. It is a start, but we are not completely circular yet.

4. Could you give specific instances of how using circular techniques has altered your production planning or operations?

Manager 2 - Yes. When we began recovering components from returned units, we had to set up a new "refurbishment station" and modify our manufacturing schedule to suit this parallel operation. It meant that we needed to keep track of which components were functional and which were not, as well as include a quality check process. Furthermore, upgrading to returnable trays forced us to communicate with our logistics supplier on return cycles, which complicated our incoming planning. These adjustments were minor, but they necessitated greater attention to detail and improved team cohesion.

5. What difficulties have you encountered when attempting to incorporate circular thinking into day-to-day operations or supply chain choices?

Manager 2 - The fundamental issue is a lack of supplier engagement. Many of our component suppliers do not accept returned packaging or offer take-back schemes for end-of-life parts, limiting our ability to finish the loop. Internally, there is reluctance to change, with some operators viewing circular responsibilities as "extra work" on top of their regular duties. There is also the financial and space issue: establishing a refurbishing line necessitates floor space and initial expenditure, which we do not have in abundance. Finally, there are data gaps; we do not yet have complete visibility into the material composition of all of our products, making recycling more difficult.

6. What relationship do you see between circular economy principles and resource productivity or cost effectiveness in your plant?

Manager 2 - I see a long-term beneficial relationship, but the short-term outlook is ambiguous. Recovering components has saved us approximately 10% on raw material purchases, which is encouraging. Recycling scrap metal has helped us lower our garbage disposal costs. However, the labour time required for sorting and reconditioning first slowed us down and reduced throughput. I believe that as we optimise and automate these procedures, resource productivity will improve and costs will decrease. For the time being, we are striking a balance by investing in the future, even if it puts a burden on current capacity.

7. Which Industry 5.0 technologies—such as digital twins, AI, IoT, collaborative robots, and human-machine collaboration—are being used or are being considered in your business?

Manager 2 - We are only beginning to investigate these. We put basic IoT sensors on two crucial machines to monitor temperature and vibration for predictive maintenance. We are also investigating collaborating robots for a repeated soldering activity that causes operator fatigue. We are in talks with a vendor about installing a modest AI-based flaw detection camera on our final inspection line. We are now unable to afford a full digital twin, so we are considering a simplified simulation tool for line balance. Human-machine collaboration is on our radar; we want technology to complement our people rather than replace them.

8. What effects have these technologies had on how your team keeps an eye on, manages, or enhances processes?

Manager 2 The IoT sensors have been a game changer for our two machines, preventing three unplanned downtimes by detecting faults early. Rather than waiting for anything to break, the team now checks the dashboard on a daily basis. The rest of the impacts are limited because we are still in the pilot phase. However, so far, the feedback has been positive: having real-time data gives operators a sense of control. We are beginning to shift from "fix it when it breaks" to "prevent it from breaking," which is a significant cultural change.

9. Which opportunities do you think Industry 5.0 presents for enhancing sustainability, quality, or flexibility?

Manager 2 - I see three major opportunities. First, consider sustainability: real-time energy monitoring can help us reduce usage and expenditures. Second, quality: AI-powered inspection can detect problems that humans miss, decreasing scrap and rework. Third, flexibility: cobots can be readily reprogrammed for new products, which is critical for us because we produce small batches for various clients. Overall, Industry 5.0 can help us achieve more with less – less waste, energy, and labour strain — while remaining competitive.

10. When using these technologies, what obstacles—technical, cultural, budgetary, and skill-related—have you faced?

Manager 2 - All of them. Technically, integrating sensors with our older machines has proven difficult; we required special adapters. Some elderly employees are concerned that automation may eliminate their jobs, so we have had to reassure them. Budget-wise, every pound counts; we can not afford large upfront investments, so we have had to phase them out cautiously. There is a substantial digital skills gap—not everyone can interpret sensor data or program a cobot. We had to hire external trainers, which increased the expense.

11. Could you give an example of a recent process redesign project motivated by new technology or environmental considerations? What was the result?

Manager 2 - We rebuilt our wave soldering line after discovering excessive energy use and solder waste. We upgraded to a new energy-efficient heater and incorporated a solder recovery system. We also reorganised the line layout to minimise operator movement. The result was a 20% reduction in energy consumption per unit, a 15% reduction in solder waste, and a 10% faster cycle time. It was not a large initiative, but it demonstrated how tiny, targeted adjustments may result in environmental and efficiency gains.

12. When rethinking procedures, how do you strike a balance between operational efficiency and sustainability?

Manager 2 - I aim for easy wins where both benefit, such as eliminating waste to save money. When they disagree, I utilise a straightforward scoring system: we rank each option based on cost, environmental impact, quality risk, and employee safety. If a sustainability project has a significant negative impact on efficiency, we gradually implement it or find a solution. I also involve the team in the decision-making process; if operators see a benefit, they are more prepared to accept a temporary speed reduction. Transparency is crucial.

13. What measurements or indicators do you use to determine whether changed processes are "more sustainable"?

Manager 2 - We track:

Waste per unit produced (kg)

Energy usage per unit (kWh)

Scrap Rate (%)

Recycling rate (percentage of garbage diverted from landfill)

Number of safety incidents.

Water use (if applicable)

The cost of garbage disposal

If these figures improve following a change, we believe it is more sustainable. We also perform a rapid cost-benefit analysis to confirm financial viability.

14. How does your organisation's process redesign take into account both environmental impact and staff well-being (a core Industry 5.0 principle)?

Manager 2 - We attempt to keep people informed. Before any redesign, we ask: "Will this make the job safer or easier?" We designed the soldering line with ergonomic lifts to reduce bending. We also ensure that adjustments do not unfairly raise the burden. Following installation, we survey operators to gather input on fatigue and satisfaction. If our well-being suffers, we make adjustments. Our success criteria include both environmental and human outcomes; neither should be prioritised above the other.

15. How has incorporating circular economy and Industry 5.0 concepts influenced how you make operational decisions?

Manager 2 - It has helped me think more holistically. Previously, I focused nearly solely on speed and cost. Now I am asking, "What is the long-term impact on resources?" Will this technology yield energy savings? "How will this impact our people?" I am also more data-driven; I will not authorise a new machine until I have seen its energy rating and maintenance records. These notions have stalled certain decisions, but I feel they are improving and making them more future-proof.

16. What kinds of trade-offs do you often make between sustainability, cost, speed, and quality?
How do you get them resolved?

Manager 2 - Speed versus sustainability is the most prevalent trade-off. Sorting recyclables, for example, takes time and causes the queue to lag. Another consideration is cost versus green investment: we want to purchase energy-efficient equipment, but the upfront cost is prohibitively expensive. We address these issues by phasing changes: we install sustainability measures gradually while assessing the impact on speed and cost. We also seek ****Funding or Grants**** for green technology. If a trade-off is unavoidable, we communicate explicitly with the team and establish a date for reassessment.

17. Which information or data do you rely on the most when considering whether to use a new technology or circular practice?

Manager 2 - I rely on first-hand information from pilot tests. I also consider the total cost of ownership (not just purchase price), energy ratings, maintenance histories, and supplier case studies. I require information on material recovery rates and waste composition to support circular practices. I am sceptical of marketing claims; I prefer concrete numbers. Our growing IoT data is becoming my most reliable source.

18. How do you include cross-functional teams or frontline staff in sustainability and digital transformation decision-making?

Manager 2 - We host monthly improvement sessions where operators, quality assurance, and maintenance personnel can exchange ideas. I also hold small seminars before major changes to solicit feedback. For digital projects, we select a "champion" from the shop floor to test the technology and provide feedback. We have a suggestion box (both real and digital), and useful suggestions are rewarded with minor prizes or acknowledgement. When people perceive that their contributions are making a difference, they get more active.

19. Which managerial competencies do you believe are most important for spearheading this kind of operations transformation?

Manager 2 - For us, the best ones are:

Pragmatism is recognising what is doable given our size and budget.

Communication - expressing the "why" clearly to sceptical employees

Problem-solving involves discovering low-cost workarounds.

Patience - change takes time, especially in a small business.

Basic data literacy entails comprehending what the numbers mean.

Empathy: listening to the operator's worries.

Without them, even good ideas might fail.

20. How can you motivate staff members to take charge of innovation and sustainability projects?

Manager 2 - Showing them that their thoughts are important. When someone offers an improvement, we implement it swiftly and demonstrate the benefits. We publicly acknowledge wins, no matter how minor, and link efforts to team goals. We also provide autonomy by allowing them to own a modest project from inception to completion. When people feel trusted and can see the results of their efforts, they take ownership. Incentives are beneficial, but recognition and respect go further.

21. Which forms of instruction or training have been most successful in fostering digital literacy and circular thinking among your team?

Manager 2 - Training that is hands-on and delivered at the right moment is most effective. For example, we conducted a 30-minute session on the IoT dashboard just before it went live, demonstrating exactly what to look for. For circular thinking, we performed a product disassembly exercise, disassembling a unit and discussing how each material may be reclaimed. Peer education is also effective; we identified a few digitally competent operators and trained them to advise others. Formal classroom instruction did not work as effectively; people tuned out.

22. Could you give an example of a time when front-line staff made a suggestion that altered your operations or sustainability strategy?

Manager 2 - Yes. An assembly operator observed that we were abandoning silicone gaskets from prototypes that might be cleaned and reused in non-critical tests. She recommended a tiny cleaning station. This resulted in a broader examination of prototype waste, and we now have a common methodology for reusing specific components. Her advice was modest yet effective, and we recognised her at our town hall.

23. In terms of Industry 5.0 and the circular economy, how do you see your company's activities changing over the next three to five years?

Manager 2 - In 3-5 years, I envision us being moderately round and digitally enabled. We will probably have recycling for most main materials, a full refurbishing line for returns, and IoT on all critical machinery. We will probably have at least two cobots working alongside the operators. Decisions will be increasingly data-driven, and sustainability will be one of our primary KPIs. I also anticipate that our staff will get more comfortable with digital tools and more aware of circular ideas – it will become a natural part of how we work, rather than an optional extra.

24. What guidance would you offer other factory managers starting a comparable strategic operations change based on your experience?

Manager 2 My advice:

Start small and prove the notion; do not try to change everything at once.

Talk to your team early on; they will identify challenges and opportunities that you may overlook.

Focus on immediate victories that save money and eliminate waste to gain traction.

Use statistics to support investments and clearly demonstrate the ROI to leadership.

Continuous training is essential, as skills are your most powerful tool.

Be realistic about your resources; you do not need to be Amazon to achieve progress.

Be persistent – transformation is a marathon, not a sprint.

Most essential, stay focused on the goal: we are doing this to develop a stronger, more resilient firm in the long run.

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