# Lean-Sustainability 4.0 in Aerospace: Developing an Integrative Operational Model through an Exploratory UK Case Study

**Mohamed Addajou**

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## Abstract

The aerospace industry is undergoing significant transformation, driven by the need to enhance operational efficiency, meet ambitious environmental targets, and respond to increasing complexity, regulation, and digitalisation. Although Lean, Sustainability, and Industry 4.0 (I4.0) have each received scholarly attention, their combined integration remains under-explored, particularly within the aerospace sector. This research addresses this gap by developing a Lean-Sustainability 4.0 (LS4.0) model tailored to the aerospace sector.

The study identifies seven higher-order capabilities - Leanness, Information, Knowledge, Technological Infrastructure, People, Collaboration, and Culture- and four contingency characteristics - Compliance, Complexity, Novelty, and Ecosystem that significantly shape how integration unfolds in aerospace operations. These capabilities and contingencies influence outcomes through a Safety, Quality, Delivery, Cost, Environment, and People (SQDCEP) performance lens. Together, these elements form a capability, and context sensitive LS4.0 model underpinned by Dynamic Capabilities Theory and Contingency Theory.

Methodologically, the research adopts an interpretivist single-case study of a leading UK aerospace organisation, combining a scoping review with fifteen semi-structured interviews, document analysis, and site observations. A two-round Delphi with a four-expert panel refines and validates the model's relevance across organisational and sectoral conditions.

This research contributes theoretically by linking Lean, Sustainability, and I4.0 within a coherent, empirically grounded framework tailored to the aerospace context. Practically, the study provides organisations with a roadmap navigating the complexities of digital and Sustainability transformation through Lean. Limitations include the single-case design and the use of small Delphi panel, which may constrain generalisability. Nonetheless, the study offers a robust foundation for future empirical testing across diverse high-value manufacturing sectors and highlights implication for theory, policy, and practice.

**Key Words:**

Lean Sustainability 4.0, Industry 4.0, Digitalisation, Lean, Sustainability Triple Bottom Line, Aerospace Industry, Sustainable Operational Excellence, Dynamic Capabilities Theory, Contingency Theory, Qualitative case study, Delphi Study, Performance measurement.

## Declaration

I declare that the work in this thesis was carried out in accordance with regulations of the University of Gloucestershire and is original except where indicated by a specific reference in the text. No part of this thesis has been submitted as part of any other academic award. The thesis has not been presented to any other educational institution in the United Kingdom or overseas.

Any views expressed in this thesis are those of the author and in no way represent those of the University of Gloucestershire.

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رَّبِّ زِدْنِي عِلْمًا

***"My Lord, increase me in knowledge."***
*(Qur'an, Surah Taha, 20:114)*

## About the author

Dr. Mohamed Addajou is an experienced professional in Operations Management and Quality Management, and holds a PhD the University of Gloucestershire, United Kingdom. He has over fifteen years of international industry experience, having worked across the United Kingdom and France.

Dr. Addajou holds an MBA from Sorbonne Business School (Université Paris 1 Panthéon-Sorbonne) and has held leadership positions in renowned international organisations, where he currently serves as an Engineering Supplier Quality Development Lead.

A Chartered Quality Professional (CQI) and IRCA certified Aerospace Lead Auditor, he combines extensive professional expertise with academic inquiry and brings a diverse cultural and international perspective to his research.

## Dedication

To my beloved parents,

for their unconditional love, enduring patience, and countless sacrifices.

This journey would not have been possible without your strength and support.

To my son, Musa,

you were born during this PhD journey.

Your smile, energy, and spirit gave me the courage to keep going,

even through the most difficult moments.

This is for your future.

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I would like to extend my appreciation to the management team at my organisation for their flexibility and support during the research process. Special thanks go to the case study organisation and its leadership for their openness, trust, and valuable contributions. Their engagement made it possible to generate meaningful knowledge that contributes to both practice and theory in the aerospace sector.

Finally, to my parents – thank you again. Your values are the compass I carried through this long and challenging road.

And to Musa - you gave this journey purpose beyond academia.

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## Acronyms and Abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| CAA | Civil Aviation Authority |
| EASA | European Union Aviation Safety Agency |
| EU | European Union |
| GDPR | General Data Protection Regulation |
| HR | Human Resources |
| I4.0 | Industry 4.0 |
| IATA | International Air Transport Association |
| IoT | Internet of Things |
| JIT | Just-In-Time |
| KPI | Key Performance Indicator |
| LS4.0 | Lean-Sustainability 4.0 |
| OEM | Original Equipment Manufacturer |
| OT-IT | Operational Technology - Information Technology |
| R&D | Research and Development |
| RQ | Research Question |
| ScR | Scoping Review |
| SLR | Systematic Literature Review |
| SME | Small and Medium-sized Enterprise |
| VSM | Value Stream Mapping |

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# Chapter One
# Introduction

## 1.1 Background and Context

The aerospace industry represents one of the most advanced and high-stakes sectors globally, driving innovation, technological progress, and national security. In the UK alone, the industry contributes over £35 billion annually, supporting more than 100,000 high-skilled jobs and positioning the country among the top aerospace producers worldwide (Department for Transport, 2020). Aerospace spans both civil and defence domains, encompassing commercial aircraft, satellites, military jets, and space systems, each governed by complex supply chains, stringent quality demands, and rigorous regulatory frameworks. Aerospace manufacturing is fundamentally distinct from other industrial sectors. It is characterised by low production volumes, high product complexity, and long development cycles, often spanning 10 to 15 years for new platforms (Amrani & Ducq, 2020, Chang et al., 2013). Each aircraft is a sophisticated system of systems, integrating advanced materials, electronics, propulsion, and control systems with little tolerance of error. This complexity is further intensified by regulatory oversight from bodies such as the European Aviation Agency (EASA) and the UK Civil Aviation Authority (CAA), which impose stringent compliance requirements across design, production, and traceability.

Historically, the industry has relied on an artisanal production model, prioritising craftsmanship, precision, and bespoke engineering over mass production. Unlike automotive industry, which optimises for scale and uniformity, aerospace builds in dozens rather than millions. This makes operational efficiency a persistent challenge and increases reliance on skilled human labour. However, in recent years, this paradigm is being challenged.

The sector faces unprecedented pressures. In civil aviation, backlogs exceeding 15,000 aircraft orders reflect surging global demands for air travel and fleet renewal (ADS, 2023, 2025). In parallel, defence aerospace is undergoing its own transformation, marked by next-generation fighter programmes, e.g., GCAP, drone warfare, and growing emphasis on digital and sustainable defence capabilities. These trends amplify the need to scale production capacity without compromising quality or regulatory compliance.

At the same time, the environmental footprint of aerospace is under growing scrutiny. The sector accounts for approximately 3% of global $CO_2$ emissions, with expectations that this share will increase without systemic change (World Economic Forum, 2022). Regulatory frameworks and stakeholder pressures are converging to push for net-zero emissions by 2050, and for many firms, net-zero operations as early as 2030. In the meantime, technological disruption via Industry 4.0 (I4.0) is reshaping manufacturing landscapes through the introduction of automation, artificial intelligence (AI), big data analytics (BDA), and cloud computing (CC), offering new tools but also raising integration and investment challenges.

In this context, aerospace manufacturers find themselves at a strategic inflection point. Traditional operational models which are highly manual, resource-intensive, and resistant to rapid change, are no longer sustainable. The need for agility, resilience, and Sustainability demands a rethinking of how operations are designed, managed and continuously improved.

This study contends that addressing these pressures requires not isolated interventions, but an integrative operational logic, what is here termed the LS4.0 model. Lean provides the foundational operational discipline through waste elimination, value creation, flow optimisation, and problem-solving (Liker, 2021, Womack et al., 1991). Sustainability, articulated through the triple bottom line (Elkington, 1998), embeds long-term thinking across economic, environmental, and social dimensions. I4.0 technologies offer the digital intelligence to accelerate, scale, and monitor this transformation (Kagermann, 2014). However, as this research shows, these paradigms are not inherently synergistic, they must be aligned through strategy, leadership, and capability development.

The rationale for LS4.0 in aerospace is therefore twofold: first, to address operational inefficiencies endemic to low-volume, high-complexity production, and second, to respond to intensifying sustainability and digitalisation imperatives in a coherent, context-sensitive way. This study investigates how LS4.0 can serve as a transformation blueprint, offering aerospace manufacturers a pathway to remain competitive, compliant, and future-ready.

### 1.2 Industry Challenges and Pressures

The aerospace sector is undergoing profound transformation, driven by a confluence of operational, environmental, and technological pressures. These challenges are not isolated, they are interconnected and systemic, creating an urgent need for a strategic response that moves beyond incremental improvements. This section critically examines the sector's key pressures and articulates why a Lean, Sustainability, and I4.0 integration approach is not only timely but essential for future competitiveness and resilience.

#### 1.2.1 Scaling under Constraint: The Backlog Challenge

A defining pressure on the aerospace industry is the unprecedented surge in demand for commercial aircraft, resulting in a backlog exceeding 15,000 civil aircraft orders worldwide (ADS, 2023, 2025). This figure reflects booming air travel markets in Asia, fleet renewal initiatives in Europe and North America, and ambitious net-zero targets that necessitate new, fuel-efficient platforms (Airbus, 2024, Boeing, 2024, IATA, 2023). Whilst this backlog signals market confidence, it also exposes structural limitations in the industry's capacity to scale production without compromising safety, quality, and sustainability.

Historically, aerospace production has prioritised quality over volume, producing aircraft and systems in small batches, often in dozens per month, through labour-intensive and highly customised processes (Alves & Alves, 2015). In contrast, today's demand environment necessitates a shift toward repeatable, scalable, and data-driven operations, similar to what has been achieved in the automotive industry. However, this transformation must account for aerospace's unique constraints – zero-defect tolerance, regulatory oversight, and multi-tier global supply chains, making a simple transfer of high-volume Lean models inadequate (Amrani & Ducq, 2020).

#### 1.2.2 Post-Pandemic Fragility and Geopolitical Tensions

The COVID-19 pandemic laid bare the fragility of aerospace supply chains. Global lockdowns halted production, disrupted logistics, and led to workforce layoffs and skills attrition. Simultaneously, geopolitical events such as Brexit and the war in Ukraine have further destabilised supply networks, particularly for critical materials such as titanium and semiconductors (McKinsey, 2024, Reuters, 2024). These disruptions have highlighted the risks of over-Lean, under-digitalised systems that lack visibility, flexibility, and redundancy.

Just-in-time (JIT) principles, once seen as efficiency enablers, are increasingly being scrutinised for their contribution to systemic brittleness (Tang et al., 2009). Aerospace manufacturers are thus being forced to reimagine Lean beyond inventory reduction, incorporating real-time visibility, predictive analytics, and resilience-by-design, all of which point to the need for Industry 4.0 capabilities integrated within a Lean foundation.

### 1.2.3 Sustainability Imperatives and Regulatory Demands

In parallel, environmental sustainability has become a strategic imperative. Aviation is responsible for approximately 3% of global CO2 emissions, and with passenger and freight demand projected to rise, this figure could double by 2050 if left unaddressed (World Economic Forum, 2022). Governments, regulators, and the public now demand measurable progress in decarbonising the sector.

In response, regulatory bodies such as EASA and global alliances like IATA have introduced ambitious targets: net-zero flight emissions by 2050, and operational emissions neutrality at the organisational level by 2030. Programmes like the EU Clean Aviation Joint Undertaking and national strategies in the UK further raise expectations for lifecycle emissions tracking, sustainable aviation fuel adoption, and circular manufacturing principles (EASA, 2023).

These trends place enormous pressure on OEMs and suppliers to embed environmental performance into design, sourcing, and operations, not as a marketing add-on, but as a core operational logic. Traditional Lean, with its narrow focus on cost, inventory, and flow, is insufficient on its own. What is needed is a Lean system reimagined through the lens of Sustainability, aligning waste reduction with carbon reduction, and continuous improvement with life-cycle responsibility.

### 1.2.4 Digital Transformation: Promise and Paradox

The fourth industrial revolution, or Industry 4.0 (I4.0), has introduced potentially new revolutionary tools, including the internet of things (IoT), artificial intelligence (AI), big data analytics (DBA), cloud computing (CC), and additive manufacturing (AM), that could change how aerospace firms design, build, and support aircraft (Antony et al., 2023, McDermott et al., 2022). These technologies offer unprecedented opportunities for process monitoring, traceability, predictive maintenance, and agile production.

However, the adoption of these I4.0 technologies is far from straightforward. Stringent aerospace certification requirements, cybersecurity risks, e.g., ITAR and data sovereignty, legacy OT-IT disconnects, and limited digital maturity across suppliers impede seamless integration (Antony et al., 2023). Furthermore, digital transformation without Lean process maturity can result in “digital waste”, automation of inefficient processes that adds complexity without value (Alieva & Haartman, 2020, Alieva & Powell, 2023, Hines et al., 2025).

Therefore, digital solution alone is not sufficient, the sector arguably requires an integrated approach where Lean provides the operational discipline, Sustainability the normative direction, and I4.0 the digital infrastructure for acceleration and scale. Therefore, the three concepts potentially act together in what this study frames as the Lean-Sustainability 4.0 (LS4.0) system.

### 1.2.5 Systemic Misalignment and Integration Gap

Despite growing recognition of these challenges, responses remain fragmented. Many firms pursue Lean, Sustainability, and I4.0 as separate initiatives, often siloed in different departments, e.g., quality owning Lean, EHS managing Sustainability, and IT or engineering driving digital tools. This results in a disjointed transformation landscape, where synergies are lost, and tensions, e.g., JIT-frequent transportation vs carbon emissions remain unresolved (de Sousa Jabbour et al., 2018, Singhal et al., 2024).

The emerging Lean, Sustainability, and I4.0 literature confirms this fragmentation: integration of the three paradigms is rare, poorly theorised, and seldom validated in high-complexity sectors like aerospace (Kamble et al., 2020, Mesquita et al., 2022). However, practitioners are left without robust models that explain how to harmonise these paradigms in practice, especially under contingency characteristics like compliance, novelty, supply chain fragmentation, and technological maturity.

## 1.3 Theoretical Foundations and Conceptual Framing

Addressing the complex operational transformation required in aerospace manufacturing necessitates more than descriptive or prescriptive models. Addressing the complex operational transformation required in aerospace manufacturing requires robust theoretical framing that explains how organisations can adapt and reconfigure capabilities over time, and how these adaptations must be shaped by the operational context in which they occur.

This study draws upon two complementary theoretical lenses: dynamic capabilities theory (DCT) and contingency theory (CT). Together, they offer a powerful framework to explore how aerospace organisations sense, seize, and transform capabilities in rapidly changing environments, and under what context conditions such integration efforts succeed. This combination provides a more holistic foundation than alternative lenses often applied in operations research.

### 1.3.1 Dynamic Capabilities Theory Over Resource-Based View

The resource-based view (RBV) has been widely used to explain competitive advantage by emphasising valuable, rare, inimitable, non-substitutable resources (Barney, 1991). However, RBV is essentially static. It explains what resources organisations have but not how they adapt and reconfigure them in fast-changing environments (Carmona, 2022, Wójcik, 2015). For aerospace, where firms face digital disruption, shifting sustainability regulations, and volatile demand, such adaptability is central. As a concept, dynamic capabilities theory, introduced by Teece et al. (1997) and further developed by Teece (2007), centres on how firms build and renew their capabilities to adapt to rapidly changing environments. Unlike static resource-based views that emphasise existing competences, DCT extends RBV by focusing on how organisations evolve and reconfigure their resources, routines, and knowledge in response to external and internal stimuli.

Dynamic capabilities theory outlines three core dimensions:

- Sensing – identifying opportunities and threats in the environment e.g., rising demand and sustainability regulations, digital disruption (Eisenhardt & Martin, 2017, Teece, 2007).
- Seizing – mobilising resources to capture opportunities e.g., investing in digital twins, reconfiguring value streams (Helfat & Peteraf, 2009, Teece, 2007).
- Transforming – continually renewing capabilities and organisational processes e.g., upskilling the workforce, embedding Sustainability into Lean routines (Helfat et al., 2009, Teece, 2007).

Recent studies including Schilke et al. (2018), Teece (2018), and Warner and Wäger (2019) have confirmed the relevance of DCT for operational transformations under Sustainability and digitalisation pressures. Akter et al. (2020) highlight how analytics capabilities reshape competitive advantage through dynamic processes, whilst Benkhati et al. (2023) and Chari et al. (2022) emphasise dynamic configuration in complex, regulated industries. Komkowski et al. (2023) specifically apply DCT to operational excellence in I4.0, arguing that sensing and seizing digital opportunities must be balanced with resilience and human-centric Lean practices. Therefore, DCT offers the conceptual agility RBV lacks, explaining how capabilities evolve in practice rather than remaining static assets (Wójcik, 2015).

### 1.3.2 Contingency Theory Over Institutional or Socio-Technical Perspectives

Whilst DCT explains strategic adaptability over time, it does not sufficiently account for the powerful contextual constraints in aerospace, particularly compliance requirements, globalised supply chains, and product complexity. For this, contingency theory (CT) provides a critical complement. CT asserts that there is no universally optimal management approach; rather, the effectiveness of strategies depends on how well they fit specific environmental, structural, and technological contingencies (Donaldson, 2001).

Alternative lenses, such as institutional theory, focus on legitimacy and isomorphism, explaining how firms conform to norms and regulations (DiMaggio & Powell, 1983). Whilst relevant for aerospace's highly regulated environment, institutional theory is less effective in explaining operational fit and performance variation across contexts. Ketokivi (2006) shows that whilst institutional pressures matter, structural contingency characteristics e.g., volume, complexity, regulation are often stronger predictors of which practices succeed.

Similarly, socio-technical systems (STS) theory has long provided insights into human-technology alignment (Trist & Bamforth, 1951). However, whilst socio-technical systems theory highlights the importance of designing work systems that balance social and technical needs, it underplays macro-level pressures such as certification timelines, ITAR compliance, or net-zero commitments. As McDermott et al. (2022) note, digital transformation in regulated manufacturing requires not only socio-technical alignment but also contingency-aware sectoral adaptation that recognises structural and compliance barriers.

For aerospace, CT's emphasis on fit explains why Lean tools proven in automotive e.g., kanban, cannot be directly transplanted. Instead, they must be adapted to low-volume engineer-to-order production, long lead times, and safety-critical processes. This logic underpins the identification of sector-specific contingencies in this study, complexity, novelty, and ecosystem, which shape the feasibility of LS4.0 integration.

### 1.3.3 Integration of DCT and CT: A Dual-Theoretical Framing for LS4.0

Together, DCT and CT provide a dual-theoretical framing that balances strategic adaptability with operational contextualisation. Based on the scoping review in Chapter Two, this framing is unique in the literature. Prior work typically applies dynamic capabilities theory to digital transformation or innovation capability without a contingent fit argument or applies contingency theory to Lean design LS4.0 without a dynamic reconfiguration lens (Browning & Heath, 2009, Komkowski et al., 2023). However, both theories have been applied independently in Lean or digital transformation studies (Åhlström et al., 2021, Holweg, 2007) and have rarely been integrated or applied to the full Lean, Sustainability, and I4.0 triad in the aerospace context. Guided by dynamic capabilities theory, the empirical data were analysed to identify capabilities that practitioners perceive as cultivating or struggling to develop in pursuit of LS4.0. Similarly, insights into barriers, supply chain constraints, and compliance issues were interpreted through the lens of contingency theory, highlighting how contextual conditions shape the feasibility and success of LS4.0 integration.

This alignment is illustrated in Figure 5-1, introduced in Chapter Five, where the LS4.0 model is presented as a capability-based system shaped by contingency characteristics and enabled through dynamic processes. This dual-theoretical framing also informs the study's qualitative case study design and its analytical focus on both practitioner perceptions (Research Question RQ2.1) and integration barriers and enablers (Research Question RQ2.2). Ultimately, the combination of DCT and CT strengthens the academic rigour and practical relevance of the LS4.0 model, ensuring it is both theoretically grounded and empirically attuned to the needs and constraints of the aerospace sector.

### 1.4 Research Motivation

The motivation for this research is rooted in both the researcher's personal and professional experience in aerospace manufacturing, and in a broader academic and practical need to respond to the mounting challenges the sector faces. The aerospace industry, whilst historically associated with engineering excellence and innovation, is undergoing a significant transformation driven by three interrelated imperatives: the urgency to improve operational efficiency, the growing demand for environmental and social Sustainability, and the accelerating adoption of I4.0 technologies. Despite the clear convergence of these agendas, current operational models remain fragmented, with limited empirical understanding of how Lean, Sustainability, and digitalisation can be integrated into a coherent and context-sensitive approach tailored to aerospace.

At a personal level, the researcher's longstanding involvement in supplier development, quality, and operational excellence within the aerospace sector has fostered a deep appreciation for the complexities of delivering high-performance outcomes in a safety-critical, low-volume, and highly regulated environment. This professional grounding has also brought into sharp relief the limitations of conventional Lean approaches when applied without adaptation to aerospace-specific realities. Simultaneously, the researcher's academic engagement with Lean thinking and Sustainability, particularly the principles of kaizen or continuous improvement, respect-for-people, and value creation, has cultivated a belief in the potential of integrated, human-centred operational systems. This dual practitioner-scholar perspective provides a unique vantage point from which to investigate the evolution of Lean in the age of digitalisation and Sustainability.

From an academic standpoint, there is a growing interest in understanding how Lean methodologies can evolve to incorporate Sustainability and advanced technologies (Buer et al., 2018, Duarte & McDermott, 2025, Sony, 2018). Whilst the individual domains of Lean, Sustainability, and I4.0 have been widely studied, their practical integration remains under-theorised, particularly, in complex and regulated industries such as aerospace (Amrani & Ducq, 2020, Fiorello et al., 2023). Literature on Lean and Sustainability integration has largely focused on environmental benefits and waste minimisation, often overlooking social dimensions such as workforce empowerment, knowledge retention, and inclusion (Garza-Reyes, 2015, Skalli et al., 2023b). In the meantime, the literature on Lean-4.0 convergence tends to focus on tool-level synergies, such as predictive maintenance or digital visualisation, whilst underexploring the capability-building processes required for their adoption (Benkhati et al., 2023, Sony & Naik, 2020). Most notably, few studies explore how Lean can act as a cultural and operational foundation upon which Sustainability and I4.0 technologies can be layered in a phased and strategic manner, an idea supported by recent contributions such as (Duarte & McDermott, 2025, Kamble et al., 2020, Sony, 2018).

The practical motivation for this study stems from the mounting pressures faced by the aerospace industry. The unprecedented civil aviation backlog of over 15,000 aircraft orders (ADS, 2023, 2025) is forcing manufactures to rethink their production strategies. The traditional craftsmanship model-characterised by bespoke, low-volume, high-mix production, is increasingly at odds with the demand for scalability, resilience, and repeatability. At the same time, Sustainability expectations are intensifying, with the aerospace sector contributing approximately to 3% of global CO2 emissions and facing growing regulatory and societal scrutiny (EASA, 2023, World Economic Forum, 2022). Commitments to achieve net-zero operational emissions by 2030 and flight emissions by 2050 necessitate a radical transformation of design, manufacturing, and supply chain practices. In parallel, the adoption of I4.0 technologies, such as CC, AI, and the IoT, offers new possibilities for efficiency and traceability, yet raises challenges related to data governance, legacy systems, and workforce digital readiness.

Despite these converging pressures, there is little empirical guidance on how aerospace firms can develop and sequence the organisational capabilities needed to integrate Lean, Sustainability, and digital transformation. The literature often assumes linear and universal paths of adoption, failing to account for the role of sector-specific contingencies, such as regulatory compliance, ecosystem maturity, and design complexity (Donaldson, 2001, Hines, Holweg, & Rich, 2004). As a result, operational leaders lack a practical, evidence-based framework to guide the transformation process.

This research is motivated by the need to address this gap by developing an LS4.0 model grounded in empirical insights from a UK aerospace manufacturer. The model is designed to be sensitive to the contingency characteristics that shape implementation feasibility, whilst also applying dynamic capabilities theory to explain how firms can evolve through sensing, seizing, and transforming (Teece, 2007). In doing so, the research offers a contribution that is both theoretically informed and practically actionable, providing aerospace practitioners with a context-specific roadmap for operational transformation in the age of Sustainability and digitalisation.

## 1.5 Research Gap

Whilst Lean, Sustainability, and I4.0 have individually been explored across various manufacturing contexts; Lean production and flow (Liker, 2021, Womack & Jones, 1997), Sustainability-oriented operations and environmental performance (Henao & Sarache, 2022, Swarnakar et al., 2022), and I4.0 technologies in production systems (Frank et al., 2019, Moeuf et al., 2018); their threefold integration within aerospace sector remains an underdeveloped research domain, both theoretically and empirically. The distinctiveness of aerospace, characterised by low-volume, high-mix production, regulatory intensity, and extended development cycles, renders much of the generic Lean-I4.0-Sustainability literature insufficiently applicable (Alves & Alves, 2015, Amrani & Ducq, 2020, Murman et al., 2023).

Historically, Lean thinking has been adapted from the automotive industry, where it originated as the Toyota Production System (TPS), optimised for high-volume, low-variability environments (Liker, 2021, Womack et al., 1991). Scholars such as Shah and Ward (2007) and Koenigsaecker (2012) have demonstrated its adaptability across sectors, but its application in aerospace remains partial and often misaligned with sectoral constraints such as bespoke production, zero-defect tolerances, and intensive documentation requirements (Alves & Alves, 2015, Martínez-Jurado & Moyano-Fuentes, 2012). As a result, Lean in aerospace often remains tool-focused and project-based, lacking systemic and strategic integration with broader organisational goals (Amrani & Ducq, 2020).

Recent studies, for example, Garza-Reyes (2015) and Zokaei et al. (2013) Lean-Green, and Buer et al. (2018) and Sony (2018) on Lean-I4.0, have begun to explore these relationships, but still tend to treat the paradigms as bilateral interactions rather than part of an integrated, evolving system. For example, Lean-Green integration is often framed through the lens of shared objectives such as waste reduction or energy efficiency (Chiarini, 2014, Duarte & Cruz Machado, 2017), but overlooks systemic tensions and trade-offs, such as the environmental impact of JIT supply chains (de Sousa Jabbour et al., 2018, Singhal et al., 2024). Similarly, Lean-I4.0 literature typically focuses on technological enablers like cyber-physical systems or data analytics without critically engaging with cultural readiness, workforce digital literacy, or strategic alignment (Benkhati et al., 2023).

Few studies such as Duarte and McDermott (2025), Foley et al. (2022), and McDermott et al. (2022) have explored how these domains intersect in practice, particularly in contexts requiring stringent compliance and long product lifecycles. Whilst conceptual models exist, such as Rahardjo et al. (2023) smart and sustainable manufacturing systems (SSMS) or Kamble et al. (2020) Lean-I4.0 frameworks, these models often remain aspirational or overly abstract when applied to highly regulated, precision-oriented environments like aerospace. Furthermore, most of these integration studies such as Kamble et al. (2020) and Rahardjo et al. (2023) fail to address how organisational capabilities, both technical and cultural, are developed and sequenced over time to enable this integration. This capability gap becomes even more acute when considering workforce empowerment, cross-functional collaboration, or the shift from project-based Lean to continuous digital-sustainable transformation.

The social dimension of Sustainability, such as worker inclusion, knowledge sharing, and employee well-being, remains underrepresented in the literature (Ghobadian et al., 2020, Skalli et al., 2023a). Similarly, the barriers posed by compliance including International Traffic in Arms Regulations (ITAR), data sovereignty, and supplier maturity, are frequent overlooked or treated peripherally despite being central to aerospace transformation (Avila, 2024, Sethi, 2025).

The existing literature also lacks empirical grounding in dynamic and capability-oriented frameworks. Whilst scholars such as Chari et al. (2022) and Wamba and Queiroz (2022) call for dynamic perspectives, there is minimal engagement with DCT or CT in the context of Lean, Sustainability, and I4.0 integration. The notion of sensing, seizing, and transforming (Teece, 2007) remains largely absent from studies on Lean evolution in regulated industries, and there is scant application of contingency theory to guide contextual alignment of integration efforts, despite aerospace's pronounced sector-specificity (Browning & Heath, 2009, Hines, Holweg, & Rich, 2004).

Furthermore, there is a lack of robust, aerospace-specific empirical models that translate these theoretical perspectives into actionable pathways (Duarte & McDermott, 2025). The few studies that exist are either conceptual (e.g.,Komkowski et al., 2023) or exploratory, lacking deep practitioner insight or context-sensitive capability mapping. There is an urgent need for research that empirically identifies how capabilities emerge, are constrained by contingency characteristics such as compliance, complexity, novelty, ecosystem and evolve through digital and Sustainability transitions.

This study directly addresses these gaps by:

1. Integrating Lean, Sustainability, and I4.0 into a unified operational model tailored to aerospace through both a conceptual and empirical lens.
2. Grounding the model in dynamic capabilities theory to explain the mechanisms of capability development and adaptation under pressure.

3. Applying contingency theory to ensure sectoral relevance, acknowledging that Lean, Sustainability, and I4.0 integration must be adapted to context-specific variables like regulatory intensity, supply chain maturity, and production volume.
4. Offering an empirically driven framework based on a qualitative case study within a UK-based aerospace manufacturer, incorporating interviews, site observations, and organisational documents, and
5. Validating and refining the model using the Delphi method to ensure its practical utility and strategic adaptability.

In achieving this, this research intends to make a novel contribution to operational excellence literature by bridging the gap between abstract integration frameworks and the lived realities of practitioners navigating the complexities of Digital-Lean-Sustainable transformation in aerospace.

**1.6 Research Problem**

Despite growing scholarly and industrial interest in Lean, Sustainability, and I4.0, their practical and theoretical integration in the aerospace sector remains fragmented and underdeveloped, particularly in ways that reflect the sector's operational complexity and compliance intensity. This fragmentation has left aerospace manufacturers without a clear, context-sensitive roadmap for transitioning from traditional craftsmanship-based models to digitally enabled, sustainable operations, capable of meeting both market and regulatory demands. The main challenge lies in the absence of a holistic, empirically grounded operational model that captures how Lean, Sustainability, and I4.0 can co-evolve in a high-mix, low-volume environment characterised by exacting safety standards, extended product development cycles, and globalised supply chains (Amrani & Ducq, 2020, Murman et al., 2023). Whilst Lean methodologies have found success in the automotive industry through systematic waste elimination and flow optimisation (Liker, 2021, Womack et al., 1991), their direct application to aerospace remains constrained by sector-specific contingencies such as traceability, manual assembly, and supplier ecosystem maturity (Alves & Alves, 2015, Martínez-Jurado & Moyano-Fuentes, 2012). At the same time, Sustainability imperatives, amplified by civil society demands, climate targets, and sectoral commitments to net-zero emissions by 2050, are reshaping the definition of operational excellence (EASA, 2023, Nations, 2022). The environmental footprint of aerospace, particularly in emissions-intensive manufacturing and materials processing, call for systematic integration of circular economy principles, lifecycle thinking, and energy optimisation (Ghobadian et al., 2020). However, these goals often run parallel rather than in conjunction with Lean strategies, creating silos in improvement efforts.

In the meantime, the adoption of I4.0 technologies, ranging from IoT and Big Data Analytics to digital twins and AI-enhanced value stream mapping, promises enhanced visibility, automation, and decision-making agility (Buer et al., 2018, Kamble et al., 2020). Yet, without a robust Lean foundation and a cultural shift towards digital readiness, these technologies risk becoming disconnected investments rather than transformative enablers (Fiorello et al., 2023, McDermott et al., 2023). Reflecting on these issues, the central problem which this study intends to address is: how can Lean, Sustainability, and I4.0 be effectively integrated in the UK aerospace industry to enhance operational efficiency, Sustainability, and adaptability?

This question addresses not just the “what” of integration, but the “how” and “under what conditions,” requiring a theoretical lens that captures both strategic change and contextual specificity. Therefore, this study adopts dynamic capabilities theory as a guiding framework. DCT explains how organisations adapt to turbulent environments by developing the ability to sense opportunities and threats, seize them through timely action, and transform their resources and routines to sustain competitive advantage (Teece, 2007). In the aerospace context, this translates into sensing Sustainability demands and technological opportunities, seizing them through integration of Lean and digital initiatives, and transforming legacy operations into agile, future-ready systems. However, DCT alone does not address the sectoral uniqueness of aerospace, including regulatory constraints, long product cycles, and supply chain immaturity. Therefore, this study also draws on contingency theory (CT), which posits that there is no one-size-fits-all solution; rather, operational strategies must be tailored to context-specific variables (Browning & Heath, 2009, Donaldson, 2001). CT is particularly relevant in aerospace, where compliance requirements, product complexity, and risk aversion demand a calibrated approach to transformation (Amrani & Ducq, 2020, Hines, Holweg, & Rich, 2004).

By combining DCT and CT, this study conceptualises integration as a capability-building journey, where context-aware sensing, seizing, and transforming processes are required to overcome barriers and to leverage enablers. This responds to recent calls to operationalise Lean-Green-4.0 readiness into actionable frameworks tailored to specific sectors and maturity levels, as highlighted by Duarte and McDermott (2025).

In response to this, the present study develops an LS4.0 model that is both theoretically robust and empirically grounded, tailored to the operational realities of the UK aerospace sector. By positioning LS4.0 as a context-sensitive framework, the study seeks to bridge the current disjunction between theory and practice, offering a strategic and operational blueprint that supports the sector's pursuit of excellence, resilience, and long-term Sustainability.

### 1.7 Research Aim and Objectives

The overarching aim of this study is to explore how Lean, Sustainability, and I4.0 concepts can be effectively integrated within the UK aerospace industry to enhance operational efficiency, Sustainability, and adaptability.

This aim reflects a growing imperative within high-value manufacturing industries to pursue operational transformation that is not only efficient, but also sustainable and future-ready. Lean has traditionally focused on waste reduction and process efficiency (Liker, 2021, Womack et al., 1991); Sustainability demands broader environmental and social responsibility (Elkington, 1998); and I4.0 introduces new digital capabilities for real-time decision-making and agility (Buer et al., 2018, Kagermann, 2014). However, how these paradigms can be integrated in a cohesive and context-sensitive manner within the aerospace sector remains underexplored (Amrani & Ducq, 2020).

In response, this study develops and validates an LS4.0 model for aerospace manufacturing, drawing upon the principles of DCT (Teece, 2007) and CT (Donaldson, 2001). This integrated model addresses the sector's unique constraints, such as high product complexity, regulatory intensity, and low-volume production, whilst supporting agility, environmental performance, and resilience.

The research is structured around the following three objectives:

**Research Objective One**

*To critically review and synthesise the core principles and concepts of Lean, Sustainability, and I4.0, and to identify their interrelationships and practical integration themes relevant to the aerospace sector based on existing literature.*

This objective establishes the theoretical foundation by conducting a scoping review, examining 43 peer-reviewed articles, and mapping out key integration pathways. It provides the theoretical and empirical foundation for the conceptual model that will be tested and refined through the empirical work.

### 1.7.1 Research Questions for Objective One

**RQ 1.1** *What is the current state of knowledge regarding the conceptual and operational integration of Lean, Sustainability, and Industry 4.0 in manufacturing industries?*

This question seeks to define the foundational elements of each paradigm, Lean, Sustainability's TBL framework (Elkington, 1998), and I4.0's digital technologies (Kagermann, 2014), and explore their synergistic relationships, as evidenced by the literature review Section 2.2.

- **RQ1.2** *What are the key enablers and barriers to integrating Lean, Sustainability, and I4.0 as identified in the literature?*

Drawing on the scoping review findings, this question identifies key characteristics such as technological, organisational, and regulatory enablers and barriers that influence the integration of these paradigms. These insights are essential for developing a realistic, context-relevant model for aerospace.

- **RQ1.3** *How can the integration of Lean, Sustainability, and Industry 4.0 be applied to the aerospace industry, considering its unique characteristics?*

This question synthesises literature findings into a conceptual framework, leveraging the interconnectedness, and approaches for their integration. This question sets the stage for the empirical exploration in Objective Two.

**Research Objective Two**

*To develop an empirical model for integrating Lean, Sustainability, and I4.0 in the aerospace sector, using insights from a qualitative case study of a leading UK aerospace organisation, guided by dynamic capabilities theory and contingency theory.*

This objective draws on semi-structured interviews with aerospace professionals supported by company documents and direct site observation. The empirical data is thematically analysed to identify how the integration is currently perceived, implemented, and evaluated in practice. This stage generates the initial version of LS4.0 model and uncovers aerospace-specific capabilities, and contingency characteristics.

### 1.7.2 Research Questions for Objective Two

- ***RQ2.1*** *How do aerospace practitioners perceive the practical relevance, benefits, and challenges of integrating Lean, Sustainability, and Industry 4.0 within their operational environment?*

This question captures the lived experience and professional insights of aerospace practitioners as they navigate the integration of Lean, Sustainability, and I4.0 in practice. It addresses a key gap in the literature, where theoretical models often lack validation from real-world perspectives. The question focuses on understanding both perceived benefits, such as performance enhancement and compliance, and challenges such as cost, workforce readiness, and technological infrastructure.

- ***RQ2.2*** *What specific characteristics, including capabilities, barriers, and enablers, influence the development of the empirical model in the case study organisation?*

This question seeks to identify the influencing characteristics, such as capabilities, barriers, and enablers, shaped by contingency conditions. This question ensures the empirical model reflects real-world constraints and leverages literature insights, aligning with the case study’s data collection methods.

- ***RQ2.3*** *How do industry practitioners evaluate the potential influence of the integrated model on operational performance and Sustainability performance in aerospace manufacturing?*

This question assesses the model's perceived value and relevance by examining its influence on key performance areas. It considers both traditional Lean indicators and Sustainability dimensions.

**Research Objective Three**

*To refine and validate the LS4.0 empirical model by achieving expert consensus, ensuring its adaptability, sectoral relevance, and effectiveness for the aerospace context.*

This objective refines the empirical model developed in Objective Two, using the Delphi method to validate its adaptability and effectiveness based on expert feedback from the case study organisation. This question ensures the model addresses aerospace's unique needs and incorporates dynamic capabilities theory's sensing, seizing, and transforming framework (Teece, 2007). This phase finalises the model's practical applicability and theoretical robustness.

### 1.7.3 Research Questions for Objective Three

- ***RQ3.1*** *How can expert feedback from the Delphi method refine the empirical model, ensuring its adaptability to evolving operational and Sustainability challenges, such as regulatory shifts and technological advancements, as framed by dynamic capabilities theory?*

This question focuses on the iterative refinement of the LS4.0 model, ensuring it remains future-proof and sensitive to emerging realities. Through the Delphi process, expert insights validate the applicability of the model and how is capable of evolving with the industry.

- ***RQ3.2*** *What adjustments, informed by Delphi method feedback, are necessary to align the empirical model with the dynamic capabilities required for resilience, scalability and adaptation in the case study organisation, ensuring it meets sector-specific demands and validates its effectiveness?*

This question ensures the model is fit for purpose for long term application in aerospace industry. The model focuses on continuous improvement and practical alignment with sector-specific needs, such as high-mix production, safety-critical components, and

Sustainability goals. The question also ensures the refined model supports dynamic learning, capability development, and strategic alignment.

### 1.8 Justification of Research Questions

This section justifies the formulation and sequencing of the research questions, ensuring alignment with the study's aim and objectives, and reinforcing its theoretical and practical contribution. The research questions are structured into three phases, each corresponding to a research objective:

- Phase 1: Literature synthesis (Objective 1)
- Phase 2: Empirical model development (Objective 2)
- Phase 3: Model refinement through expert validation (Objective 3)

The progression of research questions reflects a design that moves from theoretical exploration to applied empirical validation, underpinned by dynamic capabilities theory (Teece, 2007) and contingency theory (Donaldson, 2001).

#### 1.8.1 Relevance to the Aerospace sector

The aerospace industry operates within a context of exceptional complexity: high-mix, low-volume production, rigorous regulatory environments, long product development cycles, and critical safety demands (Amrani & Ducq, 2020, Murman et al., 2023). This makes it an ideal test field for exploring how Lean, Sustainability, and I4.0 can be operationally integrated in a context-sensitive way.

Despite widespread interest in Lean and digitalisation, most existing models derive from high-volume manufacturing sectors like automotive (Liker, 2021, Womack et al., 1991) and fail to account for the nuanced demands for aerospace. The research questions are therefore designed to close this gap by:

- Surfacing practitioner perspectives (RQ2.1)
- Identifying contextual capabilities and barriers (RQ2.2), and
- Evaluating real and potential performance impacts (RQ2.3),

Whilst staying grounded in the theoretical constructs of DCT and CT.

### 1.8.2 Justification for Research Questions - Objective One

This phase establishes the conceptual and theoretical basis of the research through a scoping review of 43 peer-reviewed articles between 2015 and 2025, focusing on the synergies and tensions among Lean, Sustainability, and I4.0.

**Research Question 1.1:** *What is the current state of knowledge regarding the conceptual and operational integration of Lean, Sustainability, and Industry 4.0 in manufacturing industries?*

This question identifies how the three paradigms have been studied in combination across manufacturing contexts. Most literature focuses on dual integrations, such as Lean-Green (Chari et al., 2022, Zokaei et al., 2013) or Lean-I4.0 (Buer et al., 2018, Sony, 2018), with limited attention to the full triad, particularly in high-complexity sectors like aerospace (Bhadu et al., 2025, Ferreira & Teixeira, 2023).

**Research Question 1.2:** *What are the key enablers and barriers to integrating Lean, Sustainability, and I4.0 as identified in the literature?*

This question extracts recurring characteristics such as top management support, cultural readiness, regulatory demands, and data integration challenges (Fiorello et al., 2023, Gatell & Avella, 2024a). Mapping these supports the identification of capabilities and contingency characteristics for model design.

**Research Question 1.3:** *How can the integration of Lean, Sustainability, and Industry 4.0 be applied to the aerospace industry, considering its unique characteristics?*

Aerospace-specific application is central to this thesis. The literature reveals a scarcity of studies tailored to regulated, low-volume industries. This question uses synthesis to develop a conceptual integration framework, drawing from aerospace’s unique features, long product lifecycles, compliance intensity, and complex supply chains (Gélain, 2021, Nightingale & Srinivasan, 2011).

### 1.8.3 Justification for Research Questions - Objective Two

This phase transitions from theory to practice through an empirical case study of a UK aerospace manufacturer. The aim is to explore how Lean, Sustainability, and I4.0 integration is perceived, could be enabled, and evaluated on the ground.

**Research Question 2.1:** *How do aerospace practitioners perceive the practical relevance, benefits, and challenges of integrating Lean, Sustainability, and Industry 4.0 within their operational environment?*

This question directly addresses the lived experience of practitioners. Whilst theoretical synergies are often assumed, practitioners face practical barriers related to skill gaps, cultural inertia, and lack of system readiness (Skalli et al., 2023a). Their insights are crucial to validate conceptual assumptions and ground the model in reality.

**Research Questions 2.2**: What specific characteristics, including capabilities, barriers, and enablers, influence the development of the empirical model in the case study organisation?

Drawing from contingency theory and empirical findings, this question focuses on how internal and external contextual conditions shape the integration is possible. These include regulatory burdens, e.g., ITAR, REACH, product design complexity, and supplier ecosystem fragility. The identification of higher-order capabilities, e.g., collaboration, culture, and knowledge stems from this analysis.

**Research Questions 2.3:** *How do industry practitioners evaluate the potential influence of the integrated model on operational performance and Sustainability performance in aerospace manufacturing?*

Integration must deliver measurable benefits to gain traction. This question explores influence using the extended SQDCEP performance lens of safety, quality, delivery, cost, environment, and people. Practitioners assess whether Lean, Sustainability, and I4.0 integration can drive meaningful change in areas like emissions, efficiency, inclusion, and traceability (Rahardjo et al., 2023).

### 1.8.4 Justification for Research Questions - Objective Three:

This phase involves refining the model through expert validation using the Delphi method, focusing on consensus-building and future adaptability. The Delphi method allows the model to be stress-tested against practitioner insight whilst preserving anonymity and rigour. This objective leverages dynamic capability theory to frame the model's adaptability (Teece, 2007) and revisits contingency theory to ensure the model addresses sector-specific demands (Browning & Heath, 2009, Crute et al., 2003).

**Research Questions 3.1** *How can expert feedback from the Delphi method refine the empirical model, ensuring its adaptability to evolving operational and Sustainability challenges, such as regulatory shifts and technological advancements, as framed by dynamic capabilities theory?*

This question is critical in refining the empirical model by leveraging expert feedback obtained through the Delphi method, ensuring the model remains adaptable to the aerospace sector's dynamic environment. The Delphi method, known for its ability to achieve consensus among experts through iterative rounds. Linstone and Turoff (1975) provide a structured approach to refine the model by addressing gaps and challenges identified in the case study. Framed through dynamic capabilities theory, this question uses expert feedback to verify whether the model can support sensing, seizing, and transforming capabilities across these shifts. The Delphi method's iterative structure supports robust refinement based on a diversity of views whilst aiming for convergence on core principles.

**Research Questions 3.2:** *What adjustments, informed by Delphi method feedback, are necessary to align the empirical model with the dynamic capabilities required for resilience, scalability and adaptation in the case study organisation, ensuring it meets sector-specific demands and validates its effectiveness?*

This question focuses on translating expert input into specific modifications that strengthen the model's practical applicability. It assesses whether the model enables key dynamic capabilities such as cross-functional collaboration, digital integration, and leadership alignment. By revisiting the context-specific characteristics of aerospace identified in previous phases, this question ensures that refinements enhance the model's ability to deliver sustained performance improvements.

Table 1-1: Research Structure

| | *Research Objective* | *Research Questions* |
|---|---|---|
| *Literature review synthesis* | To critically review and synthesise the core principles and concepts of Lean, Sustainability, and Industry 4.0, and to identify their interrelationships and practical integration themes relevant to the aerospace sector based on existing literature | RQ1.1 What is the current state of knowledge regarding the conceptual and operational integration of Lean, Sustainability, and Industry 4.0 in manufacturing industries?<br><br>RQ1.2 What are the key enablers and barriers to integrating Lean, Sustainability, and I4.0 as identified in the literature?<br><br>RQ1.3 How can the integration of Lean, Sustainability, and Industry 4.0 be applied to the aerospace industry, considering its unique characteristics? |
| *Empirical Exploration* | To develop an empirical model for integrating Lean, Sustainability, and Industry 4.0 in the aerospace sector, using insights from a qualitative case study of a leading UK aerospace organisation, guided by dynamic capabilities theory and contingency theory. | RQ2.1 How do aerospace practitioners perceive the practical relevance, benefits, and challenges of integrating Lean, Sustainability, and Industry 4.0 within their operational environment?<br><br>RQ2.2 What specific characteristics, including capabilities, barriers, and enablers, influence the development of the empirical model in the case study organisation?<br><br>RQ2.3 How do industry practitioners evaluate the potential influence of the integrated model on operational performance and Sustainability performance in aerospace manufacturing? |
| *Refinement and validation* | To refine and validate the LS4.0 empirical model by achieving expert consensus, ensuring its adaptability, sectoral relevance, and effectiveness for the aerospace context.<br>. | RQ3.1 How can expert feedback from the Delphi method refine the empirical model, ensuring its adaptability to evolving operational and Sustainability challenges, such as regulatory shifts and technological advancements, as framed by dynamic capabilities theory?<br><br>RQ3.2 What adjustments, informed by Delphi method feedback, are necessary to align the empirical model with the dynamic capabilities required for resilience, scalability and adaptation in the case study organisation, ensuring it meets sector-specific demands and validates its effectiveness? |

## 1.9 Thesis Structure

This section outlines the structure of the remaining chapters of the study. Chapter Two defines the core concepts of Lean, Sustainability, and I4.0, exploring their interrelationships through a critical synthesis of existing literature, culminating in a conceptual model that serves insights for empirical research. Chapter Three presents the research methodology, which details the qualitative case study design, including the rationale for case selection, data collection methods, and data analysis techniques. The chapter also discusses ethical considerations and introduces the Delphi method used for expert validation of the developed model. Chapter Four presents the findings from the empirical research, derived from interviews, documents, and field observations. The chapter focuses on how the concepts integration is viewed within aerospace manufacturing whilst discussing the findings to the research questions. Chapter Five introduces the LS4.0 integrative model, developed and refined through the case study and expert feedback. The model integrates the three paradigms and outlines its core components, drivers, and application mechanisms for operational and Sustainability performance. Chapter Six offers an in-depth discussion, linking findings to the literature and framework. This chapter explores the theoretical and practical contributions, drawing on dynamic capabilities theory and contingency theory to interpret integration dynamics in aerospace. Chapter Seven summarises key findings, contributions, and practical recommendations for aerospace manufacturers, reflecting on study limitations and suggesting future directions.

# Chapter Two
# Literature Review

## 2.1 Introduction

This chapter establishes the theoretical foundation for the research by critically reviewing the literature on Lean, Sustainability, and I4.0. The chapter examines the core principles of these paradigms, interrelationships, and emerging integration themes in the context of aerospace manufacturing, building on the contextual background provided in Chapter One. This literature review synthesises existing knowledge to address the research questions of Objective One: understanding the core principles and interrelationships of Lean, Sustainability, and I4.0 (RQ1.1), identifying key enablers and barriers influencing integration (RQ1.2), and consolidating theoretical insights to guide empirical exploration (RQ1.3). Although many studies such as Varela et al. (2019) and Mesquita et al. (2022) have examined the integration of these paradigms, there have been few which have developed frameworks tailored to highly regulated, high-precision environments such as aerospace, leaving important contextual issues needing to be addressed. Therefore, this chapter builds on a scoping review which examined 43 peer-reviewed articles published between 2015 and February 2025 and listed in Appendix A. The year 2015 was chosen as a starting point because discourse on the combined relationship between Lean, environmental Sustainability, and I4.0 gained momentum after the conceptual consolidation and operational framing of I4.0 within manufacturing and operational excellence literature (Buer et al., 2018, Mesquita et al., 2022, Sony, 2018). This timeframe captures the most relevant and contemporary debates, aligned with accelerated digitalisation and net-zero agenda. The scoping review was first conducted up to January 2024 and subsequently updated in February 2025 to ensure inclusion of the latest research. However, to meet the comprehensive requirements of a doctorate literature review, this chapter expands beyond the scoping synthesis through a narrative review, synthesising core integration concepts and introducing the theories framing this research. By critically analysing the interrelationships and emerging practical integration themes, the chapter identifies theoretical contributions, research gaps and informs the development of a conceptual framework.

Originally, a systematic literature review (SLR) approach was considered to map the integration of Lean, Sustainability, and I4.0. However, as the review progressed, it became evident that the field, particularly within aerospace, is both underexplored and conceptually fragmented, with only two papers mentioned aerospace in passing. Additionally, the research questions guiding this study are exploratory in nature and intended to map the breadth of a multidisciplinary field. Therefore, a scoping review methodology, following the framework of Arksey and O'Malley (2005), Levac et al. (2010), and Peters et al. (2020), was deemed more suitable. This decision aligns with the guidance of Munn et al. (2018), who argue that scoping reviews are particularly suitable when a body of literature is emergent, heterogeneous, and requires conceptual clarification rather than synthesis of narrowly defined evidence. In contrast to SLRs, which aim to answer focused questions e.g., "what is the effect of intervention X on outcome Y", scoping reviews allow researchers to map key concepts, identify gaps, and clarify the nature of research activity across diverse disciplines.

Applying this approach ensured that the review captured the conceptual diversity, cross-paradigm linkages, and practical integration themes necessary to inform the development of an LS4.0 framework.

Therefore, the objectives of this review are threefold:

1. To establish a comprehensive understanding of the theoretical foundations of Lean, Sustainability, and I4.0, exploring their interconnected nature as identified in the literature.
2. To identify and analyse the drivers, enablers, barriers, and practical integration themes associated with this integration, particularly within aerospace.
3. To highlight research gaps and synthesise insights as a conceptual framework to support the empirical investigation in subsequent chapters.

The chapter is structured as follows. Section 2.2 presents the scoping review, which is included in full due to its standalone, publication-ready format. Section 2.3 provides a narrative literature review covering theoretical and sectoral discussion, including conceptual tensions and synergies. Section 2.4 introduces the conceptual framework developed from the findings and theoretical lenses. Section 2.5 concludes with key insights and transition to the empirical chapter.

**Overview of Chapter Structure**:

Table 2-1: Overview of the chapter

| **Literature Review phases** | | |
|---|---|---|
| **Phase 1** | **Phase 2** | **Phase 3** |
| Scoping Review of Lean, Sustainability, and I4.0 integration in manufacturing and aerospace sector | Narrative Literature Review on theoretical and sectoral foundations | Conceptual framework development, including theoretical foundations, dynamic capability theory and contingency theory, and transition to empirical study |

### 2.2 Scoping Review

This section presents a standalone scoping review that served as the foundational literature synthesis for the study. Originally developed as a journal article, the scoping review is integrated here in full due to its central role identifying theoretical and practical integration themes across Lean, Sustainability, and I4.0, with particular emphasis on the aerospace sector. The paper is reproduced here with its original structure, including abstract, introduction, and contextual framing, preserved to maintain its integrity and coherence as a publication ready contribution.

# Lean and Sustainability in the Industry 4.0 Age with a perspective from the aerospace industry – a Scoping Review


## Abstract

The integration of Lean principles, Sustainability, and Industry 4.0 (I4.0) technologies has gained traction as a transformative approach in modern manufacturing, yet its application in complex, regulated industries like aerospace remains underexplored. This study conducts a Scoping Review of 43 peer-reviewed articles from 2015 to 2025 to examine the state of knowledge on these paradigms' interplay and assess their relevance to aerospace manufacturing. Employing a systems thinking lens, the review addresses three research questions: (1) What is the current conceptual and operational knowledge in integrating of Lean, Sustainability, and I4.0? (2) What are the key enablers and barriers to their integration? and (3) How can their integration be applied in aerospace, considering its unique operational context?

The findings reveal growing academic interest since 2017, with Lean positioned as a foundational enabler, amplified by I4.0 technologies such as Big Data Analytics, IoT, Additive Manufacturing, to improve Triple Bottom Line (TBL) outcomes; economic efficiency, social well-being, and environmental performance. However, challenges such as Lean's efficiency focus conflicting with Sustainability goals, e.g., JIT emissions and barriers like cost and regulatory complexity persist, particularly in aerospace. The review identifies five practical integration themes: technology integration, sustainable operational excellence, supply chain integration, circular economy advancement, and Lean as a dynamic capability. These inform a contextualised roadmap for aerospace manufacturers. The study contributes by refining Lean-Green frameworks through mediating the role of I4.0, offering both theoretical advancements and actionable insights. It also highlights the need for future empirical research to test integration frameworks in complex, regulated industries such as aerospace.


**Keywords:** Lean, Sustainability, Industry 4.0, Aerospace Industry, Operational Excellence, Triple Bottom Line

### 2.2.1 Introduction

Modern manufacturing is becoming increasingly complex, driving a shift towards more integrated, adaptive, and sustainable production models. In response, the integration of Lean principles, Sustainability imperatives, and Industry 4.0 (I4.0) technologies has emerged as a compelling area of research and practice as a means to achieve operational excellence whilst addressing broader societal and ecological challenges. In aerospace, this triadic integration is timely and necessary due to the market shifts in demand and regulation.

Whilst the synergies among Lean, Sustainability, and I4.0 have been increasingly recognised in recent literature (Bhadu et al., 2025, Mesquita et al., 2022), most existing studies adopt a sector-neutral lens, often producing abstract frameworks with limited operational applicability. In particular, little attention has been paid to how LS4.0 can be realised within highly regulated, low-volume, and engineering-intensive sectors such as aerospace. The sector's operational complexity, stringent compliance requirements, and intensifying Sustainability pressures present unique challenges that are insufficiently addressed in generic manufacturing models.

The rationale for this review stems from the dual recognition that: 1) integrated approaches combining Lean, Sustainability, and I4.0 are theoretically and practically promising, but 2) their applicability to aerospace remains underexplored, fragmented, or conceptually vague. Despite call for more empirical and sector-specific research, for example Costa et al. (2024), Mahajan et al. (2024), a coherent understanding of how these paradigms interact in aerospace operations, both conceptually and operationally, has yet to be fully articulated. This scoping review addresses this gap by systematically mapping existing literature on LS4.0 integration, identifying enabling characteristics and barriers, and proposing how these insights can be adapted to the distinctive realities of aerospace manufacturing.

To guide this investigation, the review is grounded in systems thinking (Senge & Sterman, 1992), which conceptualises Lean, Sustainability, and I4.0 as interdependent subsystems within a broader organisational ecosystem. This lens enables a holistic understanding of how multiple operational paradigms interact across processes, people, technologies, and strategic goals. Adopting this perspective also supports the identification of systemic synergies and tensions, facilitating a more grounded approach to integration.

Accordingly, the scoping review is structured around the following three research questions:

- RQ1.1 What is the current state of knowledge regarding the conceptual and operational integration of Lean, Sustainability, and Industry 4.0 in manufacturing industries?
- RQ1.2 What are the key enablers and barriers to integrating Lean, Sustainability, and I4.0 as identified in the literature?
- RQ1.3 How can the integration of Lean, Sustainability, and Industry 4.0 be applied to the aerospace industry, considering its unique characteristics?

The review begins with a broad synthesis of integration studies across the manufacturing domain to respond to RQ1 and RQ2. The approach then narrowed the focus in RQ3 to explore the implications for aerospace, a sector whose unique production logic, regulatory environment, and Sustainability imperatives make LS4.0 integration both necessary and complex. This structure enables a progressive narrative: moving from general to specific, from conceptual to context, and from theory to practical implication for aerospace, aligning with the scoping review's objective of translating broad findings into actionable, context-specific recommendations (Arksey & O'Malley, 2005).

To address these research questions, the next section presents the theoretical background, covering Lean in aerospace, Sustainability principles and the role of I4.0. Section 2.2.3 details the scoping review methodology, following established guidelines. Section 2.2.4 synthesises key findings from the literature, analysing trends, interconnections, and research gaps. Section 2.2.5 discusses practical integration strategies and Section 2.2.6 to 2.2.9 present discussions, research propositions, theoretical and practical contributions, emphasising relevance to aerospace manufacturing. Finally, Section 2.2.10 concludes the study by summarising key insights, implications and future research directions.

### 2.2.2 Theoretical Background

#### 2.2.2.1 Lean in Aerospace

Lean is rooted in the automotive industry and is considered the most successful business strategy to drive operational excellence (Samuel et al., 2015, Sony, 2018, Womack et al., 1991). The Lean concept was originally initiated by the Toyota Production System (TPS) in the 1950s to drive better performance for vehicle manufacturing and is now implemented beyond its original application to multiple sectors and organisations, including aerospace (Samuel et al., 2015, Womack et al., 1991). At its core, Lean seeks to maximise customer value by eliminating non-value-added activities, improving flow, and fostering a culture of continuous improvement (Bessant & Francis, 1999, Koenigsaeker, 2012, Liker, 2021, Netland, 2016, Shingo, 2021, Spear & Bowen, 1999).

In aerospace, Lean adoption began in the 1990s, corresponding with a period of significant transformation marked by post-Cold War defence budget reductions in the United States. This fiscal pressure compelled aerospace and defence companies to seek new ways to maintain competitiveness and operational efficiency. In response, the Lean Aerospace Initiative was launched at Massachusetts Institute of Technology in collaboration with the United States Air Force, aiming to translate Lean principles from the automotive sector to aerospace (Murman et al., 2023, Nightingale, 2004). The initiative soon gained international momentum, with Lean principles diffusing into the UK aerospace sector through government-backed programmes and academic partnerships focused on enterprise transformation (Garre et al., 2017, Nightingale, 2004). However, aerospace differs significantly from the automotive industry in several key ways, such as low-volume, high-mix production making the implementation of Lean more complex (Amrani & Ducq, 2020, Martínez-Jurado & Moyano-Fuentes, 2012). Unlike the automotive industry, where mass production ensures flow repetitiveness and efficiency, aerospace manufacturing follows a craftsmanship model where aircraft production is measured in dozens per month rather than thousands, requiring tailored Lean applications (Alves & Alves, 2015, Amrani & Ducq, 2020, Hines, Holweg, & Rick, 2004). This directly informs RQ1.2 by highlighting sector-specific barriers to Lean integration.

Despite widespread adoption, aerospace firms often struggle to sustain Lean benefits. For example, Boeing, one of the world's leading aerospace companies when first introduced Lean, failed to sustain Lean efficiencies in the assembly line of the aircraft 737. Additionally, the 787 Dreamliner programme, experienced significant delays and cost overruns (Schmuck, 2021, van Blokland et al., 2010). Crute et al. (2003) argue that aerospace lags 15 years behind automotive, a gap that Martínez-Jurado and Moyano-Fuentes (2012) further attribute to fundamental differences in production models. Martínez-Jurado and Moyano-Fuentes (2012) noted that Lean, originally is an automotive idea and encounters significant hurdles when applied to aerospace due to its low-volume, high-mix production cycle, which lacks the repetitive workflows essential for traditional Lean methods. These implementation gaps reflect broader critiques that many Western firms adopt Lean as a toolkit rather than as a holistic management system, which undermines Sustainability of gains (Hines, 2010, Netland et al., 2020). Furthermore, the sector's stringent regulatory compliance enforced by bodies such as FAA, and EASA and through standards like AS9100 mandate extensive documentation, traceability, and quality control. These demands often conflict with Lean's emphasis on flexibility and just-in-time (JIT) production (Fiorello et al., 2023). These insights build RQ1.3 by identifying the contextual challenges of applying Lean in aerospace, establishing why Lean alone may not achieve sectoral Sustainability and performance goals.

#### 2.2.2.2 Sustainability in Aerospace

Sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 43). Sustainability is commonly conceptualised through the triple bottom line (TBL) framework, introduced by Elkington (1998) which revolves around three dimensions: economic by ensuring financial viability and operational efficiency, along with social dimension which promotes employee well-being, diversity, and ethical labour practices, and finally environmental dimension whereby reducing emissions, energy consumption, and resource waste. This theoretical framing establishes how Sustainability is understood in management research and contribute to RQ1.1 by clarifying the theoretical foundations used to examine Sustainability.

Within this framework, the aerospace industry faces growing pressure to adopt Sustainability measures due to its significant contribution to global $CO_2$ emissions, currently accounting for approximately 3% annually, whilst still growing rapidly due to increasing demand for air travel and freight (World Economic, 2022). Regulatory bodies and industry leaders are pushing for carbon reduction strategies, with initiatives such as the Clean Skies for Tomorrow Coalition promoting the adoption of Sustainable Aviation Fuel (SAF), which can cut emissions by up to 90-100% (World Economic, 2021). Other Sustainability strategies include lightweight composite materials, electrification of aircraft systems (General Electric, 2021). These approaches highlight current practices, aligning with RQ1.2 by identifying enablers of Sustainability transitions in aerospace.

In 2015, the United Nations introduced the Sustainable Development Goals (SDGs), with Goal 9 emphasising sustainable industrialisation, e.g., innovation and infrastructure, along with Goal 12 focusing on responsible consumption and production (United Nations, 2022). Achieving these goals requires manufacturers to redesign sourcing, production, and supply chain strategies. Advanced technologies such as digital twins, AI-driven predictive maintenance, and blockchain-based supply chains are becoming essential in minimising environmental impact whilst maintaining operational efficiency (Ferrera et al., 2017). However, achieving a balanced approach to the TBL remains a complex challenge, requiring collaboration between regulators, manufacturers, and stakeholders (Cherrafi et al., 2016, Tasdemir & Gazo, 2018). These challenges highlight barriers to Sustainability integration and speak directly to RQ1.2 by demonstrating the organisational and industry level complexities that must be addressed.

This need for resilience in maintaining operational performance whilst responding to regulatory, environmental, and market pressures, highlights the value of integrating Lean practices with I4.0 technologies. Although Lean is often positioned as a Sustainability enabler, it has not been systematically aligned with I4.0 to drive Sustainability outcomes. For example, Varela et al. (2019) found no conclusive correlation between Lean and Sustainability pillars, suggesting that Lean's traditional focus on efficiency may not inherently address broader Sustainability goals without I4.0's technological support. This informs RQ1.3 by demonstrating the aerospace sector's reliance on an integrated Lean, Sustainability, and I4.0 approach to reconcile efficiency, compliance, and carbon-reduction objectives.

#### 2.2.2.3 Industry 4.0

Industry 4.0 (I4.0), announced by the German Government at the Hannover Industrial Trade Fair in 2011, marks the fourth industrial revolution (Bartodziej, 2017, Kagermann et al., 2016). I4.0 is driving manufacturing systems towards digitalisation through interconnected cyber-physical systems (CPS), the internet of things (IoT), and big data analytics (DBA), enabling real-time decision-making and automation (Davis et al., 2020, Frank et al., 2019, Gilchrist, 2016).

I4.0 integration occurs through three primary dimensions: horizontal, vertical, and end-to-end engineering integration (Ferrera et al., 2017, Sony, 2018). Horizontal integration refers to collaboration and data exchange across the supply chain and value networks. Vertical integration connects machines, sensors, and control systems within factories into adaptive networks. End-to-end engineering integration links product development, design, and lifecycle management to enable customised production. Recent work also highlights how cyber-physical systems and virtualisation deepen this integration by linking physical assets with digital models for monitoring and decision-making (Rosin et al., 2020, Stock et al., 2018). Together, these dimensions create the foundation for digitalised, connected manufacturing (Sony, 2018). This conceptual framing contributes to RQ1.1 by illustrating how I4.0 has been theorised as a multi-dimensional transformation framework in the manufacturing literature.

In aerospace, I4.0 presents opportunities to overcome traditional Lean constraints, particularly in achieving flow and processes interconnectivity. Recent studies such as Buer et al. (2018), Sony (2018) and Kumar et al. (2022) emphasise that integrating Lean and I4.0 can improve operational agility, reduced defects, and enhanced Sustainability outcomes.

These opportunities are realised through specific I4.0 technologies. For instance, cloud computing (CC) enables greater connectivity between processes, eliminating constraints between inputs and outputs to ensure consistency (Buer et al., 2018). Additive manufacturing (AM) reduces material waste and enables lightweight component production, improving both economic and environmental performance outcomes (Ghobadian et al., 2020, Jiang et al., 2017). Tools like big data analytics, digital twins, and real-time supply monitoring enhance efficiency and minimise resource consumption (Belhadi et al., 2020). Collectively, these innovations support Lean principles by optimising production flow and eliminating waste, whilst also advancing Sustainability objectives (Buer et al., 2018, Machado et al., 2020). This technological evidence informs RQ1.2 by identifying digital enablers of Lean-Sustainability synergy.

A key challenge, however, lies in aligning human-centric Lean methodologies with data-driven automation to create a resilient, adaptive manufacturing environment. For example, Singhal et al. (2024) identify trade-offs in just-in-time practices, where Lean's efficiency focus increases transportation emissions, a Sustainability challenge that I4.0 can address through optimised logistics using IoT. Varela et al. (2019) concurred and suggested Lean's effect on Sustainability is limited without I4.0's support, indicating that technological enablers are essential to extend Lean's efficiency focus into broader Sustainability outcomes. As aerospace firms navigate regulatory and Sustainability challenges, the adoption of I4.0 will be instrumental in shaping the future of the industry (Torres de Oliveira et al., 2023). This links directly to RQ1.3, highlighting both the potential and the contextual barriers of applying I4.0 to aerospace, where compliance intensity and Sustainability targets demand an integrated approach.

Therefore, combined Lean, Sustainability, and I4.0 emerge as interconnected yet often separately addressed paradigms. Lean provides the operational discipline and process focus, Sustainability offers the normative imperative for environmental and social responsibility, and I4.0 introduces the digital infrastructure to enable integration at scale. However, the literature reveals that these three domains are frequently studied in isolation or through dual combinations, leaving the full triadic integration underexplored. This fragmentation results in unresolved tensions, such as Lean's efficiency-driven just-in-time practices clashing with Sustainability objectives, or Sustainability ambitions lacking the operational and digital mechanisms for implementation. Addressing these gaps requires moving beyond generic manufacturing debates to examine how integration unfolds in highly regulated, low-volume, high-complexity contexts. The aerospace sector, with its unique characteristics and strategic significance, provides a critical testbed for exploring how Lean, Sustainability, and I4.0 can be combined into a coherent framework. The next section introduces aerospace as the empirical and conceptual context for LS4.0 integration.

#### 2.2.2.4 The Aerospace Sector as a Context for LS4.0 integration

The aerospace industry occupies a critical position in the global economy, contributing significantly to innovation, connectivity, and high-value employment. As one of the most technologically advanced sectors, it is shaped by extreme product complexity, rigorous safety and regulatory requirements, and long-term investment cycles. In the UK alone, aerospace contributes over £35 billion annually in revenue, positioning it as a key driver of national competitiveness and industrial capability (Department for Transport, 2020).

What differentiates aerospace manufacturing from other sectors is its distinctive production logic, unlike high-volume industries such as automotive, aerospace operates with low production volumes and high product customisation. Aircraft are manufactured in relatively small batches, often requiring meticulous assembly processes, extensive traceability, and the integration of highly specialised components. Time-to-market for new aircraft programmes can span over a decade, with supplier ecosystems carefully coordinated to deliver critical components just in time (Chang et al., 2013, Murman et al., 2023). This long-horizon, high-stakes production environment reflects not only the sector’s technical sophistication but also its vulnerability to disruptions, inefficiencies, and escalating Sustainability pressures, making it a critical test field for integrated approaches like LS4.0 that combine Lean stability, digital agility, and Sustainability accountability.

The industry’s traditional reliance on manual labour, and bespoke engineering has served its quality and safety-focused ethos well but is increasingly at odds with contemporary operational demands. Aerospace is now experiencing a major transformation driven by multiple pressures: growing commercial order backlogs, exceeding 15,000 civil aircraft globally (ADS, 2023, 2025) shifting the industry to an economy of scale, supply chain fragility exposed by COVID-19 pandemic and geopolitical tensions, workforce shortages, and mounting environmental targets, including zero flight emission by 2050 (Deloitte, 2023). These developments highlight an urgent need for scalable, responsive, and sustainable production models that retain aerospace's precision whilst improving efficiency and resilience. Major airframers such as Boeing and Airbus expect across the supply chain significant investment, cost reduction, improved quality and close to 100% on-time delivery (Gélain, 2021). This evolving context necessitates a fundamental rethinking of how aerospace production systems are designed and managed.

This study proposes that the convergence of Lean principles, Sustainability imperatives, and I4.0 technologies presents a unique opportunity in addressing aerospace challenges and developments. Lean provides a foundation for operational excellence, through customer satisfaction, employees development and processes optimisation (Duarte & McDermott, 2025, Sony, 2018), whilst Sustainability brings attention to long-term environmental, social, and economic outcomes (Elkington, 1998, Liker, 2021). I4.0, through technologies such as IoT, big data analytics, and cloud computing, enables intelligent, real-time decision-making and process automation (Kagermann, 2014). However, existing frameworks rarely accommodate the full complexity of aerospace, particularly its structural and operational systems.

To develop a contextualised integration model, it is essential to understand the sector's defining characteristics. Scholars consistently emphasise five core features: low-volume, high-mix market demand (Amrani & Ducq, 2020), complex fragmented supply chains (Manville et al., 2021), stringent regulatory oversight and certification (Thomas et al., 2016), extreme product complexity (Browning & Heath, 2009), and mounting Sustainability and technological pressures (EASA, 2023, Ghobadian et al., 2020).

**Market Demand**: Aerospace is a low-volume, high-mix, high-margin market, producing customised aircrafts and systems. The strong backlog signals a shift toward high-volume production, challenging aerospace traditional craftsmanship models (Amrani & Ducq, 2020). This demand dynamic illustrates why aerospace requires scalable and digitally supported Lean systems to move beyond its traditional craftsmanship model, a key rationale for LS4.0 integration.

**Supply Chain Complexity:** The aerospace supply chain is overly complex, vertically fragmented network with a pyramid-like structure. At the top of the structure are major airframers like Boeing and Airbus, below are tier-one suppliers, often global original equipment manufacturers (OEMs) such as GE Aerospace, Safran, and Rolls Royce, and thousands of small and medium enterprises (SME) focusing on specific technologies categorised at lower tiers, tier-two and tier-three suppliers (Manville et al., 2021). Airframers push their tier-one suppliers to become risk-sharing partners, self-financing development for exclusive contracts, whilst managing their own tier-two and tier-three suppliers (Gélain, 2021). However, reliance on many small, highly dependent suppliers to directly procure thousands of parts and sub-assemblies, often single sources, factors the supply chain vulnerability, as seen in Boeing’s 787 Dreamliner programme, where a globally dispersed supply chain and reliance on external partners led to delays and cost overruns, despite effort to apply Lean principles disruptions (Denning, 2013, Schmuck, 2021, Tang et al., 2009), reinforcing call for more resilient, risk-aware Lean supply chain designs in aerospace (Chiarini & Kumar, 2021).

**High Regulation**: The sector is governed by stringent standards including AS9100 for quality, EASA/FAA for airworthiness and safety, and ITAR for export controls, mandating rigorous documentation, supplier certifications and compliance audits (Browning & Heath, 2009, Murman et al., 2023). These requirements, as seen in Airbus 350 certification delays and the recent Boeing 777X certification delays, where evolving safety standards and regulatory scrutiny extended the certification timeline from an initial 2020 target to potentially 2026, disrupting production planning and market entry (Sakshi, 2025). Regulatory mandates drive Sustainability, with EASA initiative for sustainable aviation fuel (SAF) requirements pushing net-zero target by 2050, necessitating integrated models to balance efficiency and environmental accountability (EASA, 2023). These regulatory mandates constrain operational flexibility but also drive innovation e.g., SAF requirements. For LS4.0, regulations act as both a barrier and an enabler, shaping how Lean, Sustainability, and digital technologies must be aligned in aerospace.

**Product complexity**: Aerospace products require multi-disciplinary engineering, safety-critical components, and intricate assembly with micrometre tolerances. The industry has long been driven by a design for performance philosophy, developing products that embody the science and art of engineering, innovating the aerodynamics and propulsion, where time to market for military platforms can extend up to a decade due to extensive development, validation and certification (Browning & Heath, 2009, Murman et al., 2023). However, this strong emphasis on design excellence has often resulted in a disconnect at the operational level, contributing to prolonged lead times and production processes that are increasingly difficult to manage and optimise. Therefore, this complexity underscores the need for integrated frameworks like LS4.0 that link design excellence with Lean execution and digital monitoring, ensuring that operational systems keep pace with engineering ambition.

**Sustainability and Technological Pressures**: Sustainability pressures are growing, with aerospace accounting for 3% of global CO2 emissions annually (World Economic Forum, 2022). Initiatives like the EU's Clean Sky programme and Sustainable Aviation Fuel (SAF) adoption aim to address this impact (EASA, 2023, World Economic Forum, 2022). Parallel to these efforts, I4.0 is increasingly being explored in aerospace, focusing on additive manufacturing, generative design and Internet of Things (Ghobadian et al., 2020). However, these advancements are often pursued independently of Lean methodologies, missing opportunities for structured, synergistic approach that aligns operational efficiency with Sustainability objectives, reinforcing the need for LS4.0 to act as an integrative framework rather than fragmented initiatives.

These characteristics underscore aerospace's unique operational and strategic challenges, necessitating an integrated LS4.0 approach. This scoping literature review explores the state of current Lean-Sustainability 4.0 integration models, their alignment with aerospace-specific characteristics, and the development of a contextualised conceptual framework to guide future implementation and research.

In summary, aerospace defining features: market demand, fragmented global supply chains, stringent regulation, extreme product complexity, and rising Sustainability and technological pressures, create a uniquely challenging operational environment. These conditions limit the effectiveness of traditional Lean practices when applied in isolation, and they expose the shortcomings of stand-alone Sustainability initiatives or digital adoption programmes. What emerges is a clear need for an integrative approach: Lean provides the operational discipline to reduce waste and stabilise processes, Sustainability sets the normative direction towards net-zero and social responsibility, and I4.0 offers the digital infrastructure to enable responsiveness and scalability. The convergence of these paradigms within LS4.0 framework is therefore not optional but essential if aerospace is to reconcile efficiency, compliance, resilience, and Sustainability goals. This section establishes aerospace as the critical empirical and conceptual context for the scoping review, providing the foundation for developing a contextualised LS4.0 model.

Because this chapter reproduces the scoping review in its original, publication-ready format, a dedicated methodology subsection 2.2.3 is included to ensure transparency of the review process.

### 2.2.3 Methodology of the scoping review

This study adopted a scoping review methodology following the frameworks of Arksey and O'Malley (2005), which was refined by Levac et al. (2010) and Peters et al. (2020). This approach is appropriate for mapping emergent and fragmented literatures, such as LS4.0 integration in aerospace. The following subsections detail the review protocol and execution. Figure 2-1 summarises the process applied to the scoping review.

#### 2.2.3.1 Planning the review

**a. Step 1: Identifying the Research Purpose and Questions**

This step consisted of identifying the need for the review and formulating the research questions (Arksey & O'Malley, 2005). Currently, the area of combining Lean with Sustainability and I4.0 needs more clarification and requires an understanding of the breadth and depth of the existing body of knowledge. This scoping review specifically investigated the state of knowledge in the aerospace sector and how these paradigms interact rather than treating them in isolation or simply pairwise relationships e.g., Lean and I4.0 or Sustainability and I4.0. A preliminary assessment also revealed a lack of consolidated studies in the aerospace sector. Whilst some studies have explored Lean applications in aerospace such as Amrani and Ducq (2020) and Antony et al. (2021), few have addressed the combined integration of Lean, Sustainability, and I4.0. This underscored the need for an inclusive and exploratory scoping review strategy focused on interdependencies across these paradigms.

**b. Step 2: Developing the Protocol**

The protocol of the review was developed to enhance transparency and ensure consistency across stages. The protocol defined the inclusion and exclusion, search strategy, screening procedures, quality assessment criteria, and methods for analysis and synthesis. This protocol was reviewed with supervisors to ensure transparency and replicability. This step reduced selection bias and clarified how aerospace relevance would be determined.

#### 2.2.3.2 Conducting the scoping review

**c. Step 3: Literature Search**

This phase is comprised of five steps. The search literature, which was step 3 that involved identifying well-known electronic databases to provide comprehensive coverage including: Scopus, IEEE, and EBSCOhost. All these databases also offer practical data extraction in CVS format and in Endnote for convenient screening.

Search terms were developed iteratively, based on preliminary reading and expert guidance, combining Boolean operators of AND / OR to capture various terminologies: “Lean" AND "Sustainability" AND "Industry 4.0". Synonyms, abbreviations and related terms have also been searched for the concepts; in some instances, Industry 4.0 is referred to as digital technologies, Sustainability is referred to as TBL, green manufacturing or sustainable production. Keywords like “aerospace” and “aviation” were deliberately excluded from searches to avoid premature narrowing. In early trials, the inclusion of these sectoral terms yielded negligible results, reinforcing the appropriateness of a broader inclusion strategy. Sector-specific relevance was assessed during the screening stage to ensure that aerospace-relevant insights were not overlooked. This stage produced 122 records across Scopus, IEEE, and EBSCOhost. Including cross-sector studies from manufacturing, automotive, electronics, and energy. A preliminary scan confirmed that aerospace-specific studies were rare, reinforcing the need for inclusive cross-sectoral screening.

**d. Step 4 screening and selection:**

The inclusion criteria were: 1) English-language peer-reviewed journal articles, 2) published between 2015-2025. The year 2015 was chosen as the start year for the search as Industry 4.0 literature only started to appear in that year even though the term or paradigm Industry 4.0 had been initiated or coined in 2011 (Sony, 2018), and 3) explicitly addressing the intersection of Lean, Sustainability, and Industry 4.0. Exclusion criteria were non-English papers, and those addressing only one or two paradigms in isolation. The initial database extraction was conducted on 6 January 2024. To ensure currency, an update search was performed on 16 February 2025, which confirmed the same set leading to the final total of 43 articles. Conference papers were considered in the preliminary screening phase but were subsequently excluded due to lack of depth or relevance. Screening was conducted in three stages: Title and duplicate removal, abstract review, and full-text evaluation. Guided by established protocols (Mesquita et al., 2022, Tricco et al., 2018). From 122 initially retrieved records, 77 from Scopus, 19 from IEEE, 26 from EBSCOhost, duplicates were removed, and 46 articles were excluded at title and abstract stage, leaving 46 papers for deeper screening. At full-text stage, 3 additional IEEE papers and 5 EBSCOhost papers were excluded due to lack of relevance or insufficient coverage, resulting in a final set of 39 articles retained for synthesis (30 from Scopus, 2 from IEEE, and 7 from EBSCOhost). To strengthen coverage, 4 additional studies were identified through snowballing of references, giving a final set of 43 articles for synthesis.

**e. Step 5 Quality assessment**

Although scoping reviews do not typically exclude studies based on quality, an appraisal was conducted to evaluate conceptual and methodological relevance. Each article was assessed for conceptual relevance by ensuring coverage of all three paradigms, methodological rigour for clarity of design, data source transparency, peer-review status, and journal credibility. Studies with weaker empirical grounding e.g., conceptual frameworks without case evidence, were flagged in the synthesis but not excluded, to preserve breadth.

**f. Step 6 Extracting data**

Data extraction form was created in Excel, capturing authors, year, journal, sectoral focus and methodology. Key themes, practical integration themes, and theoretical contributions were also summarised. A snowballing technique complemented the initial search to ensure inclusion of landmark contributions. The screening and extraction process was conducted by the researcher using a structured and iterative protocol. Whilst this single-reviewer extraction ensured continuity and consistency, it also introduced a degree of interpretive subjectivity, a recognised limitation in scoping review. This is acknowledged in the limitations section and was mitigated by adhering to established methodological frameworks and triangulating insights during the narrative synthesis phase.

**g. Step 7 Data Analysis**

Quantitative data, e.g., sectoral coverage, and method types were summarised in tables and charts. For qualitative synthesis, the focus was on analysing synergistic and contextual relationships between Lean, Sustainability, and Industry 4.0, examining how integration was approached, and the dimensions emphasised across studies. Practical integration themes were identified using the affinity diagram, following the approach of Antony, et al. (2021). This technique enabled clustering of extracted insights into higher-order categories including enablers, barriers, and conceptual synergies. Iterative cross-checking against the research questions ensured analytical rigour and alignment with the study objectives.

**h. Step 8: Reporting the Findings**

The findings were synthesised and structured to respond to the guiding research questions. This included both cross-sectoral integration insights and the critical identification of sectoral omissions, particularly the absence of empirical aerospace-focused studies. The reporting aligns with scoping review guidance from Peters et al. (2020), ensuring transparency and methodological rigour. The synthesis directly informed the conceptual framework.

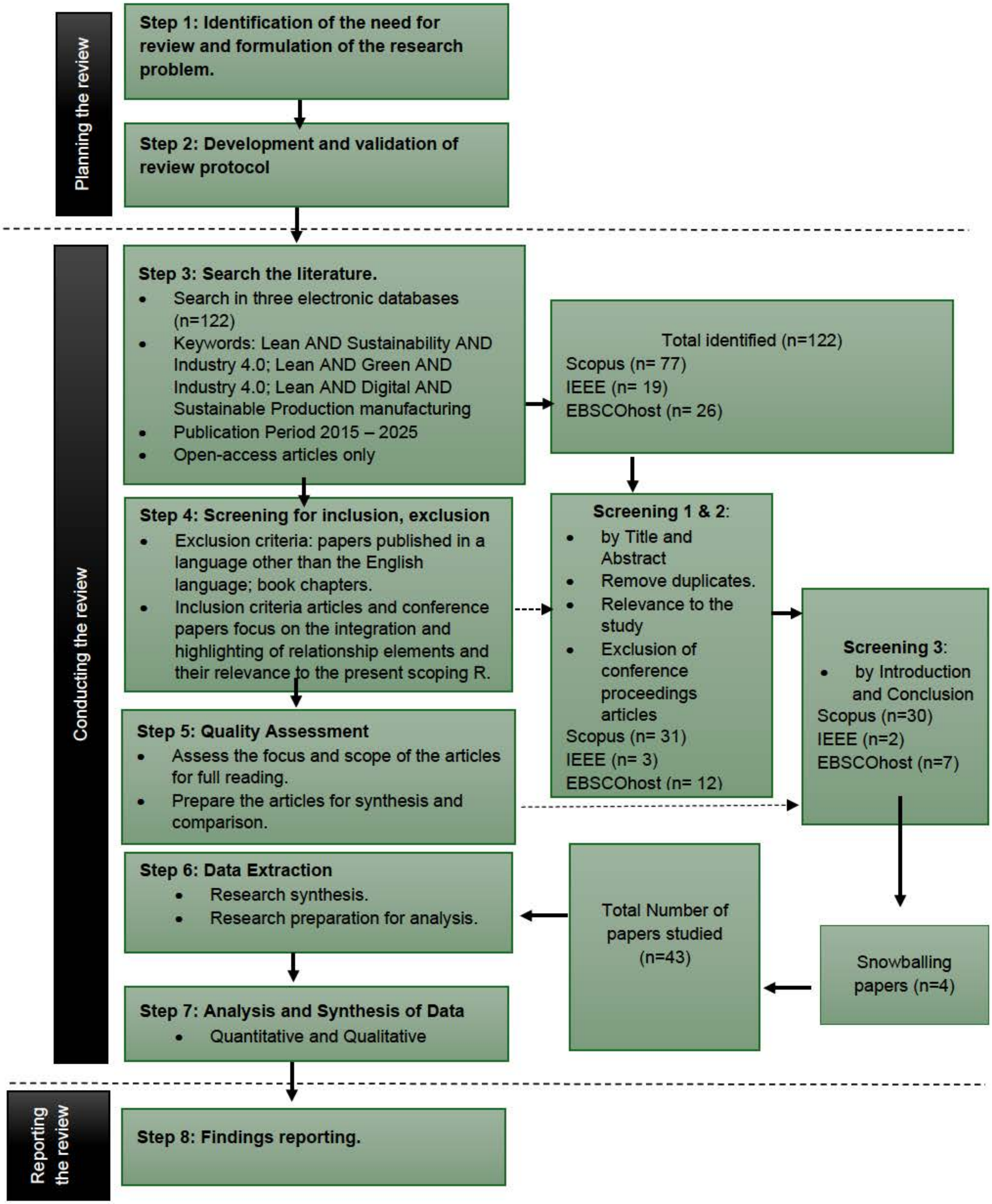


Figure 2-1: The process applied for the scoping review

### 2.2.4 The Synergistic and Contextual Relationship between Lean, Sustainability, and Industry 4.0

#### 2.2.4.1 Overview

The integration of Lean, Sustainability, and I4.0 is a contemporary and rapidly evolving field that has gained significant traction in both academic research and practice. This rising interest is reflected in the distribution of publications over the years, as shown in Figure 2-2, with 2023 and 2024 showing the highest number of published studies in the reviewed dataset. The increasing attention demonstrates a growing recognition of the potential synergies among these paradigms in enhancing operational and environmental performance (Duarte et al., 2019, Mesquita et al., 2022).

A review of leading journals, including *Business Strategy and Environment*, *Sustainability*, and *Journal of Cleaner Production*, indicates that research on this integration is predominantly driven by Sustainability agenda and strategic business perspective over operational efficiency alone. This suggests that whilst the literature recognises Sustainability imperatives, it underexplores how operational disciplines such as Lean and digitalisation can be systematically leveraged to achieve Sustainability goals, a gap this study addresses. Therefore, integration is increasingly acknowledged, but the mechanisms for achieving it remain insufficiently developed. This collective shift highlights how Lean, Sustainability, and I4.0 together support the triple bottom line of economic, social, and environmental outcomes, whilst also shaping long-term organisational competitiveness (Costa et al., 2024).

Figure 2-3 shows the distribution of selected articles across journals, whilst Table 2-2 illustrates the spread of integration efforts are expanding across sectors such as automotive, petrochemical, and mining (Cannas et al., 2025, Ghaithan et al., 2023). However, aerospace remains conspicuously underrepresented. Among the 43 reviewed articles, none focused exclusively on the aerospace sector; only few mention it tangentially (Fiorello et al., 2023, Ghobadian et al., 2020). This absence is especially striking given aerospace's operational complexity and Sustainability imperatives. Therefore, this research directly responds to the need for a tailored integration framework suited to the aerospace sector's high-mix, low-volume, safety-critical manufacturing environment.

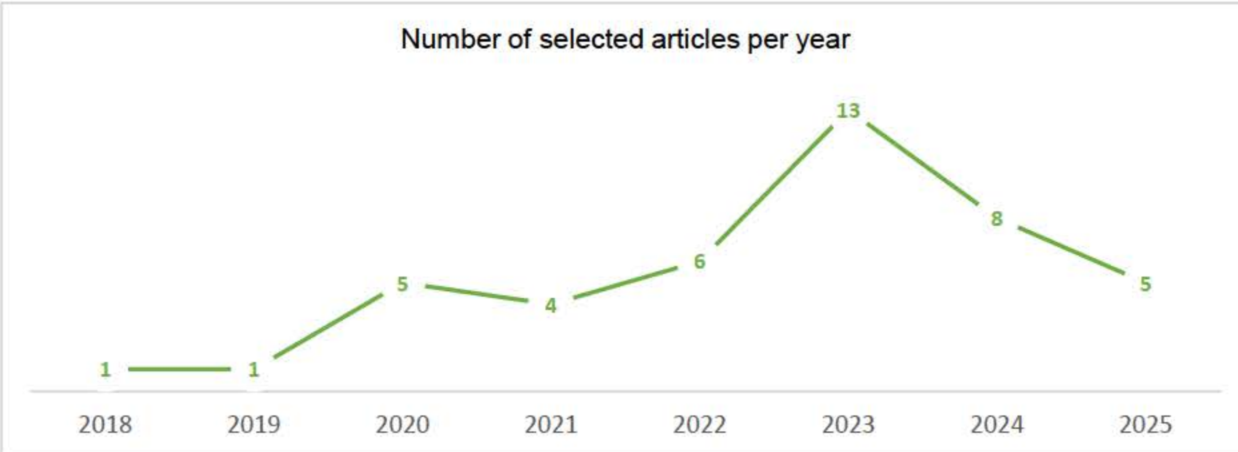


Figure 2-2: Selected papers publications per year (until February 2025)

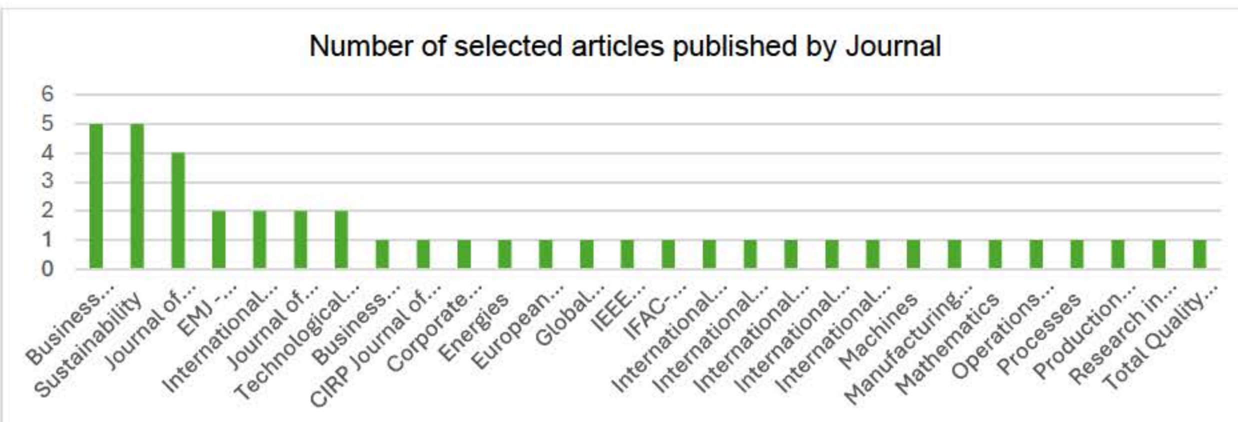


Figure 2-3: Number of selected articles published by Journal

#### 2.2.4.2 Theoretical Contributions and Empirical Evidence

Whilst the integration of Lean, Sustainability, and I4.0 is gaining attention, the early academic discourse largely focused on conceptual frameworks rather than empirical validation. Studies such Duarte and Cruz-Machado (2017) and Duarte et al. (2019) were among the first to advocate for a business model shift that leverages Lean-Green and I4.0 paradigms to drive strategic and operational improvements. Mesquita et al. (2022) documented a growing trend of integrative studies but also highlighted persistent weaknesses in empirical depth and sectoral specificity. The findings of Mesquita et al.

(2022) complement the goals of this scoping review, which aims to bridge precisely those gaps.

Recent theoretical contributions continue this trajectory. Costa et al. (2024) proposed a conceptual model linking Lean, Sustainability, and I4.0 technologies, particularly via digital twins and artificial intelligence but their study remains theoretical, reinforcing the need for empirical research that tests whether such conceptual linkages hold in practice, especially in regulated industries like aerospace. In contrast, empirical studies through surveys Ghaithan et al. (2023), Ghaithan et al. (2021) applied structural equation modelling (SEM) to quantitatively assess the synergy among these paradigms, confirming positive correlation between digitalisation and Lean-enhanced Sustainability outcomes, but offering limited insight into how these synergies translate into sector-specific practices such as aerospace manufacturing.

Other contributions take a qualitative or case-based route. For example, Goktas and Yumusak (2024) examined automotive firms implementing real-time analytics and feedback loops, whilst Cannas et al. (2025) provided case evidence from mining and petrochemicals industries. Belhadi et al. (2020), drawing on the resource-based view (RBV), empirically demonstrated how big data analytics capabilities enhance environmental performance through mediating Lean six sigma and green manufacturing practices in North African Firms. Similarly, Skalli et al. (2023a) adopted a practice-based view (PBV) to show how Lean, circular economy, and I4.0 practices interact in real manufacturing contexts, thereby moving beyond abstract conceptualisation. However, these studies underscore that whilst LS4.0 synergies are emerging, critical barriers such technological maturity, cost, organisational resistance, and workforce readiness remain underexplored. This review addresses two gaps: 1) the limited empirical validation of LS4.0 in highly regulated industries, and 2) the absence of theory-driven integration models tailored to complex manufacturing ecosystems. By addressing these two gaps, this study positions itself to provide both theoretical enrichments, by extending dynamic capabilities theory and contingency theory to the LS4.0 domain, and practical applicability, by tailoring integration models to aerospace's unique operational challenges.

As Table 2-2 illustrates, whilst a variety of industries are covered in the existing literature, most contributions remain generalised. Most existing studies fail to engage with the nuanced contingencies of sectors like aerospace, where safety regulations, design complexity, and traceability create unique integration challenges. This underlines the urgent need for contextualised frameworks, grounded in empirical evidence and supported by dynamic theoretical models. The present research directly responds to this need by developing and validating an LS4.0 framework tailored to aerospace manufacturing.

Table 2-2: Selected articles by Industry type

| Business Industry Type | Authors & Year | Number of Articles |
|---|---|---|
| **Micro-acoustic material and device** | Zhu et al. (2023) | 1 |
| **Automotive** | Goktas and Yumusak (2024) | 1 |
| **Automotive and Mining Machinery** | Tripathi et al. (2022) | 1 |
| **Energy** | Leong et al. (2020) | 1 |
| **Apparel** | Phuong and Guidat (2018) | 1 |
| **Mining Machinery** | Tripathi, et al. (2022) | 1 |
| **Petrochemical** | Ghaithan et al. (2023) | 1 |
| **Plastic and Petrochemical** | Ghaithan et al. (2021) | 1 |
| **Vacuum Degassing equipment** | Rahardjo et al. (2023) | 1 |
| **Fuel Injector Pump** | Kaswan et al. (2022) | 1 |
| **Multiple Industries** | Dixit et al. (2022), Skalli et al. (2023b), Arana-Landín et al. (2023), Arora et al. (2025), Arsalan Zahid et al. (2024), Benkhati et al. (2023), Ganjavi and Fazlollahtabar (2021), Maware and Parsley (2023), Belhadi et al. (2020), Cannas et al. (2025), De Giovanni and Cariola (2021), Dixit et al. (2022), Fiorello et al. (2023), Ganjavi and Fazlollahtabar (2021), Gholami et al. (2025), Kamble et al. (2020), Khanzode et al. (2023), Skalli et al. (2023a), Varela et al. (2019) | 18 |
| **Ceramic Industry** | Bhadu et al. (2025) | 1 |

#### 2.2.4.3 Methodological Approaches in LS4.0 Studies

The dominance of survey (37%) and literature reviews (30%) across the reviewed articles highlighted a field that is still predominantly theoretical and descriptive in nature. As shown in Table 2-3, only a minority of studies employ case-based, longitudinal, or mixed-method designs, limiting insights into implementation dynamics and contextual adaptation. Whilst structural equation modelling techniques such as those employed by Kamble et al. (2020) and Ghaithan et al. (2023) have helped quantify associations between Lean, I4.0, and Sustainability, such approaches fall short of capturing operational complexities such as change resistance, compliance demands, or workforce dynamics, especially applicable in aerospace.

Whilst Lean-Green4.0 readiness dimensions have been explored through SLR methodologies (Duarte & McDermott, 2025), few studies most notably Bhadu et al. (2025) and Leong et al. (2020), employed empirical or practitioner-validated frameworks tailored to sector-specific contexts such as aerospace. This highlights the gap between general conceptual models and context-sensitive frameworks that address the realities of regulated industries.

Notably, the scarcity of case studies and longitudinal research represents a significant methodological gap. Without such designs, it is difficult to understand how integration unfolds over time, how organisations adapt to regulatory shifts, or how capabilities are built and sustained across different contexts. In aerospace, where product lifecycles span over decades and supply chains evolve through geopolitical and technological disruptions, longitudinal and case study evidence is essential to capture temporal dynamics and sectoral contingencies.

Furthermore, this near absence of longitudinal, experimental, or in-depth case study investigations suggests that the field lacks robust evidence on how LS4.0 practices diffuse across industries or adapt to ecosystem-level challenges. Future research must address these limitations by conducting in-depth case studies and mixed-method inquiries in underrepresented sectors. In aerospace, this requires engaging both prime contractors and suppliers, capturing the interplay of strategic intent and operational execution, and validating integration pathways under the dual pressures of compliance and Sustainability.

Table 2-3: Applied Research Methodologies

| | Mixed Method | Qualitative | Quantitative | Theoretical | Grand Total |
|---|---|---|---|---|---|
| **Case study** | 4 | 5 | | | 9 |
| **Delphi Method (Survey)** | 1 | | | | 1 |
| **Literature review** | | | | 13 | 13 |
| **Literature review and case study** | | 1 | | | 1 |
| **Literature review, survey, case study** | 1 | 1 | | | 2 |
| **Survey** | | | 16 | | 16 |
| **Survey and Case study** | 1 | | | | 1 |
| **Grand Total** | **7** | **7** | **16** | **13** | **43** |

#### 2.2.4.4 The Interconnected Relationship between Lean, Sustainability, and I4.0 Technologies

A growing body of literature positions Lean as a mediating or enabling mechanism through which I4.0 technologies can enhance Sustainability outcomes. Studies as Ghaithan et al. (2021), Maware and Parsley (2023), and Kamble et al. (2020) emphasise how Lean tools, when supported by IoT and big data analytics, and automation, can improve resource efficiency, reduce waste, and promote eco-efficiency.

However, this review assumes a linear, synergistic relationship that may not hold in complex industrial environments. For instance, in aerospace, integration is complicated by regulatory oversight, long development cycles, and safety-critical control systems (Benkhati et al., 2023, Crute et al., 2003). As conceptualised in

Figure 2-4, Lean, Sustainability, and I4.0 intersect in dynamic, non-linear ways. Particularly, Sustainability operates in dual roles: as an outcome, e.g., lower emissions via TBL metrics, and as a guiding principle e.g., eco-design, circularity (Dixit et al., 2022, Zokaei et al., 2013). This duality creates ambiguity in integration strategy and measurement.

A central unresolved debate in the literature is whether Lean is inherently Sustainability-enabling or if digital augmentation is required to realise modern environmental objectives. Recent empirical work such as Alieva and Haartman (2020) and Alieva and Powell (2023) caution against premature automation and poorly aligned data architectures, showing how digital overlays can create ‘digital waste’ when introduced into unstable processes. Varela et al. (2019) found no conclusive correlation between Lean and Sustainability pillars, suggesting that I4.0 is essential for realising triple bottom line goals, particularly in volatile, high compliance industries. These insights call for sector-specific models that account for technological maturity, cultural readiness, and regulatory complexity.

In response to this complexity, Duarte and McDermott (2025) propose a multidimensional readiness framework that challenges the oversimplified synergy narrative. In their systematic review, Duarte and McDermott (2025) identify 13 dimensions across strategic, operational, and cultural domains, including leadership commitment, employee involvement, and digital maturity. Rather than assuming automatic alignment between Lean, green, and I4.0, Duarte and McDermott (2025)’s study underscores that successful integration depends on achieving coherence across these readiness dimensions, particularly in high-stakes environments such as aerospace.

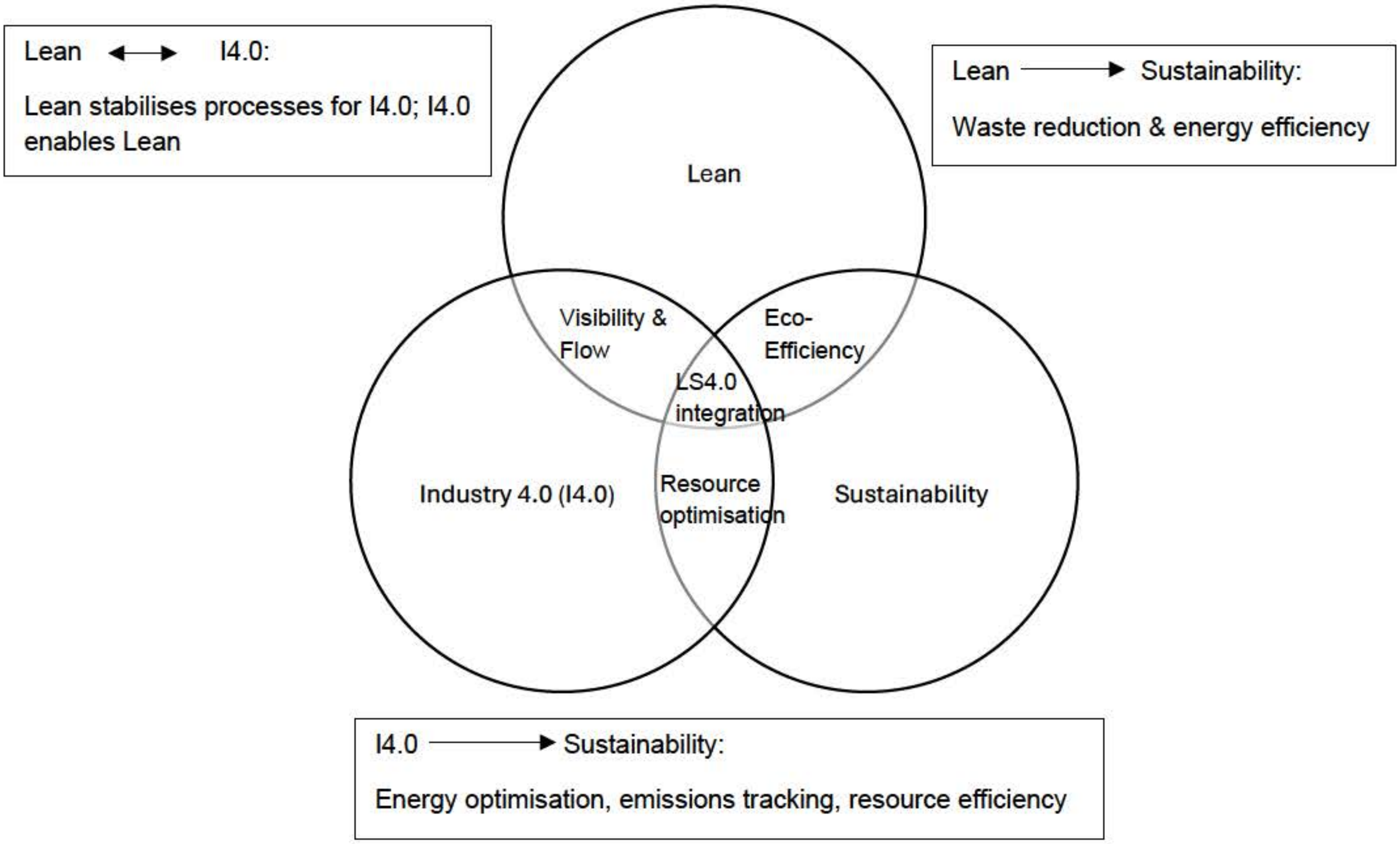


Figure 2-4: Interconnection between Lean, Sustainability, and I4.0 technologies

Building upon the observed complexities and interdependencies among Lean, Sustainability, and I4.0 technologies, it becomes critical to examine the practical enablers that support integration, as well as the barriers that hinder it. The literature offers diverse insights into the characteristics that influence implementation across various contexts. These are summarised in Table 2-4, which presents the key enablers and barriers identified in the reviewed studies, offering a cross-cutting synthesis of integration challenges and opportunities.

Table 2-4: Enablers and Barriers of LS4.0 Integration

| **Enablers** | **Articles** | **Barriers** | **Articles** |
|---|---|---|---|
| **Technology Adoption (IoT, BDA, AM, Digital Twins)** | Amjad et al. (2020), Arana-Landín et al. (2023), Benkhati et al. (2023), Ganjavi and Fazlollahtabar (2021), Kamble et al. (2020) | **High cost / investment** | Amjad et al. (2020), Benkhati et al. (2023), Ciliberto et al. (2021), Ghaithan et al. (2023), Leong et al. (2020) |
| **Training and Skills Development** | Arsalan Zahid et al. (2024), Ganjavi and Fazlollahtabar (2021), Ghaithan et al. (2023), Gholami et al. (2025), Leong et al. (2020) | **Lack of Expertise / Skills Gaps** | Arana-Landín et al. (2023), Benkhati et al. (2023), Ghaithan et al. (2021), Goktas and Yumusak (2024) |
| **Collaboration/Stakeholder Engagement** | Ghaithan et al. (2023), Ghaithan et al. (2021), Leong et al. (2020), Mahajan et al. (2024), Mahender Singh et al. (2023) | **Technological Readiness / Complexity** | Amjad et al. (2020), Arana-Landín et al. (2023), Benkhati et al. (2023), Ghaithan et al. (2023), Khanzode et al. (2023) |
| **Top Management Support** | Benkhati et al. (2023), Duarte and McDermott (2025), Goktas and Yumusak (2024), Skalli et al. (2023a) | **Resistance to Change/ Cultural Barriers** | Goktas and Yumusak (2024), Khanzode et al. (2023), Maware and Parsley (2023), Yilmaz et al. (2022) |
| **Regulatory Support / Policies** | Ciliberto et al. (2021), Costa et al. (2024), Dixit et al. (2022) | **Lack of frameworks / Roadmaps & Organisational Misalignment** | Costa et al. (2024), Duarte and McDermott (2025), Mahajan et al. (2024), Skalli et al. (2022), Skalli et al. (2023a) |
| **Lean Tools (VSM, JIT, Kaizen)** | Bhadu et al. (2025), Kamble et al. (2020), Lenin et al. (2021), Maware and Parsley (2023), Rahardjo et al. (2023), Singhal et al. (2024) | **Environmental Trade-offs** | Singhal et al. (2024), Varela et al. (2019), Yilmaz et al. (2022) |
| **Circular Economy Practices** | Ciliberto et al. (2021), Skalli et al. (2023a, 2023b) | **Regulatory Gaps / Inconsistency** | Ciliberto et al. (2021), Dixit et al. (2022) |

### 2.2.4.5 Examining the Dimensions of Lean, Sustainability, and I4.0

The current literature approaches the Lean, Sustainability, and I4.0 integration from two primary angles. At the construct level, studies focus on individual paradigms and their associated tools. For example, Ghaithan et al. (2021) examined Lean practices such as just-in-time, total productive maintenance, and supplier development, whilst Dixit et al. (2022) investigated I4.0 technologies including big data analytics, the internet of things, and cyber-physical systems. These studies suggest that Lean provides operational structural whilst I4.0 enables automation and real-time decision-making. However, this level often assumes a linear synergy and overlook the contextual and operational barriers like capital investment and workforce upskilling, particularly in aerospace, where adoption cycles are long, and cost justification is critical.

To complement this distinction between constructs and their interactions, Duarte and McDermott (2025) offer a comprehensive readiness framework that bridges these perspectives. Duarte and McDermott (2025) framework supports a more staged, context-sensitive pathway to integration, particularly useful in complex and compliance-driven sectors like aerospace. At the second interaction level, more recent research explores how these paradigms intersect to deliver Sustainability outcomes. Fiorello et al. (2023) show that advanced analytics enhancing total productive maintenance can reduce waste and energy use, whilst Rahardjo et al. (2023) demonstrate sustainable value stream mapping and digital poka-yoke improving yield in precision contexts, applicable to aerospace's traceability needs. However, these tools are often derived in high-volume sectors like automotive (Zokaei et al., 2013), requiring significant adaptation for aerospace's low-volume production, high-customisation production.

Benkhati et al. (2023) and Kamble et al. (2020) argue that I4.0 enhances integration via real-time monitoring, automation, and predictive control. However, these studies underplay the environmental trade-offs introduced by energy-intensive technologies like AI or blockchain (Amjad et al., 2020, Yilmaz et al., 2022). These contradictions reinforce the need for empirical validation in sector specific settings, where integration outcomes must be assessed holistically, not just in terms of operational efficiency but for environmental performance and regulatory compliance.

#### 2.2.4.6 Integrating Lean, Sustainability, and Industry 4.0: Competing Perspectives

The integration of Lean, Sustainability, and I4.0 has been examined from multiple perspectives. These perspectives highlight different synergies, challenges, and outcomes, offering a comprehensive understanding of their interplay. Three primary viewpoints emerge: Lean-I4.0 perspective, Lean-Green perspective, and holistic LS4.0 perspective. Each perspective provides distinct insights, yet overlaps in key themes such as operational efficiency, cost trade-offs, and environmental effects. The following sections critically examine these perspectives whilst highlighting their unique contributions.

##### 2.2.4.6.1 The Lean-I4.0 Perspective

This perspective focuses on how I4.0 technologies reinforces and accelerates Lean practices to achieve Sustainability (Ghaithan et al., 2021, Kamble et al., 2020). Benkhati et al. (2023) demonstrate through a survey across 399 firms that real-time monitoring and automation significantly enhance Lean-driven operational efficiency and Sustainability performance. Varela et al. (2019) highlight the critical role of I4.0 in linking Lean implementation with Sustainability outcomes, as presented in Table 2-5.

However, a key limitation of this viewpoint is its treatment of I4.0 as a simple enhancer of Lean rather than a transformative force. Practices such as just-in-time, whilst efficient, can increase emissions due to frequent transportation (Singhal et al., 2024). Additionally, Yilmaz et al. (2022) caution that automation can lead to socio-economic trade-offs, such as workforce displacement and upskilling demands. These concerns signal the need for more critical and sector-specific analyses of Lean-I4.0 synergies.

Table 2-5: The Lean-I4.0 Perspective

| Lean-I4.0 practices | Sustainability | Authors | Key Findings |
|---|---|---|---|
| **Advanced Analytics (AA) and TPM** | maximising equipment efficiency and reducing waste and energy consumption | Fiorello et al. (2023) | AA enhances TPM for sustainable production |
| **Advanced Analytics – Poka-Yoke**<br>**AA VSM** | Error-proofing and sustainable product development | | AA complements poka-yoke within Design for Environment. |
| **Sustainable VSM and Digital Poka-Yoke, Extended Single Minute Exchange of Die (SMED)** | Improve TBL performance | Rahardjo et al. (2023) | Digital tools enhance Lean practices for Sustainability. |
| **Real-time monitoring and automation** | Improved operational and Sustainability performance | Benkhati et al. (2023) | I4.0 enhances Lean implementation for Sustainability. |

#### 2.2.4.6.2 The Lean-Green Perspective

This viewpoint focuses on the alignment between Lean principles and environmental Sustainability, particularly through waste reduction, energy efficiency, and eco-friendly production (Duarte & Cruz Machado, 2017, Lenin et al., 2021). Lean promotes reduced overproduction and optimised resource use, aligning with Sustainability goals (Kaswan et al., 2022). However, this perspective is often overly optimistic, assuming that Lean and green always align when in reality, conflicts often emerge. This is because Lean prioritises cost and efficiency, whereas green initiatives prioritise environmental impact, leading to trade-offs (Salentijn et al., 2021, Skalli et al., 2023b). For example, just-in-time reduces inventory waste but increases transportation-related emissions due to frequent deliveries (Singhal et al., 2024). The extent to which I4.0 mitigates these trade-offs remains conditional on factors such as the energy profile of the technology deployed, whether the technologies themselves are energy-saving or energy-intensive, the maturity of supporting infrastructure, and the regulatory or organisational context. For example, technologies like machine learning and big data analytics can optimise resource use and reduce waste, but they also increase energy consumption through the processing demands of digital infrastructure (Kaswan et al., 2022). Thus, whether I4.0 enhances or undermines Lean-Green synergies depends heavily on context, such as energy sourcing, organisational digital readiness, and sector-specific compliance requirements, as seen in Table 2-6.

Table 2-6: The Lean-Green Perspective

| Lean-Green practices/tools | I4.0 Technologies | Authors | Key Findings |
|---|---|---|---|
| **Lean-Green production** | IoT, BDA, CPS | Amjad et al. (2020) | IoT and BDA improve production control and risk management but increase energy use and labour displacement risks. |
| **Smart production control for reduced delivery times** | IoT, BDA | Lenin et al. (2021) | Smart production reduces delivery times and energy consumption |
| **Machine learning in Lean-Green** | ML, IoT, BDA | Leong et al. (2020) | ML accelerates process improvements for Sustainability |
| **Digital Green Lean (DGL)** | IoT, AI | Gatell and Avella (2024a) | DGL integrates Lean, I4.0, and Circular Economy for Sustainability |
| **Circular Economy and Lean** | IoT, BDA, CPS | Skalli et al. (2023b) | Lean and I4.0 enable Circular Economy practices |

### 2.2.4.6.3 The Holistic Lean Sustainability I4.0 Perspective

This integrative perspective conceptualises Lean, Sustainability, and I4.0 as mutually reinforcing pillars of a unified manufacturing paradigm. It emphasises the pursuit of triple bottom line outcomes through systemic transformation, rather than incremental improvement (Arana-Landín et al., 2023, Dixit et al., 2022). This approach also recognises the underexplored social dimensions of Sustainability. Whilst Lean and I4.0 can optimise performance, they can disrupt traditional labour structures, requiring new competencies and potentially impacting employee well-being (Skalli et al., 2023b). Despite this theoretical promise, the holistic model faces significant practical implementation barriers. Financial investment, organisational change, and regulatory compliance issues are often underestimated, particularly in capital-intensive industries like aerospace (Skalli et al., 2023a). Studies including Kamble et al. (2020) and Rahardjo et al. (2023) offer evidence of integrated implementation, but such cases are limited and do not adequately account for sector-specific constraints (See Table 2-7).

Table 2-7: The Holistic Lean Sustainability I4.0 Perspective

| Practices/tools | Influence | Authors | Key findings |
|---|---|---|---|
| **Predictive analytics and IoT** | Improved decision-making and process optimisation | Dixit et al. (2022) | I4.0 enhances Lean for Sustainability |
| **VSM, TPM** | Reduced emissions and energy consumption | Kamble et al. (2020) | Lean tools enhanced by I4.0 improve Sustainability. |
| **Sustainable VSM, Digital Poka-Yoke** | Operational and Sustainability improvements | Rahardjo et al. (2023) | Digital tools drive Lean and Sustainability synergies |
| **Lean-I4.0 for waste reduction** | Reduced processing time, defects, and emissions | Bhadu et al. (2025) | Lean and I4.0 integration in the ceramic industry improves Sustainability |
| **Lean-I4.0-CE** | Enhanced operational and environmental performance | Skalli et al. (2023b) | Holistic integration of Lean, I4.0 and CE improves Sustainability |

In conclusion, these three perspectives offer complementary but incomplete views of Lean, Sustainability, and I4.0 integration. Whilst Lean provides a structural foundation for process discipline, and I4.0 functions as a transformative enabler through digital connectivity and automation, Sustainability operates both as a guiding objective e.g., emissions reduction, resources efficiency, and as a constraint shaped by regulatory and societal expectations. This dual role reinforces the need for sector-specific frameworks that can balance efficiency, technological innovation, and environmental accountability in complex industries such as aerospace.

### 2.2.5 Practical integration themes

This section synthesises practical integration themes derived from the reviewed 43 articles, grouped into five key categories. Particular attention was given to the "practical implications" sections of the reviewed articles. These practical implications sections frequently contained insights into how Lean, Sustainability, and I4.0 were or can be operationalised in industrial settings. An inductive coding process was applied, through which recurring ideas across the articles were systematically identified, compared, and clustered into broader categories. This approach followed similar procedures to those used by Antony et al. (2021) in their systematic review of Lean manufacturing. The analysis produced five overarching themes: technology integration, sustainable operational excellence, supply chain integration, Sustainability and circular economy advancement, and Lean as a dynamic capability.

The analysis reveals that the literature conceptualises LS4.0 integration at two levels: tactical problem-solving aimed at improving operational efficiency, and strategic transformation oriented toward long-term Sustainability and business model innovation. This dual perspective illustrates how integration can simultaneously support immediate performance gains and enables broader systemic evolution. The following subsections elaborate on each theme, drawing on specific studies to illustrate the actionable elements, their relevance to aerospace manufacturing, and the balance between short-term implementation and long-term capability development.  provides an overview of how these themes were derived from the literature and their supporting references.

#### 2.2.5.1 Technology Integration for strategic decision-making

Technology integration enables data-driven strategic decision-making to support Lean-Sustainability transformation, particularly in precision-dependent industries such as aerospace. Core I4.0 technologies include big data analytics, IoT, digital twins, and additive manufacturing, each offering distinct contributions to smarter, real-time operations. Belhadi et al. (2020) and Sony (2018) emphasise big data analytics' transformative role, noting when combined with cyber-physical systems, enables organisations the ability to identify patterns, trends, and process inefficiencies and translate insights into continuous improvement actions. Russom (2011) categorises big data analytics' core properties into volume, variety, and velocity, but scholars debate whether this "3V" framing adequately captures the complexity of strategic deployment, especially in compliance-heavy environments like aerospace, where data security and sovereignty pose additional challenges.

IoT and digital twins extend this by enabling predictive maintenance, virtual simulation, and scenario modelling, ultimately improving not only resource efficiency but also system resilience under uncertainty (Ejsmont et al., 2020, Ghobadian et al., 2020, Rahardjo et al., 2023). Yet, the debate centres on whether such digital augmentation truly embeds Sustainability or whether it risks creating "digital waste" through energy-intensive infrastructures. Similarly, additive manufacturing is also noted for enabling lighter, more sustainable designs, but adoption is constrained by certification hurdles and cost-benefit trade-offs in aerospace programmes.

Together, these technologies form the digital backbone of an integrated Lean-Sustainability system, but their impact is conditional on sectoral realities such as stringent certification, long product lifecycles, and fragmented supply chains. For this study, technology integration is examined not as a generic enabler but as a critical capability that must be aligned with Lean process discipline and Sustainability imperatives. This contextualisation is vital in aerospace, where managers must navigate trade-offs between operational efficiency, environmental accountability, and regulatory compliance which directly inform the LS4.0 model developed in this thesis.

Table 2-8: Development of Five Practical Integration Themes

| Theme | Development Description | Associated Articles |
|---|---|---|
| **Technology Integration** | Leverages I4.0 technologies e.g. BDA, IoT, Digital Twins, AM for strategic decision-making, enhancing Lean and Sustainability through data-driven insights and automation. Addresses aerospace precision needs. | Amjad et al. (2020), Arana-Landín et al. (2023), Arora et al. (2025), Arsalan Zahid et al. (2024), Belhadi et al. (2020), Benkhati et al. (2023), Bhadu et al. (2025), Cannas et al. (2025), De Giovanni and Cariola (2021), Fiorello et al. (2023), Ganjavi and Fazlollahtabar (2021), Gatell and Avella (2024a), Ghaithan et al. (2021), Ghobadian et al. (2020), Kamble et al. (2020), Kaswan et al. (2022), Rahardjo et al. (2023), Ricardo Aparecido et al. (2024), Sharma et al. (2024), Singhal et al. (2024), Skalli et al. (2023b), Tripathi et al. (2022), Varela et al. (2019), Zhu et al. (2023). |
| **Sustainable Operational Excellence** | Combines operational efficiency e.g., productivity, lead time reduction with TBL outcomes via Lean-4.0 synergy. Tactical focus on performance enhancement. | Amjad et al. (2020), Arana-Landín et al. (2023), Arora et al. (2025), Arsalan Zahid et al. (2024), Belhadi et al. (2020), Benkhati et al. (2023), Bhadu et al. (2025), De Giovanni and Cariola (2021), Ganjavi and Fazlollahtabar (2021), Ghaithan et al. (2021), Gholami et al. (2025), Kaswan et al. (2022), Khanzode et al. (2023), Leong et al. (2020), Maware and Parsley (2023), Rahardjo et al. (2023), Ricardo Aparecido et al. (2024), Skalli et al. (2023b), Varela et al. (2019) Tripathi et al. (2022). |
| **Supply Chain Integration** | Enhances collaboration and transparency e.g., JIT with IoT, blockchain for end-to-end Sustainability and efficiency. Dual tactical/strategic capability for aerospace's supply chains. | Amjad et al. (2020), Arana-Landín et al. (2023), Ghaithan et al. (2021), Kamble et al. (2020), Varela et al. (2019), Zhu et al. (2023) Tripathi et al. (2022). |
| **Sustainability and Circular Economy Advancement** | Promotes CE practices e.g., reuse, recycling via Lean-4.0, a strategic shift aligning with aerospace's environmental goals. | Ciliberto et al. (2021), Costa et al. (2024), Dixit et al. (2022), Ghaithan et al. (2023), Ricardo Aparecido et al. (2024), Skalli et al. (2022), Skalli et al. (2023b). |
| **Lean as a Dynamic Capability** | Evolves Lean e.g., VSM upgrade into smart, sustainable framework with I4.0, ensuring adaptability for aerospace. | Arora et al. (2025), Arsalan Zahid et al. (2024), Benkhati et al. (2023), Bhadu et al. (2025), De Giovanni and Cariola (2021), Goktas and Yumusak (2024), Kamble et al. (2020), Kaswan and Rathi (2020), Khanzode et al. (2023), Lenin et al. (2021), Leong et al. (2020), Maware and Parsley (2023), Rahardjo et al. (2023), Varela et al. (2019). |

#### 2.2.5.2 Sustainable Operational Excellence

The theme of sustainable operational excellence, positioned at both tactical and strategic levels, reflects the convergence of Lean efficiency with Sustainability imperatives. True excellence is redefined as the simultaneous delivery of cost, quality, time, and environmental value, rather than trade-offs between them. Studies including Khanzode et al. (2023) and Kaswan et al. (2022) argue that Lean-driven lead time reduction and productivity gains can advance Sustainability by reducing energy use, material waste, and rework. In this sense, Sustainability is not a by-product but a performance dimension that must be explicitly embedded into operational excellence frameworks.

However, achieving this integration requires organisational alignment and digital readiness (Luz Tortorella et al., 2022, Sony & Naik, 2020). Yilmaz et al. (2022) caution that high digitalisation costs and employee resistance can hinder progress, raising the question of whether operational excellence programmes risk becoming economically efficient but environmentally shallow. Effective communication and stakeholder alignment emerge as critical enablers to overcome these barriers, ensuring that technology adoption, Lean practices, and Sustainability objectives are jointly embedded into operational routines (Yilmaz et al., 2022).

This theme also emphasises the importance of embedding digital and green thinking into continuous improvement cycles, moving beyond traditional Kaizen focus solely on efficiency (Batwara et al., 2023, Lenin et al., 2021). The debate remains whether firms can genuinely balance Lean stability with Sustainability ambitions, or whether additional dynamic capabilities, such as reconfiguring processes around energy and carbon targets, are required. For aerospace, where programmes are long-horizon and compliance-driven, sustainable operational excellence becomes a strategic necessity: reducing delays, waste, and emissions whilst meeting customer and regulatory expectations. This connection makes the theme directly relevant to LS4.0 model developed in this study, where excellence is framed through an expanded safety, quality, delivery, cost, environment, and people performance lens.

#### 2.2.5.3 Supply Chain Integration

Supply chain integration involves connecting Lean, Sustainability, and I4.0 across internal and external partners. In aerospace, this requires synchronising high-complexity logistics and compliance requirements across long product life cycles, where disruptions can jeopardise both delivery schedules and certification milestones (Gélain, 2021). Collaboration tools like just-in-time supported by IoT (Belhadi et al., 2020) and traceability systems like blockchain (Fiorello et al., 2023) are shown to enhance visibility and performance by improving transparency, trust, and coordination across multi-tier supplier network. Mahajan et al. (2024) and Skalli et al. (2023b) further identify IoT and CPS as vital for transparency and green supply chain practices, whilst customer-facing technologies also promote waste reduction through demand alignment (Costa et al., 2024).

Green supply chain management (GSCM) reinforces this theme by promoting environmentally sound sourcing and procurement practices, made possible by I4.0 enablers such as digital traceability and predictive analytics (Lenin et al., 2021). Integration across the value chain, facilitated by real-time data, ensures both tactical responsiveness and strategic resilience. For aerospace, this is particularly critical given the sector’s reliance on globally dispersed, compliance-heavy supply chains, where even minor disruptions cascade into delays, cost overruns, or Sustainability trade-offs (Chang et al., 2013, Crute et al., 2003). Embedding supply chain integration into the LS4.0 model highlights how visibility, traceability, and collaboration are not only enablers of Lean efficiency but also essential for meeting environmental targets and regulatory obligations, therefore, strengthening the case for a contextualised aerospace framework.

#### 2.2.5.4 Sustainability and Circular Economy Advancement

This theme captures a major long-term shift in manufacturing, moving from linear take-make-dispose models toward circular production systems that prioritise reuse, remanufacturing, and material recovery. In aerospace, this means rethinking product design for disassembly, investing in lightweight recyclable materials, and developing recovery systems that extend product life cycles and reduce waste. Ciliberto et al. (2021) and Skalli et al. (2023a) highlight Lean-I4.0 synergies in driving circularity, particularly via AI-based optimisation and zero-waste regulatory compliance (Dixit et al., 2022). However, whilst environmental impacts such as carbon emissions, waste reduction, and energy efficiency are widely studied, the social dimension of Sustainability, such as workforce equity, inclusion, and well-being, remains underexplored in the LS4.0 discourse. This omission is significant because digitalisation and automation can generate unintended consequences, including job displacement, reskilling pressures, and inequalities across global supply chains. In highly regulated sectors like aerospace, where human expertise and tacit knowledge are central to safety and quality, overlooking these social dimensions risks producing integration frameworks that are technically advanced but socially fragile. This imbalance therefore limits the comprehensiveness and long-term viability of current LS4.0 models.

Alongside these social gaps, the literature also highlights circularity as critical environmental priority. Promoting circularity therefore requires expanding beyond environmental metrics to fully address triple bottom line outcomes (de Sousa Jabbour et al., 2018, Behl et al., 2023). For aerospace, this is especially significant because lifecycle emissions and material efficiency are strategic imperatives. Aircraft operate for decades, creating challenges in maintenance, recycling of composite, and eventual decommissioning. Furthermore, compliance regimes such as EASA's Sustainable Aviation Fuel (SAF) requirements and global carbon reduction targets are pressing firms to consider circularity not only as a technical option but as a regulatory and market necessity. Embedding circular economy principles within LS4.0 model connects Lean's waste-reduction ethos, Sustainability's normative goals, and I4.0's digital capabilities into a pathway that can deliver both environmental compliance and long-term resilience in aerospace manufacturing.

#### 2.2.5.5 Lean as a dynamic capability

This theme reframes Lean not simply as a toolbox of efficiency techniques but as a dynamic capability that underpins the effective integration of Sustainability and I4.0. Analysis of the practical implications across the reviewed articles shows that Lean is typically applied as a foundation for operational discipline, waste reduction, and process stability. In parallel, LS4.0 integration was framed in terms of capabilities, highlighting the strategic importance of developing adaptive organisational routines for long-term transformation. Together, these insights suggest that Lean's enduring relevance lies in its capacity to evolve into a capability that supports sensing opportunities, seizing digital innovations, and transforming processes for Sustainability, the very mechanisms outlined in dynamic capabilities theory (Teece, 2007).

Lean continues to play a critical role in aerospace's compliance-heavy environment, where tool-based application alone is insufficient. Practitioners face long product life cycles, rigorous documentation requirements, and global supply chain dependencies. In this context, embedding Lean as a capability means institutionalising continuous improvement, problem-solving, and standardisation as organisational routines rather than isolated projects (Guttierrez et al., 2022, Hines et al., 2020, Rother, 2009, Saabye et al., 2023). Studies such as Maware and Parsley (2023) and Ghaithan et al. (2021) link Lean's waste-reduction ethos directly to Sustainability outcomes, whilst Goktas and Yumusak (2024) challenge the notion of Lean's obsolescence in the digital age, emphasising its role as a platform for cost-effective I4.0 adoption.

Importantly, Lean's human-centric principles complement its technological alignment with I4.0. Liker (2021) underscores how Lean's emphasis on employee empowerment and Kaizen ensures that digitalisation enhances rather than undermines workforce capability, a critical factor in aerospace, where tacit knowledge and skilled labour remain indispensable. Sony (2018) reinforces this by positioning Lean as a cultural foundation of adaptability and collaboration, essential for integrating smart technologies whilst maintaining operational excellence. Psychological safety is also a critical underpinning, enabling teams to surface problems and experiment without fear of blame, which in turn accelerates learning in high-hazard settings such as aerospace (Edmondson, 1999).

In summary, Lean can be understood as a dynamic capability within the LS4.0 system. It provides the operational discipline, human-centred culture, and adaptive routines that enable firms to align efficiency, Sustainability, and digital transformation. For aerospace, developing Lean as a capability is particularly relevant, without Lean, digitalisation risks creating "digital waste", and Sustainability initiatives may remain disconnected from day-today operations. By embedding Lean as a capability, the LS4.0 model developed in this study highlights its role as both a stabilising foundation and an adaptive enabler for future-ready aerospace manufacturing.

### 2.2.6 Discussion

This scoping review reveals a dynamic and evolving interplay among Lean, Sustainability, and I4.0, offering transformative insights into how these paradigms can be integrated in manufacturing operations. The aerospace sector emerges as a highly relevant but underexplored context for applying these insights, due to its operational complexity, regulatory rigour, and increasing Sustainability pressure. However, few studies specially address this sector (Fiorello et al., 2023, Ghobadian et al., 2020). This section reviews the current academic debate by discussing the evolution of the field, identifying key enablers and barriers, and considering implications for aerospace. The section then introduces a conceptual model that synthesises these debates, grounded in dynamic capabilities theory, contingency theory, and systems thinking.

#### 2.2.6.1 Understanding the State of Lean, Sustainability, and I4.0 Integration

This subsection synthesises the literature across three dimensions: evolution of the field, enablers and barriers and aerospace-specific applications.

##### 2.2.6.1.1 Evolution of the field

Academic and practical interest in the integration of Lean, Sustainability, and I4.0 has surged since 2017, with peak in 2023-2024 (Mesquita et al., 2022). This reflects a growing recognition of their synergies in delivering triple bottom line outcomes. Lean is increasingly positioned as a mediating logic, enhanced by digital enablers like big data analytics, cyber-physical systems, internet of things, and additive manufacturing (Ghaithan et al., 2021, Kamble et al., 2020).

However, the assumption of a linear synergistic relationship implied by studies such as (Ghaithan et al., 2021) and Kamble et al. (2020) is contested. Varela et al. (2019) argue that Lean's standalone impact on Sustainability is limited and often conditional on I4.0 augmentation. Similarly, Skalli et al. (2023a) emphasise tensions between Lean's efficiency-driven orientation and broader social and environmental objectives. Together, these debates suggest that integration is not a straightforward linear progression, but a context-sensitive dynamic shaped by technological maturity, organisational culture, and regulatory constraints.

#### 2.2.6.1.2 Enablers and Barriers to Integration

Key enablers include technological advancements e.g., IoT, supportive organisational cultures (Goktas & Yumusak, 2024), and policy or regulatory incentives (Dixit et al., 2022). Yet persistent barriers such as cost, technological readiness, and workforce adaptation are frequently (Skalli et al., 2023b, Tortorella & Fettermann, 2018, Yilmaz et al., 2022).

These barriers are amplified in aerospace due to its manual-intensive processes, compliance demands, and low-volume production systems. **Error! Reference source not found.** conceptualises these dynamics, with “enablers” and “barriers”, previously synthesised in Table 2-4, interacting to shape integration potential. However, the lack of aerospace specific data limits the direct applicability of generalised frameworks.

### 2.2.7 Implication for Aerospace

The aerospace sector presents a distinct set of structural, operational, and regulatory characteristics that differ from other manufacturing environments. Despite the increasing number of integration models, few frameworks directly address these challenges. This subsection maps key aerospace characteristics against the extent to which they are addressed in existing LS4.0 frameworks. Table 2-9 highlights the gaps and blind spots, setting the stage for a context-specific conceptual model.

### 2.2.7.1 Mapping Table: Aerospace Sector Characteristics versus Existing Lean Sustainability 4.0 model's coverage

Table 2-9: Mapping Table: Aerospace Sector Characteristics versus Existing Lean Sustainability 4.0 model's coverage

| Aerospace Characteristics | Description | Addressed by existing models | Gap Identified | Author |
|---|---|---|---|---|
| **Market Demand and Diversification** | Customised, non-repetitive production, high variability in design and delivery | Poorly aligned | Models need rethinking for custom, flexible manufacturing<br>Lacks customisation for non-repetitive workflows<br>No specific Lean-I4.0 tools for high-mix production | Rahardjo et al. (2023) |
| **Supply Chain Complexity** | Globalised, multi-tier systems requiring end-to-end visibility | Partially addressed in some supply chain focused studies | Traceability and collaboration for multi-tier transparency tools remain underutilised | Mahajan et al. (2024) |
| **Regulatory Compliance** | REACH, information and products export control constraints, Certification, AS9100, EASA | Limited treatment | Limited discussion of regulatory trade-offs (e.g., Lean's flexibility Vs Compliance)<br>Aerospace<br>Weak linkage to how LS4.0 address traceability and certification requirements | Fiorello et al. (2023) |
| **Product Complexity** | High-precision, safety-critical components with complex assembly requirements<br>Long development and maintenance cycles, multi-decade product lifespan<br>Manual-intensive labour | Partially addressed | Need for model components addressing concurrent, design for manufacturing Vs design for performance.<br>Lack of lifecycle-focused frameworks and design for performance trade-off models. | Rathi et al. (2022) |
| **Sustainability Pressures** | Zero operational goals, Zero-net flights emissions | Underdeveloped | Socio-technical dynamics of digital transformation underexplored. Absence of HR capability -building, change readiness, and participative approaches in model architectures. | Chari et al. (2022) |

### 2.2.7.2 Conceptual Model for Aerospace Application

The findings indicate that Lean, Sustainability, and I4.0 are interrelated but context-sensitive constructs. For aerospace, where safety, traceability, and compliance co-exist with Sustainability and performance objectives, a tailored conceptual model is required. The conceptual model presented in **Error! Reference source not found.** synthesises three threads of the academic debate: first, the argument that Lean alone is insufficient to deliver Sustainability gains without digital augmentation (Varela et al., 2019). Second, the recognition that I4.0 offers transformative potential but introduces new trade-offs, including increased energy intensity and workforce disruption (Skalli et al., 2023a, Yilmaz et al., 2022). Third, the calls for Sustainability to be treated not only as an outcome but also as a guiding principle of integration (Skalli et al., 2023b). From this synthesis, five themes emerge as central to aerospace application, encompassing technology Integration, sustainable operational excellence, supply chain integration, Sustainability and circular economy advancement, and Lean as a dynamic capability. Together, these form a thematic, system-based lens that can be analysed through dynamic capabilities theory and contingency theory to provide both explanatory power and sectoral relevance.

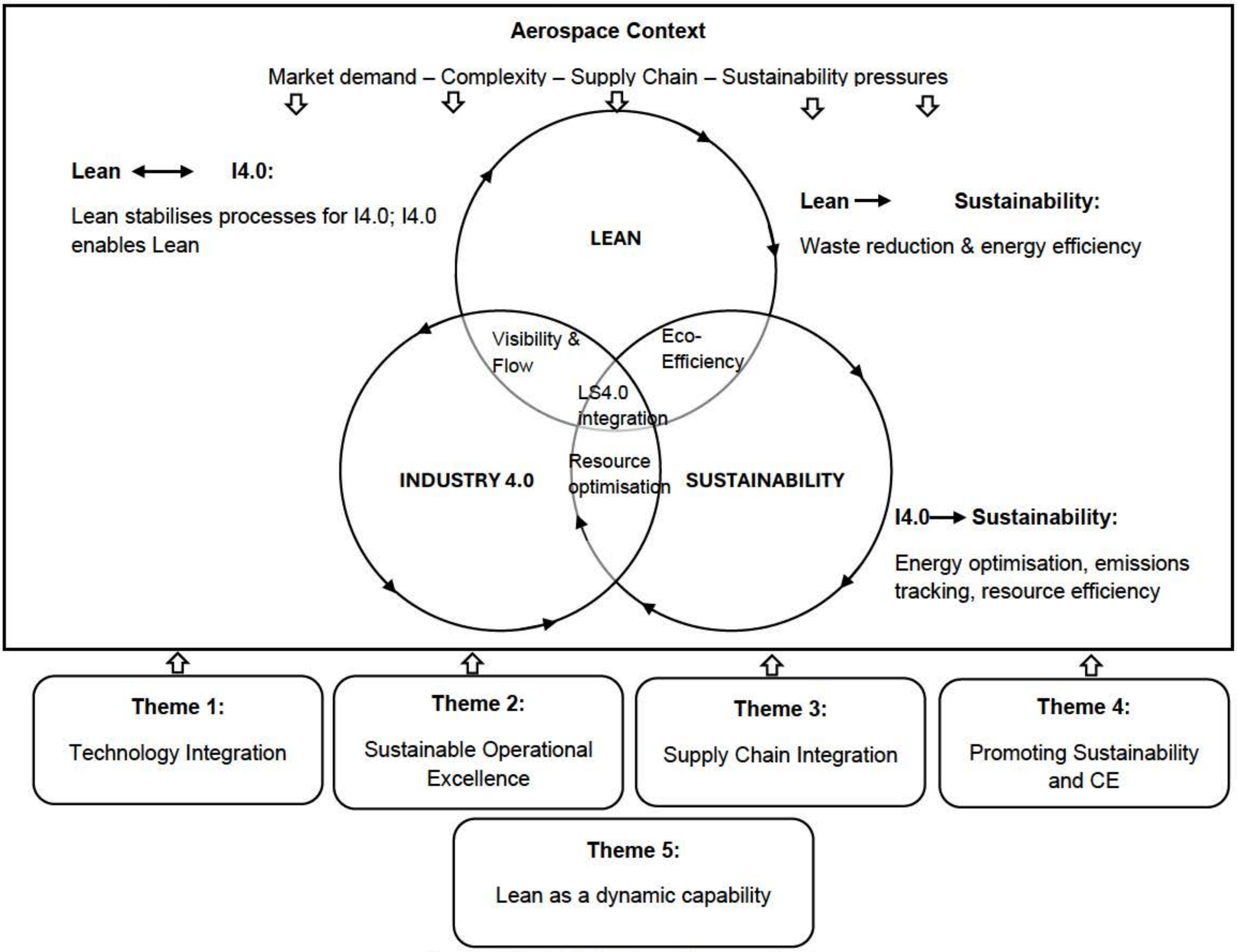


Figure 2-5: LS4.0 integration synthesis

#### 2.2.7.3 Conceptual Insights for LS4.0 Integration in Aerospace

This scoping review highlights five conceptual insights that emerge from the literature. These insights reflect the strategic and tactical dimensions that aerospace firms must address to develop capabilities for resilient, sustainable, and digitally enabled operations, and are informed by dynamic capabilities theory, contingency theory, and operations strategy literature, and they guide the conceptual framework developed in Section 2.2.7.2.

**Insight 1: Technology as an Enabler of Anticipatory Decision-Making**

The literature indicates that strategic deployment of I4.0 technologies such as IoT, big data analytics, cyber-physical systems, enable anticipatory real-time decision-making that supports Lean-Sustainability integration. Such technologies enhance resource efficiency, quality, and compliance (Ghobadian et al., 2020, Sony, 2018). However, their effectiveness is contingent on digital infrastructure maturity, integration with legacy systems, and leadership foresight. This aligns with dynamic capabilities theory's emphasis on sensing and seizing opportunities.

**Insight 2: Supply Chain Integration is Critical but Fragile**

The literature highlights that extending LS4.0 principles across supply chains enhances Sustainability outcomes and just-in-time performance. Enabling technologies such as blockchain and cyber-physical systems support traceability and collaboration (Fiorello et al., 2023, Skalli et al., 2023a). However, governance and trust mechanisms remain essential to overcome the vulnerabilities of globalised, multi-tier aerospace chains.

**Insight 3: Organisational Readiness Shapes Resilience and Sustainability**

Studies suggest that firms with integrated Lean-Sustainability initiatives, when supported by I4.0, tend to achieve stronger operational resilience and environmental performance (Khanzode et al., 2023, Yilmaz et al., 2022). Yet these outcomes are conditional upon factors such as employee alignment, communication, and digital readiness. From a contingency theory perspective, integration success depends on how internal structures and culture align with external pressures.

**Insight 4: Circular Economy Requires Balanced Sustainability**

Circular economy strategies, such as sustainable value stream mapping and zero-waste design, are increasingly advanced by Lean and I4.0 synergies (Ciliberto et al., 2021, Dixit et al., 2022). Whilst these initiatives strengthen environmental and regulatory compliance, the neglect of social dimensions limits comprehensiveness. From a dynamic capabilities theory lens, reconfiguring capabilities toward holistic TBL outcomes remains a critical challenge.

**Insight 5: Lean as a Dynamic, Human-Centric Capability**

Lean continues to provide a foundational discipline, but its role is evolving into a dynamic capability when augmented by I4.0 tools such as smart value stream mapping and IoT-assisted total productive maintenance (Goktas & Yumusak, 2024). At the same time, human-centric focus on empowerment and continuous improvement (Liker, 2021) ensures that technological transformation is socially sustainable. This dual role positions Lean as a bridge between human and digital systems. Leadership style is central to this dynamic capability role, with coaching-oriented and participative behaviours associated with stronger Lean outcomes than purely directive approaches (Alefari et al., 2020).

Collectively, these insights underscore that LS4.0 integration in aerospace is not a deterministic or linear process, but a contingent and capability-driven transformation shaped by technological maturity, organisational readiness, and sector-specific constraints.

### 2.2.8 Theoretical Implications

The academic literature reflects ongoing debate over theoretical framing of Lean, Sustainability, and I4.0 integration. One stream of research conceptualises these paradigms as co-evolving systems within a systems thinking lens (Senge & Sterman, 1992), where feedback loops and dynamic interdependencies are foregrounded rather than linear progressions. From this perspective, I4.0 is positioned not only as a technological enabler of Lean and Sustainability, but also as a potential disruptor that reshapes operational logics and resource flows (Benkhati et al., 2023).

Another stream frames I4.0 as an extension of the triple bottom line framework (Elkington, 1998), suggesting that digital tools such as big data analytics, the Internet of Things, and cyber-physical systems allow more precise tracking of environmental, economic, and social performance (Costa et al., 2024). Yet, scholars such as Singhal et al. (2024) caution that these models often overlook trade-offs, most notably between Lean efficiency and environmental outcomes, as seen in just-in-time practices that may raise carbon emissions through frequent transportation.

There is also debate over which theoretical lens is most appropriate for explaining integration. Dynamic capabilities theory has been applied to explain how digital capabilities can act as reconfigurable assets that support adaptation in volatile and capital-intensive contexts (Teece, 2007). However, its application to LS4.0 remains limited, with most studies using it only peripherally (Komkowski et al., 2023). contingency theory is invoked to highlight sectoral and organisational specificity, yet contingency theory too has rarely been applied systematically to aerospace. In contrast, some studies rely on resource-based view (RBV) (Belhadi et al., 2020) or practice-based view (PBV) (Skalli et al., 2023b) to emphasise the role of firm-level practices and resources in shaping integration pathways.

Overall, the literature reveals no consensus on whether LS4.0 integration should be theorised primarily as a system of feedback loops, as an extension of established Sustainability frameworks, or through capabilities and contingency-based approaches. This ongoing debate highlights both the richness and fragmentation of the field and underscores the need for sector-specific theoretical framing in aerospace, where compliance, complexity, and long product lifecycles are defining features.

### 2.2.9 Practical Implications

The practical relevance of Lean, Sustainability, and I4.0 integration is also contested across the literature. Some studies such as Belhadi et al. (2020), McDermott et al. (2023) emphasise the integration's transformative potential, for example, predictive analytics and IoT are reported to improve lead-time reduction and process monitoring, whilst additive manufacturing is associated with lightweight designs and reduced material waste (Ghobadian et al., 2020). Similarly, blockchain and cyber-physical systems are presented as enablers of greater supply chain transparency and traceability (Fiorello et al., 2023). These contributions suggest that when aligned with Lean principles, I4.0 can create measurable Sustainability gains whilst maintaining competitiveness.

Other scholars adopt a more critical perspective, highlighting persistent challenges. Yilmaz et al. (2022) point to the high costs of digitalisation and organisational resistance, which undermine implementation. Skalli et al. (2023a) highlight workforce-related tensions, nothing that digitalisation may exacerbate skill gaps and displace labour, raising questions about whether Lean's human-centric ethos can be preserved. Similarly, policy-related studies diverge, whilst Ciliberto et al. (2021) and Dixit et al. (2022) call for stronger regulatory and incentive frameworks to push circular economy adoption, others such as Duarte and McDermott (2025), Sony and Naik (2020) argue that firm-level readiness and capability development must take precedence.

The debate also extends to the scope of Sustainability outcomes. Whilst environmental performance e.g., emissions, energy use, material efficiency dominates most empirical studies, the social pillar covering such as workforce equity, inclusion, and well-being remains underexplored (Skalli et al., 2023a). This omission raises doubts about whether current integration models can deliver comprehensive triple bottom line outcomes, especially in sectors such as aerospace where tacit knowledge and human expertise remain essential.

In summary, the literature reveals competing perspectives on whether LS4.0 integration is best understood as a technological opportunity, an organisational challenge, or a policy-driven mandate. From a change management perspective, these challenges echo classic guidance that transformation requires not only tools but also a deliberate sequencing of urgency, coalition building and consolidation of gains (Kotter, 1996). For aerospace, this debate is particularly salient, given the sector's reliance on manual expertise, long product lifecycles, and compliance-heavy environment. Rather than presenting definitive answers, the practical implications debate highlights the need for sector-sensitive strategies that balance efficiency, Sustainability, and human-centric considerations.

### 2.2.10 Conclusion of the Scoping Review

This scoping review synthesises 43 peer-reviewed articles published between 2015 and 2025 that address the integration of Lean, Sustainability, and I4.0. The analysis reveals a fragmented landscape in which dual integrations e.g., Lean-I4.0 and Lean-Sustainability dominate, whilst holistic models uniting all three paradigms remain limited. Although theoretical contributions are growing, particularly in the form of frameworks and typologies, there is a lack of contextualised adaptations for complex, regulated, and high-mix manufacturing sectors such as aerospace.

Across literature, Lean emerges as a consistent foundation for operational discipline, often amplified by I4.0 technologies to support Sustainability goals. Yet practical limitations are repeatedly emphasised, including digital readiness, regulatory burdens, and socio-technical challenges. In aerospace, where precision, traceability, and compliance intersect with Sustainability targets, these limitations become particularly acute. Some studies such as Rahardjo et al. (2023) and Ghobadian et al. (2020) highlight the enabling role of I4.0 in overcoming Lean's constraints, whilst others such as Yilmaz et al. (2022), Amjad et al. (2020) and Skalli et al. (2023a) warn that digital adoption may generate new trade-offs, including energy use and workforce disruption.

Importantly, the literature highlights a paucity of aerospace-specific empirical studies. Whilst the conceptual framework is grounded in literature, many inferences remain untested in real-world aerospace settings. This gap signals the need for more sector-sensitive, longitudinal, and practice-oriented research that can account for regulatory, technological, and organisational contingencies.

Finally, the review underlines three enduring debates in the field: whether Lean inherently enables Sustainability or requires digital augmentation, whether I4.0 integration mainly enhances or disrupts established practices, and whether current models adequately capture the social dimension of Sustainability alongside environmental and economic concerns. These unresolved issues frame the development of a conceptual model tailored to aerospace. The review captures the state of knowledge up to February 2025, ensuring that the synthesis reflects the most recent development in this rapidly evolving field.

### 2.3 Theoretical and Sectoral Foundations for Integration

This section builds upon the findings of the scoping review by moving from mapping to interpretation. Whereas the scoping review systematically identified 43 peer-reviewed articles and synthesised their practical and theoretical contributions, the narrative review deepens the discussion by positioning Lean, Sustainability, and I4.0 within the aerospace context through a more critical, theory-driven lens. This dual approach ensures that the literature review not only catalogues prior work but also establishes the conceptual rationale for an LS4.0 framework tailored to aerospace.

Several theoretical perspectives have been applied to study integration, including the resource-based view (RBV) and the practice-based view (PVB) (Belhadi et al., 2020, Skalli et al., 2023b). RBV emphasises resources as sources of advantage and PBV focuses on practices as micro-foundations of performance. Whilst valuable, these perspectives fall short in explaining how firms adapt integration strategies in dynamic and regulated environments such as aerospace, where compliance, complexity, and novelty strongly condition outcomes. For this reason, this study adopts dynamic capabilities theory and contingency theory as its core lenses. Together, these theories allow integration to be interpreted as both a dynamic process of renewal and a context-sensitive alignment challenge.

### 2.3.1 Dynamic Capabilities and Contingency Theory

The integration of Lean, Sustainability, and I4.0 is interpreted through two complementary lenses: dynamic capabilities theory and contingency theory. Dynamic capabilities theory posits that organisations must develop the capacity to sense opportunities and threats, and seize them through timely decision making, and transform their resources base to maintain competitiveness in dynamic environments (Teece, 2018, Teece et al., 1997). This perspective aligns with the aerospace sector's need for agility in the face of increasing demand, regulatory shifts, technological change, and Sustainability imperatives. Lean provides the operational stability and problem-solving routines necessary to enable such sensing and transforming behaviours, whilst I4.0 technologies offer the sensing infrastructure e.g., IoT and BDA and transformation tools e.g., digital twins and automation that amplify dynamic capabilities.

Contingency theory argues that there is no universal set of best practices, rather, performance depends on the alignment between internal organisational features e.g., culture, structure, technology, and external environmental contingencies e, g., compliance, complexity, demand variability (Donaldson, 2001). In this light, Lean and I4.0 practices must be contextually adapted to aerospace, a sector characterised by low production volumes, high product complexity, and stringent compliance demands. CT informs this study's recognition that Lean-I4.0-Sustainability strategies must be tailored, not transferred. Therefore, in summary dynamic capabilities and contingency theories frame integration as both a dynamic and a context-sensitive process, providing the dual theoretical foundation for this study.

### 2.3.2 Integration Synergies and Tensions

The literature demonstrates that Lean, Sustainability, and I4.0 interact in complex and often contradictory ways. Lean contributes waste reduction, continuous improvement, and process discipline, I4.0 introduces digital capabilities such as sensing, connectivity, and automation, and Sustainability establishes normative goals that extend performance beyond cost and efficiency to environmental and social responsibility (Elkington, 1998). Lean, Sustainability, and I4.0 convergence creates synergies, such as green value stream mapping enhanced by real-time data, but also tensions, for instance between just-in-time and carbon emissions (Singhal et al., 2024).

These synergies and trade-offs cannot be reduced to a linear cause-effect relationship. As several authors argue (Costa et al., 2024, Duarte & McDermott, 2025, Varela et al., 2019), integration outcomes are shaped by dynamic interactions between technological capabilities, organisational culture, and external constraints. I4.0 may mitigate Lean's limitations in low-volume production and improve traceability to support Sustainability, but only when aligned with organisational culture, workforce skills, and compliance requirements. In other cases, I4.0 can create new challenges, such as high energy use or workforce displacement, which undermine Sustainability's broader objectives (Skalli et al., 2023a, Yilmaz et al., 2022). Integration, therefore, must be seen as both dynamic and contingent.

### 2.3.3 Implications for Conceptual Framework

The synthesis of theory and sectoral evidence reveals an important gap. Most existing models of integration remain overly abstract and generic, failing to capture the specific conditions of aerospace manufacturing. The existing literature typically assumes transferable practices without adequately accounting for regulatory trade-offs, supply chain fragmentation, or the socio-technical challenges of skilled labour and tacit knowledge (Fiorello et al., 2023, Rahardjo et al., 2023). There is thus a need for a framework that unites dynamic capabilities with contingency awareness, whilst also embedding practical dimensions such as technology integration, sustainable operations and supply chain collaboration.

This theoretical and sectoral grounding sets the stage for the next section, which develops a conceptual framework providing insights for the empirical exploration in aerospace.

## 2.4 Conceptual Framework Development

To address RQ 1.3 and bridge the theoretical and sector-specific gaps identified in the preceding sections, this section proposes a conceptual framework for the integration of Lean, Sustainability, and I4.0 in aerospace manufacturing. This framework is grounded in dynamic capabilities theory and contingency theory, reflecting the strategic agility and contextual alignment required in this highly regulated, low-volume, and high-complexity sector.

The scoping review highlighted a number of recurring integration themes, such as technology adoption, sustainable operational excellence, supply chain integration, and Sustainability and circular economy practices. These insights provided useful reference points for understanding how integration has been conceptualised in the broader literature. However, these themes were not adopted as structural categories in the framework, since the objective is to build a theory-informed model that responds directly to aerospace-specific contingencies. Instead, these themes serve as background inputs that sharpen the conceptual lens, ensuring the framework is informed by prior debates without being constrained by them.

As shown in Figure 2-6, the framework positions Lean, Sustainability, and I4.0 as interdependent but context-sensitive constructs. Lean provides operational discipline and problem-solving routines, Sustainability introduces normative goals and long-term accountability, and I4.0 contributes sensing, data, and automation capabilities. Lean, Sustainability, and I4.0 interaction is conceived as a synergy cycle, where feedback loops continually reinforce or challenge the alignment of operational efficiency, Sustainability outcomes, and technological advancement. This cycle is not universal but shaped by contingency factors such as compliance requirements, production complexity, and digital readiness. External drivers including Sustainability pressures, digitalisation imperatives, and customer demand for customised products, act as catalysts feeding into the system.

The resulting framework offers a conceptual foundation that captures both the dynamic processes of sensing, seizing and transforming, emphasised in DCT and the contextual alignment stressed in CT. The framework thus provides insights for the empirical investigation in Chapter Four and the subsequent development and validation of a practitioner-informed LS4.0 model in Chapter Five.

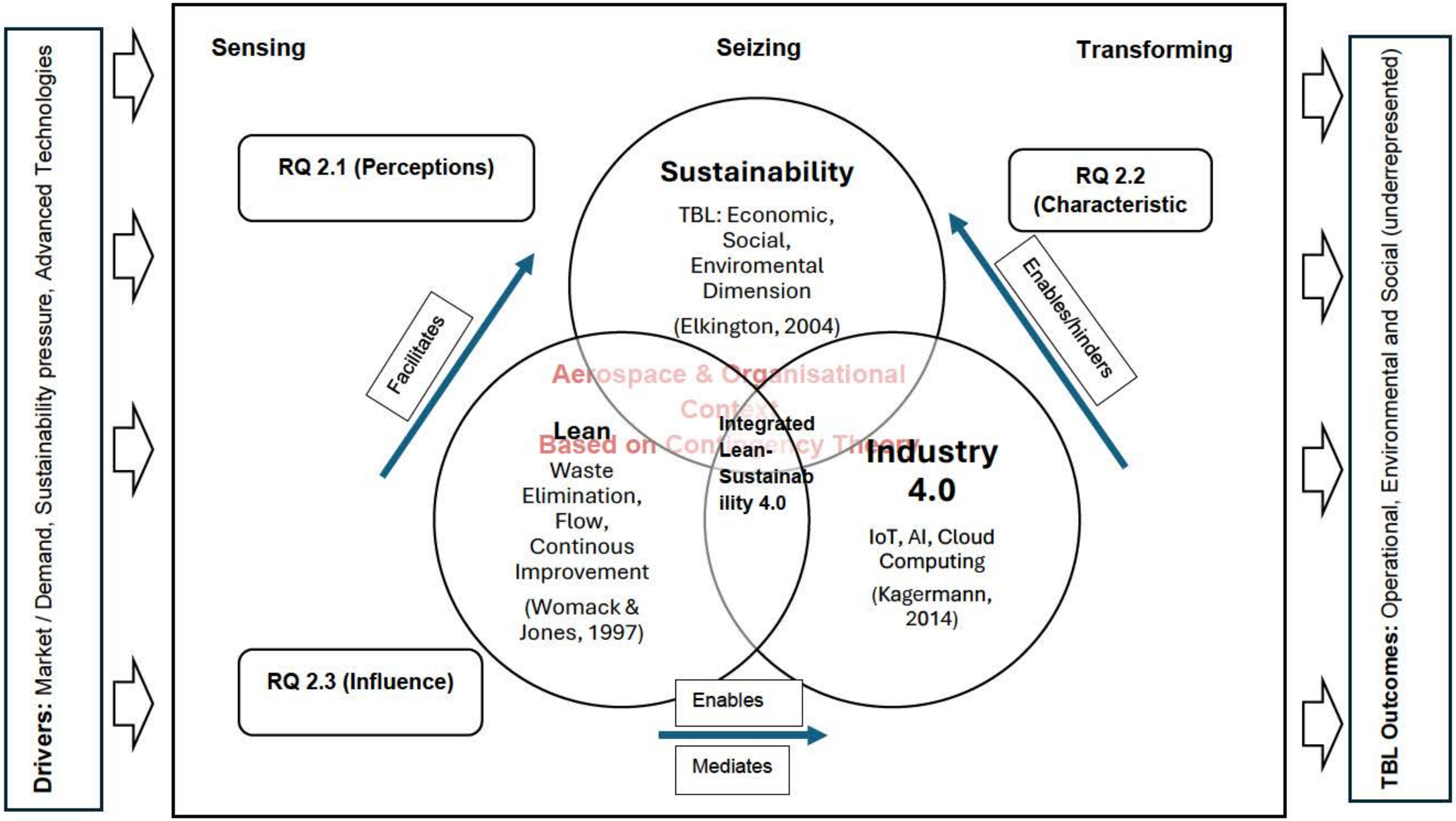


Figure 2-6: Lean–Sustainability 4.0 (LS4.0) Conceptual Framework

## 2.5 Conclusion of the Literature Review

This chapter has established the theoretical foundation for integrating Lean, Sustainability, and I4.0 in aerospace, addressing the research questions under objective One. Through a dual approach, combining a scoping review with a narrative literature review, the literature review has mapped the core principles, interrelationships, practical integration themes of the LS4.0 paradigm. The synthesis demonstrates that Lean's fundamental principles of waste elimination, flow, and continuous improvement (Womack & Jones, 1997) are well positioned to support Sustainability goals (EPA, 2000, Peter et al., 2011). This potential is strengthened when I4.0 technologies such as IoT, big data analytics, and cyber-physical systems are deployed to provide real-time monitoring, predictive insights, and automation that extends Lean's efficiency logic into measurable environmental outcomes. However, whilst there are clear synergies, several tensions persist, notably around scalability in regulated sectors, trade-offs between just-in-time and environmental goals, and the social dimension of Sustainability.

The review identified five recurring integration themes, technology integration, sustainable operational excellence, supply chain integration, Sustainability and circular economy advancement, and Lean as a dynamic capability, offer a granular view of how integration unfolds at tactical and strategic levels. Yet despite promising theoretical advances, the literature remains fragmented and lacks sector-specific validation, most studies are conceptual or focused on surveys and tend to be abstract lacking empirical testing, and social Sustainability is frequently neglected. Aerospace, with its high precision, regulatory intensity and long product lifecycles, is largely underrepresented.

To address these gaps, the chapter introduced a contextualised conceptual framework, guided by dynamic capabilities theory and contingency theory. The framework operationalises the interplay between drivers, synergy mechanisms, capabilities, and performance outcomes, all shaped by sector-specific contingency characteristics. This framework sets the stage for empirical exploration in the subsequent chapters, where practitioners' perceptions RQ 2.1, influencing characteristics RQ 2.2, and integration influence RQ 2.3 are explored through case study investigation and practitioner Delphi validation.

Ultimately, this chapter has synthesised what is known about Lean-Sustinability-I4.0 integration and clarified what remains underexplored, highlighting the urgent need for specific-tailored models that capture the aerospace sector's unique operational, regulatory, and Sustainability challenges.

# Chapter Three
# Research methodology and methods

## 3.1 Introduction

This chapter outlines the research methodology and methods employed to address the study's objectives and research questions, focusing on the integration of Lean, Sustainability, and I4.0 within the UK aerospace industry. The study aims to develop and validate the LS4.0 model, addressing three interconnected objectives across conceptual exploration, empirical investigation, and expert-informed refinement. Building on the theoretical foundation established in Chapter 2 , this chapter details the philosophical underpinnings, research strategy, and methods used to conduct the inquiry.

The focus of the investigation is to explore how Lean, Sustainability, and I4.0 can be effectively integrated within the UK aerospace manufacturing. Whilst the case study organisation has an established Lean operating system and has begun to engage with Sustainability initiatives and digitalisation, this integration remains largely implicit and uncoordinated within its formal strategic framework. Therefore, the study investigates how such integration could occur in practice, and what characteristics, enablers, and barriers shape this potential transformation.

To enable this inquiry, the chapter presents the ontological, epistemological, and axiological foundations that inform the researcher's worldview, leading to the adoption of an interpretivist paradigm. This paradigm recognises that reality is socially constructed and best understood through the lived experiences and contextual interpretations of individuals (Creswell & Creswell, 2023, Guba & Lincoln, 1994). Consistent with this, a qualitative, inductive approach was chosen, allowing theoretical insights to emerge from in-depth engagement with practitioners and organisational context. The study adopts a "bottom-up" inductive approach (Blaikie, 2007), which emphasises the development of theory from the ground up, rooted in the everyday experiences and social interpretations of actors within the organisation, This approach is especially well-suited to exploring new, complex, and context-sensitive phenomena, such as the integration of Lean, Sustainability, and I4.0, where existing theories may be insufficient or fragmented (Eisenhardt, 1989). Through inductive reasoning, the study aims to surface rich, empirically grounded insights that can contribute to theory building in the operations management and industrial Sustainability domains.

To examine a real-world and contemporary phenomenon in depth, the study adopts an instrumental single-case study strategy (Stake, 1995, Yin, 2018), focusing on a leading UK aerospace site within a multinational organisation. The case offers an ideal setting to investigate why and how Lean, Sustainability, and I4.0 technologies efforts can be shaped and aligned under sector-specific conditions.

Qualitative research offers context-sensitive insights, however, there are also notable risks such as subjectivity and limited generalisability. These are addressed through careful triangulation of data sources (Yin, 2018), including semi-structured interviews, document analysis, and direct observations. This strategy ensures trustworthiness and enhances the credibility of the findings, in line with established practices in qualitative case study research (Creswell & Creswell, 2023, Hyett et al., 2014, Morse et al., 2002).

This chapter is structured around three interconnected phases summarised in Figure 3-2. Phase One involves a literature-based synthesis to gain conceptual insights. Phase Two consists of empirical fieldwork through triangulated methods of interviews, documents, and observations within the case study organisation. Phase Three employs the Delphi method with industry experts to validate and refine the LS4.0 model. The next section 3.2 introduces the philosophical assumptions underpinning the study. Section 3.3 outlines the overall research design, including the three phases, case selection, boundaries, and unit of analysis. Section 3.4 introduces the participation selection and sampling. Section 3.5 details the fieldwork procedures, including access, ethics, researcher positionality, and secondary data collection. Section 3.6 elaborates on interviews and their role in the empirical phase. Section 3.7 presents the thematic analysis process. Section 3.8 explains the Delphi validation, whilst Section 3.9 addresses trustworthiness and authenticity. Section 3.10 considers limitations, before Section 3.11 concludes with a transition on the empirical findings in Chapter Four.

Taken together, these sections form a coherent methodological foundation for this study. The combination of interpretivist inquiry, inductive reasoning, and triangulation across interviews, documents, and observations ensures that the empirical insights developed in Chapter Four and Chapter Five are grounded in the lived realities of aerospace practitioners whilst remaining analytically rigorous. This framework strengthens the study's ability to advance both theoretical understanding and practical guidance for Lean, Sustainability, and I4.0 integration in the aerospace sector.

### 3.2 Research Philosophy

The philosophical foundations of research are critical to shaping the entire inquiry process, influencing how knowledge is understood, constructed, and interpreted (Johnson & Christensen, 2019, Saunders et al., 2023). These foundations serve as the epistemological and ontological compass that underpins the choice of methodology, research design, and data collection techniques. This section sets out the key philosophical assumptions, ontology, epistemology, axiology, and methodological implications, guiding this study (Guba & Lincoln, 1994).

The researcher's awareness of these assumptions enhances the credibility of the study by providing a clear rationale for the choice of methods and the interpretation of findings (Easterby-Smith et al., 2018, Saunders et al., 2023). The research adopts an interpretivist paradigm, which assumes that reality is socially constructed and best understood through the subjective experiences of individuals interacting with their environment (Creswell & Creswell, 2023, Guba & Lincoln, 1994). Rather than seeking objective, universal truths, interpretivism emphasises the meanings that people assign to their experiences, making it well-suited to exploring complex socio-technical phenomena such as the integration of Lean, Sustainability, and I4.0 within the aerospace industry.

Within this interpretivist paradigm, the study applies an inductive logic of inquiry, privileging empirical observations and practitioner perspectives as the basis for theoretical development. Rather than testing predefined hypotheses, the aim is to surface context-sensitive insights that can inform theory-building in operations management. This methodological orientation ensures that the emergent LS4.0 model is firmly grounded in the lived realities of aerospace practitioners, whilst speaking to broader theoretical debates (Eisenhardt, 1989, Guba & Lincoln, 1994).

#### 3.2.1 Ontology

Ontology refers to the researcher's assumptions about the nature of reality (Saunders et al., 2009). This study is guided by a relativist ontological stance, which posits that reality is not objective and singular but is multiple, constructed, and interpreted through social, cultural, and organisational lenses (Burrell & Morgan, 2019, Guba & Lincoln, 1994). In this view, organisational practices, such as Lean implementation or digital transformation, are not neutral, universal procedures, but are shaped by practitioners' interpretations, values, and contextual constraints.

This assumption aligns with the study's aim to explore how practitioners in a real-world aerospace context perceive and navigate the interrelationships between Lean, Sustainability, and digital technologies. The research therefore seeks to understand contextualised realities, rather than test generalisable laws.

### 3.2.2 Epistemology

Epistemology concerns what constitutes valid knowledge and how it can be acquired (Easterby-Smith et al., 2018). This study adopts a constructivist epistemological position, which asserts that knowledge is co-constructed through social interaction and shaped by individuals' lived experiences (Creswell & Poth, 2016). This assumption informs the use of semi-structured interviews, document analysis, and direct observations, which enable the researcher to co-produce knowledge with participants rather than extract objective facts from them. By valuing practitioners' interpretations of Lean, Sustainability, and I4.0, the study recognises that these paradigms are understood and enacted differently across organisational layers and functions, especially in complex, regulated environments like aerospace.

### 3.2.3 Axiology

Axiology refers to the role of values in research (Saunders et al., 2023). This study acknowledges that both the researcher and participants bring their own values, assumptions, and motivations to the research process. The researcher's insider role, as an employee within the case organisation, contributes professional insight and contextual familiarity but also necessitates transparency and ethical sensitivity to mitigate bias and uphold research integrity (Unluer, 2012).

Three value dimensions are particularly relevant to this inquiry. First, the researcher's professional background and personal interest in Lean, Sustainability, and digital transformation shape the focus of the investigation and the interpretation of findings. Second, organisational stakeholders bring their own priorities and perspectives, which reflect diverse operational, strategic, and ethical concerns. Finally, the study is guided by principles of informed consent, confidentiality, and respectful engagement, in line with the University of Gloucestershire's ethical protocols, details in see Section3.5.5.

### 3.2.4 Methodological implications

The interpretivist and constructivist paradigm, along with the inductive reasoning approach, led to the adoption of a qualitative research strategy using a single case study methodology. This methodological orientation is consistent with the study's aim to explore the lived experiences, perceptions, and contextual dynamics that shape the integration of Lean, Sustainability, and I4.0 in aerospace. In operations management research, the dominant alternative has historically been positivism, privileging large-scale surveys, modelling, and quantitative hypothesis testing. Whilst this tradition has advanced generalisable insights, it often overlooks contextual complexity, social processes, and sectoral contingencies (Barratt et al., 2011, Ketokivi & Choi, 2014, Meredith, 1998).

The table below summarises the contrast between positivism and interpretivism, situating interpretivism as the more appropriate paradigm for this study:

Table 3-1: Comparison of positivism and interpretivism (Saunders et al., 2023)

| ***Paradigm*** | ***Positivism*** | ***Interpretivism*** |
|---|---|---|
| ***Ontology*** | External one true reality | Multiple constructed realties |
| ***Epistemology*** | Objectivity (Facts) | Subjectivity (meanings, interpretations) |
| ***Methodology*** | Experimental / Manipulative; Verification of hypotheses, mainly quantitative methods<br>Deductive process | Hermeneutical / Dialectical; in-depth understanding through qualitative methods<br>Inductive process |
| ***Relevance to the study*** | Less suited for the exploratory nature of qualitative research | Aligned with capturing subjective meanings and interpretations |
| ***Strengths*** | Provide wide coverage of the range of situations<br>Fast and economical | Depth, theory-building, sensitivity to process and change |
| ***Weaknesses*** | Limited in generating new theory; rigid | Time and resources consuming<br>Analysis and interpretation are challenging |

This broader philosophical contrast is reflected in the findings of the scoping review, detailed in section 2.2.4.3 - Table 2-3. Among the 43 articles reviewed, 37% employed survey methods and a further 30% were theoretical in nature, whilst only 16% used case-based or qualitative approaches. The imbalance underscores the field's reliance on positivist traditions and its lack of empirical depth and contextual sensitivity, particularly in regulated, low-volume, high-complexity sectors such as aerospace.

By adopting an interpretivist paradigm and case study design, this research addresses these gaps. The research captures the socially constructed realities of practitioners, explores contextual contingencies that surveys often miss, and contributes empirically grounded insights to a literature still dominated by abstract or survey-based models. The methodological implication is therefore twofold: first, to generate theory grounded in practice and context, and second, to challenge the overreliance on positivist designs by demonstrating the value of qualitative, interpretivist inquiry in advancing understanding of Lean, Sustainability, and I4.0 integration.

### 3.2.5 Research paradigm

A research paradigm serves as the conceptual framework guiding how the research is conducted. The research paradigm is comprised of perceptions and an understanding of theories and practices that influence the conduct of research (Burrell & Morgan, 2019, Saunders et al., 2023). A paradigm can be defined as a worldview that is based on assumptions or set of beliefs that shape the approach and decisions on how to conduct the research (Denzin & Lincoln, 2017, p. 61). This study operates within a social constructivism paradigm, closely associated with interpretivism (Creswell & Poth, 2016). Whilst constructivism emphasises the importance of understanding the meanings and interpretations that individuals assign to their experiences, interpretivism, as a complementary perspective, recognises that reality is socially constructed and highlights the subjective nature of human experiences (Bryman, 2016). This paradigm acknowledges the complexity of human perception and the importance of the researcher's interpretation in understanding constructed realities.

Given that this study aims to explore how Lean, Sustainability principles, and I4.0 technologies are perceived and potentially integrated within the aerospace industry, a qualitative and inductive approach was deemed appropriate. Qualitative research is particularly valuable in studying real-world contexts where variables are complex and interdependent (Tashakkori et al., 2009).

#### 3.2.5.1 Inductive Reasoning

Inductive reasoning involves building understanding from observed patterns and participant experiences (Blaikie, 2007). Rather than testing a pre-existing hypothesis, this study seeks to explore a phenomenon and generate theoretical insights related to the operational and Sustainability performance in the aerospace sector. Through in-depth engagement with participants and contextual data, emergent patterns guide the development of a novel framework for integrating Lean, Sustainability, and I4.0. Inductive reasoning facilitates an in-depth exploration of the perspectives and lived experiences of individuals, enabling the construction of a framework grounded in participants' accounts. Blaikie (2007) characterises this as a "bottom-up" approach, where concepts and theories emerge from the everyday conceptualisations and understandings of social actors. By engaging with participants' viewpoints, the study generates insights that accurately reflect their experiences using their own words.

Although this study adopts an inductive, bottom-up logic of inquiry, it uses a qualitative single-case study design rather than Grounded Theory. Grounded Theory was not adopted because the aim was not to generate a new substantive theory, but to develop and refine the LS4.0 model using sensitising theoretical lenses such as dynamic capabilities theory and contingency theory, alongside practitioner evidence. Classic Grounded Theory relies on iterative constant comparison, theoretical sampling, and saturation to generate theory primarily from data (Glaser & Strauss, 1967, Strauss & Corbin, 1998) and typically requires sampling decisions to be driven by emergent categories rather than predefined case boundaries (Charmaz, 2014). By contrast, this research is bounded by an instrumental single case and structured to support in-depth contextual understanding and model refinement, which aligns well with case study methodology (Yin, 2018).

Case study design is well-suited to contexts where limited research exists, providing a structured pathway to develop new concepts and frameworks (Eisenhardt, 1989). Therefore, the study began by critically reviewing the literature on the aerospace sector, Lean, Sustainability, and I4.0 to establish a foundation for synthesising new insights. This process bridges theoretical understanding with practical applications in a complex and evolving setting.

### 3.2.5.2 Quantitative versus Qualitative Methods

Before determining the research strategy, it is important to outline the major research methods: qualitative or quantitative, each grounded in distinct conceptual paradigms. Quantitative research typically employs deductive reasoning and aligns with the scientific model and positivist philosophy (Tashakkori et al., 2009). This perspective views social reality as objective and external, focusing on quantitative data collection to identify patterns, relationships, and causality. Quantitative research often follows a structured, linear model using hypotheses, precise variable measurement, and statistical testing to derive generalisable conclusions (Creswell & Creswell, 2023, p. 45). In this study, the qualitative approach is consistent with the researcher's interpretivist philosophical stance, allowing for exploration of the complex relationship between Lean, Sustainability, and I4.0 technologies in enhancing operational and Sustainability performance within the aerospace sector. This approach enables a nuanced understanding of interlinked concepts interpreted through the perspectives of industry practitioners. Qualitative research is particularly valuable in studying phenomena within their real-world context. The approach enables researchers to explore subjective experiences and perceptions, uncovering context-dependent insights into organisational dynamics. In this research, understanding Lean, Sustainability, and I4.0 interaction within a manufacturing environment requires immersion in the organisational setting, aligned with the "inquiry from the inside" approach (Evered & Louis, 1981).

Denzin and Lincoln (2017, p. 45) described qualitative research as a situated activity that locates the observer in the world. This involves interpretive practices, such as field notes interviews, and recordings, that transform experiences into representations. For this study, such practices were operationalised through semi-structured interviews with aerospace practitioners, supported by document analysis and site observations, enabling multiple perspectives on how Lean, Sustainability, and I4.0 integration is understood, enacted, and challenged in practice.

In summary, qualitative methods were deemed the most suitable for this research due to their alignment with the study's aim, philosophical assumptions, and need to explore complex, evolving dynamics within a specific organisational context.

### 3.3 Research Design

The research design is a critical component of any study, as it provides the framework for data collection, analysis, and interpretation. Yin (2018) contended that every empirical study embodies an implicit or explicit research design which guides the logical sequence that connects the empirical data to the research questions and ultimately to the conclusions. Whilst traditional case study research does not always require a formally stated design, developing one strengthens the structure and rigour of the investigation (Yin, 2018, p. 83). Reflecting this perspective, this study adopted a qualitative, single-case study research design to explore how Lean, Sustainability, and I4.0 can be effectively integrated to enhance operational and Sustainability performance within the aerospace sector. The selection of this design was influenced by the exploratory nature of the research and the absence of established empirical frameworks addressing this threefold integration in aerospace manufacturing.

The formulation of research questions prior to entering the field was instrumental in shaping the focus and scope of the study. In this study, the design was therefore structured to align directly with the three overarching research objectives introduced in Chapter One. The first phase focused on addressing Objective One by conducting a scoping review and narrative synthesis to map existing knowledge and develop a preliminary conceptual model. The second phase addressed Objective Two through an in-depth case study, using semi-structured interviews, document analysis, and observations at a UK aerospace site to empirically explore the model's relevance and applicability. The third phase responded to Objective Three by applying the Delphi method with aerospace and operations experts within the case company, enabling iterative validation and refinement of the model in light of sector-specific challenges and strategic priorities.

Therefore, these phases ensured that the study progressed logically from conceptual exploration to empirical investigation and finally to expert-informed validation, strengthening both the internal coherence and external applicability of the research design.

### 3.3.1 The role of theory in Qualitative Case Study Research

The role of theory is central to ensuring rigour in qualitative case study design and analysis. The use of theoretical frameworks facilitates meaningful interpretation of findings and strengthens the generalisability of insights from the case to broader conceptual understanding (Eisenhardt & Graebner, 2007, Yin, 2018). Flyvbjerg (2011), Morse et al. (2002) and Hallberg (2013) argue that theory is essential in guiding qualitative inquiry, especially in management and organisational research where complex, context-dependent realities are explored (Hyett et al., 2014, Meyer, 2001). A well-developed theoretical proposition supports a more focused data collection process and enhances the analytical depth of the case study.

In line with this, the study draws on two complementary theoretical lenses:

- Dynamic capabilities theory: Employed to understand how organisations sense, seize and transform capabilities to adapt to technological and Sustainability-related changes.
- Contingency theory: Used to interpret how organisational and sector-specific variables e.g., compliance, complexity, novelty shape the integration process.

These theoretical underpinnings inform the design, data collection, and interpretation of findings, ensuring that the resulting LS4.0 model is not only empirically grounded but also theoretically sound.

### 3.3.2 Rationale for Case Study Methodology

To address the exploratory nature of the main research question, "How can Lean, Sustainability, and I4.0 technologies be effectively integrated to enhance operational and Sustainability performance in the aerospace sector?", the study adopts a single case study methodology (Saunders et al., 2023, Yin, 2018). The case study approach is particularly well-suited for exploring complex, real-world phenomena within a bounded context, especially when existing theoretical frameworks are limited or fragmented (Eisenhardt & Graebner, 2007, Stake, 2000). Given the limited empirical evidence on the integrated application of Lean, Sustainability, and I4.0 in the aerospace sector, a case study design offers a rigorous way to generate rich, context-dependent insights that cannot be captured through purely quantitative or multi-sectoral studies. This inductive, theory-building orientation enables the research not only to uncover novel insights but also to refine and extend existing conceptual models in a sector where empirical grounding is currently lacking (Stake, 1995). A single instrumental case was selected to deepen understanding of how these three paradigms interact in practice and to contribute to the development of a contextualised framework for aerospace operations management.

### 3.3.3 Justification for Case Study Methodology

The case study methodology is appropriate for this research for several interrelated reasons. Firstly, the case study provides contextual depth and enables an in-depth examination of how Lean, Sustainability, and I4.0 are understood, interpreted, and applied within a specific organisational and sectoral setting. This depth is particularly important in aerospace, where regulatory intensity, long product lifecycles, and high product complexity demand close attention to contextual nuance (Dul & Hak, 2007).

Secondly, the case study approach is well suited to the exploratory focus of the research. The case organisation allows the investigation of “how” and “why” questions, which are central to this study’s aim of understanding the mechanisms, perceptions, and challenges involved in integrating Lean, Sustainability, and I4.0 (Yin, 2018). Rather than testing predetermined hypotheses, the method facilitates the inductive exploration of processes that remain under-theorised in the aerospace sector.

Thirdly, the methodology supports the use of multiple data sources, including semi-structured interviews, organisational documentation, and direct site observations. This triangulation enhances the trustworthiness of the findings by allowing insights to be cross-checked across different forms of evidence, strengthening the validity of interpretation (Saunders et al., 2023).

Finally, case study research is particularly valuable for theory-building. By generating rich, empirically grounded insights, it enables the refinement of conceptual models and the development of new theoretical perspectives in underexplored domains (Eisenhardt, 1989, Yin, 2018). In this study, the case design is used to inform and validate the proposed LS4.0 model, ensuring that it reflects both academic rigour and sector-specific realities.

Although the case organisation does not currently pursue an explicit strategy integrating Lean, Sustainability, and I4.0, it is advancing maturity in each of these areas independently. This makes it an appropriate and timely setting in which to investigate implicit alignments, emerging synergies, and practitioner perspectives, providing a unique opportunity to capture how integration may evolve in practice.

### 3.3.4 Case Selection. Boundaries, and Unit of Analysis

The selected case organisation, referred to under the pseudonym AeroSkyward, is a multinational leader in the aerospace sector, employing over 50,000 people globally and generating annual revenues exceeding £30 billion. Headquartered in the United States, AeroSkyward is renowned for designing and manufacturing jet engines and electrical systems, positioning it at the forefront of aerospace innovation.

The UK site chosen for this study plays a pivotal role within both the company and the wider national aerospace industry. The organisation contributes to defence and commercial aviation platforms, collaborates with major OEMs such as Airbus and Boeing, and represents a critical hub for manufacturing, R&D, and supply chain integration. The UK site scale and centrality make it a highly relevant setting for investigating the integration of Lean, Sustainability, and I4.0.

Several features justify case selection. Firstly, AeroSkyward has institutionalised a mature Lean operating system with the pseudonym of LeanLift, which was launched in 2020 and centralised further in 2024, which provides a stable platform to study how Lean principles interact with digitalisation and Sustainability. Secondly, the organisation has made explicit Sustainability commitments, including achieving operational carbon neutrality at the UK site by 2030, whilst actively embedding green manufacturing practices. Thirdly, the organisation is pursuing a portfolio of I4.0 initiatives, such as IoT-enabled connectivity, predictive analytics, and cloud computing, that serve as entry points to examine how digitalisation can accelerate Lean-Sustainability integration. Finally, the researcher's insider role as an employee at the site provided unique access to stakeholders, documents, and daily operations, ensuring contextual depth and access to high-quality data.

The boundaries of this study are intentionally defined to focus on the UK-based manufacturing operations. These functions represent the point at which Lean, Sustainability, and I4.0 converge most directly, influencing process efficiency, resource use, and environmental outcomes. Non-manufacturing domains such as finance, sales, and after-service maintenance are excluded, as including them would dilute the operational focus. Limiting the scope to production activities also ensures alignment with the study's interpretivist paradigm by concentrating on the site where integration challenges and opportunities are most visible.

The unit of analysis is the UK site's operational and manufacturing system as a whole, encompassing its production processes, management practices, and digital initiatives. Within this setting, data were collected from stakeholders across functions such as Lean transformation, operations, Sustainability, quality, manufacturing engineering, and digital technology. This ensured variation in perspectives whilst maintaining a consistent focus on the site level as the central unit of analysis. By adopting this bounded approach, the study achieves analytical clarity and context-specific validity, supporting theory-building in a sector that has been underexplored in the Lean, Sustainability, and I4.0 literature.

Case Study

**Unit of Analysis**
**Single case organisation**

Industry model in the aerospace sector. The company designs and manufacturers civil and military engines and power systems. The company was established more than +100 years and is considered as a world major provider of innovation solutions.

The company is committed to Sustainability and dedicated to moving the aerospace industry forward.

**Location**

One of the company's sites based in the UK.

**Business Units**

- Military Business Unit
- Civil Business Unit
- Avionics
- Printed Circuit Boards (PCB) Business Unit

| Department | Role to Lean | Responsibilities | Participants |
|---|---|---|---|
| **Value Streams / Business Units** | Apply Lean practices and principles | Ensure the business is meeting quality, delivery, costs and achieving sales targets | All participants are involved in the company project of Lean implementation. All participants have significant experience in the aerospace sector and in Lean implementation and have interest in Sustainability approach and Industry 4.0 technologies. |
| **Manufacturing engineering** | Design and develop solutions to ease product manufacturability. Integrate new manufacturing solutions and methods | Achieving business efficiency and enhanced productivity | |
| **Quality** | Oversee business quality performance in terms of failure rate, rework, defects and customer satisfaction / claims | Responsible for the voice of the customer | |
| **Operational Digital Technology** | Support operations | Ensure operational connectivity | |
| **Sustainability** | An integral part of the Lean mindset | Achieve Sustainability goals | |
| **Lean** | Develop business operational model | Ensure business is meeting SQDC targets | |



Figure 3-1: The chosen case study organisation

### 3.3.5 Time Frame

The study adopts a cross-sectional design, capturing a snapshot of organisational practices and perspectives during the period 2023-2024 (Saunders et al., 2023, p. 212). Semi-structured interviews, site observations, and document analysis were undertaken within this period, focusing on stakeholders engaged in Lean implementation, Sustainability initiatives, and operational connectivity projects. This design is well-suited to the study's exploratory aim, to illuminate how integration is understood and interact at a specific point in the organisation's transformation journey. By concentrating on a bounded timeframe, the research aligns with its interpretivist stance, privileging rich contextual insight over statistical generalisation.

By grounding the study in a cross-sectional analysis enhanced by insider contextual familiarity, the research strikes a balance between methodological rigour and practitioner-informed depth. This approach supports the study's aim to generate rich, empirically grounded insights into the integration of Lean, Sustainability, and I4.0 within the UK aerospace context.

Although not longitudinal in the formal sense, the researcher has been employed by the case study organisation since 2020, providing extended exposure to the site's operational evolution. Whilst no systematic data were collected over multiple time points, this long-term engagement enhanced the researcher's contextual awareness of the organisation's Lean deployment progress, increasing Sustainability commitments, and early-stage digitalisation efforts. These informal insights did not form part of the formal dataset but served to inform interpretation and sense-making during analysis. However, in line with the researcher's methodological limitations, no claims are made regarding longitudinal validity or temporal causality.

Table 3-2 outlines the key milestones of the research process and organisational activities relevant to the study:

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Table 3-2: Time Horizon

<table>
<tr><th rowspan="2">Task</th><th>Year</th><th>2020</th><th colspan="4">2021</th><th colspan="4">2022</th><th colspan="4">2023</th><th colspan="4">2024</th><th colspan="4">2025</th></tr>
<tr><th>Quarter</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th></tr>
<tr><td>Postgraduate Research Methods</td><td></td><td colspan="3">100%</td><td colspan="18"></td></tr>
<tr><td>Framing the research, LR, PAF Completion</td><td></td><td colspan="3"></td><td colspan="6">100%</td><td colspan="12"></td></tr>
<tr><td>Research Project approval</td><td></td><td colspan="2"></td><td colspan="7">100%</td><td colspan="12"></td></tr>
<tr><td>Narrative Literature Review</td><td></td><td colspan="2"></td><td colspan="11">100%</td><td colspan="8"></td></tr>
<tr><td>Scoping Literature Review</td><td></td><td colspan="9"></td><td colspan="6">100%</td><td colspan="6"></td></tr>
<tr><td>Gaining access to the organisation</td><td></td><td colspan="9"></td><td>100%</td><td colspan="11"></td></tr>
<tr><td>Participant Selection</td><td></td><td colspan="9"></td><td>100%</td><td colspan="11"></td></tr>
<tr><td>Interview Questions Design</td><td></td><td colspan="9"></td><td>100%</td><td colspan="11"></td></tr>
<tr><td>Conducting the One-to-one interviews</td><td></td><td colspan="10"></td><td colspan="7">100%</td><td colspan="4"></td></tr>
<tr><td>Data Collection</td><td></td><td colspan="10"></td><td colspan="7">100%</td><td colspan="4"></td></tr>
<tr><td>Data Analysis</td><td></td><td colspan="11"></td><td colspan="6">100%</td><td colspan="4"></td></tr>
<tr><td>Presentation of findings</td><td></td><td colspan="15"></td><td colspan="2">100%</td><td colspan="4"></td></tr>
<tr><td>Validating the model via Delphi Method</td><td></td><td colspan="17"></td><td>100%</td><td colspan="3"></td></tr>
<tr><td>Discussion</td><td></td><td colspan="17"></td><td colspan="2">100%</td><td colspan="2"></td></tr>
<tr><td>Conclusion</td><td></td><td colspan="17"></td><td colspan="2">100%</td><td colspan="2"></td></tr>
</table>

### 3.3.6 Phase One: Literature Review and Conceptual Model Development

The first phase of the research involved a literature-based exploration to map the state of knowledge on Lean, Sustainability, and I4.0 integration. This was achieved through a scoping review in Section 2.2, supplemented by a narrative review to interrogate theoretical perspectives and sectoral applications. The scoping review identified 43 relevant peer-reviewed studies published between 2015 and 2025, highlighting enablers, barriers, and gaps in cross-paradigm integration. This analysis informed the development of an initial conceptual framework, guided by dynamic capabilities theory and contingency theory. The framework served as the foundation for subsequent empirical investigation, ensuring that fieldwork was grounded in both theoretical insight and sectoral context.

### 3.3.7 Phase Two: Case Study Exploration through Triangulation

The second phase employed a qualitative, single-case design to capture practitioner perspectives and organisational practices within a UK aerospace manufacturing site. Consistent with Yin (2018), this phase applied a triangulation strategy to strengthen construct validity and provide a comprehensive account of the phenomenon. Data collection drew on three primary sources: semi-structured interviews, document analysis, and site-based observations.

Semi-structured interviews formed the central source of evidence, enabling the collection of detailed accounts from practitioners across leadership, engineering, operations, supply chain, Sustainability, and digital technology. Document analysis complemented the interviews by providing contextual insights into formal strategies, communications, and operational systems, following the criteria of authenticity, credibility, representativeness, and meaning (Morgan, 2022). Site-based observations further enriched the evidence base, with the researcher attending Kaizen events, problem-solving sessions, and walkthroughs, recording both field notes and reflexive memos.

Taken together, this triangulation approach ensured methodological rigour, reduced the risk of bias, and captured the phenomenon through multiple organisational lenses. The full details of these methods are described in Section 3.5 - Fieldwork.

### 3.3.8 Phase Three: Delphi Method for Model Validation

The third phase of the study employed the Delphi method to validate and refine the LS4.0 model developed from the case study. Delphi was selected for its structured, iterative process that enables expert consensus-building in areas characterised by complexity and uncertainty (Hasson & Keeney, 2011, Hsu & Sandford, 2007). This phase sought to test the applicability and robustness of the LS4.0 model against the judgement of domain experts within the case organisation, ensuring its theoretical integrity and practical relevance to the aerospace sector. The Delphi process complemented the inductive case study by offering a collective validation mechanism, therefore, strengthening the credibility and transferability of the model. The methodological procedures for this phase are presented in Section 3.8.

To provide a consolidated overview, Figure 3-2 illustrates the three-phase research design. The figure highlights the alignment between research objectives, questions, methodological choices, and expected deliverables. This visual representation demonstrates the sequential and complementary nature of the phases.

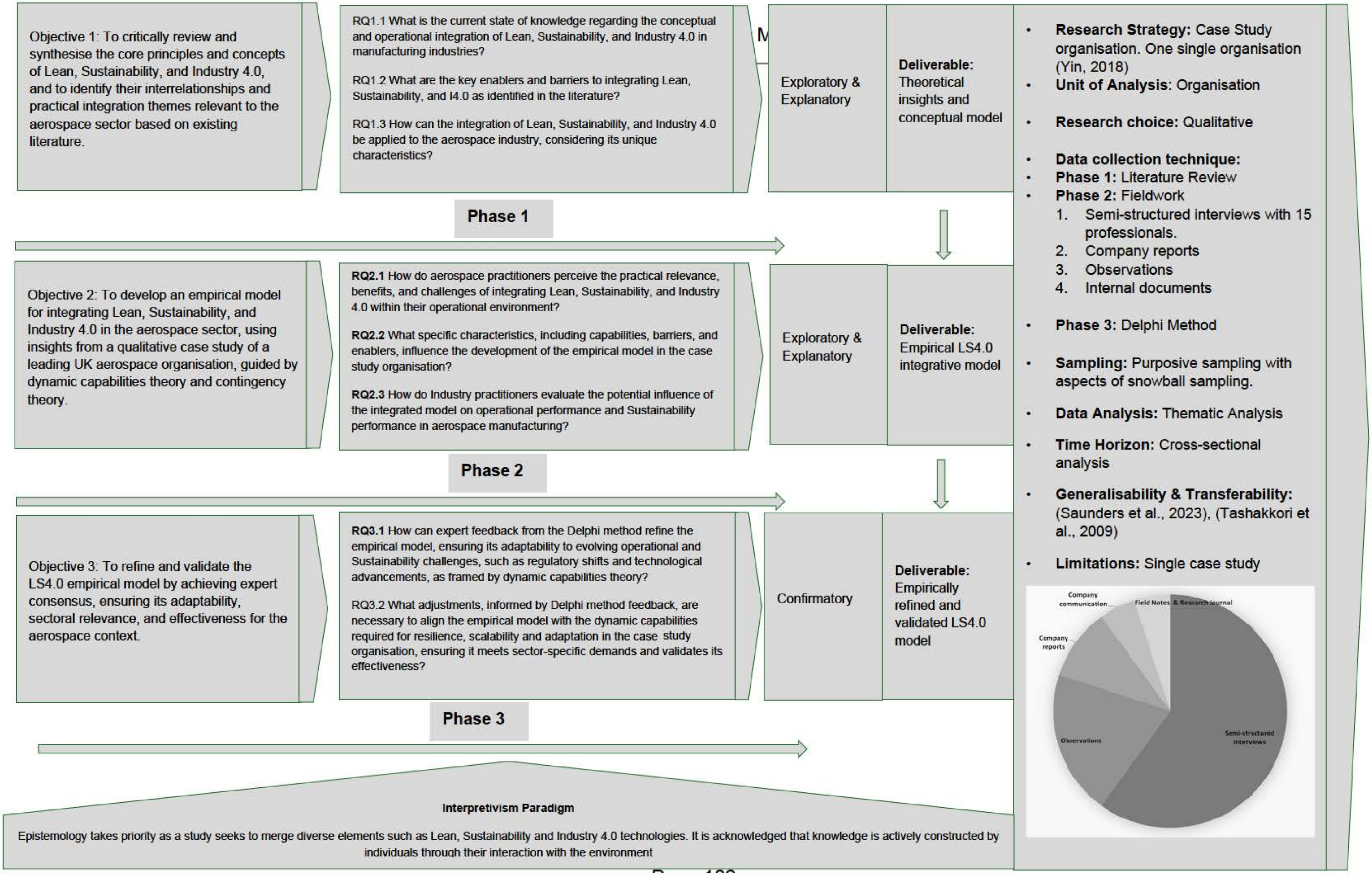


Figure 3-2: Research Design

Table 3-3: Applied research methods

| | | Data Collection Methods – Qualitative Data | | | | | Data Analysis |
|---|---|---|---|---|---|---|---|
| | | Primary Data | | | Secondary data | | |
| ***Research Objectives*** | ***Research Questions*** | Semi-Structured interviews (One to one) | Observations | Delphi Method | Company reports and communication | Literature Review | |
| ***Objective1:*** *To critically review and synthesise the core principles and concepts of Lean, Sustainability, and Industry 4.0, and to identify their interrelationships and practical integration elements relevant to the aerospace sector based on existing literature* | RQ1.1: What is the current state of knowledge regarding the conceptual and operational integration of Lean, Sustainability, and Industry 4.0 in manufacturing industries?<br><br>RQ1.2: What are the key enablers and barriers to integrating Lean, Sustainability, and I4.0 as identified in the literature?<br><br>RQ1.3: How can the integration of Lean, Sustainability, and Industry 4.0 be applied to the aerospace industry, considering its unique characteristics? | | | | | x | Scoping Review & Narrative Literature |
| ***Objective 2:*** *To develop an empirical model for integrating Lean, Sustainability, and Industry 4.0 in the aerospace sector, utilising insights the case study organisation, guided by dynamic capabilities theory and contingency theory.* | RQ2.1: How do aerospace practitioners perceive the practical relevance, benefits, and challenges of integrating Lean, Sustainability, and Industry 4.0 within their operational environment?<br><br>RQ2.2: What specific characteristics, including capabilities, barriers, and enablers, influence the development of the empirical model in the case study organisation?<br><br>RQ2.3: How do industry practitioners evaluate the potential influence of the integrated model on operational performance and Sustainability performance in aerospace manufacturing? | x | x | | x | | Thematic analysis – Field Observations |
| ***Objective*** *3:* To refine and validate the LS4.0 empirical model by achieving expert consensus, ensuring its adaptability, sectoral relevance, and effectiveness for the aerospace context. | RQ3.1: How can expert feedback from the Delphi method refine the empirical model, ensuring its adaptability to evolving operational and Sustainability challenges, such as regulatory shifts and technological advancements, as framed by dynamic capabilities theory?<br><br>RQ3.2: What adjustments, informed by Delphi method feedback, are necessary to align the empirical model with the dynamic capabilities required for resilience, scalability and adaptation in the case study organisation, ensuring it meets sector-specific demands and validates its effectiveness? | | | x | | | Thematic analysis |
| | The main research question: How can Lean, Sustainability, and Industry 4.0 concepts be effectively integrated within the UK aerospace industry to enhance operational efficiency, Sustainability, and adaptability | | | | | | |

## 3.4 Participant Selection and Sampling

Participants were selected through a purposive sampling strategy to ensure that those interviewed possessed direct relevance to the study's research questions. The process began with a scoping meeting with the organisation's Lean operations leader, where individuals actively involved in Lean deployment, Sustainability initiatives, and digital transformation projects were identified as potential contributors. Purposive sampling was deemed most appropriate in this context, as it prioritises depth and expertise over breadth, allowing the collection of rich and detailed insights from knowledgeable informants (Easterby-Smith et al., 2018, Gray, 2019). This approach was complemented by elements of snowball sampling, where initial participants recommended further colleagues with relevant expertise. This ensured a more diverse representation of functions and levels of responsibility across the organisation.

Selection was guided by three main considerations: participants' professional experience, their expertise in relevant domains, and their direct involvement in aerospace operations. On average, participants brought over fifteen years of experience in areas such as operations, manufacturing engineering, supply chain management, Sustainability, digital technology, and quality assurance. This extensive experience ensured that interviewees could speak authoritatively about both strategic and operational aspects of integration. For example, one senior participant contributed insights from supplier development and customer quality management, whilst another provided perspectives shaped by regulatory compliance responsibilities. Leaders in Sustainability, Lean transformation, and digital technology added further dimensions, capturing how these paradigms intersect in practice. The researcher's professional background as an aerospace practitioner also informed participant selection, ensuring that chosen interviewees were positioned to provide insights of both strategic and operational relevance.

The final sample group comprised fifteen participants drawn from across hierarchical levels, ranging from executives and directors to functional leaders and value stream managers. This diversity allowed the study to capture multiple perspectives, mitigating the risk of over-reliance on senior or technical viewpoints alone. Importantly, participants were selected not for statistical representativeness but for their ability to offer theoretical rich insights into the integration of Lean, Sustainability, and I4.0 within aerospace (Silverman, 2018).

All participants were individually contacted and provided with an introductory research pack that included an overview of the study's aims, a consent form, and a summary of themes to be discussed, see Appendix D. Participation was voluntary, and all participants provided informed consent. The sample size was justified on the basis of theoretical saturation, the point at which additional interviews no longer generate novel insights. Saturation was reached by the twelfth interview, when no new significant themes emerged, and the final three interviews served to confirm and enrich the themes already identified. This aligns with the guidance of Lincoln and Guba (1985), who argue that a dozen well-chosen interviews are often sufficient to reach saturation in qualitative inquiry.

Table 3-4 presents the anonymised profiles of the fifteen participants, including their roles, functional coverages, and years of experience. These details demonstrate the breadth and depth of expertise represented in the sample and provide assurance of the participants' capacity to contribute meaningfully to the study's objectives.

In total, over 240 pages of transcripts were produced, amounting to 122,788 words and more than 16 hours of recorded dialogue. This provided a rich dataset for thematic analysis (Section 3.7). Onwuegbuzie and Leech (2007) emphasise the importance of balancing data richness with manageability, an objective achieved here by monitoring emerging themes in real-time. The goal was not statistical representativeness, but theoretical richness (Silverman, 2018). By combining purposeful and snowball sampling, and continuing data collection until saturation, the study ensured a robust foundation for developing the LS4.0 model detailed in Chapter Five.

Table 3-4: Interviewees' profile

| Participant# | Identifier | Current Role | Covered Functions | Years of experience | Covered Industries |
|---|---|---|---|---|---|
| Participant #1 | 01DGPH1 | Senior Supplier Quality Engineering Staff Manager | Suppliers' development, Quality Customers management | 25 | Aerospace, Automotive |
| Participant #2 | 02APPH1 | Senior Quality Production Manager | Design engineering, operations, Quality management, customer claims management | 25 | Aerospace, Automotive |
| Participant #3 | 03RMPH1 | Value Stream Leader | Supply chain, Operations, Inventory management, Lean manufacturing | 15 | Aerospace, General Industry |
| Participant #4 | 04MTPH1 | Planning and Inventory Leader | Supply chain, Operations, fulfilment, Inventory management, scheduling | 15 | Aerospace |
| Participant #5 | 05PWPH1 | Manufacturing Engineering Director | Manufacturing engineering, Operations | 20 | Aerospace |
| Participant #6 | 06KHPH1 | Lean Manufacturing Manager | Operations, Quality, Manufacturing Engineering | 25 | Aerospace |
| Participant #7 | 07SPPH1 | Chief of Manufacturing – Senior Director | Project management, Operations, Manufacturing engineering | 30 | Aerospace |
| Participant #8 | 08JKPH1 | Quality -Senior Director | Air service, Aircraft fleet management, Regulation, aircraft repairs and certifications, Operations, Quality | 24 | Aerospace |
| Participant #9 | 09DOPH2 | Digital Technology Director | IT, Operational Connectivity | 30 | Aerospace |
| Participant #10 | 10PSPH2 | Lean Engineering Senior Executive | Lean, IT, Design Engineering | 30 | Aerospace |
| Participant #11 | 11GBPH2 | Senior Executive – Sustainability Global Leader | Sustainability, Global Strategy | 30 | Aerospace Automotive |

| | | | | | |
|---|---|---|---|---|---|
| Participant #12 | 12LOPH2 | Lean Operations Division Leader - Defence | Lean, Operations, manufacturing | 35 | Aerospace |
| Participant #13 | 13BPPH2 | Value Stream Leader | Value Stream, Operations, Lean, MRO | 25 | Aerospace |
| Participant #14 | 14BMPH2 | Sustainability Leader | Sustainability - Operations | 15 | Automotive Aerospace |
| Participant #15 | 15ANPH2 | Lean Operations Executive | Lean, Operations, Quality | 30 | Aerospace |

### 3.5 The Fieldwork

The fieldwork was designed to capture rich, context-embedded insights into the integration of Lean, Sustainability, and I4.0 within a real-world aerospace setting. This phase of the research marked the empirical foundation upon which the conceptual LS4.0 model was built, enabling the study to move from theoretical proposition to grounded insight. Data collection was conducted through a triangulated approach comprising semi-structured interviews, document analysis, and site observations. This combination of methods aligns with best practices in qualitative case study design (Eisenhardt & Graebner, 2007, Yin, 2018), allowing for depth and breadth of understanding. Each method was selected not only for its methodological rigour but also for its capacity to illuminate the multi-layered and contingent realities for organisational transformation.

The researcher's dual role as both employee and PhD candidate provided unique access to the organisational knowledge, whilst also demanding a reflexive stance to navigate potential biases and ethical complexities. The following sub-sections outline the procedures followed to gain access, support ethical standards, manage researcher positionality, and collect robust data. These steps ensured that the fieldwork remained both methodologically sound and ethically grounded, supporting the study's aim of developing a credible and practice-relevant LS4.0 model.

### 3.5.1 Gaining access to the case study organisation

Securing access to the case study organisation, a multinational leader in the aerospace industry, was a pivotal step. The researcher's dual role as both an employee and a PhD candidate provided unique opportunities and challenges. Whilst this insider status facilitated initial access and rapport-building, which also required careful navigation of ethical, procedural, and role-related complexities.

Access was formally obtained through Human Resources (HR) following submission of a research proposal that outlined the study's aims, methods, and potential contributions to the company's ongoing Lean and Sustainability transformation. Emphasis was placed on the research's alignment with organisational priorities, including Lean deployment, digital connectivity, and net-zero carbon commitments. This strategic alignment helped secure organisational support and participant engagement (Easterby-Smith et al., 2018), see Appendix D.

### 3.5.2 Ethical and Procedural Considerations for Gaining Access

Addressing ethical concerns was central to gaining and maintaining access to the organisation. A formal confidentiality agreement was signed with HR, and full ethical approval was obtained through the university's ethics committee, see Appendix E.

To ensure rigour and transparency, several principles guided access and data collection. First, both the organisation and participants were anonymised to protect identity and confidentiality. Second, sensitive information shared in interviews, documents, or observations were safeguarded, with care taken not to disclose propriety or commercially sensitive details in this thesis. Third, participation was voluntary, with all interviewees informed for their right to decline or withdraw at any stage without consequence. Finally, interviews were conducted in private settings, either on-site or via Microsoft Teams, ensuring a safe and comfortable environment for open dialogue.

These safeguards not only fulfilled institutional ethics requirements but also acknowledged the researcher's insider position. By making ethical commitments explicit to participants at the outset, trust was reinforced and potential concerns about dual roles of being a colleague and researcher were addressed transparently.

### 3.5.3 The role of the researcher

In qualitative research, the researcher is a central instrument in the inquiry process (Patton, 2014). The researcher's insider role as an employee of the case organisation provided privileged access to operational settings, documents, and participants. This positionality offered advantages, such as contextual familiarity and rapport with participants, but also carried ethical implications, particularly around potential bias, role conflict, and power dynamics (Unluer, 2012).

To mitigate these risks, several strategies were employed. The researcher explicitly disclosed their dual role at the start of each interview, clarifying that participation was voluntary and unrelated to professional hierarchies. Importantly, the researcher held no managerial authority over participants, reducing the risk of coercion. Reflexivity was built into the process through notetaking, where impressions, contextual influences, and potential biases were critically reflected upon. These reflexive practices helped differentiate between professional assumptions and participants' perspectives and supported more balanced interpretation.

The insider role also shaped the way participants were approached. Pre-existing relationships meant that rapport was quickly established, encouraging candid responses. However, these same relationships required careful handling to avoid assumptions of shared understanding. For example, during Kaizen events where the researcher was both participant and observer, care was taken to adopt a non-interventionist stance, recording observations rather than influencing outcomes.

Ethical principles were consistently upheld throughout. Anonymity was preserved, data were treated with integrity and neutrality, and findings were triangulated across interviews, documents, and observations to reduce reliance on any one perspective. Whilst insider access enriched the depth and authenticity of the data, its risks were managed through transparency, reflexivity, and adherence to ethical standards. This approach balanced the benefits of practitioner-informed insight with the methodological rigour expected in doctoral research. Reflexivity as ongoing practice is further elaborated in Section 3.5.4.

### 3.5.4 Researcher Reflexivity and Bias

In qualitative research, the researcher is not a detached observer but an active instrument in the generation and interpretation of data. Recognising this, the researcher adopted a reflexive approach throughout the study, critically examining how professional background, insider status, and assumptions might influence the research design, data collection, and interpretation (Clarke & Braun, 2021, Lincoln & Guba, 1985). Reflexivity was integral to ensuring the trustworthiness and credibility of the findings, particularly given the interpretivist stance and single-case study approach of this research.

Rather than maintaining a formally structured journal, the researcher kept flexible reflective notes at critical stages of the research process. These notes, taken during literature review, interviews, and post interviews reflections, served to capture key ideas, methodological decisions, and personal observations. For instance, following the pilot interviews, the researcher noted that some questions elicited overly general responses and subsequently rephrased them to probe deeper into organisational challenges, barriers, and opportunities for integration of Lean, Sustainability, and I4.0. These reflective notes were not maintained as a daily log but functioned as a reflexive record of key decision points and learning moments, consistent with Schön (1983) concept of *reflection-in-action* and Boud et al. (2013) emphasis on adaptive learning.

The researcher’s insider position also provided privileged access to participants and facilitated an in-depth understanding of operational practices. However, this is also risked confirmation bias or leading questions (Brannick & Coghlan, 2007). By engaging in reflexive note-taking and iterative self-assessment, the researcher actively mitigated these risks. For example, during early interviews, the researcher observed a tendency to use directive probes, such as asking generally about the evolution of Lean in aerospace, which sometimes led to high-level responses e.g., “Do you see an evolution of Lean principles within aerospace industry and in relation in enhancing Sustainability efforts across the site?”, which could shape participants’ responses. In response, questioning techniques were revised to open-ended prompts e.g., “how do you describe the challenges or obstacles the site faces when implementing Lean practices and in supporting Sustainability objectives”, which encourages richer, more authentic narrative.

These reflective practices also prompted critical evaluation of interview dynamics, such as how rapport with senior participants might influence their willingness to share sensitive information. By documenting such insights, the researcher improved both interviewing techniques and analytical depth. Triangulation with company documents and site observations helped to balance insider knowledge with independent evidence, reducing interpretive bias and strengthening the study's credibility (Patton, 2014).

Overall, this reflexive stance allowed the researcher to maintain a balance between practitioner expertise and academically objectivity. This approach enhanced the quality of data collection, the rigour of thematic analysis, and ultimately the trustworthiness of the LS4.0 model.

### 3.5.5 Ethical Considerations in Data Collection

Ethical conduct was integral to this research. Comprehensive measures were taken to ensure that participants were fully aware of their roles and rights before, during, and after the study. Flick (2021) emphasises that ethics in qualitative research must bridge abstract principles and practical implementation, ensuring that participants are not only protected but also empowered to contribute to authenticity. Accordingly, ethical approval was secured through the University of Gloucestershire ethics committee, supported by a confidentiality agreement with the case organisation. See Appendix E.

Participants were provided with the research information package and signed consent form Appendix C) that outlined the study's aims, voluntary nature, and the right to withdraw at any stage of the study. The participants were also informed that interviews would be audio-recorded with permission, transcribed securely, and anonymised through coded identifiers. All data were stored on a password-protected system and will be destroyed following completion of the thesis. The organisation itself is anonymised in the reporting of findings, and no confidential or commercially sensitive material has been disclosed.

The researcher adhered to core ethical principles of prevention of harm, beneficence, autonomy, and justice (Flick, 2021). This meant creating an interview environment where participants felt respected, safe, and able to decline questions without consequence.

Interviews were conducted in private meeting rooms or via Microsoft Teams to safeguard confidentiality. Observations during kaizen events, sourcing reviews, and problem-solving sessions were conducted discreetly and documented in reflective notes, focusing on cultural dynamics and integration practices rather than individual performance. In this way, observational data were collected responsibly without disrupting operational activity or exposing sensitive information.

The insider role carried additional ethical implications. Knowing many participants professionally risked assumptions of shared understanding or perceived pressure to take part. These risks were mitigated by clarifying that participation was voluntary and unrelated to work hierarchies, and by emphasising that the researcher has no managerial authority. Reflexive notes were kept to track moments where professional familiarity might influence interpretation. For example, in interviews with colleagues from previous collaboration, the researcher noted where prior knowledge could colour assumptions and took care to probe responses neutrally.

Power and emotion dynamics in interviews were also considered. As Edwards and Holland (2023) note, the interviewer initially holds power through question framing, but this power shifts as participants contribute their lived experiences. Being both an employee and a researcher meant navigating these shifts carefully. The researcher aimed to maintain a non-judgemental stance, actively listening and encouraging participants to lead discussions where possible. This approach was equally applied during observations, where the researcher adopted a non-interventionist stance, participating when appropriate as an employee, but recording reflections as a researcher.

Overall, ethical principles were not treated as abstract requirements but embedded in the researcher's everyday practice. By safeguarding anonymity, ensuring voluntary participation, and adopting a reflexive stance, the study balanced the advantages of insider access with the responsibility to protect participants and uphold the integrity of the research process.

### 3.5.6 Secondary Data Collection

In addition to interview and observations, secondary data were reviewed to provide contextual grounding and to triangulate emerging themes. This included both publicly available sources, such as annual reports, Sustainability reports, and industry strategy publications, and internal organisational materials, such as leadership communications, survey outputs, Lean operating system manuals, and process documentation. Following Morgan (2022) guidance on qualitative document analysis, documents were evaluated for authenticity, credibility, representativeness, and meaning. Approximately 20 documents were analysed in total, providing a sufficient yet manageable corpus for cross-comparison with primary data.

Secondary data were particularly valuable for clarifying organisational priorities and aligning participant insights with documented strategies. For example, Sustainability reports and carbon neutrality statements helped situate participants' accounts of environmental commitments, whilst internal Lean operating system materials provided a structured articulation of Lean practices through ten fundamentals, divided between enterprise and individual dimensions. At the enterprise level. Documents emphasised value stream management, operating cadence, daily and visual management, standard work, and strategic alignment via Hoshin-Kanri. At the individual level, the focus was on continuous improvement, respect for people, structured problem-solving, action planning, and customer-driven improvement. These manuals and strategy documents offered a lens into the stated strategies guiding the organisation's Lean transformation.

However, corporate documents often designed to project favourable narratives, raising concerns about bias and selective reporting. To mitigate this, interpretations were cross-checked against interview and observation data, allowing inconsistencies to surface and strengthening the credibility of the analysis.

All documents were handled in strict adherence to ethical standards. Sensitive or commercially confidential details were excluded from the thesis, and all references to the organisation were anonymised. The purpose of the document analysis was not to disclose private information, but to enhance contextual understanding and validate primary findings. By integrating documents into the broader triangulation strategy, the research captured both the stated strategies reflected in organisational communications and the enacted practices observed in daily operations. This multi-source approach ensured a richer, more credible account of Lean, Sustainability, and I4.0 integration in the aerospace case study.

### 3.6 Interviews

Interviews were the primary data collection method for this study, chosen for their ability to capture in-depth perspectives and interpretations from organisational practitioners. As Patton (2014, p. 628) notes, interviews allow researchers to “find out from them those things we cannot directly observe and to understand what we’ve observed.” In this study, this principle was particularly relevant, as the integration of Lean, Sustainability, and I4.0 is not formally documented process within the case organisation and could only be meaningful understood through the lived experiences of practitioners.

Participants were purposefully selected based on their professional expertise and strategic or operational involvement in Lean deployment, Sustainability initiatives, and digital transformation, see Section 3.4. The interviews aimed to surface tacit knowledge and context-specific interpretations, with questions designed to address the three research questions underpinning Objective Two: perceptions of Lean, Sustainability, and I4.0 integration (RQ2.1), characteristics enabling or hindering integration (RQ2.2), and the influence of integration on operational and Sustainability performance (RQ2.3).

A semi-structured format was adopted, striking a balance between consistency and flexibility. Insights drawn from the conceptual framework developed in Chapter Two, ensured alignment with the research questions, whilst open-ended prompts allowed participants to elaborate freely and the researcher to probe emerging insights. This flexibility was particularly important in exploring complex and under-researched topics, enabling the capture of rich, nuanced accounts grounded in practitioners’ lived experiences (Flick, 2021).

Semi-structured interviews were deemed more appropriate than structured or unstructured alternatives. Structured interviews, whilst offering comparability, impose rigidity and risk overlooking unexpected insights. Unstructured formats encourage narrative depth but can easily lose focus in organisational settings. Semi-structured interviews provided the optimal balance: they ensured coverage of key topics e.g., Lean maturity, Sustainability drivers, digital enablers and barriers, regulatory constraints, and cross-functional collaboration, whilst also enabling iterative adaptation as conversations unfolded (Gray, 2019, Saunders et al., 2023).

The interviews followed a protocol adapted from Creswell and Creswell (2018), comprising five stages: preparation, introduction, execution, closure, and post-interview reflection, as presented in Table 3-5. For example, preparation included sending participants a research pack and interview discussion themes in advance (Appendix D), execution involved using open-ended prompts, probing for clarification, and summarising to ensure accuracy, closure included thanking participants and outlining next steps, and reflection involved capturing methodological notes, and reflexive observations. This staged process helped build rapport and trust with participants, many of whom were senior professionals with limited availability. The protocol ensured that interviews remained focused on the study's aims, whilst still providing participants with the freedom to articulate their experiences in their own terms.

From a methodological standpoint, remote interviews offer both benefits and trade-offs compared to in-person interviews. Face-to-face interviews allow for richer non-verbal communication and more natural rapport building (Opdenakker, 2006, Saunders et al., 2023). However, video-based remote interviews, particularly when conducted via stable platforms like Microsoft Teams, can yield equally rich and detailed data, provided that proper engagement strategies are used (Archibald et al., 2019, Gray, 2019). In this study, rapport was established through pre-interview communication, the use of video, and conversational techniques such as initial icebreaker questions e.g., "Do you enjoy it here?" These approaches helped participants feel at ease and promoted openness, whether interviews were remote or in-person. Importantly, no significant differences in data richness or insight quality were observed between the face-to-face and remote interviews. Thematic saturation occurred across both modes, and the depth of responses, including examples of integration practices, strategic views, and organisational challenges, remained consistent. The use of a standardised interview protocol and flexible probing techniques further ensured methodological consistency, regardless of the interview setting.

Table 3-5: Interview protocol

| Step | Description |
|---|---|
| **Preparation** | • Develop a set of questions aligned with the research questions and ensuring they are open-ended to elicit detailed responses.<br>• Search company intranet to capture latest company communication about organisational changes<br>• Develop interview agenda; create participant codes.<br>• Contact the participant to confirm the interview and ensure if any arrangements are needed<br>• Send out the interview invitation including broader themes to be discussed for preparation, as well as research introductory package |
| **Introduction** | • Brief participants about the study's purpose, obtain informed consent, and establishing rapport.<br>• Initiate break-the-ice question<br>• Remind ethical considerations regarding confidentiality and anonymity |
| **Execution** | • Using semi-structured format to allow flexibility, ask follow-up questions, and encouraging participants to elaborate on their responses where necessary.<br>• Summarise after each question to ensure correct understanding<br>• Take notes |
| **Closure** | • Summarise key points discussed, thanking the participants, and explaining the next steps in the research process. |
| **Post-interview** | • Ensure that all interviews are accurately recorded and transcribed for detailed analysis.<br>• Reflect on the interview using the research journal<br>• Send a thank you email to the interviewee recognising their time and shared valuable insights, and to confirm when the transcript will be provided<br>• Save the interview package in its associated secured folder |

### 3.6.1 Pilot interviews

Before commencing the main interviews phase, two pilot interviews were conducted to test the clarity, sequencing, and feasibility of the interview protocol. Pilot interviews are a recognised strategy for refining qualitative instruments, helping to ensure that questions are comprehensible, appropriately ordered, and capable of eliciting rich responses (Turner III, 2010, Yin, 2018).

The pilot interviews were carried out with senior managers known to the researcher, one holding a Lean Six Sigma Black Belt with over 25 years of experience (Participant 2), and the other a Head of Supplier Quality Development (Participant 1) with extensive operational expertise. Both individuals were strategically involved in Lean, quality and the operational connectivity initiative at the case study site, making them well-positioned to provide constructive feedback on the interview design.

Each pilot interview followed the structure of the five-stage interview protocol adapted from Creswell and Creswell (2018), presented earlier in Section 3.6. The first interview lasted approximately 90 minutes, where the participant felt slightly excessive given their senior role. The second interview was streamlined to around 60 minutes, which proved to be a more appropriate duration for the main study.

The pilots also led to refinements in language and flow, whilst the thematic content and intent of the questions remained consistent. For example, some technical terms were simplified, transitions between themes were improved, and overly general questions were rephrased into more specific prompts. Initial questions such as “How do you see Lean evolving in your site?” were refined to “How do you see Lean evolving in your site in relation to Sustainability and digitalisation?” to ensure sharper focus. Informal opening question about their general experience at the site proved effective in setting a relaxed tone and encouraging candid discussion.

Crucially, the pilot interviews confirmed that the interview framework was aligned with the study’s research objectives and could elicit rich, context-specific insights. The feedback also reassured the researcher that the balance between structure and conversational openness was appropriate for exploring the complex, under-researched topic of Lean, Sustainability, and I4.0 integration.

To illustrate this alignment, Table 3-6 presents an example of pilot interview questions mapped against the study’s research questions. This demonstrates how abstract research objectives were operationalised into practical, open-ended prompts capable of eliciting detailed responses from participants.

Table 3-6: Sample of interview question

| *Theme* | *Sample Question - Example* | *Alignment with the research questions* |
|---|---|---|
| ***Lean Adoption in Aerospace*** | How do you see Lean evolving in your site in relation to Sustainability and digitalisation? | RQ 2.1 |
| ***Sustainability Integration*** | How does Lean contribute to your Sustainability goals, based on TBL dimensions? | RQ 2.1, RQ 2.3 |
| ***Technology integration*** | What characteristics enable or hinder the adoption of I4.0 technologies in your operations? | RQ 2.2 |
| ***Organisational Capabilities*** | What internal capabilities are essential for successful integration of these paradigms? | RQ2.2 / RQ2.3 |
| ***Integration Impacts*** | In your view, what performance improvements could result from this integration? | RQ2.3 |

### 3.6.2 Outcome of pilot interviews

The pilot interviews were instrumental in refining the interview protocol for the main study. The pilot interviews helped establish an appropriate interview length, confirmed the clarity and logical flow of themes, and validated the appropriateness of the research question. The revised 60-minute format proved effective for engaging senior professionals whilst respecting their time constraints.

The pilots further highlighted the importance of sequencing questions according to participants' expertise. For instance, Lean-focused topics were foregrounded in discussions with the Lean Six Sigma expert, whilst supply chain and ecosystem challenges were emphasised in the interview with the head of supplier quality engineering department. This ensured that conversations remained relevant and allowed the researcher to elicit deeper, experience-based insights, aligning with Turner III (2010)'s recommendation tailoring interviews to individual expertise.

Ethical protocols were also assessed during the pilot, confirming that the consent process, briefing materials, and data handling practices. Both participants affirmed that the procedures were transparent and that the interview setting encouraged open and candid dialogue.

Finally, the researcher's reflective notes captured key learning points, such as how specific probes encouraged narrative depth, how transitions between topics could be smoothed, and how over-technical language might discourage elaboration. These notes informed the final refinements of the interview agenda Appendix A, and improved the researcher's questioning technique, particularly in avoiding directive phrasing.

Overall, the pilot interviews validated the methodological design, strengthened the interview guide, and enhanced the researcher's ability to generate data that was both relevant to the study's objectives and grounded in a practitioner's lived experiences.

### 3.6.3 Interviews Data Collection Protocol

For both pilot and main study, a multi-layered strategy was employed to ensure that interview data were collected systematically, ethically, and with sufficient depth. The interview protocol followed the five-stage structure outlined in Section 3.6, but flexibility was retained to accommodate participant availability, context, and emergent insights.

All interviews were audio recorded with participants' consent. For in person interviews, primary recording was conducted using the Otter mobile application, which provided simultaneous recording and live transcription for the first thirty minutes. Beyond this limit, Microsoft Word's dictation function was used to capture the remainder of the discussion. A secondary backup recording was made using the iPhone's default voice recorder to minimise the risk of data loss. Remote interviews conducted via Microsoft Teams used the platform's integrated recording tool, after securing participants' approval. Recordings were subsequently transcribed manually and cross-checked against field notes to ensure accuracy. In one instance, a technical malfunction resulted in the partial loss of audio during a face-to-face interview with Participant 5. In this case, detailed note taking and post-interview reflections were used to reconstruct the discussion, demonstrating the importance of layered recording and note-taking strategies.

All recordings and transcripts were anonymised immediately after transcription. Participants were assigned codes, see Table 3-4, and no identifying details were retained in the transcripts. Data were stored on an encrypted drive accessible only to the researcher, in compliance with GDPR and the University of Gloucestershire's ethics protocols. Participants were informed that transcripts could be shared with them upon request, reinforcing transparency and accountability.

In addition to verbatim transcription, the researcher maintained reflexive notes during and immediately after each interview. These notes captured impressions of participant engagement, contextual influences, and emerging patterns. For example, notes highlighted when regulatory pressures dominated participants' interpretations, or when organisational jargon required clarification. Such reflections supported critical self-awareness, minimising bias and improving the rigour of subsequent thematic analysis (Clarke & Braun, 2021).

Interviews were conducted both face-to-face and remotely via Microsoft Teams. Whilst face-to-face settings allowed richer engagement with non-verbal cues, remote interviews provided greater flexibility and accessibility, particularly for senior participants operating across different geographies. Rapport was fostered in both settings through pre-interview communication, icebreaker question, and conversational engagement. Importantly, no significant differences in data richness were observed across modes. In total, fifteen interviews were completed, producing more than sixteen hours of recordings and over 240 pages of transcripts, approximately 122,788 words. This volume of qualitative data provided a substantial empirical foundation for the thematic analysis described in Section 3.7. By combining careful planning, multiple safeguards, and reflexive practice, the interview data collection process ensured both methodological rigour and the trustworthiness of the evidence base.

### 3.6.4 Analysing and Coding Interview Data

Following data collection, all interview recordings were transcribed and anonymised to ensure consistency and confidentiality. Transcripts were reviewed manually against field notes and, where applicable, Otter-generated text to correct errors, capture pauses or emphases and remove any identifiers. For the one instance of partial data loss (Participant 5), detailed reflective notes taken during and after the interview were used to reconstruct the main themes and ensure inclusion of the dataset.

Once transcribed, interview data were prepared for thematic analysis (Clarke & Braun, 2017, 2021). Each transcript was read multiple times to develop familiarity with the content before codes were applied. Coding was conducted manually rather than using NVivo or other software, as this maintained closer interpretive engagement with the data, consistent with the interpretivist stance of the study. Codes were inductively generated, drawing directly from participants' language, and iteratively refined into higher-order categories through constant comparison.

A structured qualitative codebook was developed in MS Excel (see Appendix G). This codebook documented each code, its definition, relevance to the research questions, and illustrative quotes from participants. The iterative development of the codebook allowed for reflexive engagement, with new codes added as fresh insights emerged and redundant codes merged or eliminated. The process ensured transparency and provided a clear audit trail from raw data to themes.

The coding process produced a rich set of categories that were subsequently clustered into broader themes aligned with the study's research objectives. For example, early codes around "data & digital tools", "IoT-enabled monitoring" and "generative design" were integrated into the theme of "role of advanced technology."

This systematic coding and clustering process provided the foundation for the thematic synthesis presented in Chapter Four. By combining inductive coding with constant comparison and reflexive interpretation, the analysis ensured the emergent insights were grounded in participants' lived experiences, whilst also aligned with the conceptual insights gained in Chapter Two.

### 3.7 Thematic Analysis

This study employed thematic analysis (TA) to interpret qualitative data from semi-structured interviews. TA was chosen for its flexibility and its ability to surface both semantic and latent meaning in data, consistent with the study's interpretivist stance (Clarke & Braun, 2017, 2021, Guest et al., 2012). The thematic analysis process was initially informed by insights gathered during two pilot interviews with senior managers. These exploratory discussions proved formative in shaping the initial interview protocol and sensitising the researcher to sector-specific issues such as regulatory complexity, design-for-manufacturing gaps, and Lean misconceptions. Pilot themes, such as Lean applicability in aerospace, Sustainability integration, and digital readiness, also prompted early alignment with dynamic capabilities theory and continency theory, validating their relevance to the study. Whilst the pilot data were not formally included in the final coding matrix, they contributed substantively to refining the study's conceptual lenses and interview prompts, establishing a foundation for the full-scale thematic analysis.

TA enabled the researcher to identify patterns across participant narratives, focusing on lived experiences and the perceived interconnections between Lean practices, Sustainability objectives, and I4.0 technologies. This approach supported the content-driven analytic purpose of the study, aiming to understand how these operational paradigms integrate within the UK aerospace sector. Thematic analysis thus served as a bridge between participants' perspectives and the development of the LS4.0 model.

TA process followed Clarke and Braun's (2021) six-phase framework:

**Phase 1: Data familiarisation**

Data familiarisation began with transcribing the interviews, involving a diligent review of the transcripts generated by the Otter mobile application and Microsoft Word. Correcting errors, pausing to understand the language nuances, and reviewing a 60-minute transcript ~ 7,200 words, took approximately eight hours per interview. This stage included identifying recurring themes and patterns, immersing the researcher in the data, and initiating analytical reflection. Transcription occurred during the empirical phase to check transcripts against the researcher's field notes in real time, ensuring all details were captured, and reflecting on the interview guide for future interviews (Rashid et al., 2019). For Participant 5, the first minutes of the interview could not be transcribed due to an audio issue (Section 3.5.4). Consequently, the researcher relied on detailed handwritten notes during the interview and post-interview recall, cross-referenced with field notes to reconstruct the missing data, ensuring accuracy.

**Phase 2: Data coding**

Data coding involved categorising the participants' views into codes, systematically labelling similar meanings to facilitate data comprehension by grouping units with shared meanings for further examination (Saunders et al., 2023). Codes, either a single word or short phrase, were adapted to capture participants' views, encompassing both explicit and implicit meanings (Clarke & Braun, 2021). Some codes were refined during the coding process, resulting in rearrangement and reclassification with other codes (Saldaña, 2016). For consistency, each final code was defined, linked to relevant conditions of use, and supported with illustrative quotes. NVivo 12 software was trialled during the pilot phase, but the main study adopted MS Excel for a manual coding approach, which supported closer interpretive engagement with the data.

**Phase 3: Initial theme generation**

Most codes were explored through inductive data analysis, such as the "design for manufacturing" code, which emerged directly from participants' language, which is referred to as *in-vivo* coding advocated by Creswell and Poth (2018). Initial theme generation was not linear but iterative and reflexive, involving amendments to codes through constant comparison, re-reading transcripts, reviewing code lists, and re-coding to ensure consistency across the dataset (Saunders et al., 2023). Themes were developed by grouping similar codes into shared patterns of meaning, with explicit attention to their relevance to RQ 2.1-2.3 (Clarke & Braun, 2021).

**Phase 4: Theme development and review**

Theme development and review involved assessing initial themes across the full dataset for occurrence and non-occurrence. The researcher drew on Clarke and Braun's (2021, p. 89) guiding questions: *Does each theme tell a convincing and compelling story about* *an important pattern of shared meaning related to the dataset? Do the themes highlight the most important patterns across the dataset in relation to the research question?* These questions supported the iterative evaluation of themes, ensuring alignment with existing knowledge, aerospace practices, and the study's objectives of integrating Lean, Sustainability, and I4.0.

**Phase 5: Theme refining, defining and naming**

Themes were refined to ensure clarity, distinctiveness, and alignment with the study's aims. Redundancies were removed, overlaps consolidated, and each theme articulated around a strong core concept (Clarke & Braun, 2021). To enhance transparency, each theme was documented in a "theme identity card" outlining its definition, associated codes, and related sub-themes – see Appendix G.

**Phase 6: Writing up**

Although writing began during coding, this phase consolidated the analysis into a coherent narrative (Clarke & Braun, 2021). In Chapter Four, themes are presented with vivid data extracts that illustrate participants' perspectives on integration. Each theme is explicitly linked to RQ2.1 on perceptions, RQ2.2 on characteristics and capabilities, and RQ2.3 on influence on performance, whilst also linking the themes to relevant literature and situating them with the UK aerospace context.

## 3.8 Delphi Method

The Delphi method, a systematic and iterative approach, was employed to gather expert insights and achieve consensus on the LS4.0 model. The model is designed to integrate Lean principles, Sustainability triple bottom line, and I4.0 technologies for the case study (Linstone & Turoff, 1975). Originally developed by the RAND Corporation during 1950s for policymaking, Delphi has since evolved into a versatile tool for addressing complex and multifaceted issues across operations, Sustainability, and strategic (Hsu & Sandford, 2007, Loo, 2002). The Delphi method, with its structured process emphasising anonymity, iteration, and controlled feedback, is well suited for validating and refining models in dynamic contexts (Hasson & Keeney, 2011).

This study used Delphi to validate the model's alignment with aerospace realities, refine the model based on expert insights, and identify areas of consensus and divergence. Compared to surveys, Delphi's structured expert group process produces more reliable foresight than unstructured group discussions, making it highly appropriate for model validation in operations research (Goktas & Yumusak, 2024). The method complemented the study's inductive, qualitative approach by bridging empirical data and practical utility.

### 3.8.1 Delphi Panel Composition

A purposive sampling strategy was used to select a panel of four experts from the case study organisation, chosen for their deep expertise in Lean practices, Sustainability, and I4.0 technologies. Each expert possessed over 20 years of professional experience and had been directly involved in strategic projects spanning Lean deployment, digital transformation, and Sustainability initiatives. The experts' roles covered operations management, digitalisation, Sustainability, and quality assurance, ensuring diverse technical, managerial, and strategic perspectives.

The choice of a four-member panel is supported in Delphi literature. Brady (2015) validates the use of small panels e.g. 4, in qualitative Delphi studies, particularly when experts possess highly specialised knowledge and the study is exploratory in nature. Similarly, Hasson et al. (2000) argue that 3-5 experts are sufficient when the scope is narrow and participant expertise is high, whilst Skulmoski et al. (2007) highlight that panel quality outweighs panel size. Rowe and Wright (1999) also note that Delphi panels have ranged from 3 to 80 participants, with no consistent relationship between size and effectiveness. In this context, the study's focus on a single aerospace organisation and the limited pool of site-specific Lean experts made a panel of four both pragmatic and methodologically defensible, aligning with qualitative saturation principles (Keeney et al., 2011).

Each expert received an introductory package including the LS4.0 model report, study objectives, and their role in the Delphi process. Anonymity was assured to encourage open, unbiased input, and participation was voluntary. This preparatory stage established a shared understanding of the process and facilitated timely, informed responses (Hsu & Sandford, 2007).

### 3.8.2 Delphi Process and Protocol

The Delphi method was conducted in two iterative rounds between February and May 2025. The process followed established protocols for structured communication, consensus-building, and model refinement (Hasson & Keeney, 2011). The main purpose of the Delphi method was to validate and refine the LS4.0 model presented in Chapter Five, ensuring its relevance and applicability to aerospace operations.

Round One focused on gathering broad qualitative insights, whilst Round Two combined quantitative ratings with qualitative explanations to confirm areas of consensus and highlight points of divergence. Data collection was carried out through open-ended questionnaires sent by email, followed by a second round that blended scaled ratings with explanatory comments. To reduce participant burden, the questionnaires were designed to be concise and directly aligned with the study's objectives. Responses were requested within two weeks for each round, and anonymised summaries of Round One were shared back with participants at the start of Round Two to encourage reflection and iteration.

The analysis combined thematic interpretation of Round One responses with aggregation of ratings from Round Two. This process allowed the researcher to identify both convergence and divergence of views across key areas such as model relevance, clarity, core capabilities, and integration logic. Consensus was defined at 75% agreement on critical model elements, such as capabilities and performance metrics, in line with criteria recommended by Hasson and Keeney (2011).

To maintain rigour, anonymised feedback from Round One was distributed to all experts before Round Two, ensuring that participants could reconsider and refine their positions without being influenced by professional hierarchies. Facilitation of the process was managed by the researcher, who oversaw the distribution of materials, monitored responses, and ensured adherence to timelines. Round One included a Word document with the LS4.0 model report and questionnaire, while Round Two included a refined version of the model, a summary of Round One feedback, and the revised visual representation, see Figure *5-1* Chapter Five.

Anonymity and voluntary participation were upheld throughout. Informed consent was obtained before the process began, and data were stored securely in line with institutional ethical standards. This protocol ensured that the Delphi process remained systematic, transparent, and grounded in both methodological rigour and ethical integrity.

### 3.8.3 Round 1: Initial Feedback and Validation

The first round of the Delphi study was designed as an exploratory stage to gather broad-based, qualitative feedback from experts on the initial LS4.0 model. This round aimed to critically assess the model's foundational logic, conceptual clarity, and applicability within the aerospace context. As recommended in Delphi research design Hasson and Keeney (2011), this initial stage prioritised open expression and idea generation to surface as many issues, suggestions, and validations as possible before model refinement and consensus-building.

#### 3.8.3.1 Objective and Process

The objective of Round One was to evaluate the LS4.0 model's relevance, clarity, integration logic, capabilities, adaptability, and practical applicability in an aerospace manufacturing setting. Experts were asked to critically assess both the conceptual architecture of the model and its applicability.

To facilitate this process, participants were provided with a detailed report of the LS4.0 model, including supporting rationale, along with a structured questionnaire comprising 26 open-ended questions Appendix J). These questions were grouped around six themes: (1) model components such as drivers, contingency characteristics, enablers, and capabilities; (2) strategic alignment with the case organisation; (3) integration logic between Lean, Sustainability, and I4.0; (4) clarity and visual accessibility of the representation; (5) contingency adaptability; and (6) the results and performance framework. Experts were given two weeks to respond.

Although not initially planned, each expert also participated with the researcher in a follow-up discussion of approximately 30 minutes. These conversations, held informally, provided an opportunity for clarification and elaboration of written responses. They were not recorded but the researcher kept detailed notes to capture interpretive nuance. This approach allowed experts to explain the reasoning behind their questionnaire feedback and gave richer context to the qualitative analysis of Round One.

### 3.8.3.2 Key insights from Round One

#### 3.8.3.2.1 Relevance and Strategic Fit

All four experts agreed that the model was highly relevant and well-timed. There was an acknowledgement about the model’s alignment with key aerospace priorities, including regulatory compliance, operational resilience, and digital transformation. In particular, the integration of continency characteristics was seen as reflective of real-world complexity and strategic pressures in aerospace manufacturing. Views on clarity of the visual model (Figure 5-1) were mixed: Experts 1 and 3 found the layered logic straightforward, whilst Expert 2 and 4 recommended simplifications to enhance accessibility for wider stakeholders.

#### 3.8.3.2.2 Capabilities and Conceptual Structure

There was broad consensus on the importance of the seven core capabilities outlined in the model. However few refinement suggestions were offered. Expert 1 and 4 recommended renaming “Data” as “Information” to highlight actionable insights. Expert 1 proposed adding “Organisational Learning” as a dynamic capability, whilst Expert 3 suggested explicitly recognising Six Sigma as a complementary methodology. Expert 4 argued that “People” should not only function as a capability but also as an outcome, reinforcing the need for human-centric operational excellence.

#### 3.8.3.2.3 Integration of Lean, Sustainability, and I4.0

Experts largely supported the model’s integrative logic, particularly the treatment of Lean as the foundational layer. Expert 1 and 3 endorsed the maturity-based structure, whilst Experts 2 and 4 noted that organisations with lower maturity may face cultural and resource barriers. The role of Sustainability was acknowledged as well-conceptualised, and several participants highlighted the importance of balancing technological adoption with leadership engagement on the shopfloor.

#### 3.8.3.2.4 Practical and Performance Metrics

The experts validated the SQDCIE framework but raised concerns about the "Improvement" dimensions. Expert 1 and 4 recommended substituting this with "People" to better reflect modern operational excellence and social Sustainability priorities. Additional barriers highlighted included change fatigue (Expert 1), leadership instability (Expert 2), and resource limitations for digitalisation (Expert 4).

#### 3.8.3.2.5 Adaptability and Contingency Fit

The model's adaptability to sectoral contingencies such as compliance, complexity, novelty, and ecosystem interdependence was affirmed. Expert 1 recommended incorporating business continuity planning, whilst Expert 4 pointed to AI acceptance and governance as emerging contingencies.

### 3.8.3.3 Refinements Based on Round One

In response to the above feedback, several key changes were incorporated into the model prior to Round 2. First, the term "Data" was renamed to "Information" to reflect more meaningful knowledge flow, as data when converted into information better support decision-making and knowledge creation. Second, the visual model presented in Figure 5-1 was revised to include a clearer representation of voice of the customer and stakeholders (VoCS) and customer satisfaction feedback loops. Third, the "Improvement" performance metric was removed and replaced with "People", following recommendations to foreground human-centricity within the framework. In addition, Implementation considerations such as change management, leadership stability, and commitment through gemba, were annotated for inclusion in the Delphi Round 2. Finally, cultural alignment and leadership support were noted as critical enabling conditions to be further explored in the validation phase.

#### 3.8.3.4 Summary of Round 1 findings

Table *3-7* consolidates the Round One finding:

Table 3-7: Delphi Round One summary

| ***Core Category*** | ***Round 1 Insights Summary*** |
|---|---|
| ***Relevance*** | All the experts confirmed the model's strong fit to aerospace priorities, including resilience, regulatory compliance and digitalisation. |
| ***Clarity*** | Experts 1 and 3 found the model clear; Experts 2 and 4 proposed simplifications of the visual |
| ***Capabilities*** | Core capabilities validated; suggestions to relabel "data", add organisational learning, integrate six sigma, and foreground "people". |
| ***Integration*** | Lean, Sustainability, and I4.0 integration perceived as essential but needs clearer illustration |
| ***Performance Alignment*** | SQDCIE validated, but "improvement" questioned; suggestion to include "people" as a more relevant outcome |
| ***Contingency Fit*** | Validated key contingencies: Compliance, complexity, novelty, ecosystem. Business continuity planning and governance noted. |
| ***Cultural and Organisational fit*** | Need for leadership buy-in, culture shift, and support systems for transformation |

### 3.8.4 Round 2: Refinement and Consensus Building

#### 3.8.4.1 Objective

The second round of the Delphi process aimed to validate the refinements made after Round One, to assess the model's feasibility and clarity, and to build expert consensus on the LS4.0 core components. This stage focused on confirming the relevance, resolving areas of ambiguity, and evaluating the practicality of implementation within the aerospace context.

#### 3.8.4.2 Design

Round Two followed a hybrid format, combining structured ratings with open-ended feedback. A 13-question instrument was distributed, consisting of eleven Likert-scale items (1-5) and two qualitative questions. The questionnaire addressed key categories that emerged from Round One feedback, including the clarity of the model's visual representation, the relabelling of "Data" to "Information", the integration of the voice of the customer and stakeholders, the alignment of Lean and Sustainability, and the relevance of capabilities.

Each expert received a summary that included (1) a reminder of the research problem, (2) a summary of Round One findings, (3) the revised LS4.0 model and updated Figure 5-1, and (4) instructions for completing the questionnaire. Experts were asked to respond within two weeks, and anonymity was maintained throughout to encourage open and unbiased feedback.

Consensus was predefined as at least 75 per cent of ratings of four or five on the five-point scale, which in a panel of four experts equates to three experts. The median was also monitored as supportive indicators of central tendency and dispersion, consistent with established Delphi reporting practice (Hasson & Keeney, 2011, Keeney et al., 2011). Qualitative responses were analysed thematically to capture further refinements, ensuring that the process retained both quantitative and interpretivist dimensions.

#### 3.8.4.3 Summary of Round Two Findings

Round Two confirmed a strong level of agreement among experts on the model's foundational architecture. The average ratings across domains were above 3.5 out of 5, and most items met the 75% consensus threshold. Experts reaffirmed the relevance of the model to strategic industry priorities, particularly regulatory compliance, digitalisation, and operational resilience.

However, some aspects required further attention. Whilst VoCS integration was highly endorsed and retained as a core feature, the clarity of the visual representation improved. Experts also reinforced the importance of human-centric outcomes, leading to the replacement of the "Improvement" dimension in the SQDCIE framework with "People", creating the final SQDCEP structure. Capabilities such as “Organisational Learning” and complementary tools like Six Sigma were also noted as useful additions.

Consensus was strongest around the role of Lean as the practical entry point into Sustainability, the inclusion of contingency characteristics such as compliance and complexity, and the recognition of culture and leadership alignment as critical enabling conditions.

Divergent perspectives emerged regarding the balance between traditional gemba-based leadership practices and digital oversight enabled by I4.0 technologies. Whilst some experts viewed this tension as a potential barrier, others framed it as a complementary relationship to be carefully managed.

Below, Table *3-8* summarises reporting schema, key themes, and model actions

Table 3-8: Delphi Round Two summary

| ***Section*** | ***What is assessed in Round 2*** | ***How analysed*** | ***Key Comments /Themes*** | ***Implication for Model*** |
|---|---|---|---|---|
| ***Relevance of model*** | Fitness to aerospace operational excellence, Sustainability, and I4.0 | Number of responses, percentage of ratings at 4 or 5, median, mean, standard deviation consensus at 75% at 4 or 5 | Strong alignment with aerospace strategy | Model retained with no change |
| ***Clarity of the visual representation*** | Ease of understanding, clarify component relationship | As above | “Figure busy”, simplify, make data to info to knowledge flow explicit | Figure simplified, flow made explicit. |
| ***VoCS integration*** | Strength of customer and stakeholder feedback loop | As above | All experts supported, improves feedback loop | Integrated fully in refined model |

| | | | | |
|---|---|---|---|---|
| ***Lean-Sustainability Link*** | Lean as practical pathway into Sustainability | As above | Viewed as pragmatic entry point | Retained as the model's core |
| ***Capabilities layer*** | Adequacy of seven capabilities, visibility of organisational learning | As above, plus priority summary | People and culture repeatedly prioritised, organisational learning emphasised into knowledge capability | Added to refined capabilities layer |
| ***Practicality*** | Feasibility under current resources, early steps | As above | Change fatigue taken into consideration, need pilot-first, leadership role modelling | Staged roadmap, "doing not telling" emphasis, leadership gemba |
| ***Final Feedback*** | Overall thoughts of the model's key capabilities | As above | Readiness, Culture and change fatigue are hurdles<br>Top capabilities: Culture, People, Knowledge | Top 3 ranked capabilities emphasis in the study |
| ***Implementation*** | Confidence in near-term adoption | Qualitative only | Need for leadership buy-in, pilot approach, clear comms | Implementation roadmap proposed |
| ***Technology Vs Gemba*** | Balance digital oversight with physical realities | Qualitative only | Gemba validation over technology | Added explicit gemba practice statement |

### 3.8.5 Final Model Refinements

The second Delphi round provided both quantitative consensus and qualitative nuance, enabling a final refinement of the LS4.0 model. The model's theoretical robustness and its practical applicability to the aerospace sector, whilst also prompting adjustments to ensure greater clarity, usability, and alignment with practitioner realities.

Consensus across the four experts was high, with average rating above 4/5 for most categories, validating the model's foundational architecture. Several refinements were incorporated following Round Two feedback. Firstly, the performance measurement framework was modified. In its original form, the model employed the widely recognised SQDCIE structure, which is safety, quality, delivery, cost, improvement, and environment. Experts argued that "Improvement" overlapped with continuous improvement practices already embedded within Lean capabilities. Instead, the recommendation was foregrounding "People" as a distinct performance pillar, reflecting the growing consensus in both practice and literature that human-centricity is essential in the era of I4.0 and Lean 5.0. The final performance framework was therefore revised to SQDCEP: safety, quality, delivery, cost, people, and environment, explicitly recognising social Sustainability alongside traditional Lean metrics.

Secondly, the construct of voice of the customer and stakeholder (VoCS) was strongly endorsed and retained as an integral element. Experts emphasised VoCS role in anchoring digital and Sustainability initiatives in stakeholder expectations, ensuring that operational transformation does not drift from external demands or internal cultural realities. The revised model highlights VoCS as both driver of integration and a feedback loop for continuous alignment.

Thirdly, refinements were made to the capabilities layer. "Data" was relabelled as "Information" to emphasise the transformation of raw data into actionable knowledge. Experts also recommended incorporating organisational learning as a dynamic capability, recognising its importance in sustaining long-term transformation. In addition, one expert highlighted the utility of six sigma as a complementary performance management tool, strengthening analytical rigour within Lean-Sustainability-digital integration.

Finally, the Delphi panel underscored the contingency dimensions already embedded in the model. Compliance, complexity, novelty, and ecosystem interdependence were validated as central to aerospace transformation. Additional considerations, such as change fatigue, business continuity planning, governance, and AI acceptance, were suggested as emerging contingencies to be monitored as the model evolves in practice.

Despite strong consensus, some tensions remained unresolved. Most notably, experts diverged on the relationship between gemba-based leadership and digital oversight. Whilst some experts argued that excessive reliance on digital tools risks distancing leaders from operational realities, others saw digital connectivity as a vital complement to physical presence. This tension, rather than being resolved, was retained within the model as a dual requirement: successful integration demands both digital visibility and direct human engagement on the shop floor.

In summary, the Delphi process confirmed the relevance and utility of the LS4.0 model, whilst refining its performance framework, capabilities, and representation of stakeholder alignment. The final model integrates expert consensus with practitioner realities, offering a balanced, empirically grounded framework that addresses the distinctive challenges of aerospace operations. The final refinements ensure that the model is both theoretically rigorous and practically actionable, forming the basis for its presentation and discussion in Chapter Five.

### 3.8.6 Delphi Outcomes

The Delphi method provided structured, practitioner-informed validation of the LS4.0 model. Across two iterative rounds, the four experts reached high degree of consensus on the model's core architecture, confirming its relevance to aerospace realities, its strategic alignment with sectoral priorities, and its applicability as a practical framework for integration.

Key outcomes of the Delphi process included several refinements that enhanced both conceptual clarity and practical utility. Firstly, the capability "Data" was reconceptualised as "Information", highlighting the need for actionable and decision-oriented knowledge flows. Secondly, the performance framework was revised from SQDCIE to SQDCEP, embedding people not only as an enabling capability but also as a central performance dimension. This adjustment reflected a strong practitioner consensus around the importance of human-centric values in contemporary operational excellence. Thirdly, the voice the customer and stakeholders' loop were reinforced as a core feedback mechanism, ensuring integration efforts are grounded in stakeholder expectations rather than technological or Lean imperatives alone.

The Delphi panel also identified important implementation considerations, including the need for cultural alignment, leadership commitment, and mitigation of change fatigue. These insights provided practical guidance that complemented the theoretical contributions of the study, grounding the model in the lived realities of aerospace transformation.

Overall, the Delphi outcomes strengthened the empirical credibility and sectoral relevance of the LS4.0 model. These outcomes ensured that the final version presented in Chapter Five reflects not only conceptual synthesis and case study findings but also the collective wisdom of seasoned practitioners, enhancing its value as both a theoretical contribution and a practice-oriented tool.

### 3.9 Trustworthiness and authenticity of the study

In qualitative research trustworthiness and authenticity are critical concepts for evaluating rigor, fairness and neutrality (Patton, 2014). Qualitative inquiry seeks to produce honest, meaningful, credible and empirically supported findings (Guba & Lincoln, 1981). Baxter and Jack (2008) identify several elements as essential to ensuring quality in qualitative research, including the clarity of research questions and theoretical frameworks, the suitability of the case study design, the appropriateness of sampling strategies, the systematic management of data collection, and the rigour of data analysis.

In this study, clarity was achieved by presenting explicitly formulated research questions across three phases: RQ 1.1-1.3 explore theoretical integration, RQ 2.1-2.3 examine empirical insights and RQ 3.1-3.2 focus on model refinement and validation. The theoretical framework, grounded in dynamic capabilities theory and contingency theory, is detailed in Section 2.3 and provides a structured basis for examining integration capabilities and contextual characteristics (Hines, Holweg, & Rich, 2004, Teece, 2007). The single-case study design, presented in 3.3, was chosen to provide a contextualised exploration of LS4.0 integration within a UK aerospace company. The unit of analysis, practitioner perception, was clearly defined, with scope, boundaries, and organisational context aligned with exploratory aims of the research in Section 3.3.4 (Yin, 2018).

The selection of participants was achieved through purposeful and snowball sampling, allowing access to individuals with deep domain expertise as detailed in Section 3.4. Data saturation was reached after the twelfth interview, in line with Lincoln and Guba (1985) argument that a dozen well-chosen participants can yield rich and sufficient data. The consistency and transparency of the process were reinforced through systematic data management: interviews were recorded and transcribed, field notes were maintained, and a reflective journal captured the researcher's ongoing interpretations as detailed in Section 3.6.3. Finally, data analysis followed Clarke and Braun's (2021) six-step thematic analysis protocol, which ensured systematic coding, theme development, and pattern recognition. Participant quotes were incorporated throughout to preserve narrative authenticity and support analytic claim, see Appendix H.

### 3.9.1 Credibility

Credibility refers to the extent to which findings genuinely voice participants' lived experiences and perspectives (Guba & Lincoln, 1981). In this study, credibility was strengthened through several interconnected practices (Patton, 2014). Fieldwork was undertaken diligently, with careful attention to building rapport and creating a safe environment in which participants left comfortable sharing candid reflections. Pilot interviews detailed in Section 3.6.1 further enhanced credibility by ensuring the relevance and clarity of the interview guide.

The process of developing themes contributed to credibility by enabling the clustering of codes into coherent conceptual categories, such as supply chain complexity, and broader themes, such as Lean adoption in aerospace. These themes were consistently anchored in verbatim participant quotes, therefore, ensuring that interpretation was grounded in lived narratives, detailed in Section 3.7. The researcher's professional background in aerospace engineering and auditing also contributed to credibility, providing the expertise to engage deeply with participants and interpret their accounts meaningfully. Transparency in the overall research design further supported trust in the findings.

Credibility also depends on the philosophical stance of the reader. Those who value the depth and contextual richness of qualitative inquiry are more likely to find such studies convincing. This research adopted an interpretivist paradigm that privileges contextually situated understanding, aligning with Patton's (2014) assertion that qualitative studies are most credible when they reflect the complexities of lived experience rather than striving for statistical generalisability.

### 3.9.2 Transferability

Transferability refers to the extent to which the findings of a qualitative study can be applied to other contexts or settings (Lincoln & Guba, 1985). Rather than seeking statistical generalisability, this study offers "thick description" (Section 3.3.2) of the UK aerospace sector and the organisational setting, enabling readers to assess relevance to other regulated, engineering-intensive environments (Saunders et al., 2023). The study's intention is to provide conceptual insights that are contextually bounded but sector informative.

### 3.9.3 Dependability

Dependability concerns the consistency and replicability of the research process (Guba & Lincoln, 1981). In this study, dependability was ensured through an explicitly defined research design, as presented in 3.3, which established the methodological boundaries and guided all subsequent stages of inquiry. A detailed audit trail was maintained to document key decisions and data collection processes, therefore, allowing the logic of the research to be followed transparently. Coding procedures and theme development were systematically recorded and presented in Appendix G, providing evidence of how raw data were translated into higher-order insights. In addition, reflective records were kept capturing the rationale for methodological adjustments, such as revisions to interview questions following the pilot phase. Taken together, these measures provide a structured and transparent account of the research process, enabling another researcher to follow the same procedures and arrive at comparable interpretations, even if not identical conclusions.

### 3.9.4 Confirmability

Confirmability assures that findings reflect the perspectives of participants rather than being shaped by researcher bias (Miles & Huberman, 1994). In this study, confirmability was reinforced in several ways. Themes were developed directly from participants' verbatim quotes, ensuring that interpretations were grounded in their lived experiences. Triangulation across multiple sources, including interviews, documentary evidence, and site observations, was employed to cross-validate insights and minimise reliance on any single perspective. Reflexivity also played a central role throughout the research journey, as the researcher critically reflected on assumptions and positionality during interviews, analysis, and interpretation. These measures collectively ensured that the study's conclusions remained rooted in participants' accounts and context rather than in the researcher's preconceptions.

### 3.10 Limitations

All research methods have limitations, and qualitative research often faces questions regarding generalisability, which may affect the extensiveness of the proposed framework. However, the LS4.0 model developed in this study is designed for further enhancement and testing on a broader scope. A single case study at a UK aerospace site was used, presenting a limitation in applying the framework to other aerospace companies in different countries. Specific contingencies, such as cultural differences, regulatory variations, and core activities, could limit the framework's acceptability in other contexts (Browning & Heath, 2009, Murman et al., 2023).

Flyvbjerg (2011, p. 301) acknowledges this limitation, noting that although a single case cannot fully represent a broader class of phenomena, the case study can be especially useful in the early stages of inquiry by providing hypotheses for later systematic testing. This is significant in aerospace manufacturing, where firms may address Lean, Sustainability, and I4.0 in ways suited to their culture, values, and principles. This research argues that the capabilities and contingency characteristics developed such as Leanness and compliance require testing in a broader context with multiple cases to enhance generalisability.

Flyvbjerg (2011) further emphasises the distinctive value of case studies, highlighting that context-dependent knowledge and expertise are central to advancing understanding. This research aimed to build such expertise through immersion in the studied organisation and by integrating participants' feedback throughout the process. The debate on generalisability was central to this study. Whilst some qualitative methodologists argue that findings from a single case cannot be generalised (Yin, 2018), the researcher aligns with Flyvbjerg's (2011) view that case-based knowledge is often more valuable than the pursuit of universal theories. Science is about generating understanding, and generalisability is only one pathway to that goal. A well-executed case study can therefore provide insights that inform broader theory development and practice. In this study, the careful selection of a leading UK aerospace organisation as a model company enhances the potential transferability of findings, offering lessons that may inform similar contexts within the sector (Amrani & Ducq, 2020).

### 3.11 Conclusion

This chapter has outlined the research methodology and methods for exploring the integration of Lean, Sustainability, and I4.0 within the UK aerospace sector. Guided by an interpretivist paradigm and qualitative orientation, the study positioned reality as socially constructed and best understood through a practitioner's lived experiences. This philosophical stance informed the adoption of a single-case study strategy, enabling a deep, context-specific exploration of organisational practices, perceptions and challenges.

The research design was structured into three interconnected phases. Phase One involved a literature-based synthesis current knowledge and develop conceptual framework. Phase Two comprised empirical fieldwork, using semi-structured interviews, document analysis, and site observations to generate rich, and triangulation data. Phase Three employed the Delphi method, engaging expert practitioners to refine and validate the LS4.0 model. Together, these phases ensured that the study combined theoretical grounding, empirical insight, and practitioner validation.

Rigour and trustworthiness were enhanced through systematic procedures for participant selection, pilot testing, data collection, and thematic analysis. Issues of credibility, transferability, dependability, and confirmability were addressed explicitly, supported by reflexivity and ethical safeguards. These measures ensured that the findings are not only contextually grounded but also analytically robust and transferable within the aerospace sector.

The next chapter presents the empirical findings from the case study, drawing on fifteen participant interviews, organisational documents, and site observations. The next chapter highlights emergent themes that explain how Lean, Sustainability, and I4.0 are understood, operationalised, and linked within the case study organisation. These findings set the foundation for Chapter Five, which introduces the LS4.0 model, and Chapter Six, which critically discusses the theoretical and practical implications, before the thesis concludes in Chapter Seven.

# Chapter Four
# Findings

## 4.1 Introduction

This chapter presents the findings from the empirical research conducted to explore the integration of Lean, Sustainability, and I4.0 technologies within a UK aerospace organisation. Data were collected between July 2023 and October 2024 through semi-structured interviews with 15 experienced practitioners, supplemented by company documentation and on-site observations. This process yielded over three hundred pages of transcribed material. The findings directly address Research Objective 2, focusing on three research questions:

- RQ2.1 How do aerospace practitioners perceive the practical relevance, benefits, and challenges of integrating Lean, Sustainability, and Industry 4.0 within their operational environment?
- RQ2.2 What specific characteristics, including capabilities, barriers, and enablers, influence the development of the empirical model in the case study organisation?
- RQ2.3 How do industry practitioners evaluate the potential influence of the integrated model on operational performance and Sustainability performance in aerospace manufacturing?

The chapter is structured into three main sections. Section 4.2 outlines the data collection process and an overview of the participants' profiles, establishing the empirical foundation. Section 4.3 presents the themes that emerged directly addressing the research questions. These themes form the basis for the LS4.0 model, a major outcome detailed in Chapter 5 . Section 4.4 synthesises the findings, linking them to the research questions and laying the groundwork for theoretical and practical discussions in Chapter Six.

The findings illuminate the case organisation's strategic alignment to Lean via its LeanLift, a pseudonym for the company's Lean operating system, to Sustainability, targeting net-zero operational emissions by 2030, and to innovation, through its operational connectivity and digital transformation initiatives. Through the lenses of practitioners' experiences, the analysis offers a grounded, sector-specific understanding of integration dynamics, contributing to both academic discourse and industry practice.

This chapter particularly adapts a dual approach, both descriptive and analytical. It presents a thick description of empirical data through direct participant insights, document analysis and site observations whilst offering analytical interpretation of the emerging patterns in relation to the research questions and the broader theoretical framing. The findings are not only reported but critically examined to extract operational and strategic implications, forming the empirical foundation for the LS4.0 model presented in Chapter Five.

### 4.2 Overview of Data Collection Process

Data were gathered using a multi-method qualitative approach, combining semi-structured interviews, document analysis, and observations, conducted over a 15-month period. This approach allowed for data triangulation and the ability to capture emerging insights, consistent with established qualitative approaches (Eisenhardt, 1989, Yin, 2018). Fifteen practitioners were selected purposively from a leading UK aerospace organisation for their expertise across manufacturing engineering, operations, quality, Lean, digital transformation, and Sustainability. Interviews averaged 65 minutes and were conducted face-to-face or via Microsoft Teams, generating more than 240 pages of transcript data.

The participant group included twelve UK-based leaders and directors and three executives based in the USA, the latter offering global perspectives due to their wider roles across the site. Most participants had long-standing careers in aerospace, offering deep industry-specific knowledge. Four participants (Participant 1, 2, 11, and 14) also brought valuable comparative insights from the automotive sector, where Lean and Sustainability practices are more advanced and mature (Zokaei et al., 2013). This contrast provided a valuable benchmark and comparative frame of reference. For example, Participant 1, with over 25 years of experience, provided a benchmark for Lean's cultural integration in high-volume settings, contrasting it with aerospace's slower adoption pace. Participant 1, noted: "Automotive is much further down the road with Lean than aviation due to faster volume and change." This reflection highlights the structural differences between sectors. In automotive, rapid product cycles and higher volumes accelerate the institutionalisation of Lean, whilst in aerospace, long programme lifecycles and low production volume slow adoption. The implication is that aerospace organisations cannot simply transfer Lean practices as a whole but must adapt them to their regulatory and technological contingencies. This comparative insight provides an early signal of the sector-specific challenges in embedding Lean, which became a recurring theme across participants.

The diversity of roles of participants, ranging from engineering leaders to quality directors, ensured a holistic view of operational, technological, and Sustainability dynamics. The case study organisation was chosen for its explicit commitment to Lean through the LeanLift operating model, its 2030 net-zero target for Scope 1 and 2 emissions, 2050 net-zero flight emissions, and its engagement with I4.0 through initiatives such as digital operational connectivity. The site's maturity in Lean implementation provided a rich context for exploring the intersection of Lean, Sustainability, and digital technologies. Interview discussions were guided by a semi-structured protocol aligned with RQ2.1 to RQ2.3 and focused on perceptions of applicability, integration challenges, enabling conditions, and anticipated influence on performance. This design enabled the study to report findings across three lenses, perceptions, influencing characteristics and performance influences, mirroring RQ2.1 to RQ2.3. The resulting dataset offers a robust, context-specific evidence base that informs both emergent themes in Section 4.3 and the development of the LS4.0 model Chapter Five.

### 4.3 Emerged Themes Informing Lean-Sustainability and I4.0 Integration

This section presents the findings from the semi-structured interviews, company documents, and observations, organised into three categories addressing the research questions. These categories are the perceptions of integration, characteristics influencing integration, and influences of integration. Together, they reflect the real-world dynamics of integrating Lean, Sustainability, and I4.0 in the UK aerospace sector, using the case study organisation as a vehicle to inform sector-wide strategies. The study first explores how practitioners conceive integration in Section 4.3.1, then identifies conditions including enablers, constraints and capabilities shaping the integration in Section 4.3.2, and finally evaluates what integration should deliver in practice in Section 4.3.3. Together these inform the empirical LS4.0 model Chapter Five, a major finding of this research.

### 4.3.1 Perceptions of integration

This section explores how practitioners within the case study organisation perceive the integration of Lean, Sustainability, and I4.0 technologies, focusing on practical relevance, implementation barriers, and cultural dynamics. The analysis reveals a layered understanding of integration across key domains of aerospace operations, reflecting how organisational structures, regulatory demands mediate change.

#### 4.3.1.1 Theme 1: Lean Adoption in Aerospace

Practitioners expressed a range of perceptions regarding Lean's applicability in the aerospace sector, highlighting both its relevance and challenges due to the industry's unique characteristics. Whilst Lean is widely successful in high-volume industries like automotive (Antony et al., 2021), it faces hurdles in aerospace's low-volume, high-mix environment, and highly complex designs (Crute et al., 2003, Martínez-Jurado & Moyano-Fuentes, 2012). Participant 1 noted:

> "Lean is an excellent methodology that works and has been shown to work …but aviation is very slow to change, lower volume… So it makes applying those things a bit more challenging making benefits less obvious in the short term…There are some very tried and tested tools used in automotive that are finding their way into the aviation industry now, but with some modifications and so on to adjust for the fact that there is a very different kind of aviation culture and a different volume associated with that typically."

This perspective of Participant One underscores the structural barriers that limit Lean's visibility and perceived payback in aerospace. The long programme lifecycles, often 10-15 years for military platforms, coupled with regulatory constraints, reduce opportunities to demonstrate Lean's short-term benefits and slow cultural uptake. As a result, Lean adoption is often incremental rather than transformational.

Participant 2, with extensive automotive experience, contrasted aerospace with automotive:

> "In automotive, Lean is not a project or it's not a scheme that you do or something you apply to your factory. Lean is integrated into everything you do. It's part of your makeup and everybody is involved in Lean, you don't just have pockets of Lean, the whole it's part of the culture … obviously it wasn't always there, but certainly in the latter years it is there, it becomes natural because you become good at it. And it makes sense and it's really good for high volume manufacturing. It's not to say it isn't good for low volume manufacturing, but it's optimal for high volume manufacturing. It works very well. When you look at aerospace, my initial view on what they were doing in aerospace concerned me."

This comparison highlights aerospace's slower adoption pace, attributed to its specialised supply chains and regulatory requirements. The divergence between the two industries demonstrates that the aerospace operational model requires a contingency-driven approach. Lean cannot be transplanted wholesale from automotive but must be tailored to aerospace's compliance-heavy, engineer-to-order environment, aligning with contingency theory (Browning & Heath, 2009, Donaldson, 2001). This contextual dependency later becomes a foundation for the LS4.0 model.

Participant 10, added:

> "We have very specialised supply bases, and so sometimes that means that you can't do everything in house, or you can't create good flow between things and so, I think for all those reasons, it means the supply chains tend to be a little longer and they tend to be very complex so they can be a challenge to manage. I think the high volume of the automotive industry, the advantage that it provides was leverage over the supply base where they can make them move closer to the manufacturing site or have them efficiently move through cross docks. And so, some of those elements are readily accessible, I would say in the aerospace industry, but we have our own versions of that."

This viewpoint of Participant 10 illustrates how aerospace supply chain complexity disrupts continuity and flow, reducing opportunities for Lean optimisation. Aerospace supply chain complexity also highlights the need for stronger collaboration and digital coordination to compensate for this structural constraint. Hence, digitalisation is not optional in aerospace. Complex, globally dispersed supply chains cannot sustain Lean flow without visibility tools such as digital connectivity, which participants later linked to real-time data integration. Thus, Lean adoption in aerospace is inseparable from digital capability building, a key of LS4.0.

Participant 3 expressed caution about Lean tools like just-in-time (JIT):

> "If we did just in time (JIT) today, we would never deliver to our customers. That principle today with the supply chain issues that we currently have with the recovery from COVID, the shortages, that would be detrimental to us in my view."

This perspective reflects vulnerabilities in aerospace supply chains, where Lean ideals such as JIT can clash with resilience needs during disruption. This insight echoes post-COVID supply chains scholarship which warns against uncritical application of Lean (Chiarini & Kumar, 2021, Hyder, 2021). In aerospace, resilience and compliance often override efficiency, meaning Lean adoption must be balanced with Sustainability and risk mitigation goals. For LS4.0, this means Lean tools must be deployed alongside contingency measures that ensure operational robustness.

Despite these challenges, the participants recognised Lean's philosophical mindset, value creation and waste reduction, as universally applicable. Participant 4, highlighted the value of Lean tools:

> "Value Stream Mapping was the next big thing…We used to spend an afternoon or morning or even a full day in a room with relevant stakeholders we value stream map we saw where the wastes were and we got it right here are 50 different actions that we need to go away and do and that was all well and good and I thought the value stream map was a good visual and it definitely allowed you to expose all of the weaknesses within the process."

This perspective of Participant Four suggests that, whilst Lean tools require adaptation, these tools remain relevant for identifying inefficiencies in aerospace's fragmented supply chains. However, the impact depends on embedding actions into the culture, rather than treating value stream mapping as an on-off exercise. Participant Four implied that cultural follow-through is missing. Value stream mapping exposes waste, but unless actions are embedded, the benefits dissipate. This underscores the need for leadership alignment and cultural readiness, which emerge later as enabling capabilities within LS4.0.

Participant 7, noted:

> "Things that were previously, said from an engineering perspective were impossible. Through focus and hard work and determination, a number of major Lean enablers were changed. So, the 360 wing is now made in a frameless factory, rather than horizontally like racks moved by a crane each time that was built laying flat… so the difficulty is that the opportunity to make a leap [aircraft turbo engine] in Lean only comes when you have a major new investment programme. And those only come along every 10/20 years. [AeroSkyward] has a new engine every 5/10 years…You need the technical enablers to be solved in order for the Lean to happen…. So you need solutions about jig fixture drill and fasten and temporary [supports]… so that all your tolerances are maintained and respected."

Participant Seven cited a past experience at the Airbus 360-wing frameless factory as an example of significant Lean progress. This illustrates that Lean transformation in aerospace is feasible but typically requires alignment with new investment programmes and technical enablers. Such contingencies confirm that Lean tools must be matched to contextual variables such as volume, variability, and regulatory stringency (Holweg, 2005). The implication is that Lean adoption is event-driven in aerospace, advancing predominantly through major programme investments rather than continuous incremental improvement.

#### 4.3.1.1.1 Flow

Flow refers to the uninterrupted movement of materials, information, and value across the value stream, a foundational principle of Lean and operational excellence (Womack & Jones, 1997). However, achieving flow in aerospace manufacturing presents unique challenges due to the sector's inherently slow pace, low production volume, and specialised, often fragmented supply chains. Despite its centrality to Lean, the concept of flow has been relatively marginalised in the Lean, Sustainability, and I4.0 integration literature, where greater emphasis is often placed on waste elimination, energy efficiency, or digital technologies.

For aerospace, the flow challenge becomes particularly significant because maintaining flow continuity is both operationally difficult and essential for balancing Lean efficiency, the triple bottom line of Sustainability, and resilience. At the case site, interviews and observations pointed to fragile and fragmented flow across value streams, shaped by low production volumes, long product lifecycles, complex certification requirements, and dispersed supply chains.

Participant 10, drew out the supply chain dimension of this problem:

> "… you can't do everything in house, or you can't create good flow between things…it means the supply chains tend to be a little longer and they tend to be very complex so they can be a challenge to manage."

This aligns with Browning and Heath (2009) analysis of disrupted flow in engineer-to-order environments and Gélain's (2021) findings on aerospace supply chain fragmentation. Such discontinuities undermine Sustainability performance, as inventory buffers, transportation inefficiencies, and resource overutilisation are often introduced to compensate for broken flow (Singhal et al., 2024).

Interestingly, Participant 10 recognised that I4.0 technologies, such as digital twins, simulation models, and generative design, can help forecast and regulate flow disruptions. This suggests a novel integration of Lean flow principles with digital foresight tools, echoing Rosin et al. (2020) and Stock et al. (2018), who argue that I4.0 acts as a flow enabler in high variability environments by improving visibility, predictive maintenance, and capacity coordination. In aerospace context, this possibility materialises through the use of digital twins for engines and complex assemblies, which provide real-time data to anticipate flow interruptions before they manifest on the shop floor. Simulation models are taking their place at the case site in design offices to model throughput scenarios, whilst generative design tools allow engineers to evaluate multiple design variants without costly physical prototypes. These practices directly address sector-specific challenges such as long programme lifecycles, limited production runs, and fragmented supplier networks. By virtually validating manufacturability and flow at the design stage, organisations can reduce iteration loops, avoid excessive buffers, and synchronise supply chain activities. Thus, whilst Lean flow in aerospace is difficult to achieve physically, I4.0 provides a digital pathway to approximate smooth flow.

These practitioner insights were triangulated by documentary and observational evidence. Internal LeanLift documentation emphasised the role of practices at the individual and enterprise levels to ensure smooth flow through quick problem-solving, supplier engagement and scheduling. On-site observations reinforced the fragility of flow achievement: for example, in the printed circuit board (PCB) production unit, apparent achievement of the on-time-delivery in some cases, masked hidden inefficiencies and waiting time between process steps, highlighting discontinuities in flow despite formal Lean structures. Furthermore, supplier audit reports revealed recurring delays in documentation e.g., incomplete first article inspection (FAI) records and corrective actions closure, further illustrating how compliance requirements disrupted smooth value flow. Together, these non-interview sources triangulate the interview data, confirm that flow in aerospace remains fragmented but could be partially stabilised through digital enablers, reinforcing LS4.0's integration of Lean and I4.0 capabilities.

#### 4.3.1.1.2 Design for Manufacturing

A recurring theme was the disconnect between engineering design and manufacturability. Participants described how late-stage design freezes often occur before full manufacturing considerations are integrated, which constraints downstream flow and inflates rework.

Speaking from a senior engineering and operations point of view, Participant 10 described how design priorities shape manufacturing in practice:

> "A lot of the focus is on the design of the engine and not necessarily the design for manufacturing. There is a clear difference…where those decisions are made much later and the design is already fixed. And so that means you cannot create as much flow as you'd like to right off the back. And we also have very specialized [products] because we're at the very edge from a technology standpoint."

This highlights the design-manufacturing divide widely discussed in concurrent engineering literature (Sosa et al., 2011), where late design freezes prevent manufacturability feedback and constraint flow. In aerospace, the effect is amplified by the sector's heavy reliance on novel design technologies and unique low-volume products, meaning missed opportunities for early manufacturability review have long-lasting effect on costs, quality, and flow due to rigours change-control procedures.

From a leadership perspective, Participant 11 highlighted how regulation intensifies the challenge:

> “Every single component, every single bolt, has to be tested and validated, you know, like all the paperwork, every single thing, and God forbid that you have to change the material, or something like that. You have to start all over again. So, I think that's, you know, because it's a highly regulated industry.”

This illustrates how compliance magnifies design for manufacturing challenges. For qualified systems and products, design changes that could improve flow are often abandoned due to prohibited requalification requirements. However, signs of progress were reported through the recent introduction of advanced product quality planning (APQP) in aerospace, which was credited with embedding manufacturing considerations earlier in the product lifecycle.

Participant 1 explained both the opportunity and the limits of transfer to aerospace:

> “APQP that we were looking at, from an automotive where it's been 25 years and proving how effective it is. it's very, very slow to get going in aviation. Design for manufacture is a massive thing in this business anyway...Our designs are not easy to manufacture…. And things like a APQP will help with that. So, it makes [with] Lean. There are certain impacts that they can give you then as a benefit particularly with technologies but also there are going to be some restrictions because some things are quite difficult assemblies within aviation. That makes them challenging.”

At the interface between design and operations, Participant 8 described what earlier, structured collaboration looks like and why it matters:

> “We don’t link up our manufacturing engineers with our design engineers early enough…APQP means a lot more checks earlier…you can get the design changed very early on without adding particularly cost…Technology takes 10 years to change within our design because of the qualification and testing… But these new people are coming and going, ‘Why does it need to be like that?’ Why? they're trying to change it in a different way. And that that's where I think Lean can go hand in glove with the sustainment because they're bringing new ideas with Sustainability challenge. But there's an element still that says… work within a framework... And if you ignore that, you will start going back in time and seeing maybe events that we don't want to see.”

Taken together, these accounts of Participants 8 and 1 show how advanced product quality planning represent a partial transfer of best practice from automotive, introducing structured checkpoints that enable earlier cross-functional collaboration. For aerospace, this could reduce downstream inefficiencies, costly rework, and material waste, aligning with Lean's waste reduction ethos whilst supporting Sustainability goals. However, the quotes also underline that cultural and regulatory barriers continue to limit Lean's impact.

These views are consistent with Lean product development literature, which emphasises front-loaded decision making and cross-functional collaboration as mechanisms for reducing waste and improving product-process fit (Ghobadian et al., 2020, Liker, 2021). The incorporation of advanced product quality planning reduces inefficiencies by aligning sustainable design, and minimising costly post-design iterations (Stamatis, 2018) .

The rise of generative design and simulation technologies, as part of the company's I4.0 agenda, was also seen as a promising enabler.

Empirical insights also pointed to digital enablers that can front-load manufacturability decisions. Returning to the design toolchain, Participant 10 outlined how current technologies can compress iteration and expose manufacturability risks earlier:

> "Lots of ways you have you know things from like model-based enterprise as a concept. And then you have things like generative design, so you can iterate on designs faster. All the way through simulation where instead of physically building things, you can actually simulate results with generative designs and optimize without builds. Things that used to take 10 years can be done with simulations now."

This aligns with recent Lean, Sustainability, and I4.0 research that identifies digital design tools, such as digital twins and generative algorithms as critical to enhancing design-for-manufacture and design-for-Sustainability (Costa et al., 2024, Ooi et al., 2023). These tools allow organisations to virtually test and optimise product architectures, reducing material usage, energy consumption, and design cycle time, hence, reinforcing Lean and Sustainability synergies within LS4.0.

Documentary and observational evidence further triangulated these insights. Internal engineering standards reviewed during the study confirmed that manufacturing considerations were often incorporated late, with design freezes preceding full manufacturing validation. This was particularly evident in both legacy programmes, and current military programmes such as F35 where the programme was developed in the late 1990's, where some supplier assemblies drawing revisions were still dated in the early 2000's, reinforcing participant's 8 concern about insufficient early collaboration. Similar challenges were noted in long-running commercial platforms, where outdated design decisions constrained opportunities for manufacturability improvements. In one observed case, a tooling review has to be repeated after a design change was already locked, causing delays and additional costs. These findings support the view that cultural and procedural gaps, not just technical ones, lies at the heart of the design-for-manufacturing challenge.

During the period of research, however, evidence also pointed to ongoing improvements. The site had formally introduced advanced product quality planning initiative, with the quality organisation designating it a 2024 priority in collaboration with the leadership team. Cross-functional collaboration was observed between design engineers, manufacturing engineering, programme management, and even customers' technical teams, marking a shift towards earlier manufacturability integration. For instance, in the Boeing 777X programme and in several supplier work transfer activities, design upgrades were closely coordinated with suppliers and programme engineers, reflecting a more mature advanced product quality planning practice. Whilst Participants' concerns remain valid for legacy and ongoing programmes initiated before advanced product quality planning approach adoption, the observed shift suggests that aerospace firms are beginning to address these gaps through structured, cross-functional governance.

Finally, despite this shift, the aerospace context presents structural barriers. The heavy certification burden, long product lifecycles, and fragmented supplier ecosystems mean that even when design feedback loops are improved, organisational agility remains limited. Therefore, integrating Lean, and Sustainability into design practices requires not only digital capability, but also cultural readiness, strategic alignment, and leadership commitment, elements that underpin the design for manufacturing element within the LS4.0 model.

#### 4.3.1.2 Theme 2: Lean-Sustainability Linkage

Participants consistently perceived Lean and Sustainability as interconnected, viewing Sustainability as a natural extension of Lean principles, particularly through waste reduction. Participant 7 emphasised this overlap:

> "I see Lean and sustainable overlap hugely in the area of some of the wastes, overproduction, transportation and waste in particular. And if one can make sure that you are following a Lean manufacturing process, methodology, you will drive out waste, you will drive down a number of these wastes which will improve your Sustainability. There are a whole host of digital tools, which will help you implement Lean and help you to improve things like defects, reducing defects. So yes, I see they're very complementary... I see Lean and Sustainability as something that coexist together."

This reflection positions Lean not only as an operational efficiency system but as an indirect Sustainability mechanism, particularly where eliminating waste in production also reduces material, energy, and resource usage. Building on this, Participant 7 contrasted the long-term ambition with the site's current maturity, noting that the real gains come when Lean routines are embedded and begin to pull digital capabilities and faster product introduction together. Participant 7 stated:

> "By doing Lean, you get Sustainability for free. If you do it a certain way, you advance your digital agenda. You can introduce new products faster, you know, it's a win-win. But the way we do Lean is very young. Stick and string."

The site sits at an inflection point; Lean is still consolidating whilst Sustainability ambition, including net-zero operations target by 2030 provides a strategic frame. The company's own operating system materials support this practitioner viewpoint by presenting the LeanLift model as the vehicle that links daily problem-solving to culture and performance, and by treating Sustainability as advanced through that operating system and the product roadmap rather than as a detached initiative.

##### 4.3.1.2.1 Synergy in Waste Reduction

Participants repeatedly linked environmental improvements to Lean levers such as stabilising flow, reducing changeovers and reworks. Participant 12 explained the organisational choice to merge leadership and routines and then described how this appears in practice:

> "We started to link Lean and Sustainability about two years ago together, which is why, you know, in my organization, Kate is actually the Sustainability lead and the Lean leader, or [*LeanLift*] leader, as we're now calling them, and that was to start looking at the holistic approach of removing waste from a business…even if you think around how we've evolved our Kaizen events, five day Kaizen events, they were very traditionally based on shop floor waste reduction with not much emphasis on Sustainability. But now, the last two years, our Kaizen events all have a Sustainability aspect within them."

Participant 15 reinforced this shift from intent to routine:

> "We are very intentional also to run a Sustainability Kaizen, so that we're looking through the eyes of Sustainability with our Lean mindset to be able to drive that change."

Participant 3 also extended this operational framing down to workstation design, noting how improvement conversations were beginning to include Sustainability considerations alongside flow and ergonomics:

> "When we have improvement in workstation sometimes, we'll talk about adding like Sustainability consideration or environmentally safe consideration… what kind of material you would use, do you also think of its end-life etc."

Together, these testimonies show how the organisation has begun to institutionalise Sustainability into Lean routines, with Kaizen explicitly reframed to capture energy, packaging, and carbon considerations alongside process waste. Documentary evidence confirmed this shift, as Sustainability targets are being considered alongside cost and quality objectives. Observational evidence from Kaizen events participation also revealed Sustainability dimensions integration, providing tangible signs of this evolving integration.

Participant 2 offered a concrete operational example of how Lean tools enables environmental gains:

> "Lean should be driving Sustainability because Lean is about reducing waste… For example, we may have a line turned off over the weekend. So, your power down the reflow oven on a Friday afternoon and you started off on a Monday morning. Or you may decide that you only need it for two days a week. So that it itself becomes a win for Sustainability because leaving the reflow ovens which are massively heavy on our power consumption leaving them on 24/7 is particularly bad for the environment. We're running these things at 200 degrees. So, it's a lot of power we put in into those ovens. So, Lean would help us load balance the work that's going into the machines to

> make sure we've got a constant flow of work. It would ease our changeover times of the machines, so we get faster change over time. So, our utilisation of the machines goes up, and therefore we don't need so much reliance on the second machine. Many examples of that in the shop, where, by implementing the Lean you will ease of your secondary win of Sustainability on a reduction in scrap or reduction in rework or reduction in power usage and all those things…Lean should drive you to be cheaper and faster. Everybody wins. environment wins, the customer wins, we win."

This perspective of Participant 2 illustrates how Lean scheduling and flow logic can translate into significant energy and emissions savings. Observations during shopfloor walks confirmed this practice, with visual boards showing in the printed circuit board production unit that machine shutdown routines embedded into the unit metrics board, reducing unnecessary energy consumption, contributing to an estimated £200,000 in electricity saving within the site between the period of 2023 and 2024.

The interconnection of Lean and Sustainability was further articulated by Participant 14, who drew an important conceptual distinction:

> "Lean seems like a linear process… you want to reduce as much waste as you can within this process. Sustainability is a circle… something that is sustainable in the very long term. But you cannot be sustainable if you're not Lean."

From this perspective Sustainability is understood as a higher-order logic, but one that cannot be achieved without Lean maturity as a foundation. The evolution of Sustainability kaizens' observed in both company reports and practice, reflects how the company operationalises this linkage by applying a Lean mindset to longer-term Sustainability goals.

However, several participants stressed that progress depends on credible measurement. Without a transparent baseline, Sustainability ambitions cannot be translated into daily management or Hoshin Kanri targets. Participant 11, the Sustainability executive, explained the starting point and the work undertaken to build that baseline and stated:

> "When I came here (in 2022) to the company, there was not really like a good process to even account for the emissions. So, during the last two years, we have been working on creating the methodology, the process, to disclose our numbers in our voluntary report, which is going to be released in September in our CDP reporting…and we're going to have a first time third party validation of data so I would call that a win. So at least you know, we are

> setting the baseline so on and so forth for scope one, two... So that's the first thing that I did for the scope one and two, so one and two are just operations... When I joined the company, we need to get there by 2030. Because we have a carbon neutral by 2030 commitment…But Scope three… is the big elephant in the room. That is not integrated in our Lean strategy, in Hoshin Kanri, in any KPIs."

This candid admission illustrates both progress and gaps. Emissions accounting for Scope 1 and 2 is maturing, supported by external validation. Scope 3, encompassing supply chain, logistics, and upstream impacts, remains disconnected from Lean governance. Documentary evidence supported this, with the company's Sustainability report confirming verified Scope 1-2 disclosures but only partial estimates for Scope 3. Participant 14 confirmed the procurement side of that gap, noting that lifecycle and carbon price are not yet factored into routine trade-offs but would need to be as the system matures:

> "It's the right approach… Sustainability in purchasing, lifecycle, carbon price — those are not factored yet. Eventually purchasing will have to include those variables in decision making."

From an operational level, Participant 3 cautioned that measurement only helps if it shapes the right behaviours:

> "We have too many KPIs too many metrics… it's all about the behaviour that that metric drives. If it doesn't drive a Lean behaviour that is not the right metric."

This reinforces the local risk of metric overload and the need to integrate Sustainability indicators into the existing Lean cadence, rather than building parallel dashboards that dilute focus.

Participant 11 recognised that external context shapes depth and speed by emphasising the differences across regions:

> "Airbus, you know, they are doing a lot… Being, not too much, because Airbus is European, and there is a lot of regulation and push in Europe and the UK in this area."

Based on the above, the same Lean routines can produce different Sustainability trajectories depending on regulatory pressures and customer expectations. That contingency is visible in enterprise disclosures, and it is reflected in the site's path, where inside-the-fence gains are consolidating through the energy saving and electricity provider change, whilst supply-chain reach is still emerging.

**4.3.1.2.2 Social Sustainability**

The social dimension of Sustainability also emerged from empirical insights. This dimension refers to organisational practices and outcomes that affect people's well-being and fairness including health and safety, empowerment and engagement, equity and inclusion and human rights across the value chain. This dimension also encompasses contributions to communities and how such outcomes are sustained by the management system over time.

From a governance perspective, the Sustainability function described its remit and current mode of operation before commenting on integration. Participant 11 outlined the portfolio of social programmes that sit under the Sustainability umbrella and then reflected on how far they are embedded in daily operations:

> "My team works on putting together a Sustainability report. Which is kind of consolidation of the environmental and social practices. So, when we talk about social you have, you know, DEI, you know, that's a big piece of the social practice: Diversity, Equity and Inclusion.... You have, you know, like employee talent attraction, that is another topic under Social. We have communities, which is our feeling philanthropic, you know, outside of the business. We have the human rights... So, we have all of these programs that together are part of the social umbrella, but as far as I know, none are integrated into Lean. For example, we do audits for suppliers in China, but is that operationalised to Lean? I don't think so."

A second perspective came from the Sustainability lead, who contrasted environmental practice with social and governance application. Participant 14 observed the current emphasis of Lean enabled Sustainability work:

> "Lean's seven wastes align with environmental goals—reducing energy waste, scrap, etc. But I've never applied Lean to social or governance pillars."

These reflections highlight a critical gap, whilst Lean and environmental Sustainability are strongly linked, social Sustainability remains peripheral. Observation of DEI in the site portal and activities, and supplier audit reports confirmed that these practices were managed separately from the LeanLift operational model, reinforcing the fragmentation between Lean and the broader Sustainability agenda.

A people-centred perspective also emerged. Participant 15 articulated Lean as the foundation of sustainable operations:

> “To be sustainable, we want to be able to produce what we need at the right time according to demand and right first time… not too much and not too little, then the ecosystem of which we operate in would be balanced…There hasn’t been any change in the methodology or the principles. I think what’s changing is our ability to learn to see how to use it… to help us be more sustainable.”

This reinforced Lean’s role as a mindset for balanced operations, where Sustainability is achieved by calibrating production to demand. This view also reflects the iterative learning process by which Lean principles are repurposed for Sustainability objectives, an idea central to the LS4.0 model. At the same time, the literature cautions that Lean can adversely affect social outcomes when poorly designed or implemented, termed often as “The dark side of Lean”. Salentijn et al. (2021) synthesise evidence that Lean’s hard and soft factors can yield either positive outcomes such as engagement, organisational learning and empowerment or negative outcomes such as heightened job stress, reduced satisfaction and diminished well-being, depending on how the overall system is configured and led. In other words, execution determines whether social outcomes improved or deteriorated. Salentijn et al. (2021) review underlines that soft, human-centred practices e.g., teamworking, training, communication and empowerment mediate social outcomes, and that focusing only on hard tools risks work intensification and poorer worker experience, emphasising the need to manage Lean as a whole system rather than a toolkit.

Taken together, these findings show that practitioners perceive Lean as the foundation for Sustainability, but the maturity of this integration varies. Environmental Sustainability is increasingly embedded in through Kaizen and waste reduction practices. Supported by energy-saving initiatives and combined leadership roles. However, gaps remain in measurement, especially Scope 3 emissions, and in embedding social Sustainability within Lean frameworks. Documentary and observational evidence triangulated these insights, showing that Sustainability is entering the LeanLift cadence through metrics at the case site, whilst procurement and social domains have yet to be fully translated into the same boards, meetings and routines. Enterprise disclosures are consistent with this pattern, casting the operating system as the lever for operational emissions and resource efficiency and setting out product and ecosystem dependencies for the harder, system-wide elements of decarbonisation, including fuel transitions and new architectures. These findings directly inform the LS4.0 model, highlighting the need for culture, people, and measurement capabilities that embed Sustainability into Lean's operational and strategic logic, moving beyond efficiency to holistic value creation.

#### 4.3.1.3 Theme 3: Perceptions of the Role of Advanced Technologies

Advanced technologies were widely perceived not as standalone solutions, but as enablers of Lean and sustainable operations, particularly when deployed in alignment with organisational context and strategic intent that reflect the sector's complexity, regulatory constraints, and legacy systems. Participants conveyed a shared view that technology's value lies in its capacity to support, not replace, Lean principles, particularly in environments defined by legacy systems, manual complexity, and high compliance standards. During the research period, the operational connectivity initiative was being piloted at the case site, within the printed circuit boards (PCB) business unit. Led by the Chief Engineering Leader, Participant 7, this initiative aimed to connect local and inter-sites workstations through sensors and cloud computing to capture real-time data on machine efficiency, yield, rework, and energy use. The pilot formed part of AeroSkyward's broader LeanLift strategy, the company's global digital Lean operating system integrating analytics, visibility, and continuous improvement.

Participant 9 explained the intended capability:

> "We are looking to create an environment that would provide improved OEE type capability, yield information, consumption type information… lots of opportunity for us to gather data…turn that into useful information."

At the site level, the operational connectivity initiative aims to provide a digital foundation for LeanLift by transforming local shop-floor data into actionable insight. This integration exemplified the company's wider ambition, described in corporate reports as "data-driven flow management," linking digital infrastructure with Lean problem-solving to achieve sustainable competitiveness.

Framing the strategic ambition, Participant 10, a Lean senior executive, emphasised the advantage of coupling data with flow discipline:

> "Companies of the future are driven by data…the companies that harness the combination of digital infrastructure and flow concepts will have the competitive advantage."

Field observation reinforced this rationale. A prime example of this shift was observed within the PCB business unit, where despite strong performance against on-time-delivery and sales targets, which are widely celebrated by the site's leadership, on the ground observations revealed a different reality. Through informal discussions with Participant 7 and extended shadowing of production area, it became clear that several inefficiencies remained hidden behind headline key performance indicators. These included high rework rates, excessive overtime, and avoidable energy usage from prolonged long machine cycles, factors not immediately visible in on-time-delivery dashboards but critically important for cost and environmental performance. The intent behind the operational connectivity initiative was precisely to address such blind spots by delivering real-time visibility not only of output but of the true cost of production, financial, energy-related, and human. By connecting local workstations and tracking performance via sensors and cloud-based analytics, this shift towards transparency resonates with the company's corporate decarbonisation strategy for Scope 1 and 2 emissions, largely through LeanLift-enabled process optimisation and digital energy monitoring, and aims to shift leadership focus from lagging, aggregated metrics to real-time, granular indicators that can detect waste early. This example illustrates a core insight shared by many practitioners: that without digitalisation of performance data at the operational level, critical waste streams, rework, overproduction, energy overuse and overtime remain invisible and therefore unmanaged. This perspective also reinforces the idea that I4.0 should not be used to reinforce traditional top-down metrics but rather uncover and act upon deeper process inefficiencies aligned with Lean and Sustainability goals.

The operational connectivity initiative among others within the company's wider digitalisation strategy illustrates the convergence of digital infrastructure with Lean principles, an interplay that aligns with the Lean two key fundamentals concepts of just-in-time and Jidoka, or automation with human oversight in Lean thinking (Buer et al., 2018, Liker, 2021). Participant 7 reminded the original role of technology which supports both process reliability and operator safety and remarked:

> "That's where automation and that has a part to play, to keep people safe…dealing with quite big engines, wings and things you can't pick up and put it over your shoulder."

Such perspectives reinforce the dual function of I4.0: enhancing efficiency and mitigating operational risks in a sector characterised by manual complexity and stringent safety demands. Expanding on this, Participant 15, a senior executive and Lean transformation expert, reflected on how these principles remain central to both quality and Sustainability TBL goals, stated:

> "JIT, just in time is what I need, when I need it, where I need it. And then Jidoka, stop for abnormality through automation. Two very simple principles…that really are the pillar from which a Lean operating system can rise."

Participant 15 argued that Lean, advanced technologies, and Sustainability share a common logic: the pursuit of right-first time production at the rate of demand. In Participant 15 view, the true opportunity of digital technologies lies in enabling the design and industrialisation processes to align with just-in-time and Jidoka principles, hence, reducing rework, overproduction, and emissions across the product lifecycle. This vision of Jidoka resonates strongly with current I4.0 capabilities such as real-time sensors, machine-learning-based anomaly detection, and cyber-physical systems response loops, tools that extend traditional visual control systems into digital ecosystems. Such perspectives echo socio-technical interpretations of Lean (Shah & Ward, 2007), where the success of automation is measured not by how much is digitalised, but by how well technology serves human-centred problem-solving and systemic stability. However, some participants expressed caution about over-reliance on technology, particularly when foundational processes lack maturity.

Participants also cautioned against automating unstable processes. As Participant 12 warned:

> "One of the dangers when we're in a technical age is to say, how do we automate everything now? Now, the reason I say that and bring that out is there is a danger that you automate something that's wrong and you still end up with a wrong output."

This critique echoes insights from Alieva and Powell (2023) and Alieva and Haartman (2020), who demonstrate that Lean maturity is a prerequisite for successful I4.0 integration. Alieva and Powell (2023) and Alieva and Haartman (2020) caution that without this foundation, automation risks producing what they term as 'Digital Waste', meaning that misinterpreted, uncollected, or unprocessed data that undermines value creation resulting from misaligned automation. The practitioners' insights reinforce the digital waste argument that technology must follow and enable Lean, not precede it. A sentiment that reflects a process-centric rather than a tool-centric approach to operational improvement.

#### 4.3.1.3.1 Perceived Technological Infrastructure and Readiness Challenges

Practitioners consistently underscored that data accessibility and digital readiness were central to realising the potential of I4.0 technologies. The impression within the site was that the transformation of raw data into usable insights remained limited. Several participants described the organisation as being "rich in data but poor in insight", a phrase used by Participant 2 and supported by others across functions. This statement reflects a systemic challenge of data infrastructure fragmentation and limited compatibility between systems, a common issue in legacy-heavy, compliance driven sectors (Frank et al., 2019, Sony, 2018, Sony & Naik, 2020).

Building on this theme, several interviewees explained that whilst modern equipment and systems generate large volumes of information, extracting and combining that information for timely analysis is difficult due to disconnected platforms and inconsistent data structures. Participant 1 explained:

> "The data that we can capture is massive now. the technology and what it allows us to do, in all aspects of life, whether it be automation whether it be capturing visual information whether it be capturing measurements... The big problem I see at the moment in this business is, you know, a lot of the time we capture loads of data but you've got to be able to get that data back out of the systems… in order to analyse it and sometimes that can be a challenge

> and it shouldn't be… the data is there but to get it into a format that you can actually do something and analysing to get benefit from, is sometimes challenging."

Participant One's reflection pointed to the misalignment between data availability and analytical capability. Several existing systems, including the enterprise resource planning (ERP) platform, the quality database, and production performance trackers, were not harmonised, limiting cross-functional data flow. The issue was not the absence of data but the lack of interoperability and tools for transforming raw information into actionable insight at the point of use. Consequently, the potential of I4.0 was perceived as under-realised, pending the development of more platforms and analytics integration. An illustrative example was provided by

Participant 2, who described how smart soldering equipment had been embedded in with sensors to monitor performance:

> "We can plug in models to those, and we can tell you how many good soldering joints. An operator's made and how many. Let's not say bad joints, but joints are not optimal have been made. We can tell you how many they've done in a day. We can tell you the usage of the soldering iron tip fits in there. So, if someone's thrown it in the bin and it has done, it's 10,000 cycles, which we'd expect 100. So, we can, we're very data rich, and we're getting more and more data rich as time goes by, but we're not very good at harvesting that data. So, we've got the data, but we don't do anything with it. So, it's great having industry 4.0 giving us all this information and it just needs a little bit more to make it simple that people can extract that data and make use of it."

This example revealed a growing awareness of how even manual tasks could be enhanced by real-time data feedback, offering not just quality assurance but also continuous learning opportunities. Yet, such examples remained exceptions, not the norm, underscoring the uneven diffusion of I4.0 tools across the site. At the company level, similar limitations have been acknowledged. AeroSkyward's Sustainability report notes that although real-time monitoring systems are in place across major test and manufacturing facilities, the next strategic step is to "strengthen analytics capability and cross-platform integration to accelerate the conversion of operational data into Sustainability intelligence.", similarly, the annual report highlights that the transition from legacy infrastructure to connected digital ecosystems remains an ongoing transformation requiring harmonisation of disparate data systems and upskilling of employees to interpret insights. These statements validate practitioners' observations that the challenge is not technical availability but the maturity of supporting structures and competencies.

Participant 9 expanded on this by identifying a structural capability gap between information technology (IT) and manufacturing engineering:

> "So, we're talking about sort of machine connectivity. So, in order that we can effectively pull data from machines, operational technology, and pull that into the Information Technology networks, so that we can analyse it. At the moment, we here are very immature in terms of our journey. We do have quite a bit of equipment that is network connected in a secure way. But what we're not doing is very effectively leveraging that data and turning that into useful information…One of the key gaps that we've got is really the role that plays the interface between IT and the manufacturing equipment... understanding data structures that machines tend to use is not a traditional IT role. But also interpreting and incorporating that data into the IT environment is not also traditionally a manufacturing engineering role. So, where I see we've got some skill gaps and capability gaps role that sits in between IT and manufacturing engineer."

Observation confirmed that IT and manufacturing engineering teams operated within separate functions, with no dedicated translator role bridging process knowledge and data modelling. This organisational misalignment hindered the conversion of raw machine signals into standardised metrics or continuous-improvement insights. The participant's account parallels the corporate admission that AeroSkyward's digital maturity varies across functions and the new hybrid skillsets, blending operations, data science, and Lean, are required to sustain digital transformation. These findings are also aligned with the literature that a structural misalignment between digital systems and existing functional boundaries, a key theme in digital transformation literature, where new hybrid roles are required to translate data into insight (Buer et al., 2021, Sony, 2018).

AeroSkyward's broader transformation agenda reflects awareness of this challenge. The 2025 Sustainability report emphasises the company's shift toward "data-enabled Sustainability", embedding analytics and AI within its energy-management platforms to convert environmental data into predictive insights. The company reports ongoing deployment of advanced tools such as AI-supported energy management information systems (EMIS) to improve visibility of resource consumption across global sites. This directly parallels Participant 14's comment on the case site's EMIS upgrade:

> “What we have here…provides us with some data, but the analytics is to be improved…we are launching and upgrading this to a new system…integrating AI into statistical analysis.”

These consistent narratives across organisational levels demonstrate that the company’s digital transformation is evolving from data collection to data intelligence, a trajectory also observed within the case site. However, practitioners remained cautious that without cultural readiness, capability alignment, and system integration, I4.0 tools risk under-realisation.

Overall, these findings reveal a multi-layered picture, at the operational level, fragmentation of systems and role boundaries limits the use of available data. At the organisational level, AeroSkyward recognises similar gaps in analytics capability and talent alignment. Strategically, the company is moving toward AI-enabled Sustainability management as part of its LeanLift transformation.

This coherence across levels supports the interpretation that digital maturity and human capability development are preconditions for the successful integration of I4.0 technologies into Lean and Sustainability practices. The case evidence thus reinforces the view that technological transformation is not solely a matter of hardware or software but of organisational design, skill evolution, and systemic learning, all of which underpin the LS4.0 model advanced in this research.

#### 4.3.1.3.2 Perceived Data Accessibility and Use

Beyond technical applications, participants reflected more conceptually on what I4.0 meant for the future of Lean and Sustainability in aerospace. Crucially, perceptions were neither utopian nor dismissive, rather they were characterised by pragmatic optimism, conditioned by operational constraints, compliance obligations, and organisational culture. Several participants viewed I4.0 as a means to extend Lean capabilities, particularly through predictive analytics and process simulation.

Participant 7 captured this connection, highlighting the role of data visibility in defect prevention and waste reduction:

> “There are a whole host of digital tools, which will help you implement Lean and help you to improve things like defects, reducing defects…we're constrained in terms of digital analytics, and understanding what's really

> causing the yield losses what needs to be done to fix it? How to prevent getting into an overproduction situation? If testing is at the end of the process... I've got the same parts and the same defects while it's taking too long to analyse that information...That's where I see industry 4.0 helping drive up the amount of sensoring like that. So, the available data of what's going on in your manufacturing system and being able to detect things earlier and take corrective action, that's going to drive defect free product, which is a key enabler to Lean…So I think that's where industry 4.0 can help."

This articulation of real-time sensing and pre-emptive correction positions I4.0 not as a separate philosophy but as a natural evolution of Lean, a shift from reactive problem-solving to predictive control. The alignment between I4.0 and Lean were further illustrated by Participant 10, who described from experience, a co-production, cross-functional way of working in which Lean practitioners and AI specialists build solutions together:

> "I have a Lean and an artificial intelligence team sitting on the same group... And then we do the traditional value stream map with the Lean team. We take that exact same value stream map that the Lean team made with data flow on the top. And the AI team works the data infrastructure and ingestion of it."

This statement exemplifies an evolving multi-disciplinary practice, wherein traditional Lean tools like value stream mapping are being enhanced through algorithmic data curation and simulation, rather than replaced.

The most strategic articulation of I4.0's potential came from participant 9, who emphasised the role of digital twins in shaping the future state of value streams:

> "So, digital twin is the concept of you recreate your factory digitally, with all the inputs and outputs and bottlenecks associated with each of the machines. And then what you can do is you can then simulate changes to the environment in order that you can then look for opportunities to reduce bottlenecks to improve takt-time."

This vision aligns with the concept of cyber-physical systems, central to I4.0 frameworks (Kagermann, 2014), and reveals a clear aspiration to move from reactive Lean problem-solving to proactive, scenario-based process optimisation.

Participant 9 also underscored the importance of aligning I4.0 deployments with strategic intent, arguing that:

> "You need to have that strategic business intent…what is it that we want to achieve? then you start implementing the Lean principles to solve problems."

This logic mirrors the contingency-based perspective of Buer et al. (2018), who assert that the value of I4.0 is dependent on problem-context, business priorities, and process maturity. Further insights came from Participant 14, the organisation's Sustainability lead, whose perspective expanded the scope of I4.0 beyond production metrics to environmental performance.

Participant 14 discussed the current use of the energy management information system to monitor global consumption and emissions, whilst also noting its limitations:

> "What we have here…provides us with some data, but the analytics is to be improved..."

Participant 14 comment reflects a growing recognition of AI and cloud technologies as essential tools for scaling Sustainability performance, improving energy intelligence, and enabling advanced forecasting. An illustrative example of data-enabled decision-making beyond the shop floor is the company's pilot-facing digital initiative known internally as *Flightrack (*pseudonym). Whilst outside the direct operational scope of this study, its relevance lies in demonstrating how digital tools support Sustainability objectives across the product lifecycle. The tool allows pilots to access their individual flight data, including fuel usage and route efficiency, enabling them to make informed decisions that reduce fuel burn and carbon emissions. By visualising real-time and post-flight performance metrics, *Flightrack* exemplifies the broader potential of I4.0 to empower frontline actors with actionable insights, thereby fostering behavioural change aligned with triple-bottom-line goals. Although this initiative sits within the aviation-services domain, its logic reinforces the core argument of this research: that data accessibility and human-centred analytics are foundational enablers of Lean-Sustainability integration in aerospace.

Overall, practitioners viewed I4.0 technologies as valuable, but conditional, enablers of Lean and Sustainability integration. Their utility is not assumed, but contingent upon strategic alignment, operational maturity, cultural readiness, and capability development. These perceptions collectively reinforce that the successful integration of I4.0 into Lean and Sustainability efforts must be interpreted through a systems lens. Technology alone does not guarantee improvement, it is the convergence of tools, people, processes, and priorities that defines transformative potential. This understanding directly informs the LS4.0 model developed in this research.

#### 4.3.1.4 Theme 4: Strategic Alignment and Leadership Role

Leadership commitment emerged as critical for driving integration of Lean, Sustainability, and I4.0 technologies. Leadership was not only seen as a top-down directive but also as a cultural and strategic force shaping organisational behaviour, resource allocation, and long-term alignment. This theme explores three interrelated dimensions: leadership commitment, strategic alignment through Hoshin Kanri, and mechanisms for cultural transformation. Together, these dimensions underpin the leadership role embedded within the LS4.0 model, as presented in Section 5.3.6.

##### 4.3.1.4.1 Leadership Commitment

Participants emphasised that the success of LS4.0 integration efforts was directly proportional to the extent of leadership involvement and visibility. Rather than delegating the agenda to programmes or tools, senior figures were expected to sponsor it in person and in practice, setting intent and aligning resources with the few problems that matter most for performance and Sustainability. Participant 7 captured the expectation of visible commitment:

> “People want to see that the management take it seriously. They want to see investment going on and then they will get behind it and go on, now people want to get ahead and they want to get the topic, it's an official thing. As the all-hands [Management meeting] we just came from. If you want to get a conversation with [CEO], you need to put Lean in it somehow and he will go very interested, and he walks the talk”.

Beyond such personal involvement, leadership commitment was institutionalised through explicit behavioural expectations. The company developed three core leadership behaviours: *act with humility, lead with transparency, and deliver with focus*. These three behaviours are embedded into performance reviews and incentive structures, reinforcing the cultural dimension transformation. By codifying behaviours within formal appraisal systems, AeroSkyward sought to translate leadership values into measurable, repeatable practice, signalling that behavioural alignment carries the same importance as technical performance.

Participant 10 framed leadership behaviours as sequenced capabilities, where humility enables transparency, and transparency enables focus:

> "We talked about lead with humility, and then transparency and then focus, and you have to do those things in that order, because the one enables the next which enables the next and so. The first one is humility…if a leader isn't walking…with a mindset that they're most likely wrong... Then people won't be transparent… then you can't make good decisions… so you can't stay focus."

This positions humility not as a soft virtue but as an operational precondition for daily management and problem-solving. This view also explains why "visible leadership" is more than plant tours: without leaders modelling inquiry at the gemba, information quality collapses and the improvement cadence stalls. This mirrors Liker (2021) view that sustaining Lean success depends on leaders who "model the philosophy," and Schein's (2010) notion of leadership as the primary vehicle for culture creation and reinforcement.

To turn these expectations into day-to-day practice, prior research breaks Lean leadership into level-specific routines. Netland et al. (2020) break Lean leadership into level-specific practices: senior leaders "go and see" and signal cultural commitment at the gemba, middle leaders run structured gemba and daily management, and front-line leaders coach on-the-job problem solving. In practical terms, gemba engagement is level-dependent: top leaders focus each visit on few visible areas, promote principles over tools, and coach middle managers, middle leaders conduct gemba more frequently, front-line leaders coach continuously at the point of work.

Cadence also matters. Netland et al. (2020) describe "daily layered accountability", short stand-ups at each level with rapid escalation of non-conformance, ensures every manager knows the status of operations every day, breaking silos and keeping improvement fast and fact-based. At the case site this cadence is institutionalised through cell control centre (CCC) at the operators and supervisors' level, the business unit control centre (BUCC) with middle management and cross-functional teams, and the plant control centre (PCC) with the site executive and functional leaders.

As Participant 7 summarised, "Leaders must model Lean principles." Netland et al.'s (2020) caution that when leaders default to directing rather than coaching, or when subordinates must “coach up,” transformations stall, reinforcing participants’ emphasis on humility, consistency and presence.

Such field insights align closely with AeroSkyward’s corporate stance. The annual report describes leadership as the key differentiator in sustaining the operating system and explains that senior executives spend more time at the gemba to remove obstacles and build a culture of improvement. The annual report also identifies, visible leadership at all levels, as a primary enabler of both operational excellence and Sustainability performance.

The Sustainability report similarly states that leadership accountability drives progress toward the 2050 net-zero ambition, embedding Lean thinking and Sustainability into every business decision. These statements in the annual and Sustainability reports validate the field observations that effective leadership in the company is not merely directional but performative and cultural, influencing how employees interpret and enact LS4.0 values.

Leaders were therefore perceived as cultural architects, shaping norms by modelling behaviours such as transparency, problem solving, and long-term thinking. This aligns with Schein (2010) concept of leadership as the primary vehicle for culture creation and reinforcement. In this context, Lean leadership was viewed as the foundation for integrating environmental and digital transformation agendas.

#### 4.3.1.4.2 Strategic Alignment through Hoshin Kanri

At the case site, strategic alignment is maintained through Hoshin Kanri, which links the enterprise vision to value stream and cell-level objectives and reviews. Participants describe Hoshin Kanri role as the bridge between intent and daily improvement. Particularly, Participant 10, a senior executive, stressed why this discipline matters today:

> “We use Hoshin Kanri, which is a standard Lean tool to convert strategy…all it means in Japanese is basically: it's the direction and the management of that direction. And so you're setting your strategy and then you're managing how the organization is executing against that strategy. So, what I would say is both skills are necessary… but where I have seen a shift probably in the last 20 years is because of the speed and the rate of change of technology and product launches is getting shorter and shorter.”

By translating high-level goals into measurable, time-bound targets, Hoshin Kanri served as a connective tissue between strategic intent and frontline execution. Hoshin Kanri provided clarity on questions such as “What do we want to achieve?” and helped ensure that continuous improvement activities were not isolated efforts but aligned with overarching organisational goals (Hines, Holweg, & Rich, 2004). Through Hoshin Kanri, the case organisation attempted to synchronise Lean initiatives with Sustainability objectives and digital transformation efforts, making the integration effort not merely technical but deeply strategic. This integrative logic also aligns with dynamic capabilities theory (Teece, 2007), whereas strategic routines like Hoshin Kanri enable sensing, seizing, and reconfiguring capabilities in response to evolving contexts.

Participant 12 underscored Hoshin’s transformative intent:

> “… Hoshin Kanri is saying, what's our vision in five years’ time... It should be transformative in nature…I want to take where I am today and create a capability that I don't have today.”

The company’s LeanLift is strategically deployed as the means to cascade customer, Sustainability, and digital priorities to all sites, noting that executives “spend more time at the gemba” to review Hoshin progress and remove obstacles. The report emphasises “visible leadership at all levels” and the use of tiered reviews to keep strategy execution fast and fact based.

The company Sustainability report states that leadership accountability for the company’s 2050 net-zero ambition is operationalised by embedding environmental targets within Hoshin Kanri. The supplementary Sustainability data book further indicates that carbon and energy KPI are incorporated in operating “bowlers” at manufacturing sites and reviewed within the same cadence as SQDC metrics, evidence that environmental goals are not parallel to operations, but integrated into the same strategy-deployment routine.

#### 4.3.1.4.3 Cultural Transformation and Change Mechanisms

Leadership’s role also extended into fostering cultural transformation, a necessary but critical and complex element of Lean, Sustainability, and I4.0 integration. Participants described the importance of practical mechanisms to install new ways of thinking, particularly through kaizen events, cross-functional workshops, and training programmes.

When asked what ultimately shifts behaviours beyond tools and projects, Participant 3 reflected: “It’s a cultural thing…how you get people to be thinking in that particular way.”

Participant 3 described a deeply rooted cultural conservatism at the site, shaped by technical engineering practices and legacy mindsets. Whilst such cultures offer stability, they can inhibit agility, experimentation, and the mindset shift required for LS4.0 to thrive (Liker & Convis, 2012). Hines (2010) reinforces this view through the notion of Lean culture as *below-the-waterline* work: strategy and alignment, leadership, behaviour and engagement, which enable the visible “*above-the-waterline*” artefacts of processes, technology and tools. Hines’s (2010) argument is that tools only endure when the organisation has first shaped the norms, such as trust, openness, consistency and reflection, and removed the roadblocks in policies and measures that restrain engagement. Only then do tools, technology and techniques such as visual management become self-propelling and *above-the-waterline*. Hines (2010) further emphasised that sustainable Lean requires a management system that turns employee ideas into action quickly, reinforces the seven Lean skills through recruitment and appraisal, and measures maturity as much by how work is led as by what tools are present.

In this sense, real LS4.0 integration rests on cultural foundations that make the integration intrinsic to organisational philosophy and mission.

From the perspective of day-to-day behaviour, Participant 1 pointed to resistance that can slow change:

> “…People tend to fall into a certain pattern and tend to be less from what I've seen anyway, less open to not change but you know, being a little bit more inventive or imaginative with solutions…there's a lot of people that are very reluctant to do things.”

To counter this inertia, leadership had initiated practical mechanisms such as Kaizen events, green teams, diversity and inclusion initiatives, training workshops, cross-functional problem-solving, and pulse surveys to gauge engagement and readiness. These reflections resonate with Liker’s (2021) assertion that Lean tools alone do not create transformation unless accompanied by deep cultural reinforcement. Tools such as visual management, A3 thinking, and daily stand-ups can fail to produce meaningful change when deployed in a culture that lacks psychological safety, shared ownership, and leadership support (Kagermann, 2014, Schein, 2010).

The integration of I4.0 technologies introduced additional culture tensions. On the one hand, digital platforms offered opportunities to democratise information and empower teams. On the other hand, several participants raised concerns about technocentrism, where digital tools risks overshadowing human-centric Lean values.

Framing this caution, Participant 12 warned against automating unstable processes:

> "I would say that one of the dangers when we're in a technical age is to say, how do we automate everything now? Now, the reason I say that and bring that out is there is a danger that you automate something that's wrong and you still end up with a wrong output. So, first of all, we have to prove our processes then automate when we've got to a mature state."

Such concerns align with Alieva and Haartman (2020), who emphasise that premature digitalisation, in the absence of Lean process stability, often leads to inefficiencies. Alieva and Haartman (2020) describe this phenomenon as "digital waste", where technological investments do not address underlying systemic issues or cultural readiness. In this context, cultural transformation must not only support continuous improvement but also prepare teams to critically engage with digital systems, questioning when and how technology should be applied to complement human judgment and operational purpose.

Participants also perceived a need for cultural alignment with Sustainability goals. At the site, the net-zero by 2030 commitment has begun to shape messages from leadership and the way targets are discussed in operational channels. Participant 11 expressed the urgency for the site's target: "We need to get there by 2030" reflects a cultural shift towards Sustainability. At the same time, Participant 3 warned that progress must protect workforce well-being: "If we don't Lean out processes, staff burn out" suggests that cultural transformation must also address social Sustainability. These insights confirm the interdependence between cultural readiness, leadership behaviour, and people-centred Lean transformation. Participants also reinforce the need to approach integration not as a technical project, but as a long-term cultural.

Recent empirical work by Gutierrez et al. (2022) further locates this cultural work within a capability logic. Gutierrez et al. (2022) show that Lean practices in operations and the supply chain cultivate the micro-foundations of dynamic capabilities, sensing, seizing and transforming, and that learning-oriented Lean cultures strengthen these effects, with innovation-oriented cultures additionally amplifying the link from operations practices. In other words, culture is not merely atmosphere, it is the moderator that turns routines into adaptability and, downstream into process innovation. This helps to explain why similar toolsets in the case site sometimes produced adaptation and, at other times, stagnation.

Company documents show exactly this cultural work being codified in the formal management system. AeroSkyward uses energy and emissions practices embedded in site routines through an energy management information system with standardised methods and invoice validation, signalling that environmental performance is managed with the same visibility and discipline as production. Culture is reinforced on the social side too, a global EHS framework and a new ergonomic technical standard have been used to reduce musculoskeletal risks through a Lean practices approach, linking daily routines to employee well-being and safety.

Finally, cultural transformation at the case site was recognised as a multi-layered challenge requiring leadership consistency, cross-level participation, and a balanced approach to technology. Whilst leadership has initiated foundational mechanisms, cultural change was still emerging, reflected in pockets of success rather than systemic shift. These findings reinforce the centrality of culture as a capability in the LS4.0 model, particularly as it mediates the adoption of Lean principles, the pursuit of Sustainability goals, and the responsible use of digital technologies.

### 4.3.2 Characteristics Influencing Integration

This section addresses RQ2.2 by identifying the characteristics that shape how Lean, Sustainability, and I4.0 can be integrated at the case site. The analysis indicates four interdependent domains that together condition implementation: technological and data structures, organisational learning and process efficiency, leadership and collaboration, and contingency characteristics including: compliance, complexity, novelty and the wider ecosystem. Each domain maps directly the capability dimensions of the LS4.0 model developed in Chapter Five.

#### 4.3.2.1 Characteristics Influencing Technology Integration

Several characteristics were identified influencing the integration of I4.0 technologies, including both enablers and barriers. The site's operational connectivity initiative, launched in 2023, leverages sensors, cloud computing, and AI to enhance the LeanLift system with real-time data. Participant 7 highlighted a key enabler: "Automation keeps people safe" illustrating Jidoka's role in Lean safety (Ohno & Bodek, 1988). Additionally, the launch in June 2024 of a generative AI platform with Microsoft Azure was another enabler to improve the employees' productivity, the questions that would take many hours to answer, AI platform allows a human interaction so that employees can have their answers quickly. Speaking to the engineering side of this opportunity, Participant 10 reflected on generative design strategic value: "You can iterate on designs faster… all the way through simulation…Things that used to take 10 years can be done now." Achieving a potential up to 50% reduction in development timelines through generative design and simulations (Pilagatti et al., 2023).

However, technological readiness emerged as a significant barrier. Explaining how regulation constraints architectural choices for data platforms, Participant 9 stated, "Our data regulation says we cannot leverage commercial cloud due to UK government and ITAR data constraints," reflecting compliance issues that limit I4.0's potential. Describing the site's current data landscape, Participant 1 added, "We captured loads of data but getting it out is a challenge…it's an aviation thing." Indicating technological immaturity in data accessibility. In detailing a capability gap at the IT and operations boundary, Participant 9 further elaborated, "One of the key gaps we're got is really the interface between IT and manufacturing equipment…we're not effectively leveraging that data into useful information," underscoring infrastructure and skills challenges.

The site's proactive efforts to address these barriers were evident. On the compliance front, Participant 9 noted "We're working closely with government to certify data hosting," this statement showed the active work to overcome compliance constraints through collaboration with government to certify data hosting so that secure, scalable analytics can be deployed. Participant 10 described combining traditional value stream mapping with AI to curate and structure data and confirmed: “We use traditional VSM with AI to curate data” highlighting an innovative approach to leveraging technology, despite manual processes persisting. Participant 12 also cautioned, “There’s a danger you automate something that’s wrong,” emphasising the need for process validation before automation. These characteristics enablers like AI and barriers like compliance, inform the model’s Information and technological infrastructure capabilities.

#### 4.3.2.2 Characteristics Influencing Organisational Learning and Efficiency

Organisational learning and operational efficiency were frequently cited as interrelated capabilities essential to driving Lean and Sustainability integration. Participants reflected on the challenges and opportunities associated with knowledge capture, problem solving agility, and the role of digitalisation in shaping learning routines. These insights align with the model’s “knowledge and Leanness capabilities,” highlighting the need to institutionalise learning cycles and streamline the feedback between insight and action.

A recurring theme across the interviews was the uneven application of Kaizen as a structured learning mechanism. Whilst Kaizen events were viewed as instrumental in translating Lean principles into action, participants highlighted inconsistencies in their deployment. Participant 12 illustrated a progressive shift in mindset and stated:

> “We started to link Lean and Sustainability…our Kaizen events all have a Sustainability aspect.”

However, the same participant further added a lack of continuity in these efforts as it takes in average 6 weeks to prepare for a Kaizen event involving scoping, data collection, stakeholder alignment, and explained that this lengthens scheduling and slows cadence. Participant 12 stated:” I think we’ve got our first Kaizen event coming up at the end of November…we haven’t done much recently.”

This gap between aspiration and execution reflects the challenge of embedding structured improvement activity within operationally constrained environments. In practice, Kaizen at the case study site is coordinated by the Lean team in collaboration with the business unit leader, typically delivering a one-week intensive event. The week is described as “tense”, involving focus diagnostics through value stream mapping, followed by rapid implementation. Most actions are closed within the same week, an approach that appears both distinctive and normative within aerospace contexts. This compressed Kaizen deployment rhythm underscores an industry-specific adaptation of Lean, highly concentrated bursts of learning designed to deliver immediate and visible results.

This finding resonates with Saabye et al. (2023), who conceptualise Lean as an action-learning system in which improvement routines such as Kaizen and plan-do-check-act (PDCA) represent structured cycles of reflection, experimentation, and knowledge renewal. From this perspective, learning is not an outcome of Lean but its engine, the mechanism through which organisations adapt processes, challenge assumptions, and sustain capability development. The uneven Kaizen deployment observed at the case site therefore signals not only operational discontinuity but a disruption of the organisation’s learning cycle. Embedding Lean effectively thus requires cultivating reflective practice, where each improvement even feeds collective knowledge and informs subsequent iterations of problem-solving. In this sense, learning and efficiency become mutually reinforcing rather than competing priorities, a balance critical to LS4.0 integration.

Efficiency was also interpreted through the lens of turnaround time and response velocity. Participant 3 articulated the importance of reducing problem resolution cycles:

> “I would measure the success of our problem on the turnaround time…I know today it’s on average 30 days and I want it to be 5 days. The reason I want it to be 5 days is because it improves the flow in the shop.”

This framing aligns with Lean’s emphasis on flow but also reflects an underlying aspiration to embed faster learning loops. The capacity to respond quickly to disruptions or process instability was seen as integral to both productivity and organisational learning. Despite increasing investments in data infrastructure such as the operational connectivity initiative, several participants pointed to persistent barriers in leveraging digital tools for insight generation.

To illustrate the gap between data collection and usable insight, Participant 2 explained: “We’re very data rich…but we’re not very good at harvesting that data.” This disconnects between data availability and actionable insight signals a structured gap in the site's digital maturity. Participant 7 further emphasised the legacy burden: "There's still a lot of manual processes in aviation." These comments reflect the tension between aspiration and reality in digital transformation, whilst the tools exist to support smarter problem-solving, the surrounding systems and workflows often inhibit their effective use. As such, digitalisation has yet to fully operationalise the site's organisational learning potential.

Collectively, these perspectives suggest that learning and efficiency are tightly coupled, but not yet fully integrated. Knowledge capture remains as hoc, problem resolution slow, and digital capabilities under-leveraged. Addressing these gaps requires targeted interventions in feedback structures, capability development, and technology integration, pillars central to the knowledge and Leanness capabilities proposed in the LS4.0 model.

#### 4.3.2.3 Characteristics Influencing Leadership and Collaboration

Collaboration and leadership emerged as critical characteristics influencing Lean-Sustainability-4.0 integration. Across the interviews, and company data, strategic direction, leadership behaviour, and inter-functional cooperation collectively shaped the organisation's capacity for systemic change. These insights align the model's "collaboration and culture" capabilities, illustrating that operational excellence is not merely technical but deeply social.

Within this context, strategic alignment was often discussed through the lens of Hoshin Kanri as the organisation's strategy-deployment routine that links long-term intent to day-to-day execution. Framing Hoshin in this practical role, Participant 10 explained: "It's the direction and management of that direction," facilitating strategic alignment across the organisation and reinforcing the role of leadership visibility as not optional but fundamental. Participant 10 added:

> "Lean is without a doubt…something that has to be led from the top of the organisation. Its non-delegable."

This perspective highlighted the symbolic role of leadership in shaping culture and sustaining direction. This was not simply about governance but about presence, attitude, and consistency. The same executive then clarified the tone leaders must set and expanded further: “There has to be this humility at the CEO level…technology just falls into tools. It changes all the time.”

These observations are consistent with Alefari et al. (2020), who show that leadership is the cornerstone of Lean success. Alefari et al. (2020) study demonstrates that transformational leadership, centred on vision, inspiration, and individual empowerment is fundamental to embedding Lean thinking across organisational layers.

Effective leaders in Lean environments act less as controllers and more as coaches, fostering communication, motivation, and psychological safety. Such leadership behaviours transform Lean from a set of tools into a sustained organisational philosophy. Conversely, directive or transactional leadership styles were shown to erode engagement and limit employee ownership of improvement activities, an observation consistent with several participants’ reflections that Lean progress depends on leaders “taking it seriously” and remaining visibly engaged.

This view also resonates with the behavioural principles underpinning the Shingo model, particularly the emphasis on humility, respect, and constancy of purpose (Shingo, 2021). Leadership, in this context, was as much about modelling Lean behaviour as it was about setting performance targets or enforcing compliance.

Collaboration within the organisation was largely facilitated through structured Lean activities such as Kaizen and pilot projects where different functions e.g. manufacturing engineering, IT teams, converge around a shared improvement agenda. However, collaboration beyond the organisation, particularly with suppliers, was more problematic. Reflecting that concern, Participant 11 observed the basic awareness barrier that often appears in supplier discussions about Sustainability:

> “If you talk to some of our suppliers about Sustainability… they don’t know what it means.”

This insight underscores a key limitation in the current ecosystem: whilst internal efforts are becoming more aligned, the upstream supply chain lacks the awareness, capability, or incentive to support Sustainability objectives. The finding highlights the need for broader supplier engagement and targeted education to enable value chain-wide transformation.

Finally, vision was repeatedly identified as a critical leadership capability. In interviews about how leaders mobilise cross-functional effort and keep initiatives coherent over time, several participants stressed the importance of compelling true north that turns strategy into shared purpose. Summarising that expectation, Participant 10 stated:

> "You have to have a vision…you have to be able to paint it in a compelling way."

This framing positions vision not only as a communication tool, but as a cultural enabler. In the absence of clear, compelling direction, collaborative efforts risk fragmentation.

Together, these reflections reinforce the centrality of leadership and collaboration in driving Lean-Sustainability-I4.0 convergence. Strategic intent, behavioural consistency, and inter-functional engagement form the foundation through which change is operationalised. The findings thus highlight that effective Lean leadership is not purely hierarchical but relational, rooted in vision, humility, and empowerment, and that these qualities from the relational infrastructure required to sustain transformation in high-complexity environments like aerospace.

#### 4.3.2.4 Contingency Characteristics: Compliance, Complex, Novelty and Ecosystem

The integration of Lean, Sustainability, and I4.0 should not occur in a vacuum. Instead, it should be deeply shaped by a set of contingency characteristics namely compliance, complexity, novelty, and ecosystem dependencies, that influence not only what was possible, but how, when, and to what extent integration could be pursued. These characteristics reflect the inherent contextual variability of the aerospace sector and align with contingency theory (Donaldson, 2001), which posits that organisational effectiveness depends on the fit between internal practices and external circumstances.

Compliance emerged perhaps the most immediate and tangible contingency. Practitioners repeatedly described how regulatory were not peripheral constraints but central to shaping both the technological infrastructure and cultural mindset. Setting out the consequence for cloud adoption, Participant 9, for instance, spoke about how data sovereignty regulations prevented the adoption of global cloud services and stated:

> "With military datasets comes higher levels of data regulation…the service providers who would be offering us new capabilities just aren't able to offer us that government-certified cloud environment."

This constraint did not only limit digital scalability but also reinforced a cautious, risk-averse culture, where innovation had to be justified through compliance lenses. In this environment, the need for validated, secure data systems shaped the design of digital tools and informed the cautious pace of I4.0 adoption.

Complexity, especially in relation to product design and operational flow, emerged as a persistent undercurrent. Aerospace, by nature, is a low-volume, high-mix, and tightly regulated sector where standard Lean routines, like takt-time based flow or cellular layout, often clash with engineering and regulatory realities. Before discussing digital solutions, Participant 10 reflected on aerospace supply chain structure and mentioned:

> "You cannot create as much flow as you'd like to right off…things don't just align."

This comment underscored a key issue observed in practice: Lean methods could not simply be transplanted from automotive context, they need to be reinterpreted and re-engineered (Browning & Heath, 2009, Hines, Holweg, & Rich, 2004). Observed on site was an electrical power unit assembly where operators repeatedly struggled with alignment despite parts meeting design tolerances, illustrating how system complexity converts latent design inefficiencies cascade into operational waste, despite appearing compliance on paper. Complexity, therefore, did not merely obstruct Lean flow, complexity generated invisible work and masked inefficiencies that Lean tools alone could not solve.

Novelty refers to the degree of newness, uncertainty, or innovation required to meet emerging operational and strategic challenges (Browning & Sanders, 2012). Rather being a barrier, novelty was interpreted as a source of energy and direction, especially driving shifts in how work was conceived, executed, and improved. However, novelty introduced uncertainty, particularly for teams unfamiliar with new tools or frameworks. This uncertainty was managed not through rigid standardisation, but through agile experimentation, exploratory pilot projects, and adaptive workforce engagement. As described in section 4.3.1.3, participants viewed how learning with AI tools, digital twin, or cloud platforms required cultural and behavioural shifts, not just technical upgrades.

This evolving operational landscape reshaped how Lean, Sustainability, and I4.0 were approached. Rather than static checklists or toolkits, they become learning systems dynamic capabilities that allowed the organisation to sense, adapt, and transform in response to novelty. For example, Participant 7 emphasised the potential of sensing technologies to move from reactive to predictive quality and added:

> "Being able to detect things earlier…that's going to drive defect-free product."

Such developments required cross-functional collaboration, new skillsets, and a mindset open to continuous experimentation, features aligned with the dynamic capabilities framework underpinning this study (Teece, 2007). Crucially, novelty did not render Lean irrelevant, but it reframed Lean as a flexible, evolving practice, one that had to integrate transformation new digital routines, support faster learning cycles, and align with Sustainability imperatives. As participant 15 remarked in a separate discussion, the logic of "right-first time, at the rate of demand" remained valid, but the tools and data enabling that logic were changing rapidly. Overall, novelty informed the development of people and knowledge capabilities in the LS4.0 model, reinforcing the importance of cultivating adaptability, digital fluency, and cross-disciplinary problem-solving capacity.

Ecosystem structure emerged as a powerful but uneven influence. When participants spoke about working with suppliers, particularly small and medium enterprises, they described gaps in capability and alignment that affected both Lean and Sustainability. Setting that context, Participant 1 reflected on overall maturity across the chain and stated: "The whole supply chain in my experience is very immature." Interviews and documents described post pandemic fragility, including the need to support a critical supplier through financial stress, which made dependence on a small specialist base clear. At the same time, this fragility opened a window for rethinking supplier relationships, not as transactional but as co-creative partnerships.

Together, these characteristics of compliance, complexity, novelty, and ecosystem, did not operate in isolation, they interacted in nuanced ways, often amplifying or mitigating each other's effects. For example, the desire to adopt advances analytics driven by novelty was constrained by compliance rules on data handling, whilst ecosystem immaturity intensified internal complexity by lengthening lead times and adding variation. These characteristics interdependencies illustrate why integration cannot rely solely on replicable tools or frameworks. Instead, as this study argues, LS4.0 integration must be grounded in a contingency-sensitive understanding, where capabilities are shaped, paced, and configured according to the sector's lived realities.

This empirical framing complements the conceptual elaboration in Chapter Five, Section 5.3.5, where these four characteristics inform the design logic of the LS4.0 model and its associated capabilities. Overall, the technological, organisational, leadership, and contextual characteristics identified in this section constitute the empirical precursors of the LS4.0 capability set namely, information, knowledge, technological infrastructure, collaboration, culture, and Leanness.

Table 4-1 summarises this mapping and lists the key enablers and barriers observed. A full trace from codes to capabilities is provided in Appendix I.

Table 4-1: Summary of Characteristics Influencing LS4.0 Integration and Their Associated Capabilities

| Characteristics category | Associated Higher-Order Capabilities | Enablers Identified | Barriers Identified |
|---|---|---|---|
| **Technological & data structures** | Information, Technological Infrastructure | Generative AI, Digital Twins, Operational Connectivity | ITAR compliance, fragmented data systems, legacy infrastructure |
| **Organisational learning & efficiency** | Leanness, Knowledge | Kaizen events, cross-functional VSM, turnaround time goals | Ad hoc learning routines, slow kaizen cycles, underuse of data |
| **Leadership & collaboration** | Culture, Collaboration | Hoshin Kanri, Executive Sponsorship | Supplier immaturity in Sustainability, siloed functions, uneven engagement |
| **Contingency characteristics** | All seven capabilities contextualised by Compliance, Complexity, Novelty, Ecosystem | Executive awareness of compliance risk, strategic supplier support | Regulatory, uncertainly, product complexity, design variability, ecosystem fragility |
| **People** | People | AI assistant platform, continuous improvement, culture, skills training | Skill gap, resistance to role change, lack of incentives for innovation |

### 4.3.3 Influence of Integration

Having outlined how perceptions and influencing characteristics shape integration, this section turns to the influence of LS4.0 on performance including Sustainability triple bottom line outcomes, thereby addressing RQ 2.3. The findings are interpreted through the lens of the company's performance measurement framework. Whilst the organisation traditionally applied the safety, quality, delivery, and cost (SQDC) model, empirical insights and literature reviewed in this study suggest this framework lacks the scope to fully assess the systemic and people-centric outcomes of integration (Kamble et al., 2020, Yilmaz et al., 2022). Therefore, the research extends the SQDC framework by incorporating environment (E) and people (P) dimensions, resulting in the SQDCEP model. This model enables a comprehensive understanding of how LS4.0 integration affects performance across operational, ecological, and social domains.

The traditional SQDC framework focused on safety, quality, delivery, and cost, has long served as a cornerstone of Lean performance management systems, particularly in high reliability industries like automotive and aerospace. The strength of this framework lies in its ability to monitor operational efficiency and stability across core operational dimensions. However, a growing body of literature on green Lean integration and sustainable performance measurement highlights the limitations of SQDC in the context of Sustainability and I4.0 (Duarte & McDermott, 2025, Garza-Reyes, 2015, Kamble et al., 2020). These studies argue that whilst many organisations incorporate Sustainability principles at the corporate level, often through environmental and social governance via ESG reporting, there remains a conspicuous absence of mechanisms to track environmental (E) and people (P) dimension at the operational level (Cherrafi et al., 2017, Tripathi et al., 2023). This disconnection risks undermining the integration of Sustainability into day-to-day Lean routines, where continuous improvement should ideally extend to ecological performance and employee wellbeing. To address this gap, this study proposes an extension of SQDC framework by adding environment and people, resulting in the SQDCEP model.

#### 4.3.3.1 Influence on Operational Performance and Maturity

Operational performance and maturity emerged as critical dimensions of LS4.0 integration, reflecting how Lean, Sustainability, and I4.0 combine to influence outcomes across the extended the SQDCEP framework. Whilst the organisation traditionally uses the SQDC framework focusing on safety, quality, delivery, and cost, the findings suggest that environmental performance also requires systematic monitoring to capture the broader influence of integration.

The participants emphasised that performance gains were dependent not only on tool adoption but on the stability and maturity of underlying processes. Participant 1 argued: “Measure the maturity of the process, not just output,” and added “What’s the reoccurrence of that issue? If it comes up again, it hasn't stuck." This viewpoint of Participation 1 reflects an emphasis on learning retention, root-cause elimination, and stable processes, aligning with maturity in Lean systems. Participant 9 also acknowledged uneven maturity across the business and noted: "The business is at different stages, there are definitely pockets where we're more advanced." This variability illustrates that integration outcomes were contingent upon maturity levels across departments.

Process maturity was seen not only as a performance driver, but also as a diagnostic lens to understand variation across departments. Cross-sector comparisons reinforced the importance of maturity in eliminating operational waste. Participant 2, drawing from automotive experience explained:

> "In automotive, you can't afford rework…you focus on fixing causes."

By contrast, Participant 7 described aviation operations as still reliant on manual processes and added:

> "There's still a lot of manual processes in aviation."

These statements from Participant 2 and 7 highlighted a maturity gap limits the real-time responsiveness and continuous improvement needed for Lean, Sustainability, and I4.0 synergy. Literature reinforces that such gaps reduce the ability to extract value from I4.0 investments and compromise Sustainability alignment (Luz Tortorella et al., 2022, Sony & Naik, 2020).

Environmental performance, which informs the 'E' in SQDCEP, was similar, dependent on the maturity of data systems and operational routines. Participant 11 reflected:

> "When I joined, there was no process to account for emissions…we're building that now."

In discussion about how environmental performance can be tracked at the value stream level, Participant 5 proposed integrating Sustainability metrics directly into Lean diagnostics and shared: "Map productivity and Sustainability footprint side by side…the weight, environment waste, power, water." This suggestion aligns with Tripathi et al.

(2023), who advocate for dual mapping of Lean and green key performance indicators to advance operational transparency and ecological efficiency.

Taken together, these findings illustrate that operational maturity is a cross-cutting capability underpinning all SQDCEP outcomes. Mature processes reduce rework affecting quality (Q) and cost (C), enable predictive maintenance affecting safety (S) and delivery (D) which support Sustainability tracking environment (E), and create the stability required for people empowerment (P). As such, operational maturity is not simply a contextual characteristic, but a prerequisite for meaningful integration of Lean, Sustainability, and I4.0.

#### 4.3.3.2 Influence on Employee Empowerment

Participants highlighted the influence of integration on employee empowerment, particularly through technology and training. In this context, empowerment refers to the degree to which employees are granted the authority, confidence, and resources to make decisions, solve problems, and take responsibility for continuous improvement within defined limits (Roslin et al., 2019). By converting Lean principles into daily behavioural ownership, empowerment creates a sense of accountability and engagement across organisational levels. When effectively embedded, it strengthens problem-solving capability, learning and responsiveness, key attributes for sustaining LS4.0 integration. In practice, empowerment functions as a mechanism that shapes day-to-day behaviour in three ways.

Firstly, greater problem ownership at the point of work. Several participants including Participant 3 and Participant 11 linked empowerment to faster closure of issues and less reliance on escalation. Framing empowerment in cycle time of problem resolution, Participant 3 offered a concrete target for the daily management system and stated:

> "I would measure the success of our problem on the turnaround time… I know today it's on average 30 days and I want it to be 5 days. The reason I want it to be 5 days is because it improves the flow in the shopfloor."

This reflects a shift toward local ownership with speed, consistent with tiered stand-ups and rapid corrective actions closure (Liker, 2021, Netland et al., 2020, Spear & Bowen, 1999). Research on empowered work design also links discretion and real-time information to shorter feedback loops and higher problem-solving efficacy (Parker et al., 2001, Spreitzer, 1995). In LS4.0 contexts, digitally visibility strengthens this effect by putting actionable signals in the hands of frontline teams, therefore accelerating learning cycles (Buer et al., 2018, Rahardjo et al., 2023).

Second, broader participation is what counts as improvement. As Lean routines absorbed Sustainability considerations as detailed in Section 4.3.1.2.1, participants perceived empowerment expanding beyond flow and defects to environment consideration at the workstation. Participant 3 described conversations that now include material choices and end-of-life thinking, indicating that teams feel responsible for outcomes that reach beyond quality to energy and resource use. This pattern mirrors evidence that employee involvement is a key driver of operational “green” performance when integrated with Lean routines (Cherrafi et al., 2017, Daily & Huang, 2001, Longoni & Cagliano, 2015). Participant 7’s emphasis on visible leadership: “People want to see management take it seriously…they want investment” was interpreted by practitioners as permission to act, which in turn widened participation in improvement and reinforced a sense of shared purpose (Liker & Convis, 2012, Netland et al., 2020).

Third, empowerment remained bounded by compliance and workload realities. Empirical data highlighted that autonomy operates within strict procedural and regulatory framework. For example, Participant 3 cautioned that empowerment without simplification risks social strain: “If we don’t Lean out processes, staff burn out.” Participant 3 reflects the risk identified in the literature, where Lean empowerment, if not accompanied by process simplification and adequate support, can unintentionally create work intensification (Jones et al., 2013). Jones et al. (2013) caution that in some Lean environments, empowerment can become an illusion, employees appear to have autonomy, yet their decision-making remains tightly constrained by hierarchical and operational controls. Within aerospace, where compliance and safety dominate, empowerment functions as a guided autonomy: employees are encouraged to contribute to problem-solving and improvement, but always within strict procedural and regulatory frameworks. This interpretation reflects a balance between responsibility and control, where empowerment is real but bounded, enabling participation whilst maintaining the discipline required in a high-risk environment. Participant 11 extended this boundary to ecosystem, noting that empowerment also implies educating partners and stated: "We need to educate suppliers…build a shared knowledge base," signalling that responsibility for outcome is increasingly shared along the chain (Bortolotti et al., 2015, Gutierrez et al., 2022).

Taken together, the influence on the "P" in SQDCEP is twofold: increased local decision-making and faster closure of issues that affect flow, quality, and energy use, and a wider conception of responsibility that now includes environmental behaviours at the point of work and, progressively, in the supply base. At the same time, these gains are contingent on process stability and capacity design. Without that foundation, the influence can invert toward fatigue (Jones et al., 2013, Salentijn et al., 2021). This pattern aligns with the cautions in Section 4.3.1.2.2 and reinforces LS4.0 view of empowerment as a capability outcome that depends on the maturity of Lean routines and the surrounding management system (Buer et al., 2018, Liker & Convis, 2012, Netland et al., 2020).

**4.4 Synthesis of the findings**

This section summarises the empirical findings presented in sections 4.3.14.3.3, synthesising the interrelated perceptions (RQ2.1), influencing characteristics (RQ2.2), and organisational performance influence (RQ2.3) into cohesive, practitioner-informed perspective on LS4.0 integration. Rather than viewing Lean, Sustainability, and I4.0 as discrete or sequential initiatives, participants increasingly framed them as interdependent, mutually reinforcing components of a future-oriented operational strategy. This perspective marks a shift from fragmented implementation toward a holistic operational logic, in which Lean provides the foundational discipline, Sustainability delivers strategic intent, and I4.0 technologies serve as amplifiers and enablers. A key insight emerging from the interviews was the need for sequencing and layering in integration efforts. Participants 2, 7, 10 advocated establishing Lean maturity before embedding Sustainability principles or deploying advanced digital tools. As Participant 7 advised, "First fix flow, then layer in Sustainability. Doing both at once overwhelms teams." This aligns with studies such as Kamble et al. (2020), Rahardjo et al. (2023) and Buer et al. (2018) that position Lean as the operational backbone upon which Sustainability and digitalisation can be integrated. This sequencing and layering approach echo dynamic capabilities theory, which emphasises the importance of sequencing sensing, seizing, and transforming activities to enable complex capability integration (Teece, 2007). Importantly, Lean was not perceived merely as a toolbox of techniques, but as a cultural and managerial infrastructure necessary to support long-term transformation. As Participant 7 observed:

> "I see Lean and Sustainability as something that coexist together. And I4.0 is an enabler."

This aligns with Rahardjo et al. (2023) smart and sustainable manufacturing system (SSMS) framework, which positions Lean as the structural base, I4.0 as the digital accelerator, and Sustainability as the normative compass guiding continuous improvement.

Leadership and strategic alignment emerged as a central theme underpinning successful integration (Gatell & Avella, 2024b, Liker & Convis, 2012, Netland et al., 2020). Participant 13, a senior manager, highlighted the practical burden of sponsorship and orchestration: "It won't work without leadership commitment. It's taken a lot of my time to drive these changes." Within the dynamic capabilities lens, leadership does more than set direction and reconfigure assets. Leadership also performs the sensing function by spending time at the gemba, scanning external signals from regulators and customers, reviewing operational environmental data, and convening cross-functional dialogues that surface weak signals before they become failure modes (Teece, 2018). In other words, leaders catalyse sensing, convert it into seizing through resource alignment and priority setting, and sustain transforming by removing obstacles reinforcing new routines. Digital technologies were widely recognised as powerful enablers because of what they do in practice. AI-enabled mapping and analytics turn dispersed data into structured information that links flow, defects, and energy use, making losses visible at the point of decision. Digital twins allow teams to simulate design and process scenarios, test tolerance stacks virtually, and de-risk changes before release. Cloud-based dashboards deliver real-time visibility, alerts, and traceability, shortening feedback loops and supporting predictive maintenance and quality. These functions amplify Lean routines and accelerate Sustainability outcomes when a stable process foundation is in place.

The participants also cautioned against techno-centric approaches detached from process maturity. Participant 12, in particular, warned that automating unstable processes creates digital waste. This is consistent with Delphi Expert 3, who emphasised on the importance of validating digital insights through physical gemba practices, reinforcing the notion of hybrid validation logic that blends digital intelligence with human judgment.

The performance influence of LS4.0 integration, as captured in Section 4.3.3, were perceived as multi-dimensional and measurable across the SQDCEP framework, covering safety, quality, delivery, cost, environmental, and people. Yet, the realisation of these benefits was contingent upon addressing constrains identified in the study. Compliance in low-volume, high-mix environments creates variability that challenges standard flow. Novelty introduces uncertainty that must be absorbed through experimentation and learning. Ecosystem fragility, especially among suppliers, delays diffusion of Lean and Sustainability practices.

Taken together, the holistic LS4.0 view that emerges from this study is not one of instant convergence, but rather a layered capability development process, where each domain reinforces the other. Lean instils operational stability and structured learning, Sustainability offers a broader ethical and performance horizon, and I4.0 technologies provide the agility, intelligence, and traceability to embed and sustain transformation. When underpinned by strong leadership, cross-functional collaboration, and strategic coherence, this integration enables the emergence of a resilient, adaptive, and future-ready aerospace manufacturing system, a model further elaborated in Section 5.3.6.2 - Chapter 5

# Chapter Five
# Lean-Sustainability 4.0: an integrative operational model for the UK aerospace industry in the age of digitalisation

## 5.1 Introduction

This chapter presents the development of the LS4.0 model developed through empirical research conducted at a leading UK aerospace site. The model integrates Lean principles, Sustainability's TBL, and I4.0 technologies into coherent operational framework grounded in dynamic capabilities theory and shaped by aerospace-specific contingency characteristics.

The content of this chapter is adapted from a comprehensive report originally prepared for the Delphi validation phase. The report was submitted to domain experts as part of a two-round Delphi process, where it served as the primary study report for critical review, feedback, and refinement. As such, the report represented not only the central finding of this study but also a practitioner-facing tool co-developed and validated through expert engagement (Hsu & Sandford, 2007, Okoli & Pawlowski, 2004). To ensure confidentiality and preserve organisational anonymity, sensitive information, such as specific operational systems, proprietary data have been redacted. Apart from these adjustments, the report remains consistent with the version used in expert consultation.

This chapter begins by outlining the model development process in Section 5.2, followed by a detailed presentation of the conceptual architecture of the LS4.0 model in Section 5.3, and model validation and final reflections on the iterated version in Section 5.4. Together, these sections articulate a dynamic and sector specific model designed to support aerospace manufacturers in achieving resilience, sustainability, and continuous improvement.

## 5.2 Model Development Process

The development of the LS4.0 model followed a rigorous and structured process grounded in empirical evidence, practitioner insights, and theoretical framing. The model was iteratively constructed through three key stages: data collection, data analysis, and model synthesis. Each stage was guided by the principles of qualitative case study methodology and informed by dynamic capabilities and contingency theories, ensuring the model's contextual relevance and adaptability to the aerospace sector (Donaldson, 2001, Teece, 2007, 2018).

The data collection phase involved multiple sources to ensure depth and triangulation. Semi-structured interviews were conducted with departmental leaders and manager across operational, Sustainability, and digital functions to gather insights on how Lean, Sustainability, and advanced technologies intersect within the organisation. Company communications, public reports, and strategic information to contextualise the organisation's operational excellence and Sustainability vision. In parallel, shop floor observations were carried out to capture real-time practices, challenges, and opportunities for Lean, Sustainability, and I4.0 initiatives, allowing the validation of interview insights against operational realities.

The data analysis stage applied a reflexive thematic approach to identify recurring patterns and themes related to Lean implementation, Sustainability integration, and I4.0 adoption. The findings were organised into themes and subsequently elevated to higher-order capabilities, reflecting the micro-foundations of sensing, seizing, and transforming as defined by dynamic capabilities theory. This process enabled clarification of how these capabilities operate dynamically within the aerospace context. The codebook and the step-wise derivation from codes to capabilities are documented in Appendix I. In addition, the analysis identified four sector-specific contingency characteristics namely, compliance, complexity, novelty, and ecosystem, which define the context in which integration efforts occur and align with the "fit with context" logic of contingency theory.

The model synthesis phase integrated these insights into a coherent conceptual framework. The core elements of the model, Lean, Sustainability, and I4.0 technologies, were conceptualised based on the relationships and dependencies emerging from empirical evidence. The contingency characteristics were embedded to represent the contextual realities of the aerospace sector, providing a configuration lens for capability deployment. The traditional SQDC, safety, quality, delivery, and cost, performance framework was also extended to SQDCEP by incorporating environment and people dimensions, reflecting the organisation's net-zero ambitions and its people-centred transformation strategy. This extension enables assessment across both operational and Sustainability performance dimensions.

This iterative, evidence-based development process ensures that the LS4.0 model is both grounded in theory and empirically driven. The model offers a practical and adaptable pathway for operational transformation in aerospace by integrating human-centric Lean principles with Sustainability imperatives and I4.0.

### 5.3 The Lean-Sustainability 4.0 Model (LS4.0)

Building directly on Chapter 4 Four, the LS4.0 model distils empirical characteristics into seven higher-order capabilities derived from thematic analysis and then abstracted into organisational capabilities in line with the guidance of Clarke and Braun (2021). These capabilities are integrated with aerospace contingency conditions to form a closed-loop architecture, assessed through the SQDCEP performance framework.

#### 5.3.1 Overview

The LS4.0 model, illustrated in Figure 5-1, presents a structured framework for integrating Lean-Sustainability and I4.0 technologies within aerospace operations. The model figure brings together empirical findings, theoretical insights, and practitioner expertise into a unified operational architecture. The model establishes a closed feedback loop between strategic intent and performance results, measured through the extended SQDCEP framework encompassing safety, quality, delivery, cost, environmental, and people dimensions. At its core, the model is underpinned by the dynamic capabilities of sensing, seizing and transforming, which function as interpretive mechanisms explaining how the seven higher-order capabilities information, knowledge, culture, people, collaboration, technological infrastructure, Leanness operate in practice.

The model further incorporates four contingency characteristics named complexity, compliance, novelty and ecosystem, which capture the distinctive characteristics of the aerospace sector. These characteristics influence how the LS4.0 model is implemented, interpreted, and experienced across different organisational levels. Together, the capabilities and contingencies form a dynamic and adaptive system, positioning Lean-Sustainability integration not as a static framework but as an evolving operational capability responsive to the sector's contextual realities.

#### 5.3.2 Core of the model: Lean-Sustainability Integration

At the heart of the model Figure 5-1 lies the integration of Lean and Sustainability's triple bottom line dimensions, represented as overlapping concepts. This reflects the perspectives shared by practitioners during the interviews, who emphasised that Lean and Sustainability are inherently interconnected**.** Lean's focus on efficiency, respect for people, and profitability aligns closely with Sustainability's economic, social and environmental dimensions. This integration is deeply human-centric, rooted in a culture of empowerment and continuous improvement. Lean serves as the model's foundation, emphasising process efficiency and respect for people within a system that aligns business operations with strategic objectives whilst navigating industry-specific constraints.

#### 5.3.2.1 Economic Dimension

Lean principles focus on value creation for the customer and stakeholders. This is achieved by eliminating waste and enhancing efficiency, optimising processes and ensuring cost savings. Sustainability-driven Lean practices ensure profitability whilst delivering value to all stakeholders, directly informing the Leanness capability of the model.

#### 5.3.2.2 Social dimension

Lean functions as a techno-social system (Mesquita et al., 2022, Shah & Ward, 2003), promoting workforce development, engagement, and a culture of collaboration problem-solving. This strengthens social Sustainability outcomes and contributes to organisational learning and inclusiveness, reinforcing the people and culture capabilities.

#### 5.3.2.3 Environmental dimensions

Lean inherently supports environmental Sustainability objectives by minimising waste and energy consumption. At the case site, this aligns with the site's net-zero operational emissions objective for 2030. Environmental impact is mitigated through practices such as energy-efficient processes and resource optimisation, feeding directly into the information and technology infrastructure capabilities. A synergy cycle around the model's core, indicated in Figure 5-1, visualises the continuous reinforcement between Lean and Sustainability, positioning them as interdependent mechanisms for long-term transformation.

Overall, to achieve sustainable results, organisations must explicitly design Lean approach to address the triple bottom line, economic, social, and environmental Sustainability. A synergy cycle, indicated by arrows around the core, underscores the continuous interplay between Lean and Sustainability, ensuring they mutually reinforce each other within the broader model.

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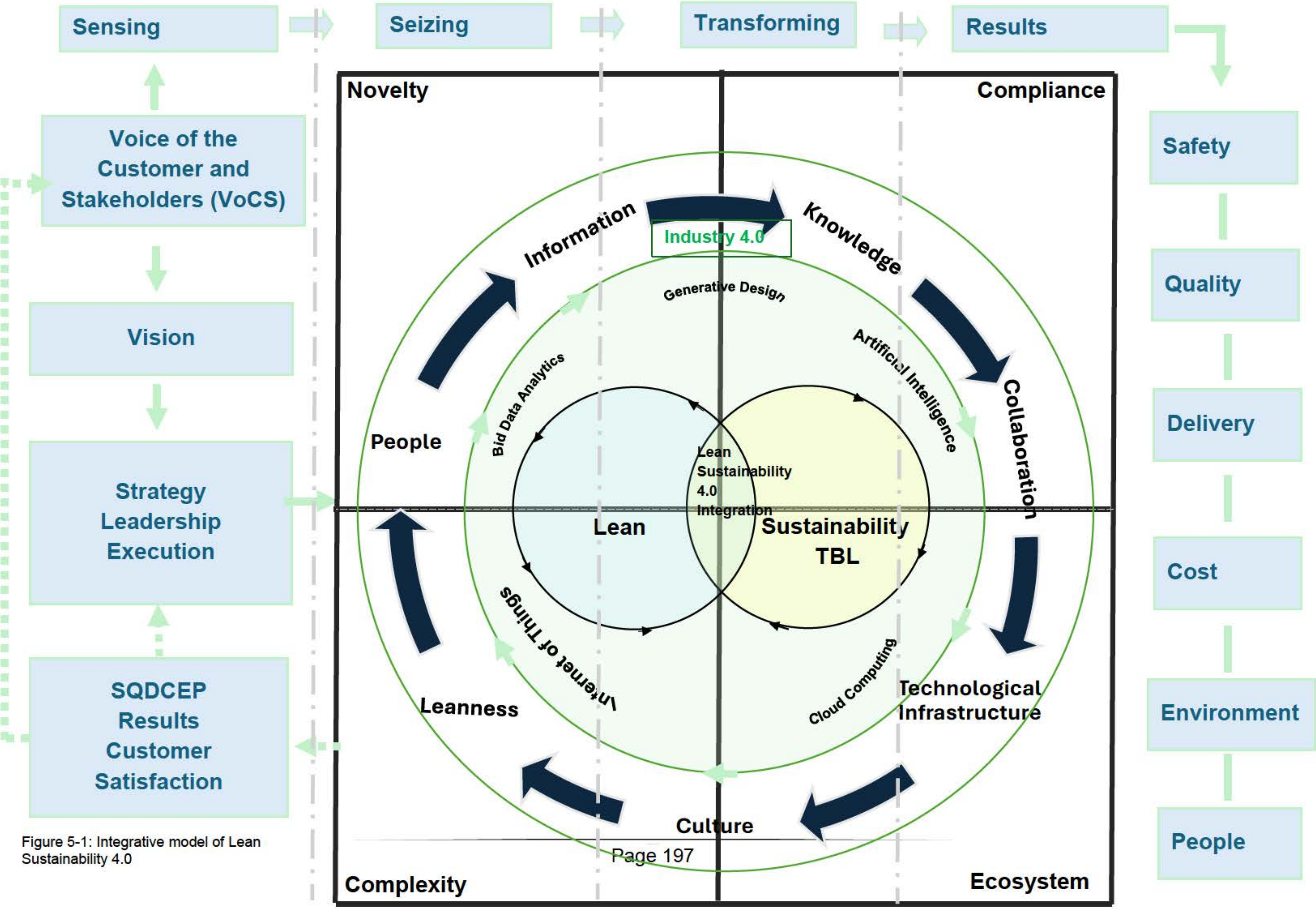


Figure 5-1: Integrative model of Lean Sustainability 4.0

### 5.3.3 Industry 4.0 as enabler

Surrounding the Lean-Sustainability core is a supporting ring representing I4.0 technologies used at the case company, such as generative design, artificial intelligence, IoT, and cloud computing Figure 5-1. These technologies act as conditional enablers rather than functioning as independent drivers, their value is realised when aligned with Lean maturity and Sustainability objectives, consistent with the contingency logic of Donaldson (2001) and the enabling role of dynamic capabilities (Teece, 2007).

Empirical evidence from Chapter 4 illustrates this enabling role. The generative AI platform launched in 2024 enhanced employee productivity by automating information retrieval, therefore, freeing capacity for innovation and problem-solving. Similarly, the operational connectivity initiative embedded sensors and cloud analytics within the PCB production area and reported directly to the company's operating system, LeanLift, which aims at creating real-time visibility of flow disruption, hidden rework, and energy inefficiencies, capabilities not captured by traditional key performance indicators. These examples demonstrate how digital technologies support Lean principles of flow, Jidoka, and problem transparency while simultaneously advancing Sustainability objectives.

Participants consistently framed such technologies as supporting rather than substitutive, which was illustrated by Participant 10:

> "Things that used to take 10 years can be done with simulations now".

In aerospace, the obstacle to smooth flow between processes is not ideological but contextual related to low volumes, long change cycles and designs frozen for performance rather than manufacturability. Participant's 10 point clarifies why simulation matters by shifting verification "left" into the virtual domain through model-based enterprise, generative design and process simulation, the organisation can test tolerance stacks, fixtures, and routings before release. That reduces late rework loops, shortens design-industrialisation lead time, and protects flow once the build starts. The same mechanism also cuts material trials and test-cell energy, creating an environment dividend from the very act of designing for manufacturability earlier.

Participant 10 further emphasised the data-driven future:

> "The companies that harness the combination of digital infrastructure and flow manufacturing concepts will have the competitive advantage."

Participant 10's point is that digital infrastructure only creates advantage when it is harnessed to flow routines. When sensor data, traceability, and cloud networks are organised around takt-time, constraints management, and first-time yield, leaders see losses as they form, not weeks later. A robust digital infrastructure shortens design to industrialisation cycles, stabilises schedules, and reduces working capital by cutting work-in-progress and rework. An effective digital integration also lowers energy and scrap by preventing defects earlier. In dynamic capabilities terms, digital improves sensing through real-time visibility, flow disciplines drive seizing by allowing fast, standard responses, and together they enable transforming operation using better methods. The result is a system that learns faster with fewer surprises, more predictable delivery, and structural lower cost.

In this sense, I4.0 is not a parallel transformation but an amplifier of Lean-Sustainability synergies. When deployed in alignment with context, these technologies provide three enabling mechanisms:

- **Data-Driven Decision-Making**

Data analytics are used to uncover inefficiencies and guide Sustainability improvements. As reflected earlier in the operational connectivity initiative, there is a strong belief on the site that companies of the future are companies driven by data and use data to make informed decisions.

- **Real-Time Optimisation**

Technologies like IoT and cloud computing (CC) support real-time monitoring, predictive analysis, and rapid response, enabling both Lean and Sustainability goals to be achieved more effectively.

- **Dynamic adaptability**

The model builds adaptability into its design, enabling firms to respond to evolving market, environmental, and regulatory conditions. This is particularly relevant in navigating contingency characteristics such as novelty, complexity, compliance, and ecosystem dynamics.

### 5.3.4 Intersection of Lean-Sustainability and I4.0

The overlap between the Lean-Sustainability core and I4.0 enabling ring represents the integrated operational system of LS4.0. At this intersection, digital technologies strengthen

Lean practices to achieve operational and Sustainability objectives, consistent with the dynamic capabilities logic of sensing, seizing and transforming (Teece, 2007, 2018).

Empirical insights show that integration is still emergent, but practitioners identified clear opportunities where digital tools could enhance Lean-Sustainability outcomes. Participant 10 illustrated this potential by describing how traditional value stream mapping can be augmented with artificial intelligence to curate and process data more effectively:

> "We do the traditional value stream map with the Lean team. We take that exact same value stream map that the Lean team made with data flow on the top. And the AI team works the data infrastructure and ingestion of it."

Whilst not yet institutionalised at the site, this example illustrates how digital augmentation could evolve Lean tools to capture wider dimensions, including sustainability footprints. Other examples, such as Kaizen events increasingly incorporated Sustainability targets, reflect how Lean routines are beginning to expand in scope. I4.0 technologies were perceived as enablers that could accelerate and scale such initiatives by providing real-time data, predictive insights, and improved visibility of waste streams aspects hidden in manual reporting systems.

Participant 7 emphasised the importance of sequencing LS4.0 integration, Participant 7 argued that LS4.0 cannot compensate for process immaturity and warned against concurrent layering of too many aims at once.

Participant 7 advised:

> "First fix flow, then layer in Sustainability. Doing both at once overwhelms teams."

The rationale of this guidance lies in its operational logic. In a low-volume, engineer-to-order environment, stabilising flow, through standard work, visual controls, limits on work in progress (WIP), alignment to takt-time and rigorous constraint management create the repeatability needed for meaningful environmental measurement and digitalisation. Without that baseline, Sustainability metrics fluctuate with process noise, and digital tools amplify instability by surfacing inconsistent signals such digital waste. Participant 7's position reflects the contingency logic described by Donaldson (2001), where Lean maturity forms the operational stability on which Sustainability and digitalisation can be layered effectively.

At the intersection of these three paradigms, Lean, Sustainability, and I4.0, three reinforcing mechanisms emerge. The first is hybrid diagnostics, where Lean tools such as value stream mapping and A3 are digitally enhanced to include environmental and resource flow data, allowing for more holistic performance analysis. The second is collaborative improvement, achieved through cross-functional Kaizen initiatives that now incorporate Sustainability objectives and are increasingly supported by digital platforms for data sharing and decision-making. The third is adaptive transformation, in which digitalisation accelerates learning loops and enables experimentation, helping institutionalise Sustainability-oriented improvements.

Although the LS4.0 intersection remains a developing practice rather than a fully embedded system, LS4.0 intersection demonstrates the distinctive value of integration. Lean provides the cultural and process foundation, Sustainability establishes the strategic direction, and I4.0 technologies deliver the amplification necessary for achieving synergy under complex and compliance-driven aerospace conditions. Table 5-1 below summarises how the model was developed based on participants' insights.

Table 5-1: Lean Sustainability 4.0 model formation

| Interview Theme / Observation | Example of Supporting Quote/Data | How informed the model |
|---|---|---|
| **Lean is fundamental for Sustainability** | "By doing Lean, you get Sustainability for free…Because Lean should be driving Sustainability because Lean is about reducing waste" (Participant 2).<br><br>"We started to link Lean and Sustainability about two years ago together…now, the last two years, we've started our Kaizen events all have a Sustainability aspect within them" (Participant 12). | Lean and Sustainability are inherently connected. To achieve a lasting sustainable Lean, Lean needs to incorporate TBL dimensions.<br>To achieve Sustainability, Lean plays a major role in social and environment responsibilities. Lean activities such as Kaizen events can be directly linked to Sustainability. The integration of Sustainability into Lean practices strengthens the argument that Lean plays a key role in achieving Sustainability. |
| **Industry 4.0 as enabler** | "If you do it (Lean Sustainability) a certain way who pull the right bits. you advance your digital agenda. You make yourself more competitive. You can introduce new products faster, you know, it's a win-win" (Participant 7).<br><br>"Technology can be useful in helping you close that gap. When you can't physically close that gap (gap between processes and gap in supply chain). Because it can provide information and data in create better relationships between the communication between those" (Participant 10).<br><br>"Technology is developing all the time capability of what it can tell you and so…technology tends to deliver improvement in efficiency" (Participant 1). | I4.0 technologies enhance the synergy cycle, enabling data driven decisions, real-time optimisation, and adaptability for improved efficiency and Sustainability. |

### 5.3.5 Contingency Characteristics

#### 5.3.5.1 Overview

The aerospace industry's unique landscape presents characteristics that shape the LS4.0 model, ensuring its relevance and adaptability. Four key contingency characteristics namely, compliance, complexity, novelty, and ecosystem, emerged from the empirical findings and directly influence the development and deployment of the model's capabilities. These characteristics reflect the sector's regulatory demands, operational challenges, innovative pressures, and collaborative dynamics, guiding organisations towards a proactive approach. The following sub-sections explore how these characteristics impact the model's foundation, setting the stage for its strategic drivers.

#### 5.3.5.2 Compliance

Aerospace operations are governed by strict regulatory standards and customer-specific requirements. This was evident at the site under study, which operates in the defence market and faced challenges in leveraging cloud computing. Data sovereignty regulations required the use of UK-based sovereign or Ministry of Defence-accredited cloud providers, limiting the adoption of standard cloud services.

Another significant regulatory framework impacting the aerospace sector is the Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) regulation, enforced by the European Chemicals Agency (ECHA). The primary objective of REACH is to protect human health and the environment by ensuring greater safety in the production and use chemical of substances. This regulation requires companies to identify and manage risks associated with the substances they manufacture and market within the EU, ensuring safe usage and providing comprehensive risk management measures to all users. The European Union Aviation Safety Agency (EASA) collaborates closely with ECHA to ensure aviation safety whilst implementing the REACH Regulation. For instance, substances like chromium trioxide, used in surface treatments to prevent corrosion, have been subject to authorisation under REACH due to their classification as substances of very high concern. This characteristic represents these constraints and informs the information and culture capabilities driving the need for secure, validated data inputs, and fostering accountability to meet compliance requirements.

#### 5.3.5.3 Complexity

The aerospace industry is inherently complex, shaped by bespoke product requirements, highly engineered systems, and fragmented supply chains. These conditions create difficulties in achieving consistent flow and implementing standard Lean practices at scale. A notable challenge is the imbalance between design for performance and design for manufacturing. As Participant 10 explained: “There is a lot of the focus on the design of the engine and not necessarily the design for manufacturability…so that means you cannot create as much flow as you’d like.”

At the case site, this complexity is evident during the assembly of an aircraft’s electrical power system. Operators encountered difficulties in aligning parts, as many parts go together, a slight deviation will accumulate stack-up tolerance issues, making assembly impossible. In other cases, even when all parts met design dimensions and tolerance, misalignment occurred. These issues pointed to gaps in design review, tolerance analysis, or drawing over dimensioning and suppliers manufacturing capabilities. Complexity is also exacerbated by aerospace's low-volume, high-mix nature, which lacks the repetitive cycles needed to build operational maturity, as seen in high-volume sectors like automotive.

In response, the site has introduced practices like advanced Product quality planning to bring manufacturability forward into earlier gate decisions and is deploying digital twin and simulation to test tolerance stacks, fixtures, and routines before release. Together, these measures address complexity by protecting flow, shortening design to industrialisation lead time, and reducing late rework. Therefore, complexity significantly shapes the Leanness, collaboration and technological infrastructure capabilities, underscoring the need for both adaptive knowledge and people capabilities that can absorb these tools and translate their outputs into stable standards.

#### 5.3.5.4 Novelty

Novelty refers to the degree of newness, uncertainty, or innovation required to meet emerging operational and strategic challenges (Browning & Sanders, 2012). In the aerospace sector, novelty is not only technological but also systemic, affecting how organisations design, manufacture, and operate to meet evolving demands. This characteristic captures the maturity of organisations and teams in responding to unfamiliar objectives or processes. The LS4.0 model recognises novelty as a catalyst for organisational learning and innovation. At the case study site, novelty manifested through the increasing reliance on digital R&D tools, including advanced data analytics and artificial intelligence, to explore new ways of working. Participant 9 explained:

> "We're more advanced in terms of research capability, looking at big data and AI and very high-speed networking for aircraft platforms... When it comes to actually providing on site operations for day-to-day here. We are still not really leveraging a significant amount of modern technology."

This contrast highlights an adoption gap. Exploratory digital competence is maturing in research environments where models and proofs of concept can be iterated quickly, whilst day-to-day operations remain constrained by legacy equipment, certification routines, and data sovereignty rules that limit the use of commercial cloud services. In practice, the site is building from a secure, on-premise base and extending operational technology connectivity to create a minimal backbone for performance data such as equipment efficiency, yield and consumption. That pathway is intentional and allows the organisation to translate novel tools into validated information streams that can survive regulatory audits, integrate with daily management, and scale without compromising compliance.

Viewed through LS4.0 lens, novelty therefore reinforces the link between dynamic capabilities and continuous learning. The knowledge capability must enable the capture and application of emerging insights, whilst the people capability must support the development of skills necessary for operating in a digitally enabled and innovation-driven environment. This dynamic aligns with the sensing and transforming functions in DCT (Teece, 2007), enabling firms to respond flexibly to evolving technological, market and environmental expectations.

#### 5.3.5.5 Ecosystem

The aerospace supply chain is complex and highly specialised, consisting of large OEMs and smaller SMEs. Post-pandemic disruptions have exposed weaknesses in the supply base's ability to scale, adapt, and align. This has amplified the need for robust "collaboration" mechanisms and ecosystem-wide "Leanness", fostering transparent communication, supply chain integration, and mutual goal setting. Participant 1 remarked that "The whole supply chain in my experience is very immature."

This perspective of Participant 1 underscores the critical need for robust collaborative capabilities and transparency mechanisms that extend beyond traditional transactional relationships. The LS4.0 model addresses these conditions through two levers: collaboration and Leanness. Collaboration involves cultivating long-term partnerships, co-design initiatives, and real-time information sharing with external stakeholders. In the meantime, ecosystem-wide Leanness focuses on aligning continuous improvement practices and flow optimisation across the entire value chain, rather than within isolated organisational context. This perspective reinforces the model's systemic orientation, Lean and Sustainability practices must not only function internally but also extend across boundaries to synchronise operations, reduce shared risks, and co-create value. The ecosystem characteristic thus strengthens the transforming function of dynamic capabilities by enabling supply chain actors to respond collectively to complex industry shifts.

#### 5.3.5.6 Summary and implications

Understanding these contingency characteristics enables organisations to proactively tailor the LS4.0 model in response to their complex and evolving operational environment. The four characteristics were developed through a combination of empirical fieldwork, supported by practitioner insight, and theoretical inspiration, ensuring the model remains deeply rooted in aerospace realities. Whilst compliance and ecosystem emerged inductively from participants' lived experiences and operational contexts, the conceptual framing of complexity and novelty was also informed by the contingency constructs proposed by Browning and Sanders (2012). However, in all cases, the labels serve as analytical tools to organise patterns that were strongly grounded in the empirical evidence.

Table 5-2 summarises the four contingency characteristics, links each to a representative practitioner quotation, and shows how each characteristic informed the LS4.0 capability design is supported by practitioner insight.

The contingency characteristics operate as context setters for capability configuration, explaining why similar tools yield different results across units and sites (Donaldson, 2001). As the following section explores this contextual understanding, this section provided the foundation upon which strategic drivers, vision, leadership, and stakeholder voice can effectively direct transformation.

Table 5-2: Contingency characteristics and their influence

| Contingency Characteristic | Supporting data / Quote | How informed the model |
|---|---|---|
| **Compliance** | "With military datasets comes higher levels of data regulation. So be it export controlled and ITAR type regulations or data sovereignty, laws, UK, government data regulation… And at the moment, the service providers who would be offering us new capabilities just aren't able to, to offer as that government certified cloud type environments" (Participant 9).<br><br>"We have the regulatory compliance, so we need to report our emissions. That's one of the biggest the second one is our own goal, our own public commitment" (Participant 14). | Shapes operational processes to align with regulatory and safety requirements, ensuring audit readiness and Sustainability reporting. |
| **Complexity** | "Programmes would be like 10, 20 years and so, yeah, there's a difference from a design perspective then because your designs are older" (Participant 1).<br><br>"There is a lot of the focus is on the design of the engine and not necessarily the design for manufacturability. There is a clear difference that I do see with that... And so that means you cannot create as much flow as you'd like to right off the back…you can't create good flow between things" (Participant 10). | Impacts Lean efforts by introducing variability in production systems, requiring adaptive Lean tools and advanced digital solutions. |
| **Novelty** | "Technology is developing all the time capability" (Participant 1).<br><br>"Were more advanced in terms of research capability, looking at big data and AI and very high-speed networking for aircraft platforms... When it comes to actually providing on site operations for day-to-day here. We are still not really leveraging a significant amount of modern technology." (Participant 9). | Drives the need for flexibility and innovation in Lean processes to accommodate emerging technologies and customer demands. |
| **Ecosystem** | "(Suppliers) they tend to specialise because it's the low volume high mix versus high volume, low mix…The whole supply chain in my experience is very immature." (Participant 1).<br><br>"Aerospace is characterised by a number of large organisation building" (Participant 5).<br>"a very specialized supply base. And so sometimes that means that you can't do everything in house" (Participant 10). | Encourages collaboration and integration with stakeholders across the value chain to achieve shared objectives. |

### 5.3.6 Drivers of the model: Vision, Strategy, and Leadership

The left-hand segment of the model, as shown in Figure 5-1 highlights the fundamental drivers: voice of the customer and stakeholders, vision, strategy & leadership that guide the model's deployment and adaptability. These drivers are shaped by aerospace sector's contingency characteristics including compliance, complexity, novelty, ecosystem, and align with the dynamic capabilities framework of sensing, seizing, and transforming. Their integration ensures that the model is both strategically grounded and operationally agile. Together, these drivers provide the direction and governance needed for effective transformation, with customer satisfaction acting as a driver and as a feedback-oriented metric. Rather than being static inputs, these drivers adapt based on results, reflecting the model's responsiveness to regulatory changes, technological advancements, and evolving stakeholder expectations.

By integrating sensing, seizing, and transforming capabilities, these drivers enable effective execution of LS4.0 principles, ensuring that continuous feedback loops inform and refine strategic direction. Customer satisfaction, captured through SQDCEP results, functions as a key performance indicator rather than a direct driver, reinforcing the model's adaptability and responsiveness to evolving market, regulatory, and technological demands. Therefore, the LS4.0 synergy is not only shaped by strategic intent but also sustained through iterative learning and operational refinement, creating a resilient and future-ready transformative process.

#### 5.3.6.1 The Voice of the Customer and Stakeholders (VoCS)

The Voice of the Customer and Stakeholders (VoCS) represent the broad ecosystem of stakeholders that influence and are influenced by aerospace operations. These include customers e.g., airlines, military organisations, investors, regulators such as the Civil Aviation Authority (CAA), and local communities. In Lean thinking, value is always defined from the customer's perspective (Womack & Jones, 1997), and the inclusion of broader stakeholder views aligned with Sustainability's TBL principles (Elkington, 1998).

At the case site, this translated into mechanisms for engaging customers and regulators in defining improvement goals, such as emissions reporting, on-time delivery, and digital transformation. The model integrates VoCs as a dynamic feedback node: evolving in response to performance outcomes, informing strategic adjustments, and maintaining alignment with stakeholder demands.

#### 5.3.6.2 Vision: From Top-Down Alignment to Bottom-Up Empowerment

A compelling, forward-thinking vision emerged from participant insights as essential for driving LS4.0 model integration. This vision must go beyond compliance to proactively embed Lean and Sustainability into the core business strategy. For example, the case site's commitment to achieving zero operational emissions by 2030 reflects a vision where Sustainability and Lean are no longer add-ons but strategic imperatives. Participants emphasised the need to embed Sustainability targets into value stream design and Lean problem-solving. This approach necessitates clarity from leadership whilst also empowering cross-functional teams to experiment, innovate and own improvement actions.

Traditionally, Lean implementations in western organisations have been deployed through a top-down governance deployment models. These models are heavily reliant on executive sponsorship, deployment champions, hierarchical target cascading and formal review mechanisms. As several participants reflected, this approach was instrumental in institutionalising Lean during its early adoption phases. However, the limitations of this model became increasingly apparent as the integration of Sustainability and digital technologies introduced new layers of complexity, interdependence, and the need for local adaptability.

To conceptualise this evolving governance logic, Figure 5-2 was developed based on synthesis of empirical data, direct observations and validated through Delphi panel. The figure illustrates the transition in management approach across three stages: Traditional Lean, Lean-Sustainability, and LS4.0. The Y-axis captures the governance orientation, ranging from top-down to bottom-up, whilst the X-axis reflects the temporal progression across the transformation journey. The plotted trajectories are interpretive, not quantitative, illustrating how governance influence shifts over time. Each trajectory, top-down, mixed, and bottom-up represents a continuum of influence, rather than discrete categories. The development of the figure was informed by patterns in the fieldwork data: early Lean efforts were overwhelmingly centralised, but more recent initiatives, particularly those involving Kaizen events with Sustainability aspects, were observed to rely increasingly on team-level decision making and self-regulation. This shift was also reflected in how new Sustainability metrics were not just imposed but co-developed through mixed approach, with operational teams and collaborative workshops.

Figure 5-2 was reviewed by expert participants during Delphi Round 2, who confirmed that LS4.0 governance must operate as a dual structure: leadership sets the strategic intent, but digitalisation and capability development enabled decentralised execution. Leadership provides strategic direction and enables the system, but teams must own and drive the transformation.

This vision transformation is further supported by the literature. Bortolotti et al. (2015) and Liker (2021) both argued that sustainable Lean practices require not only process efficiency but also cultural evolution, where continuous improvement is democratised across all levels of the organisation. This shift also aligns closely with the dynamic capabilities theory (Teece, 2007), where organisations must develop the ability to sense external signals, seize opportunities through internal alignment, and transform their routines and capabilities accordingly. In this context, empowering local actors becomes a strategic necessity, not an optional cultural initiative. Furthermore, as to the contingency theory, for Donaldson (2001) reinforces that governance must be sensitive to the operational context. As the aerospace sector becomes increasingly complex and intertwined with digital ecosystems and Sustainability regulation, a one-size-fits-all governance structure is no longer viable. The LS4.0 model supports a flexible, hybrid governance system that accommodates both strategy consistency and operational adaptability.

#### 5.3.6.3 Strategy and Execution: Cascading Vision through Hoshin Kanri

Translating vision into action requires robust deployment mechanisms. At the case study site, this is achieved through Hoshin Kanri, a strategic alignment methodology that cascades long-term objectives into executable tasks across levels. This ensures strategic coherence from executive decisions to operational practices.

Contingency characteristics influence this cascading process. For example, complexity in the supply chain requires strategic agility and integrated supplier plans, whilst ecosystem dynamics necessitate engagement with external stakeholders to co-create value. The LS4.0 model embeds strategic thinking into day-to-day execution, ensuring Lean practices and Sustainability targets are not separate initiatives but interwoven into unified agenda.

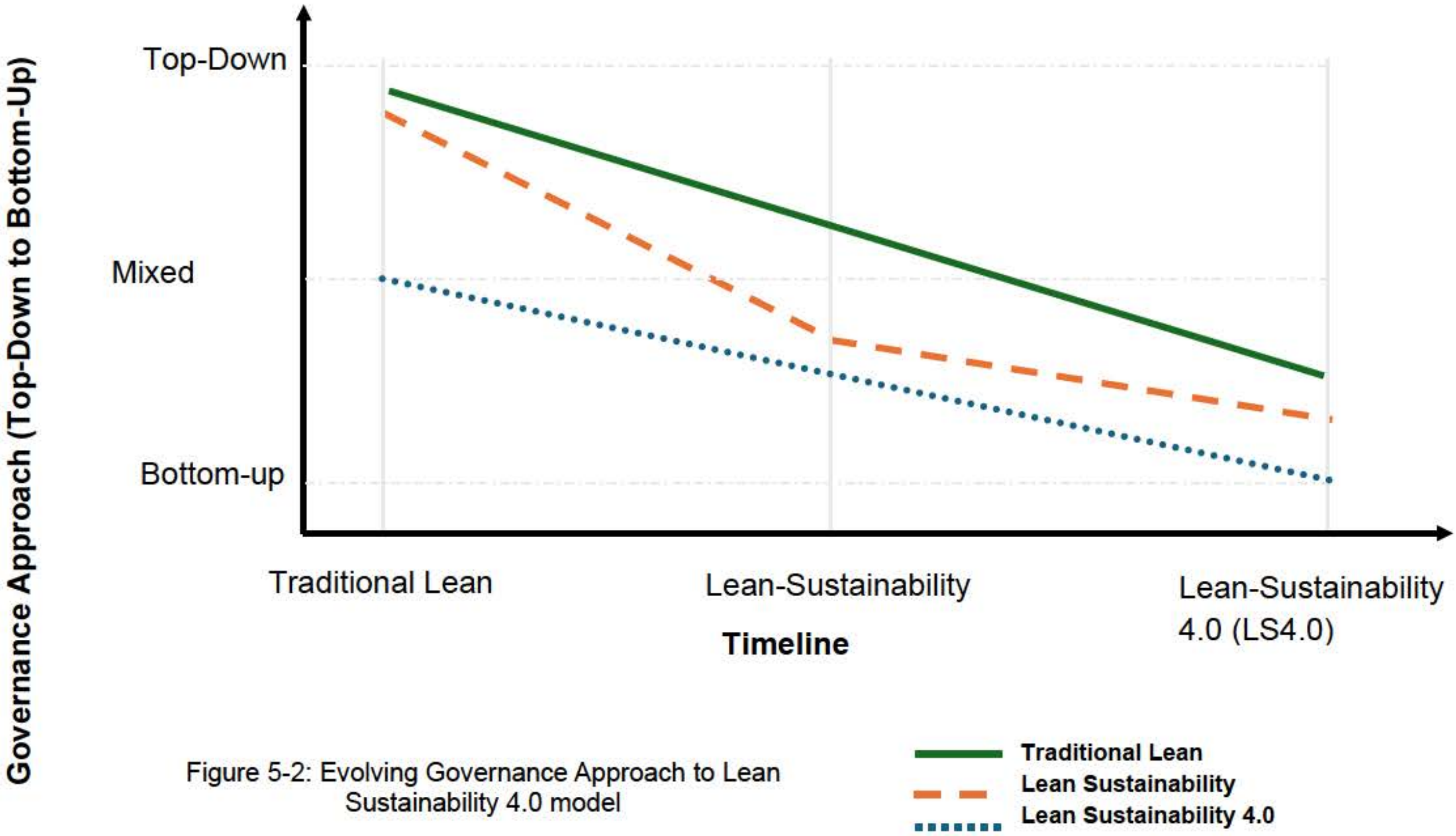


Figure 5-2: Evolving Governance Approach to Lean Sustainability 4.0 model

### 5.3.6.4 Leadership Commitment

Leadership commitment is critical to the success of LS4.0. At the case site, this commitment was demonstrated through active participation in gemba walks, daily management, Kaizen events, and visible support for employee development. Effective leadership in this context goes beyond setting direction, it involves cultivating an enabling environment. Delphi method experts emphasised the role of leaders, instead of issuing top-down mandates, leaders engaged in co-learning environments that empower operational teams to shape Sustainability objectives from the ground up.

The company developed three core behavioural expectations: act with humility, lead with transparency, and deliver with focus. These behaviours are built into performance reviews and incentive structures, reinforcing the cultural dimensions of Lean-Sustainability transformation.

Building on Expert 2 feedback in Round 1, “Respect for People” principle strengthens the model in positioning leadership as key enabler of cultural resilience. This becomes especially critical under novelty, where rapid technological shifts demand adaptive thinking, and under compliance, where leaders must model accountability. For example, leaders at the company played a crucial role in promoting training and initiatives around net-zero goals and encouraging experimentation with AI tools to solve engineering challenges.

Delphi experts’ insights further reinforced the role of leadership element. According to expert panel, effective leadership in LS4.0 is grounded in consistent behaviour and shared purpose, not hierarchical control. Leaders act as both sense-makers and boundary-spanners, connecting strategic imperatives with frontline realities and translating Sustainability commitments into actionable behaviours. In this capacity, leadership facilitates the continuous loop sensing, seizing, and transforming. Leaders champion innovation, sustain cultural norms, and drive alignment across diverse functions. Therefore, in the LS4.0 model, leadership is not a static directive force but a dynamic, relational capability that powers systemic change.

#### 5.3.6.5 Section summary and link to the next section

The integration of VoCS, vision, and strategy and leadership, initiates the LS4.0 cycle and sets the foundation for execution. These drivers collectively channel sensing, seizing, and transforming into aligned strategic intent. As illustrated in the closed-loop feedback from SQDCEP results act as the mechanism that sustains continuous improvement within the system. The relationship between SQDCEP performance outcomes and strategic renewal operates through two complementary feedback pathways. The first, represented by a solid arrow in the model, reflects how results directly inform updates to strategic plans and resource configurations, ensuring that decision-making remains evidence based. The second, illustrated by a dashed arrow, shows how performance outcomes reshape stakeholder expectations, allowing organisations to adjust their priorities and remain contextually relevant in an evolving environment.

Together, these dual feedback loops embody Lean’s principle of continuous improvement principle (Koenigsaecker, 2012, Liker, 2021) and embed adaptive responsiveness within the strategic layer of LS4.0 model. As aerospace organisations confront growing complexity, regulatory scrutiny, and sustainable pressures, these drivers ensure that human capital, technological innovation, and strategic foresight are mobilised in concert to sustain long-term competitiveness and resilience.

### 5.3.7 Capabilities of LS4.0

The study treats the following as higher-order capabilities in the sense of dynamic capabilities theory (Teece, 2007), empirically grounded in Chapter 4 and theoretically positioned here as the mechanisms translating strategy into SQDCEP outcomes.

#### 5.3.7.1 Overview of Capabilities

The LS4.0 model transforms strategic vision into operational outcomes through seven higher-order capabilities: information, knowledge, technological infrastructure, collaboration, culture, people, and Leanness. These capabilities, grounded in dynamic capabilities theory (Teece, 2007), empower organisations to sense market/demands signals, seizes relevant opportunities, and transform processes to maintain competitiveness.

Derived from empirical insights at the case study site and validated through the Delphi method, the capabilities reflect the dynamic interface between strategy and execution. These capabilities also reinforce the Lean-Sustainability synergy cycle: a human-centred transformation process where Lean principles become enablers of sustainable impact. Appendix I provides the derivation process, showing how micro-foundations identified in the codebook were clustered to higher-order capabilities and subsequently embedded within the LS4.0 model. Expert 1 and Expert 2 emphasised the importance of these dynamic foundations in navigating regulatory challenges, fostering innovation, and mobilising continuous improvement. Table 5-4 maps how these capabilities align with DCT's micro-foundations and SQDCEP outcome dimensions of safety, quality, delivery, cost, environment, and people.

#### 5.3.7.2 Detailed Capabilities

The following capabilities reflect the operational mechanisms needed to enact the LS4.0 model. These capabilities are shaped by aerospace-specific contingency characteristics, as details below.

**Information**: Evolved from the initial term "Data" based on Experts' feedback to reflect information strategic value. This capability builds on Nonaka et al. (1996) knowledge creation model, where data is transformed into insights to inform decisions. The case site's operational connectivity project exemplifies this: Cloud platforms generate real-time performance metrics that validate gemba findings and inform agile responses. As Expert 2 remarked, “Data needs to be structured and validated before it becomes useful for action.” In LS4.0 terms, that means clear operational definitions for each metric, data ownership, automated, quality checks for completeness and accuracy, and audit trials that show when and how figures changed.

Under compliance pressures such as UK sovereign cloud rules, these controls are not optional, they are the mechanism that converts sensing into seizing and then into transforming by ensuring that what teams see on screens is reliable enough to change plans, rebalance flow, and evidence improvements.

**Knowledge**: This capability aligns with the concept of “organisational learning” (Liker, 2021), as emphasised by Expert 1. The site’s emphasis on daily management, knowledge sharing channels, and Kaizen reviews reinforces continuous learning. Particularly, the site’s exploration of digital Kaizen preparation platform reflects sensing through gap identification, seizing through process improvement, and transforming by institutionalising learning under conditions of novelty. Participant 12 highlighted the pain point driving this effort: “Kaizen preparation takes 6 weeks and takes too much effort”. The platform is intended to standardise scoping, surface prior lessons, and shorten preparation lead time so that emerging knowledge is captured, reused, and embedded more effectively.

**Technological Infrastructure**: Reflecting I4.0’s transformative potential (Kagermann, 2014), this capability enables scalability, integration, and process reliability. Delphi experts agreed technological infrastructure is a critical enabler under complexity but influenced by compliance, particularly, where fragmented legacy systems pose challenges. Although full IoT deployment has not yet been realised at the case study site, significant steps have been taken to leverage generative AI for engineering and design optimisation. The adoption of AI-driven tools has enabled rapid simulation and iteration and improving manufacturability. As Participant 10 noted, “Things that used to take 10 years can be done with simulation now”. These practices, whilst not yet institutionalised at the case site, illustrate how technological infrastructure may develop under conditions of complexity and compliance.

Delphi Expert 3 cautioned against over-reliance on digital systems without physical validation. Drawing from lived experience, the expert illustrated how poorly integrated I4.0 initiatives when not grounded in operational reality can lead to inefficiencies, misalignment, and even production loss. This insight reinforces the need for physical gemba validation alongside digital dashboards, ensuring that leadership remains engaged in verifying system accuracy. As Expert 3 put it, “Data in its truest nature is only as good as the inputs.” Consequently, the site’s approach combining advanced technology integration with gemba validation, embodies a hybrid model that respects both technological potential and human insight.

**Collaboration**: Inspired by supply chain integration literature, such as Christopher and Holweg (2017), this capability fosters internal collaboration e.g. through cross-functional Kaizen and external collaboration through supplier-customer partnerships. The site’s ecosystem challenges are addressed through trust-building and co-innovation directly influenced by ecosystem demands, with sensing identifying partnerships, seizing formalising agreements, and transforming fostering collaborative innovation, impacting delivery and cost efficiency.

**Culture**: Culture is the glue that sustains LS4.0 values across the organisation. At the case site, values such as humility, transparency, focus, and environmental responsibility are reinforced through daily routines and leadership modelling. Compliance influences this space by shaping accountability norms and promoting clarity in cross-functional roles.

**People:** Rooted in the Lean’s “respect for People” principle (Liker, 2004, Liker, 2021, Ohno & Bodek, 1988), this capability focuses on empowerment, skill development, and autonomy, reflecting how human development and autonomy serve as the engine of sustainable transformation. At the case study site, the introduction of AI generative platform, a secure, organisation-wide assistant embedded within the site’s internal digital ecosystem. This AI platform enabled employees to access information instantly, draft communications, and accelerate problem-solving. Over 500,000 queries and 200,000+ documents were processed within the first few months, demonstrating strong workforce engagement and trust in the tool. Such initiatives accelerate capability building, allowing individuals to spend more time solving customer’s toughest problems rather than navigating bureaucracy.

This outcome aligns with the sensing function of DCT where skills gaps and opportunities are identified through employee interaction with intelligent systems. The seizing dimension is reflected in how the AI platform enhances task performance, creativity, and knowledge accessibility. Finally, transformation occurs as employees adapt their roles, engaging more deeply in LS4.0 initiatives and strategic innovation.

**Leanness**: Based on fundamental Lean literature (Hines, Holweg, & Rich, 2004, Ohno & Bodek, 1988), this capability ensures flow, standardisation, and waste elimination. Delphi feedback reinforced the view that Leanness must be continuously reconfigured under emerging pressures. Digital VSM for example, was discussed as a promising extension to map energy flows and bottlenecks as well as energy consumption and emissions, exemplifying the synergy between tools and Sustainability targets. Ecosystem and complexity characteristics strain flow, making adaptive Lean solutions vital.

#### 5.3.7.3 Integration with the Model

These seven capabilities operationalise the LS4.0 model by bridging strategic drivers into performance outcomes. These capabilities embody the dynamic functions of sensing e.g., identifying inefficiencies, seizing, for example, implementing LS4.0 tools, and transforming which is related to the restructuring teams or processes. Shaped by the four contingency characteristics, they enable the organisation to respond fluidly to internal and external demands.

As detailed in Appendix I, the micro-foundations underpinning each capability e.g., Kaizen events, A3 learning, cloud dashboards constitute the building blocks that, when aggregated, form the higher-order capability set illustrated in the LS4.0 model. Appendix I, hence provides the traceability from codebook themes to capabilities, reinforcing the empirical grounding of the model. For example, information and technological infrastructure support compliance-driven traceability, whilst collaboration and Leanness improve flow within a fragmented ecosystem. People and knowledge reflect the site’s response to novelty, promoting agility and innovation. Meanwhile, culture aligns individual behaviours with strategic purpose, reinforcing the synergy cycle. This coherent integration is observable in site practices such as Sustainability-driven Kaizen events, AI-enabled knowledge capture, and cross-functional gemba walks, where all capabilities are activated to support SQDCEP outcomes.

#### 5.3.7.4 Synthesis and implication for LS4.0

Together, these seven capabilities form the dynamic engine of the LS4.0 model. They enabled the organisation to translate vision into results, sustain cultural transformation, and maintain performance alignment amid complexity. Grounded in Delphi-informed refinement, these capabilities reflect both theoretical robustness and empirical authenticity, offering a practical roadmap for embedding Lean-Sustainability in aerospace.

Table 5-3 below summarises the influence of contingency characteristics on capabilities and the mechanisms through which these impacts materialise.

Table 5-3: Influence of Contingency Characteristics on Capabilities

| Contingency Characteristics | Capabilities Influenced | Influence Mechanism | Example Impact |
|---|---|---|---|
| Compliance | Information Culture | Requires secure data inputs, promotes accountability | Secure cloud adoption, emissions reporting |
| Complexity | Leanness, Technological Infrastructure | Challenges flow, demands scalable solutions | Generative AI for design optimisation |
| Novelty | Knowledge, People | Drives Innovation, requires skill evolution | I4.0 technology for Kaizen, net-zero training. |
| Ecosystem | Collaboration, Leanness | Fosters partnerships, enhances resilient flow | Supplier collaboration post-COVID |

Table 5-4: High-order capabilities and DCV

| Dynamic Capabilities – Higer Order | Sensing | Seizing | Transforming | Results |
|---|---|---|---|---|
| **Information** | Identify stakeholders' needs e.g. customers, partners, employees, society, and shareholders through validated data and gemba. | Leverage cloud computing, big data for real-time monitoring. | Develop agile data-driven decision such as accuracy and speed. | Safety |
| **Knowledge** | Capture and translate organisational knowledge. | Apply captured knowledge to innovate and optimise processes. | Build knowledge-sharing platforms and continuous learning systems. | Quality |
| **Technological Infrastructure** | Explore emerging technologies e.g., CC, AI, Iot and automation. | Invest in scalable, and flexible technologies<br>Vertical and horizontal integration. | Integrate and adapt technology across value chains for operational alignment. | Delivery |
| **Collaboration (Internal & External)** | External: Identify and establish partnerships with suppliers, customers and stakeholders.<br>Internal: extend Sustainability, IT teams in kaizen events. | External: Formalise collaboration agreements and shared values.<br>Internal: Close cross-functional processes, include IT engineers into kaizen events. | Build trust, align objectives, and foster co-design and innovation. | Cost |
| **Culture** | Sense cultural alignment with Lean Sustainability principles. | Promote a shared vision of innovation and continuous improvement. | Embed Lean and Sustainability culture through policies, practices and bonuses. | Environmental |
| **People** | Identify skill gaps and assess workforce needs, adhere to the principle of respect for people. | Develop training and reskilling programmes aligned with Industry 4.0 and Sustainability. | Empower employees with decision making authority and tools. | People |
| **Leanness** | Identify sources of waste, inefficiencies and non-added activities. | Adopt Lean tools (VSM, Kaizen, 5S, kanban) combined with digital tools.<br>Extend kaizen events to environmental and social dimensions<br>Adopt systemic problem-solving capability. | Build Lean systems enabled by digital technologies to continuously improve flow, eliminate waste, and align processes with Sustainability goals. | |

### 5.3.8 Performance Results – SQDCEP framework

#### 5.3.8.1 Overview

The case site uses the traditional safety, quality, delivery, and cost (SQDC) framework embedded into the company Lean operating model. These dimensions are prioritised in that order, starting with safety and ending with cost, and are applied systematically from the corporate level through the business unit and production cells. During the research process, however, it became evident that two critical performance dimensions-environmental Sustainability and social Sustainability were not explicitly captured in the existing framework. Although practitioners actively engaged in Sustainability Kaizen events, digital transformation projects, and social programmes, these initiatives lacked formal metrics for systematic monitoring and integration into strategic performance dashboards. Similarly, whilst environmental objectives such as the site's target for zero operational emissions by 2030 were prioritised, these goals were not yet fully embedded within the company's performance measurement systems.

To align performance management with the holistic orientation of the LS4.0 model, the traditional SQDC framework has therefore extended to SQDCEP, introducing two new dimensions: people (P) and environment (E). This enhancement captures both human-centric and ecological imperatives underpinning sustainable operational excellence. The revised framework ensures that performance measurement extends beyond efficiency and cost optimisation to encompass capability development, empowerment, and environmental stewardship. The revised SQDCEP framework thus provides a holistic compass for the aerospace sector, supporting alignment across cell, value stream, plant, and corporate levels.

Initially, this research considered extending the traditional SQDC framework by incorporating improvement (I) and environment (E) as additional dimensions. However, longitudinal engagement with practitioners and Delphi expert reflection demonstrated that people (P), representing capability development, empowerment, and engagement, was not only a fundamental capability but also a measurable outcome in its own right. This reconceptualisation positions human potential as the main source of continuous improvement and sustainable transformation. It also reflects the company's recent shift toward employee ownership and shared-value creation, where employees are regarded as co-creators of performance and Sustainability outcomes.

#### 5.3.8.2 Safety (S)

Safety remains a foundational value within aerospace manufacturing, where both physical and psychological well-being are essential components of operational integrity. Within LS4.0 model, safety extends beyond compliance and incident prevention to encompass proactive risk identification and the cultivation of a culture of care and accountability. Digital enablement supports predictive safety through real-time monitoring, alerts, and data-driven risk mitigation. These practices ensure that safety is not only a baseline expectation but also a leading indicator of overall organisational health.

#### 5.3.8.3 Quality (Q)

Quality performance in LS4.0 context reflects the organisation’s capacity to meet or exceed customer expectations in design, production, and delivery. I4.0 technologies, such as digital traceability systems and analytics, enhances non-conformance detection, reduces rework, and strengthens supplier quality collaboration. Continuous feedback loops reinforce learning and promote the development of robust, first-time-right processes.

#### 5.3.8.4 Delivery (D)

Delivery performance focuses on the reliability and responsiveness of production and supply systems. LS4.0 enables greater agility through real-time visibility, predictive scheduling, and digitally connected value streams. The adoption of cloud-based monitoring platforms allows for dynamic coordination between production units and suppliers, reducing lead times and improving on-time delivery rates. Transparency and synchronisation across the supply chain ensure that operational performance is both efficient and resilient.

#### 5.3.8.5 Cost (C)

Cost performance is addressed through the dual lens of Lean efficiency and sustainable resource optimisation. Waste elimination energy conservation, and process simplification contribute to cost reduction without compromising quality or safety.

I4.0 technologies enhance the precision of cost management by identifying inefficiencies in real time e.g., inventory, and optimising resource allocation. In the aerospace context, where cost pressures coexist with stringent regulatory and quality demands, such digital-Lean integration enables smarter decision-making and long-term value creation.

#### 5.3.8.6 People (P)

The people dimension captures the essences of human-centric transformation, emphasising empowerment, learning, and engagement as performance outcomes. Employees are recognised not merely as contributors to improvement but as key enablers of transformation. Capability building through targeted training, digital literacy, and Kaizen participation reflects a shift from compliance-driven behaviour to proactive ownership of improvement. The LS4.0 model embeds empowerment as a systemic capability, ensuring that continuous improvement and innovation are sustained through human development.

#### 5.3.8.7 Environmental (E)

The Environmental dimension integrates the company's Sustainability ambitions with its operational performance framework. This dimension encompasses both Scope 1 and Scope 2 emissions, focusing on direct emissions from manufacturing operations and indirect emissions from purchased energy. Performance measurement in this dimension includes energy consumption per unit produced, renewable energy utilisation, and waste reduction initiatives. Environmental performance is therefore operationalised as a quantifiable metric aligned with the company's objective of achieving zero operational emissions by 2030. This integration reinforces environmental stewardship as a strategic imperative rather than a peripheral goal.

#### 5.3.8.8 Summary and implications

The SQDCEP framework operationalises the performance outcomes of the LS4.0 model, providing a dynamic mechanism for linking capabilities to measurable results. By extending the traditional Lean focus on safety, quality, delivery, and cost to include people and environment, this framework responds to the evolving human and ecological dimensions of competitiveness in aerospace manufacturing. This results framework reinforces the model's closed-loop logic, wherein feedback from performance outcomes informs strategy refinement, capability development, and digital investment decisions. This cyclical alignment ensures that operational excellence, Sustainability, and innovation evolve cohesively.

As illustrated in Figure 5-3, the SQDCEP framework symbolises the balanced integration of six performance dimensions radiating from the LS4.0 core. The figure depicts LS4.0 at the centre as the unifying capability system driving performance across safety, quality, delivery, cost, environment, and people. Bidirectional arrows indicate continuous feedback between enablers and outcomes, reflecting the dynamic and adaptive nature of the LS4.0 paradigm in the aerospace sector.

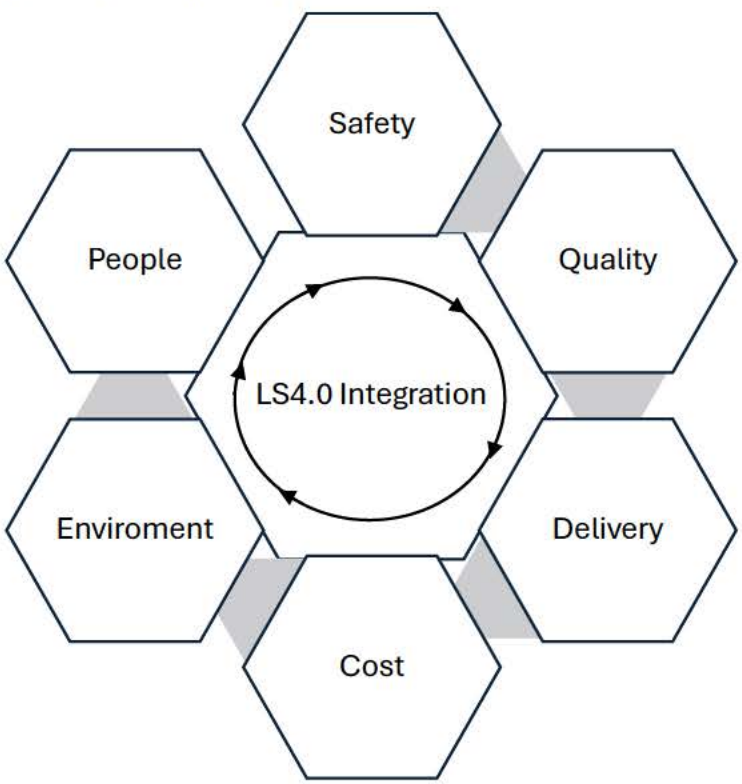


Figure 5-3: SQDCEP Performance Framework- LS4.0 as the integrative driving force

## 5.4 Model Validation and Final Reflections on the LS4.0 Model

### 5.4.1 Model Validation

The validation of the LS4.0 model was conducted through a structured, two-round Delphi study involving four aerospace experts. This process ensured that the model's theoretical foundation was systematically tested and refined through practitioner insight. Following the exploratory case study, the initial LS4.0 framework was shared with experts for iterative critique to confirm its clarity, relevance and feasibility within the aerospace context.

Round One gathered qualitative feedback that informed key revisions to the model's capability architecture, performance framework, and feedback mechanisms. These revisions clarified constructs, surfaced information as the relevant capability, and strengthened the voice of the customer and stakeholders loop. Round Two adopted a mixed-method format, combining Likert-scale assessments and open-ended responses to verify consensus. Agreement was defined a priori as rating ≥4, consensus was set at ≥75% of ratings at this level. All the major items met the consensus threshold, and the overall means were above 3.5/5, indicating robust support with manageable dispersion. Experts endorsed the integrated view of Lean, Sustainability and I4.0, and confirmed the appropriateness of the seven higher-order capabilities: information, knowledge, technological infrastructure, collaboration, culture, people, and Leanness. The experts also further endorsed the contingency dimensions: compliance, complexity, novelty, and ecosystem, as critical contextual characteristics influencing the model's applicability in aerospace operations. Substantive refinements emerged from the validation process: The "data" capability was relabelled "information" to emphasise the transformation of raw data into actionable intelligence. The voice of the customer and stakeholders loop was reinforced as a central feedback mechanism, ensuring that transformation initiatives remain anchored in stakeholder expectations. Most importantly, the performance framework evolved from SQDCIE to SQDCEP, with the inclusion of people as a standalone dimension representing empowerment, engagement, and human-centric capability building. Detailed item-level statistics for Round Two are reported in Appendix K.

### 5.4.2 Final Reflections on the LS4.0 Model

The LS4.0 model presents a structured, practitioner-informed approach to integrating Lean, Sustainability, and I4.0 technologies within the aerospace sector. Developed from rich empirical data at a leading UK aerospace site and theoretically underpinned by dynamic capabilities theory (Teece, 2007) and contingency theory (Donaldson, 2001), the model addresses the dual pressures of environmental responsibility and operational complexity. The LS4.0 model enables firms to sense emerging challenges, seize opportunities through resource alignment, and transform processes for long-term resilience. The model is built around seven higher-order capabilities, information, knowledge, technological infrastructure, collaboration, culture, people, and Leanness, each shaped by key contingency characteristics, compliance, complexity, novelty, ecosystem, unique to the aerospace context. These capabilities form the operational engine of the model, translating strategic vision into daily practice and creating a dynamic operational backbone that is both robust and adaptable.

Practitioner validation confirmed that the model's systemic coherence and adaptability make it feasible across different maturity levels. Experts and site practitioners highlighted its practical value through initiatives such as cross-functional Kaizen events targeting triple-bottom-line outcomes and AI-driven optimisation projects addressing design and production complexity. The model's modularity allows organisations to focus on capability areas most aligned with their transformation stage, whether enhancing cultural readiness, digital infrastructure, or collaboration networks. Finally, the LS4.0 model operationalises human ingenuity and technological innovation as complementary forces. The model offers the aerospace sector a roadmap for navigating disruption, compliance, and transformation whilst maintaining competitiveness. By embedding Sustainability and digitalisation within the Lean philosophy, LS4.0 equips organisations not only to enhance performance but also to contribute to a more resilient, inclusive, and environmentally responsible future (Naik et al., 2024, Sony, 2018).

# Chapter Six
# Discussion

## 6.1 Introduction

This chapter offers a critical interpretation of the empirical findings presented in Chapter Four and the model development and validation reported in Chapter Five. The study examined how Lean, Sustainability, and I4.0 technologies can be effectively integrated in the UK aerospace sector to strengthen operational and Sustainability performance. Empirical data were collected between July 2023 and October 2024 through 15 semi-structured interviews, company documentation, and site observations, generating over three hundred pages of rich qualitative material. The findings informed the development of the LS4.0 model, which was subsequently refined through expert validation using the Delphi method.

The discussion in this chapter is organised into five analytical sections that reflect the major thematic categories emerging from Chapter Four. This structure is chosen to provide a clear analytical arc from perception and context to mechanism and outcomes. Together, the sections address the three research objectives by showing how conceptual insights from Chapter Two are realised in practice, how practitioners perceive, experience and shape integration in the real world, and how expert feedback consolidated and sharpened the model presented in Chapter Five.

Each analytical section also synthesises the empirical findings in Chapters Four and Five with the literature reviewed in Chapter Two, whilst drawing on dynamic capabilities theory (Teece, 2007) and contingency theory (Donaldson, 2001) to explain how organisations navigate transformation under the constraints of complexity, compliance, novelty, and ecosystem interdependence.

The chapter is grounded in the study's qualitative single-case design and Delphi validation, which collectively provided a robust evidential base, ensuring that the interpretations presented here are both empirically grounded and theoretically rigorous. This integrated design allowed for the convergence of practitioner perspectives, contextual observations, and expert consensus, enabling a holistic understanding of how

Lean, Sustainability, and I4.0 principles interact within the complex and regulated environment of aerospace manufacturing. The next sections therefore focus on interpreting how these findings contribute to theory development and practical transformation within the sector.

### 6.2 Lean as Foundation for LS4.0 Integration in Aerospace

Lean remains the operational backbone of the LS4.0 model. In aerospace, however, Lean's fit is conditioned by low volume, high mix, long qualification cycles and fragmented specialised supply base. Prior work shows that Lean excels where product variety is limited and flow and takt-time are designable (Amrani & Ducq, 2020, Browning & Heath, 2009). The findings of this study align with that view. Flow continuity is structurally harder to secure in engineer-to-order contexts, which help to explain why digital enablers such as model-based engineering, simulation, digital value stream mapping and real-time visibility are increasingly required to approximate flow and stabilise variability before improvements can stick (Rosin et al., 2020, Stock et al., 2018).

At the same time, Lean operates as mindset and management system, not just a toolkit. Episodic, concentrated event-based improvement such as one-week Kaizen events delivered visible wins at the case site, but the literature suggests that such practice underperforms compared with embedded daily management routines sustained by coaching leaders (Bessant & Francis, 1999, Liker, 2021, Netland et al., 2020). The implication is that aerospace requires both: pragmatic, time-boxed interventions to unlock near-term bottlenecks in complex programmes, and a parallel investment in the below-the-waterline's cultural work that normalises frequent problem-solving and learning (Hines, 2010).

These findings also resonate with critiques of Western Lean adaptation. In many firms the approach has been introduced as a collection of discrete tools rather than an integrated philosophy underpinning the Toyota Production System. That pattern reflects legacy incentive systems, accounting logics focused on local efficiency, and leadership turnover, all of which can fragment improvement and weaken the emphasis on respect for people and long-term capability building (Bessant & Francis, 1999, Hines, 2010, Liker, 2021, Netland et al., 2020). Where Western implementations have succeeded, they have typically done so by rebuilding the management system around coaching behaviours, routine problem solving and end to end flow rather than by expanding a catalogue of tools (Koenigsaecker, 2012, Liker, 2021).

External contingencies further moderate the choice of Lean practices. Post-pandemic supply fragility and certification requirements tend to bias decision making towards resilience and compliance rather than pure just-in-time efficiency (Chiarini & Kumar, 2021, Tang et al., 2009). These conditions do not invalidate Lean, but they change the emphasis within Lean bundle. Inventory policies may become risk-buffers, cross-functional readiness and supplier capability building become critical, and throughput targets must be balanced with quality, people and environmental objectives (Browning & Heath, 2009).

For example, during the post-COVID period, which was characterised by ramp-up in production, aerospace suppliers faced severe financial and capacity constraints, with some required direct intervention from original equipment manufacturers to avoid production stoppages. At the case study site, leadership supported a single-source casting supplier to ensure continuity of critical programmes. Airbus likewise provided assistance to struggling small and medium enterprises (SMEs) supplying aerostructures, recognising that supplier fragility could jeopardise ramp-up targets for programmes like the A320neo (Dubois, 2020, Kollewe, 2024, Times, 2025). Earlier experience on the Boeing 787 programme shows how extensive outsourcing to a widely dispersed network can generate delays, quality issues and cost overruns, with aircraft certification arriving in years later than planned (Denning, 2013, Tang et al., 2009). These cases underline that Lean efficiency must be complemented by risk management and resilience, which are reflected in the LS4.0 model's contingency characteristics of complexity and compliance.

Internal dynamics also can constrain Lean maturity. A recurring pattern at the case site was the intense focus on customer schedules, with delivery taking precedence over other dimensions such as quality, cost, people and environment. Whilst understandable given customer pressure and high stakes contracts, this narrow focus can crowd out systemic improvement and long-term Sustainability aims. The literature cautions that undue emphasis on output in aerospace tends to create hidden wastes, including misalignment between engineering, supply and production (Browning & Heath, 2009). The way problems are handled reinforces the point. Even minor issues often escalated into extended due diligence with multiple functions and suppliers. Rigour is essential in safety critical settings, yet the frequency and breadth of escalation interrupted flow, led to overtime and weekend working, and drew teams into lengthy investigations and sign offs. Such patterns signify a lack of differentiated problem-solving structures that separate true bottlenecks from lower value tasks, a characteristic sign of earlier Lean maturity.

Taken together, the evidence points to two connected conclusions. Firstly, Lean remains the cultural and operational base from which Sustainability and I4.0 initiatives should evolve. Lean principles of waste reduction, respect for people and disciplined problem solving naturally support both Sustainability and digital transformation (Peter et al., 2011, Shah & Ward, 2007). Secondly, the structural and contextual realities of aerospace, including fragmented flow, regulatory constraints and low production volume, make integration necessary. By combining Lean with Sustainability and I4.0, organisations are better able to address these systemic constraints (Buer et al., 2018).

From a theoretical perspective, these findings reinforce dynamic capabilities theory. Lean's sensing and transforming functions are complemented by the data-driven insights of I4.0 and the normative aims of Sustainability. In practical terms, the aerospace sector benefits from adaptations such as combining traditional value stream mapping with digital tools and from aligning leadership routines with daily problem solving. Overall, Lean in aerospace is both enabling and bounded in aerospace. Whilst Lean provides a proven framework for operational excellence, its full potential requires augmentation through Sustainability principles and advanced technologies. LS4.0 is positioned as a solution that builds on Lean's strengths whilst addressing its limitations, creating a holistic and future-ready model.

### 6.3 Advanced Technological Enablers and Barriers in LS4.0

The findings reveal that advanced technology plays a dual role in LS4.0: as a transformative enabler that amplifies Lean principles and Sustainability objectives, and as a potential barrier when hindered by organisational maturity gaps, legacy systems, or strict regulatory constraints. This duality aligns with the literature, which highlights I4.0 as a driver of operational agility, real-time decision-making, and Sustainability improvements (Buer et al., 2018, Kagermann et al., 2016), whilst also cautioning that its benefits are contingent upon organisational readiness and cultural alignment (Luz Tortorella et al., 2022, Sony, 2018).

In practice, three technological roles stand out. Firstly, data acquisition and connectivity shorten learning cycles. IoT sensors, machine information and energy metering convert dispersed signals into time-stamped data that can be queried at the point of decision. This visibility strengthens classic Lean problem solving by revealing the location, frequency and cost of losses that often evade aggregated key performance indicators, from rework and overtime to unnecessary energy consumption. Secondly, analytics and AI turn raw data into actionable intelligence. Pattern detection, anomaly identification and predictive models support right-first-time quality and timely maintenance, echoing the Jidoka logic of detecting abnormalities early and stopping to fix causes. Thirdly, virtualisation tools such as model-based engineering, simulation and digital twins allow teams to test product and process changes virtually, exposing bottlenecks and tolerance risks before release and reducing physical iteration loops. Together, these functions align with established accounts of cyber-physical systems integration, where data and models tighten the link between sensing, deciding and acting (Frank et al., 2019, Rosin et al., 2020, Stock et al., 2018).

The same evidence also shows why sequencing matters. Lean stability remains the foundation through standardised work, clear flow logic and problem escalation routines create the conditions under which digital signals translate into improvement rather than waste. Where processes are immature, digital overlays tend to generate even more dashboards without solving root causes, an effect described as digital waste in recent studies of premature automation and misaligned data architectures (Alieva & Haartman, 2020, Alieva & Powell, 2023). Readiness, in this sense, is not an abstract maturity score but the practical ability to absorb new information into daily management and close the loop rapidly.

Contextual constraints shape both system architecture and the pace of adoption. In defence settings, export controls and cross-border data rules can restrict how data are stored and shared. In the case organisation, the need to exchange data with US sites introduced cross-border constraints that limited the use of commercial cloud and wide-area IoT connectivity across the site. In practice, this directed solutions toward tightly controlled environments and certified data pathways, with greater emphasis on cLean data models, robust interfaces and security by design.

A further contingency is the product and volume profile of aerospace. Low volumes, engineering change and long qualification cycles constrain the degree to which flow, and takt-time can be engineered into the physical system. Digital techniques partially compensate by providing foresight and faster feedback, but they do not eliminate the need for careful configuration of inventories, capacities and support coordination. In aerospace sector, the most effective digital programmes are those that are explicitly problem-led, tied to value streams, and governed through existing Lean rhythms so that view insights feed directly into daily control and tiered reviews.

Viewed through the dynamic capabilities lens, technology enlarges the organisation's capacity to sense opportunities and threats in real time, to seize them through targeted interventions, and to transform routines by institutionalising superior ways of working (Teece, 2007, 2018). Sensing is strengthened when high-granularity data reveal deterioration before it becomes failure. Seizing improves when analytics and visualisation help teams prioritise where to act and with what countermeasures. Transforming takes hold when these digital practices are embedded into standard work, coaching strategy deployment, rather than remaining as parallel initiatives (Netland et al., 2020).

The people dimension remains decisive. Human in the loop arrangements and leader standard work ensure that digital outputs are interrogated at the gemba and translated into practical experiments, preserving the socio-technical character of Lean systems (Shah & Ward, 2007). Where leaders model inquiry, protect time for improvement, and resource the OT-IT interface, adoption accelerates. Where leadership is episodic or tool-centric, technology tends to outpace culture and stalls at the pilot stage.

Overall, the evidence supports a contingent, staged view of technological integration. Digital tools deliver their strongest effects when they are problem-driven, process-ready and culturally owned. Constraints arising from regulation, legacy infrastructure and supply complexity do not invalidate LS4.0, they specify the design brief, which in aerospace priorities secure architectures, cLean data pipelines, hybrid OT-IT roles and governance that routes digital intelligence into the cadence of Lean. Under those conditions, technology acts not as a separate programme but as an accelerator of operational discipline and Sustainability outcomes.

## 6.4 Lean and Sustainability Integration

The evidence across this study reinforces a well-established proposition that Sustainability is a natural extension of Lean thinking. When waste is defined broadly to include materials, energy, motion, overproduction and defects, Lean's pursuit of flow and stability directly advances environmental performance (Duarte & Cruz Machado, 2017, Zokaei et al., 2013). What the case site adds is how that extension works in practice in aerospace. In a low-volume, high-mix, tightly regulated setting, the integration progresses most reliably when Sustainability is embedded into existing Lean routines rather than bolted on as a parallel programme. In other words, the operating system becomes the vehicle for Sustainability, not a competing lane.

Two integration mechanisms are particularly important. The first is aligning diagnostics. When value stream analysis and daily management incorporate energy use, scrap, alongside quality, costs and delivery, the losses that matter environmentally become visible at the same cadence as operational losses. Recent work on circular or dual value stream mapping supports this move from concept to practice by placing green indicators on the same page as productivity metrics (Batwara et al., 2023, Ciliberto et al., 2021, Costa et al., 2024, Tripathi et al., 2023). The second is aligning routines. Kaizen, standard work, and tiered reviews provide the behavioural underpinning through which environmental improvements are specified, tested, and locked in. Where environmental targets live inside these routines, progress compounds, however when environmental targets sit outside, progress fragments (Skalli et al., 2023a, Varela et al., 2019).

Measurement remains the keystone. Much of the literature criticises the gap between corporate ambition and operational metrics (Cherrafi et al., 2016, Ejsmont et al., 2020). The case echoes that critique and clarifies the remedy by treating environmental indicators with the same operational discipline as SQDC, tying them to value streams, and audit them with the same regularity. Doing so, turns Sustainability from a quarterly narrative into a daily problem-solving routine.

The social dimension is both essential and often under-specified. Lean's respect for people principle is not an abstract value, but it governs whether change creates engagement or strain. Studies show that when Lean is implemented as a whole system with teamworking, training, communication and discretion alongside tools, well-being and learning improve. However, when Lean is implemented as a cost cutting, work intensification and stress follow (Salentijn et al., 2021). The LS4.0 model therefore positions people as both a capability and an outcome. Empowerment, skills development and psychological safety are preconditions for sustained Lean-Green performance, not incidental benefits that might emerge later.

Ecosystem maturity sets the frontier of what is achievable. Supplier capability and incentive determine how far beyond the factory boundary improvements can travel, especially for Scope 3 emissions. The literature is clear that upstream collaboration, shared standards and targeted education are necessary to diffuse Lean-Green practices along the chain (Singhal et al., 2024). In aerospace, where specialist small and medium enterprises sit at critical nodes, this implies a patient, capability-building approach. Supplier Kaizen, co-developed metrics, and phased adoption are more effective than transactional compliance. The implication is that organisations must invest in partner learning as deliberately as they invest in internal learning if they want environmental gains to propagate across programmes.

Digitalisation functions as the bridge between strategic intent and everyday practice. By linking consumption data, process loss and flow stability at fine granularity, analytics and visualisation help teams identify where environmental and operational waste coincide, and test countermeasures at speed. This is where the three pillars of LS4.0 reinforce one another. Lean provides the discipline, Sustainability supplies direction, and I4.0

accelerates learning. Through a dynamic capabilities lens, integration strengthens sensing by making ecological losses legible in real time, improves seizing by prioritising high-leverage interventions, and supports transforming when Lean-Green practices become standard work rather pilots (Teece, 2007, 2018).

A further contribution of this study is to specify the conditions under which integration sticks in aerospace. Firstly, Lean must be approached as a mindset, not only as a toolbox. Secondly, the integration alignment must be architectural, not only rhetorical. Sustainability indicators should be designed into the same boards, meetings and escalation routines that already govern delivery and quality. Thirdly, integration must be paced realistically. Low volumes, long qualification cycles and complex supply networks mean that some manufacturing constraints cannot be engineered out quickly. The practical response is to keep Sustainability work tied to the value stream, with improvements batched into programmes and gated by readiness. Fourth, integration must remain people-centred. Capability building in problem solving and green literacy is required so that frontline teams can interpret environmental signals and act confidently. Without this, digital tools risk generating data without decisions.

The case site also clarifies what does not work. Parallel dashboards and parallel meetings create noise and dilute accountability. Environmental targets that are not tied to root-case analysis devolve into reporting. Supplier maturity without support and development plans, generates compliance risks and underperformance rather than process change. Each failure mode points to the same conclusion: The operating system is the smallest viable unit of sustainable transformation in aerospace. When environmental objectives are woven into that system, they gain cadence, governance and credibility.

In conceptual terms, the study extends Lean-Green scholarship by showing that integration in aerospace is most effective when environmental goals are operationalised through the same routines that govern flow and quality, supported by digital tools that shorten feedback loops. In practical terms, the study offers a clear design logic. Integrate Sustainability indicators through Lean diagnostics. Run improvements through the operating system. Invest in people-centred practices to avoid the dark side of Lean. Build supplier capability intentionally so that gains can travel along the chain. When these conditions hold, Sustainability ceases to be adjacent to Lean, it becomes part of how the system works.

### 6.5 Cultural Shifts and Change Management

Cultural transformation emerged as the decisive variable in the integration of LS4.0, directly addressing RQ2.2 on the enablers and barriers influencing the model development in terms of reshaping organisational mindset. As the findings in Chapter 4 Four reveal, practitioners at the case site increasingly recognise that technical tools and digital systems cannot drive sustainable change unless embedded within a culture of continuous improvement, openness and collaboration. This aligns with the literature, where Lean's success is frequently attributed to its cultural foundations through leadership behaviour, shared purpose, respect for people, learning orientation, and holistic problem-solving (Gutierrez et al., 2022, Hines, 2010, Hines et al., 2020, Liker, 2021). In this view, culture is not a soft accompaniment to technical work but the operating context that determines whether routines are enacted with rigour or drift into ritual.

Three pillars of cultural work matter most. The first is everyday discipline. Daily management, visual controls, and standard work are often treated as mechanical instruments. Their deeper value is that they create a cadence for noticing variation, surfacing weak signals and testing countermeasures at a tempo that outpaces drift. Studies of high-performing Lean systems show that this rhythm sits beneath tool choice and programme labels, knitting improvement into the work itself rather than into separate initiatives (Bessant & Francis, 1999, Netland, 2016, Spear & Bowen, 1999). For LS4.0, this same cadence is what allows digital signals to be interrogated rather than merely displayed, and Sustainability indicators to be acted upon rather than reported.

The second pillar is leadership behaviour. The most effective transformations are led by managers who model inquiry at the gemba, teach problem solving, and align incentives to behaviours as well as outcomes. This is the leadership stance emphasised in the Shingo tradition and in contemporary Lean scholarship, where humility, transparency and focus are presented as behavioural preconditions for flow and quality to stabilise over time (Liker, 2021, Shingo, 2021). Change programmes stall when leaders do not standardise their own work around coaching, tier reviews and cross-functional alignment, since these actions convert aspirations into repeatable practice.

The third pillar is learning quality. Aerospace organisations operate amid engineering complexity, long qualification cycles and heavy compliance. In such conditions, learning needs to be deliberate. Empirical and conceptual work on Lean learning systems argues for structured, iterative routines that move beyond one-off events towards compounding capability. In practice, this means A3 thinking which is a one-page, evidence based narrative that clarifies the problem, root-cause, countermeasures, and follow-up, paired with plan-do-check-act cycles to trial changes in small increments, and kata-style coaching to reinforce scientific habits of mind (Liker, 2021, Rother, 2009, Saabye et al., 2023). When these routines are present, digital tools accelerate insight rather than overwhelm teams with data. When routines are absent, technology tends to amplify noise and stretch attention.

These three cultural elements connect directly to the social dimension of Sustainability. Respect for people in Lean is expressed as work design that balances demand and capacity, clarifies decision rights and reduces unnecessary physical and cognitive strain. Evidence shows that whole-system Lean where teamworking, training and communication sit alongside technical methods, improves well-being and engagement, whilst tool-only deployments risk work intensification and fatigue (Salentijn et al., 2021). LS4.0 therefore treats people not only as a resource to be trained on new tools but as a capability to be developed. Empowerment, green literacy and data fluency are not add-ons but preconditions for integrating environmental and digital agendas into daily work.

Change management in this context is better understood as capability building than as mobilisation around discrete projects. Classic guidance remains relevant: generate visible short-term wins to build confidence, whilst deliberately connecting those wins into a longer arc of practice so that momentum does not dissipate once a workshop ends (Kotter, 1996). The literature such as Tortorella and Fettermann (2018) and Buer et al. (2018) also cautions against initiative overload. Competing dashboards, parallel meetings and uncoordinated programmes fragment attention and dilute accountability. The remedy is architectural alignment. Sustainability and digital indicators should be designed into the same boards, meetings and escalation pathways that govern delivery and quality, so that discussion, ownership and follow up are shared rather than split.

Middle management is pivotal. Frontline teams experience can change through supervisors and value stream leaders, whilst strategic intent arrives through objectives and reviews. Research on Lean transformations highlights the bridging role of middle managers in translating strategy into routines, filtering noise, and protecting time for improvement work so that firefighting does not become the norm (Hines et al., 2020, Liker, 2021, Netland et al., 2020). In LS4.0 this role extends the OT-IT interface. Someone must curate data definitions, steward simple visualisations, and ensure that analytics inform standard work. Without this translation layer, digitalisation sits adjacent to operations rather than within it. Psychological safety underpins all of the above. Teams need licence to surface defects, challenge assumptions and run small experiments without fear of blame. Empirical work on learning organisations repeatedly shows that error reporting, peer review and open retrospectives correlate with faster adaptation and better outcomes, especially in high hazard settings (Edmondson, 1999). For aerospace, the implication is that safety culture and improvement culture are complements. When incident learning and process learning are run through the same disciplined routines, both safety and performance benefits.

A dynamic capabilities perspective helps to explain why these cultural investments matter. Culture shapes sensing by making anomalies visible and discussable, seizing by aligning resources to the few problems that matter and transforming by institutionalising superior ways of working so that gains persist beyond the individuals who initiated them (Teece, 2007, 2018). In other words, culture is the mechanism that turns episodic fixes into cumulative advantage.

The change pathway that follows from this analysis is clear. Start by stabilising the daily cadence so that teams can see and respond to variation. Embed leadership behaviours that privilege coaching, cross-functional alignment and presence at the point of work. Build learning routines that reduce the distance between data and decision. Integrate environmental and digital indicators into the same governance that drives delivery and quality. Invest in the OT-IT bridge so that analytics are simple, trusted and actionable.

Guard against overload by rationalising duplicate meetings and consolidating governance into the operating system at the place where integration occurs.

Viewed through these elements, cultural shift is not a backdrop to LS4.0 but its enabling core. When the social architecture is coherent, Lean, Sustainability, and digital technologies reinforce one another. When it is not, even well-funded programmes stall. The consequence for practice is straightforward. Organisations should treat cultural capability as an explicit design choice, measured and developed with the same seriousness as technical capability. Only then do the promises of LS4.0 translate into stable flow, improved environmental performance and resilient learning at scale.

### 6.6 Strategic Alignment and Leadership Commitment

Leadership is the binding force for LS4.0. Strategy can set ambitions for Lean, Sustainability, and digital, yet only leadership converts those ambitions into coherent priorities, stable routines and sustainable behaviour. The literature is clear, Lean-based transformations ensure when leaders act as cultural architects and systems designers, not simply as sponsors of projects (Liker & Convis, 2012, Shingo, 2021). In LS4.0 this role deepens, because leaders must orchestrate three agendas at once, operational discipline, environmental and social intent and the selective use of advanced technologies (Liker & Convis, 2012, Shingo, 2021).

Recent LS4.0 research sharpens this point. Maturity work on digital-green-Lean shows that progression depends on leadership-driven alignment across four areas, strategy, processes, technology and culture, with governance and measurement knitting them together. Leadership commitment is not a background condition in these models. Leadership is the mechanism that links intent to deployment, ensures indicators of digital and environmental performance sit alongside SQDC, and sustains cadence in review meetings so that learning compounds over time (Gatell & Avella, 2024a, 2024b). Readiness synthesis in Lean-Green 4.0 reaches a similar conclusion. Organisations advance when leaders create the preconditions of culture, skills, architecture and metrics that allow Lean, Sustainability, and I4.0 reinforce one another, rather than compete for attention (Duarte & McDermott, 2025).

Strategic alignment is the first task. In high-complexity sectors such as aerospace, objectives fragment easily across programmes, functions and suppliers. Policy deployment and Hoshin Kanri exist to prevent that drift by translating a small set of breakthrough priorities into measurable objectives, then reviewing progress at a cadence that keeps effort convergent rather than dispersed (Hines, Holweg, & Rich, 2004). Where this discipline is strong, Lean, Sustainability, and digital initiatives do not compete for attention but are framed as mutually reinforcing routes to the same few outcomes, and they are resourced, escalated and learned from through one governance spine. Where that discipline is weak, activity expands, dashboards multiply and momentum dissipates.

Leadership behaviour is the second task. Research shows that constancy of purpose, humility and transparency are not soft virtues but enabling conditions of flow, quality and learning to stabilise over time (Liker, 2021, Shingo, 2021). Leaders who model inquiry at the gemba, teach problem solving and align incentives to behaviours as well as to results create an environment where teams surface problems early and improve them quickly. Netland et al. (2020) describe this as level-specific leadership: executives set direction and remove obstacles, middle managers run tiered reviews and daily management, front-line leaders coach at the point of work. In LS4.0 the same pattern applies, with the added expectation that leaders insist digital insights and environmental indicators are examined in the very forums where delivery and quality are already governed (Liker & Convis, 2012, Netland et al., 2020).

A dynamic capabilities lens helps to explain why these behaviours matter. Leaders shape sensing when they standardise routines that make anomalies visible, from safety signals to energy losses and data quality gaps. Leaders seize by committing and coordinating resources to act on what has been sensed, allocating funding, talent and time, adjusting governance, and redesigning processes to implement the chosen response. Leaders also shape transforming when they institutionalise superior ways of working, so that gains persist beyond individual champions or isolated pilots (Teece, 2007, 2018). In practice this means making the operating system the place where LS4.0 lives. Strategy deployment, daily layered accountability and coaching become the channels through which digital tools and Sustainability goals are absorbed into work, rather than left to run in parallel.

The LS4.0 literature adds two refinements that are directly relevant to aerospace. Firstly, the leadership mandate extends to circular-economy intent. Studies such as de Sousa Jabbour et al. (2018) and Behl et al. (2023) on the intersection of I4.0 and circular-economy indicate that data-rich traceability, lifecycle-oriented product and service redesign, and condition-based maintenance are more likely to yield measurable environmental gains when leadership ties them to value streams and locks them into operational governance. Otherwise, circular ambitions remain aspirational whilst throughput pressures dominate day-to-day decisions. Leadership is therefore responsible for turning circularity into design criteria, operational standards and supplier expectations rather than leaving it as a parallel narrative (Gatell & Avella, 2024b). Secondly, LS4.0 readiness depends on people and culture as much as technology. Synthesised evidence identifies leadership as the antecedent that convenes OT-IT collaboration, sponsors skills for data fluency and green literacy, and insists that digital and environmental measures enter the same review boards as delivery and quality. Without that synthesis, digital programmes grow in isolation and sustainability devolves into reporting rather than improvement (Duarte & McDermott, 2025).

The style of leadership matters. Studies of Lean consistency find that transformational and coaching-oriented behaviours foster motivation, participation and psychological safety, whereas highly transactional or directive approaches can undermine engagement and limit ownership of improvement (Alefari et al., 2020, Liker & Convis, 2012). Aerospace organisations face the additional pull of compliance and delivery pressure. Without careful design, that pressure can trigger escalation-heavy routines that consume attentions and displace structured learning. The countermeasure is leadership standard work that balances due diligence with proportionate response, differentiates true bottlenecks from noise and protects time for experimentation within the guardrails of safety and regulation.

Middle management is pivotal in this arrangement. Front-line teams experience can change through supervisors and value stream leaders whilst strategic intent arrives through objectives and reviews. In LS4.0 this bridging role now spans the OT-IT interface.

Someone must govern data definitions, keep visualisations simple and ensure that analytics inform standard work. The maturity literature such as Gatell and Avella (2024b) underscores that this translation layer is what prevents digitalisation from sitting adjacent to operations. That layer is also the place where environmental indicators are woven into the routine rather than appended as a second set of charts. Where this layer is missing, improvements fragment and momentum stalls (Gatell & Avella, 2024b, Hines et al., 2020, Netland et al., 2020). Leadership also signals what counts. When behaviours are codified in performance reviews and recognition systems, the message is that modelling Lean principles, building people capability and using data to learn are as valued as hitting short-term output. This alignment reduces the risk of initiative overload and tool chasing. This same alignment also addresses a common failure mode in green and digital programmes, where targets exist but are not tied to root-cause analysis, and therefore slip into reporting rather improvement. The LS4.0 readiness view reinforces that remedy by treating culture, skills and governance as design choices that leaders must make explicit and then maintain through the operating activities (Duarte & McDermott, 2025, Skalli et al., 2023a, Varela et al., 2019, Zokaei et al., 2013).

Finally, leadership has an external dimension. Scope 3 performance, supplier reliability and data-sharing constraints sit beyond the factory fence. Leaders must set expectations for supplier development, invest in partner capability and create secure pathways for information and flow across borders and tiers. This is not discretionary add-on. In aerospace, the maturity of the ecosystem is part of the operating system rather than a separate programme (Singhal et al., 2024).

In summary, strategic alignment and leadership commitment are not background conditions but active capabilities in LS4.0. Alignment focuses effort on the few things that matter and keeps them joined up. Behaviour anchors improvement in daily practice and makes learning cumulative. A dynamic capabilities perspective clarifies the mechanism: leaders enable the organisation to sense with discipline, seize with focus and transform by sustained reconfiguration. Where these elements are present, Lean, Sustainability, and digital reinforce one another. Where they are absent, even strong technical programmes stall.

# Chapter Seven
# Conclusion

## 7.1 Introduction

This chapter concludes the research journey that investigated the integration of Lean principles, Sustainability imperatives, and I4.0 technologies within the UK aerospace sector. The central aim of the study was to examine how these paradigms can be operationally aligned through an empirically grounded, context-specific model, termed as LS4.0, to enhance both operational and Sustainability performance.

The research was grounded in the recognition that aerospace manufacturing, whilst renowned for its precision, safety, and regulatory compliance, is now navigating an increasingly complex environment. This environment is characterised by a shift in demand, high-mix production systems, fragmented and specialised supply chains, mounting environmental pressures, and ambitious net-zero targets. In light of this, the convergence of Lean, Sustainability, and I4.0 technologies presents a timely and potentially transformative opportunity to drive operational excellence and long-term resilience. However, this intersection remains underexplored, particularly within the context of aerospace.

To address this gap, the study was guided by three objectives, each aligned with a specific set of research questions. Objective One focused on synthesising theoretical principles and interrelationships across Lean, Sustainability, and I4.0, with particular attention to the aerospace context. This objective was fulfilled through a scoping review in Chapter 2 , based on 43 peer-reviewed studies published between 2015 and 2024, with an updated version in February 2025, mapping the state of knowledge and identifying the enabling and constraining characteristics for integration. Objective Two explored the empirical perceptions of practitioners, the characteristics influencing integration, and the influence on performance, through a qualitative single study at a leading UK-based aerospace manufacturer in chapter Four. This was achieved through semi-structured interviews, site observations, and document analysis, providing rich insights into the sector's operational realities leading to the development of LS4.0 model.

Objective Three involved the refinement, and validation of LS4.0 model in Chapter 5 , which was subsequently evaluated through a Delphi study with the case senior experts to ensure its contextual relevance, practical utility, and theoretical rigour.

This concluding chapter critically synthesises the contributions of each research objective and highlights the significance of LS4.0 model. The chapter specifically reflects on how the research objectives have been addressed, what new knowledge has emerged, and how the study contributes to academic theory and industrial practice. This chapter also acknowledges the methodological and contextual limitations of the research and identifies opportunities for future studies. Grounded in an interpretivist stance and a single-site qualitative case study design, this research aimed to co-construct knowledge through practitioner insights, ensuring that the LS4.0 model is both theoretically sound and contextually situated within the realities of the UK aerospace sector.

The next section 7.2 summarises the key findings in relation to the three research objectives, drawing together insights from the literature synthesis, empirical findings, and the model development and validation process. Section 7.3 highlights the study's contributions to knowledge, emphasising how LS4.0 model extends Lean-Sustainability 4.0 or Lean-Green 4.0 research through a novel theoretical synthesis grounded in dynamic capabilities theory and contingency theory. Section 7.4 discusses the implications for practice and provides a roadmap for implementation within aerospace organisations. Section 7.5 critically discusses the study's limitations, including its single-case design, scope and generalisability. Section 7.6 offers directions for future research, such as longitudinal validation and supply chain-focused studies. Section 7.7 concludes the thesis with reflective remarks on the research's academic and professional journey and the potential impact of the research on the field of operations management.

## 7.2 Summary of Key findings

This study explored the integration of Lean principles, Sustainability imperatives, and I4.0 technologies within the UK aerospace sector, addressing the overarching research question: *how can Lean, Sustainability, and I4.0 be effectively integrated in the UK aerospace industry to enhance operational efficiency, Sustainability, and adaptability?*

The findings were generated across three interconnected phases: a structured scoping review of existing literature in Chapter 2 , and in-depth qualitative field study involving 15 semi-structured interviews, site observations, and company document reviews, and a Delphi-based validation process to refine and enhance the proposed LS4.0 model in Chapter 5 . Collectively, these phases provided a holistic understanding of the opportunities, barriers, and enabling mechanisms shaping LS4.0 integration. The key insights are summarised below according to the three research objectives.

### 7.2.1 Research Objective One: Scoping the Knowledge Landscape (RQ 1.1-1.3)

The first research objective addressed the fragmented body of knowledge concerning conceptual and operational integration of Lean, Sustainability, and I4.0 within manufacturing sectors. A scoping review of 43 peer-reviewed articles revealed that whilst interest in integrating these paradigms has grown significantly, particularly in light of Industry 5.0's human-centric and circular economy agendas, much of the literature remains sector-neutral, conceptual, or focused on dual integration e.g., Lean-Green or Lean-digital, rather than addressing the threefold interplay in full. Few empirical studies which were relevant to this study explicitly targeted the aerospace sector, with exceptions such as Browning and Heath (2009), Amrani and Ducq (2020), and Nightingale and Srinivasan (2011), all which remained predominantly Lean-oriented.

In response to RQ 1.1, the scoping review identified core constructs principles: Lean as a logic of flow, value and waste elimination (Liker, 2021, Womack & Jones, 1997, Womack et al., 1991). Sustainability as a normative orientation defined by triple bottom line (Elkington, 1998, Zokaei et al., 2013). I4.0 operates as an enabling layer encompasses AI, IoT, additive manufacturing, and big data (Buer et al., 2018, Kagermann, 2014, Sony, 2018). However, it was RQ 1.2 that illuminated the critical interdependencies between these paradigms, with Lean offering the operational discipline, I4.0 acting as a visibility and scalability amplifier, and Sustainability providing long-term direction and legitimacy (Kamble et al., 2020, Rahardjo et al., 2023).

Notably, tensions also emerged. Lean's just-in-time practices were found to conflict with environmental priorities due to increased transportation emissions (Singhal et al., 2024). I4.0 technologies whilst their optimisation promise, were associated with high energy demands and resource use. RQ 1.3 led to the formulation of a preliminary conceptual framework outlining five key integration avenues: technology integration, sustainable operational excellence, Sustainability-circular economy advancement, supply chain integration and Lean as a dynamic capability. This early model offered relevant insights that informed rather constrained, the empirical phases that followed.

### 7.2.2 Research Objective Two: Exploring Empirical Perceptions, Characteristics, and Influence (RQ 2.1-2.3)

The second objective investigated the practical relevance, influencing characteristics, and perceived performance influence of LS4.0 integration through 15 semi-structured interviews, complemented by document analysis and site observations. Four key themes were inductively developed and critically refined using Clarke and Braun's (2021) thematic analysis framework.

#### 7.2.2.1 RQ 2.1 Practitioners' Perceptions

The study revealed that Lean remains deeply embedded in aerospace operations, but its adoption is uneven and often misinterpreted. Participants described Lean as necessary yet insufficient on its own, particularly in high-complexity, low-volume environments where regulatory constraints and legacy systems hinder agility. Lean was frequently reduced to implementation "toolbox" rather than a cultural or systemic shift. Yet Lean's relevance to Sustainability was increasingly acknowledged, especially when viewed as a foundation for flow efficiency, resource stewardship, and cross-functional alignment.

Sustainability, although widely recognised as a strategic imperative, particularly in the context of net-zero targets and stakeholders' pressures, Sustainability was marked by immature implementation. The study also observed a lack of clear ownership, inconsistent key performance indicators, and limited integration into design and procurement processes. I4.0, in turn, was perceived as a promising enabler to both Lean and Sustainability ambitions, but its adoption was contingent on organisational readiness, infrastructure, and workforce digital literacy.

#### 7.2.2.2 RQ 2.2: Influencing Characteristics

Characteristics influencing integration spanned both internal and external domains. Internally, leadership commitment, cross-functional collaboration, and capability building acted as essential enablers. Externally, contingencies such as compliance requirements, supply chain volatility, and ecosystem interdependencies frequently operated as barriers. Across the empirical phase, four contingency characteristics dominated: compliance, which imposed strict documentation and traceability disciplines. Complexity, sharpened by high-mix production and demanding design engineering. Novelty reflected the organisation's need to adapt to emerging expectations. Ecosystem maturity, especially the readiness of small and medium-sized suppliers to align with LS4.0 practices.

Within this context, the study identified a multilevel interplay of enablers, barriers, and capabilities that shape LS4.0 implementation. Key enablers included advanced digital tools such as artificial intelligence for generative design and predictive maintenance; visible, long-term leadership alignment; and strong collaboration between information technology and operations, including closer synergy between IT specialists and engineering teams. Main barriers arose from data-access constraints linked to the use of commercial cloud services for defence work in the United Kingdom during the data collection period, immaturity across parts of the supply base, particularly Tier-2 and smaller suppliers with limited capital, resources, and Sustainability literacy, and cultural resistance driven by change fatigue and uneven Lean and digital skills.

Cutting across these conditions, culture, knowledge creation and sharing at both individual and organisational levels, and people development emerged as the capabilities most critical to navigating obstacles and operationalising LS4.0 effectively. These were prioritised by the Delphi expert panel in the second round, as detailed in Appendix J.

#### 7.2.2.3 RQ 2.3: Influence on Performance

The study identified a broad range of potential performance improvements from LS4.0 integration. On the operational side, these included shorter lead times, faster problem-solving, high efficiency, enhanced employee productivity, and improved visibility through real-time data. From a Sustainability standpoint, the integration was seen as a gateway to achieving both social and environmental goals, especially when supported by meaningful metrics.

To capture these dimensions, this study extended the traditional SQDC framework by adding environment and people, resulting in SQDCEP. Some participants also suggested including customer satisfaction to better reflect external stakeholder expectations and drive accountability, but the latter is reflected in the traditional performance framework dimensions. This shift represents a more balanced and future-ready performance measurement approach that aligns operational metrics with sustainability and human-centric objectives.

### 7.2.3 Research Objective Three: Refine and validate the LS4.0 model (RQ 3.1-3.2)

Although the LS4.0 model was initially conceptualised during Objective Two, its refinement and validation were achieved through Objective Three, using a two-round Delphi study with senior aerospace experts. The model was structured around seven higher-order capabilities and are supported by strategic alignment mechanisms such as the voice of the customer and stakeholders and feedback loops. These capabilities were shown to interact dynamically within the four contingency characteristics to produce variable performance outcomes, structured using SQDCEP framework. Importantly, the model highlights that integration cannot be uniform or prescriptive, rather, it must evolve through iterative cycles of sensing, seizing, and transforming, thus embodying the adaptive logic of dynamic capabilities theory.

#### 7.2.3.1 RQ 3.1: Model Development

The final LS4.0 model brings three threads together into a single operational logic. First, strategic drivers, the voice of the customer and stakeholders, vision, strategy, and leadership, set intent and direction (Liker, 2021, Womack & Jones, 1997). Second, a synergy cycle shows how Lean's flow, waste elimination, value creation, respect for people inherently support Sustainability's triple bottom line, and I4.0 through information, connectivity, cyber-physical systems capability reinforces one another when sequenced appropriately (Duarte & McDermott, 2025, Elkington, 1998, Sony et al., 2021). Third, seven higher-order capabilities named: Leanness, information, knowledge, technological infrastructure, collaboration, culture and people, translate strategy into practice and, through feedback loops, convert practice back into learning, consistent with dynamic capabilities theory's sensing, seizing, and transforming (Teece, 2007, 2018). Performance is read through an extended SQDCEP lens. In short, leadership sets intent, capabilities do the work, SQDCEP reads the results, and feedback loops keep the system adaptive. Critically, the model is non-prescriptive, LS4.0 recognises that compliance, complexity, novelty, and ecosystem conditions shape how the seven capabilities are configured and paced, aligning with contingency theory (Donaldson, 2001).

#### 7.2.3.2 RQ 3.2 Model Validation

Two Delphi rounds with the case senior aerospace experts stress-tested the model's fit for aerospace and sharpened its language. Experts endorsed the capability set and the contingency layer but made important refinements. These included "Improvement" (I) in the performance frame was replaced with "People" (P) to reflect human-centric industry directions and the social pillar of Sustainability aligning with Industry 5.0 discourse. Experts asked to distinguish raw data from decision-usable information, aligning the model with the sensing stage of dynamic capabilities theory and the site reality that "data-rich" is not "insight-rich". The voice of the customer and stakeholders was reframed as a true feedback mechanism, rather than a static "input" was positioned as loop that updates strategy in light of SQDCEP results. Delphi Panel guidance also emphasised *governance* over tools, visible leadership through gemba and go and see, careful sequencing, and small project pilots to avoid change fatigue, exactly the contingency-sensitive stance the model adopts (Donaldson, 2001, Teece, 2007).

In summary, the three research objectives collectively informed the design, development, and validation of a novel operational integrative model grounded in the lived realities of aerospace practitioners, offering both theoretical advancement and applied relevance for the next generation of sustainable, digital, and Lean manufacturing systems.

### 7.3 Contributions to Knowledge

This study makes original contributions to both theory and practice by critically examining how Lean, Sustainability, and I4.0 technologies can be integrated to address the evolving challenges of the UK aerospace sector. At the core of these contributions is the LS4.0 model, a novel, empirically informed, and context-specific framework that positions Lean not merely as a cost-reduction tool but as a strategic enabler of Sustainability and digital transformation. The contributions are categorised into three main domains: theoretical, methodological, and practical.

### 7.3.1 Advancing Theoretical Understanding

This study addresses a critical gap in existing literature by developing one of the first empirically validated LS4.0 model tailored to aerospace manufacturing. Whilst previous studies often explored Lean, Green, or digital paradigms in isolation, or at best, in pairs, few have approached their integration as mutually reinforcing systems within a specific sectoral context. Furthermore, most frameworks remain conceptual or lack empirical validation.

This research advances theory in three distinct ways:

#### 7.3.1.1 Holistic Integration of Paradigms

Unlike studies that examine Lean-Green (Garza-Reyes, 2015) or Lean-I4.0 synergies (Buer et al., 2018, Kamble et al., 2020, Sony, 2018), this research demonstrates that the integration of all three paradigms can generate superior outcomes when aligned with sector-specific challenges. The research shows that Lean is not only an efficiency tool but a Sustainability triple bottom line enabler, and that I4.0 technologies can augment Lean practices by improving data access, visibility, and responsiveness.

#### 7.3.1.2 Application of DCT and CT Theories

Drawing on dynamic capabilities theory (Eisenhardt & Graebner, 2007, Teece, 2007), the study illustrates how aerospace organisations develop and reconfigure their operational capabilities to sense opportunities, seize them through targeted resource deployment, and transform process in response to environmental volatility, Sustainability pressures, and digital disruption. The LS4.0 model shows that these dynamic capabilities are abstract routines but manifest through interlined capabilities such as information, knowledge, collaboration, and Leanness. These capabilities operationalise the sensing, seizing, and transforming. Sensing identifies improvement opportunities. Seizing converts insights into process changes and transforming institutionalises new learning cycles.

This study therefore advances dynamic capabilities theory in two important ways:

Firstly, the study extends the theory into the under-explored domain of operations and Sustainability integration, showing that dynamic capabilities are not limited to market or technological adaptation, but also encompass socio-technical transitions that embed environmental and social objectives within operational systems. Secondly, the study confirms that dynamic capabilities are shaped by contextual conditions, hence introducing a contingent interpretation to dynamic capabilities theory. Whilst prior research often assumes that capability reconfiguration inherently leads to advantage, this study reveals that in aerospace manufacturing such outcomes depend on regulatory flexibility, supplier ecosystem maturity, and digital infrastructure readiness. Thus, the study provides an empirically grounded refinement of dynamic capabilities theory by linking dynamic capability activation to sector-specific constraints and maturity levels, addressing calls by Schilke et al. (2018) for contextualised examinations of dynamic capabilities theory.

Simultaneously, the model integrates contingency theory (Donaldson, 2001) by embedding the four emergent characteristics named compliance, complexity, novelty, and ecosystem interdependence, demonstrating that successful LS4.0 integration in context-dependent rather than universally prescriptive. The LS4.0 model empirically supports contingency theory's core proposition that organisational effectiveness results from a "fit" between structure, environment, and strategy. However, the study also extends contingency theory by introducing dynamic fit rather than static alignment as aerospace firms must continuously recalibrate their structures and routines as technologies, regulatory regimes, and stakeholder expectations evolve. This dynamic interpretation moves contingency theory beyond its traditional focus on equilibrium, aligning it with the adaptive logic of dynamic capabilities theory.

By combining dynamic capabilities theory and contingency theory, this research provides a novel theoretical synthesis that bridges the micro-foundations of capability development with the macro-contextual conditions of industrial environments. The LS4.0 model thus advances both theories by demonstrating that:

1. Dynamic capabilities are manifested through interconnected Lean, Sustainability, and I4.0 routines that translate sensing, seizing, and transforming into measurable operational behaviours.
2. The effectiveness of those capabilities is moderated by contextual contingencies that shape when and how transformation can occur.

Therefore, this research empirically validates and extends both dynamic capabilities theory and contingency theory. The study confirms that organisational transformation in highly regulated, high-complexity sectors like aerospace is not solely a function of internal reconfiguration but also of contextual alignment and learning velocity. The LS4.0 model therefore provides a dual-theory contribution: it grounds dynamic capabilities theory in a socio-technical Sustainability context and evolves contingency theory into a dynamic framework capable of explaining adaptive alignment in I4.0 enabled environments.

#### 7.3.1.3 SQDC (Safety, Quality, Delivery, and Cost) performance framework extension

The study expands the performance measurement discourse by introducing the SQDCEP framework, which builds on the widely used safety, quality, delivery, and cost by adding environment and people as equally important performance dimensions. This modification reflects the evolution towards human-centric Industry 5.0 thinking and addresses social Sustainability issues, such as workforce empowerment and resilience, which were highlighted by practitioners during interviews.

Finally, by adopting dynamic capabilities theory, this thesis sheds light on how aerospace organisations can dynamically sense opportunities, seize them through digital and Lean-driven interventions, and transform operations to achieve continuous improvement. capabilities like information, knowledge and Leanness are shown to work synergistically to build competitive advantage whilst meeting Sustainability imperatives, thus bridging the often-siloed discussions of operational efficiency and environmental responsibility.

### 7.3.2 Methodological advancements

The methodological contribution lies in the combination of a qualitative single-site case study with a Delphi validation process, which together enabled iterative development and expert validation of the LS4.0 model. This sequential design transformed the research from descriptive exploration into an empirically grounded and practitioner-informed framework, ensuring both depth and practical relevance.

The methodological advancement resides in the theory integration, rather than in the use of multiple methods alone, the case study was explicitly guided by dynamic capabilities theory and contingency theory, ensuring that data collection, coding, and interpretation were aligned with the constructs of sensing, seizing, transforming and contextual fit. The subsequent Delphi phase extended this alignment by criticising and refining the model's practical applicability and theoretical coherence through expert consensus, hence operationalising theory refinement in a structural manner.

Triangulation across semi-structured interviews, documentary analysis, and on-site observations enhanced credibility and allowed cross-verification of insights from different points within the organisation (Yin, 2018). Reflexivity was supported through the use of a researcher journal and field notes to capture observations and personal insights during data collection and analysis. Although the journal was not maintained in a rigid, systematic structure, it effectively served as a reflective tool to minimise bias and guide iterative improvements to interview protocols. In qualitative research, such flexibility is acceptable as long as reflexivity is visible and documented, which this study achieves through triangulation and transparent reporting of methodological decisions (Lincoln & Guba, 1985).

Finally, the integration of an inductive thematic analysis with Delphi refinement constitutes a methodological robust process that links empirical enquiry with theoretical testing. This combination not only validated LS4.0 model but also ensured that it reflects both theoretical robustness and practical applicability in a regulated aerospace environment.

### 7.3.3 Practical Contributions

From a practical-oriented perspective, this research provides a roadmap for aerospace organisations seeking to operationalise Sustainability without undermining quality, compliance, or competitiveness. The LS4.0 model serves as decision-support framework, helping organisations evaluate their readiness, prioritise capability investments, and align transformation programmes with strategic and regulatory requirements.

The model's voice of the customer and stakeholder driver ensures that operational strategies remain closely aligned with both customers and regulatory expectations. For example, incorporating stakeholders such as regulators and local communities into the feedback loop are essential for achieving long-term Sustainability targets.

The Delphi experts consistently emphasised that leadership commitment, strategic alignment, cultural maturity, and governance are far more critical to LS4.0 success than technological infrastructure alone. Whilst I4.0 tools such as AI and IoT were recognised as valuable enablers, experts highlighted that these technologies only deliver value when guided by a strong strategic vision, gemba-based leadership engagement, and an organisational culture open to change and continuous improvement.

One particular novel practical contribution is the emphasis on dual value stream mapping, where both productivity and Sustainability footprints are visualised side by side. This approach, highlighted by participants as a concrete method for balancing operational and Sustainability gains.

The research also underscores the centrality of people and culture. Lean transformations in aerospace cannot succeed without leadership commitment, exemplified by gemba and go and see practices that connect senior managers to operational realities on the shop floor. As several participants noted, without cultural buy-in and workforce upskilling, even the most advanced technologies will fail to deliver sustainable improvements. By integrating people as both a capability and a performance outcome, the LS4.0 model addresses the social dimension of Sustainability that is often neglected in technical frameworks.

By capturing these expert insights and embedding them into LS4.0 model, this study provides aerospace practitioners with a roadmap that balances technological adoption with human-centric enablers. This makes the model not just a technical framework but a strategic transformation guide that can be scaled across organisations with varying digital and Lean maturity levels.

## 7.4 Implications for Practice

The findings of this research hold significant implications for aerospace practitioners, senior leaders, and operational strategists, offering a structured pathway to integrate Lean, Sustainability, and I4.0 technologies in a way that is both practical and context specific. The LS4.0 model is not merely a theoretical construct, it's a decision-support and improvement tool that can help organisations evaluate their current state, prioritise capability-building efforts, and embed Sustainability and digitalisation into the heart of Lean transformations.

By aligning strategic drivers such as voice of the customer and stakeholder, strategy, and vision detailed in see section 5.3.6 with operational mechanisms including capabilities, the synergy cycle, and feedback loops, LS4.0 model provides a dual-level approach to transformation. At the strategic level, LS4.0 model ensures that high-level organisational priorities such as customer Sustainability expectations and regulatory compliance requirements, cascade effectively into actionable objectives. At the operational level, LS4.0 offers practical mechanisms such as dual value stream mapping, people empowerment, and real-time data integration to achieve measurable improvements across the SQDCEP performance dimensions. This alignment allows organisations to translate Sustainability ambitions into tangible performance outcomes, ensuring coherence between long-term strategy and day-to-day extension.

### 7.4.1 Implementing the LS4.0 model

Effective implementation of LS4.0 model requires three fundamental conditions, as reinforced by the Delphi rounds findings. First, leadership alignment and commitment are essential. Senior leaders must go beyond advocacy to actively engage with operational routines, through gemba walks, daily management practices, and visible problem-solving, to model the behaviours expected from teams. Second, cultural readiness and governance are required to ensure that digital and Lean initiatives are not perceived as isolated projects but as part of an integrated organisational strategy. Third, capability maturity must be established before advanced technologies are deployed at scale. This includes ensuring that Leanness, knowledge management, and collaboration mechanisms are sufficiently developed to support digital and Sustainability integration.

The model's main drivers such as voice of the customer and stakeholders, vision and strategy operate as the levers for integration. The voice of the customer and stakeholders mechanism ensures that Sustainability and quality requirements are understood not only from customers but also regulators and wider community (Antony et al., 2021, Duarte & McDermott, 2025). For example, regulatory initiatives such as the European Aviation Safety Agency's net-zero targets must be systematically translated into operational objectives through policy-deployment mechanisms such as Hoshin Kanri (EASA, 2023).

The synergy cycle operationalises these drivers by promoting continuous alignment between Lean, Sustainability, and I4.0 capabilities. Information and knowledge capabilities play a central role in this process, as the empirical findings in Chapter 4 Four indicated that real-time data collection and actionable insights are fundamental to both achieving operational excellence and Sustainability measurement.

A key practitioner insight that emerged from the Delphi panel is the principle of "doing, not telling". Change fatigue often arises when initiatives remain overly conceptual or detached from day-to-day realities. Early pilot projects focused on visible process improvements and workforce benefits are therefore essential to demonstrate the practical value of LS4.0 and to foster buy-in across all organisational levels.

### 7.4.2 Post-COVID Aerospace Lessons for Commercial Platform

The post-COVID recovery exposed structural weaknesses in the aerospace industry, offering valuable lessons on the limitations of traditional Lean practices in a sector defined by low-volume and high-complexity production (Hyder, 2021). The sharp rebound in air travel demand following global lockdowns, combined with severe supply chain disruptions and labour shortages, led to a period of operational turbulence that highlighted the fragility of systems designed primarily for cost-efficiency rather than resilience (Bushey, 2021). Unlike high-volume industries such as automotive where Lean methodologies have matured over decades to handle fluctuations in demand, the aerospace sector struggled to adjust, with production ramp-ups delayed and supplier networks strained to breaking point (Amrani & Ducq, 2020).

At the heart of these challenges was the prioritisation of delivery dimension within the traditional SQDC framework, often at the expense of other dimensions such as quality, cost, people and environment, as observed at the case study site. This imbalance created a culture where “hitting the numbers” risked overshadowing systemic improvement and long-term resilience.

Within this context, LS4.0 acts as a coherence mechanism: Lean disciplines stabilise flow and problem-solving, Sustainability broadens the performance horizon beyond schedule pressure alone, and I4.0 adds the sensing and response capacity required under volatility. Practically, the LS4.0 model enables organisations to firstly, rebalance performance attention so that safety, quality, people, and environment dimensions are not eclipsed by short-term schedule imperatives. Secondly, sequence digital investments after stabilising processes. Third, build supplier-side capability to avoid pushing risk upstream.

Framed through dynamic capabilities theory (Teece, 2007), LS4.0 operationalises sensing such as real-time visibility, seizing, deployment of resources and transforming governance and culture to support ramp-up without compromising compliance or Sustainability goals, thus, enhancing scalability and resilience.

#### 7.4.2.1 Resilience and LS4.0 as an Enabler

Resilience in aerospace is not merely about recovery after disruption but about designing operational systems that pivot quickly without compromising safety, compliance, quality, or Sustainability goals (Chari et al., 2022, Reichsthaler et al., 2023). LS4.0 model contributes to this by integrating Lean, Sustainability, and I4.0 technologies into a cohesive framework that is both forward-looking and adaptive. Whilst Lean provides a foundation for process discipline and waste reduction, I4.0 adds the predictive and real-time visibility tools needed to sense disruptions early and respond effectively. For example, IoT-enabled sensors and advanced analytics can provide early warnings of supply chain bottlenecks, enabling organisations to reconfigure production schedules before problems escalate.

Dynamic capabilities theory (Teece, 2007) offers a useful lens here. The ability to sense, seize, and transform is particularly critical in aerospace, where lead times are long and the cost of misalignment between demand and supply is significant. Lean practices, whilst effective for steady-state operations, are often insufficient in environments characterised by rapid fluctuations in demand. LS4.0 model embeds continuous sensing mechanisms through its voice of the customer and stakeholders driver, whilst the feedback loops in the model allow organisations to “seize” opportunities and “transform” operations based on real-time insights. This capability was notably absent in many organisations during the recovery period, as observed in chapter Four.

#### 7.4.2.2 Scalability: Operational and Sustainability Dimensions

Scaling aerospace production is not simply a matter of increasing throughput. Scaling involves synchronising multi-tier global supply chains, maintaining stringent regulatory compliance, and managing the environmental footprint of increased production volumes. Post-COVID recovery has made it clear that scalability and Sustainability must go hand in hand. Traditional Lean tools like value stream mapping to evolve into dual value stream mapping, capturing not just productivity metrics but also environmental impacts such as carbon emissions and energy use (Batwara et al., 2023, Fontoura et al., 2023). This aligns with empirical insights and reflects an emerging recognition in the literature that operational excellence must incorporate environmental and social metrics (Ghobadian et al., 2020, Sony, 2018).

The LS4.0 model explicitly integrates this dual perspective through the SQDCEP framework. The post-COVID period demonstrated that neglecting “people” aspects, such as workforce resilience and skills development can undermine recovery efforts, leading to burnout and attrition.

#### 7.4.2.3 Digital Enablers for Forecasting and Agility

Whilst advanced analytics for demand forecasting was not explicitly framed as a theme in earlier chapters, it is a natural extension of the LS4.0 model’s information and knowledge capabilities. By leveraging historical data and real-time inputs from suppliers and customers, aerospace firms can better predict demand fluctuations and adjust resources proactively (Belhadi et al., 2020, Suh & Ryerson, 2019). This is particularly critical in a sector where lead times can span months or years, and misjudging demand can result in either costly overcapacity or missed delivery commitments (Browning & Heath, 2009).

Digital traceability, achieved through technologies such as blockchain and digital twins, also plays a key role (Powell et al., 2024). Digital traceability enables full visibility across complex supply chains, ensuring that compliance, quality, and Sustainability requirements are met at every stage (Antony, McDermott, et al., 2021, Duarte & McDermott, 2025). Whilst not previously highlighted as a standalone theme, this thesis argues that digital traceability is implicitly linked to the LS4.0 collaboration and information capabilities and is an essential enabler of post-pandemic resilience.

#### 7.4.2.4 Positioning LS4.0 in the Literature

To the best of this researcher's knowledge, no prior studies have explicitly framed resilience and scalability through an LS4.0 lens tailored for aerospace. The few aerospace-focused Lean studies, such as Amrani and Ducq (2020) who examined Lean implementation at a business-class seat manufacturer called "Aeroseat", and Browning and Heath (2009), who analysed the Lockhead Martin F-22 programme, primarily concentrated on Lean adoption and its operational challenges. Whilst insightful, these works neither address Sustainability imperatives nor integrate I4.0 technologies.

The broader literature reviewed in the scoping study remains largely conceptual and sector-neutral, often exploring only pairwise relationships such as Lean-Green (Lenin et al., 2021) or Lean-I4.0 synergies (Kamble et al., 2020). This thesis advances a model that unites Lean, Sustainability, and digitalisation into a single framework. LS4.0 not only addresses aerospace's operational performance gaps but also positions resilience and Sustainability as strategic capabilities to navigate post-pandemic demand surges and emerging regulatory pressures.

### 7.4.3 Capability Development

The research highlights that capabilities are the backbone of LS4.0 implementation. Among the seven capabilities identified in the model, people, knowledge, and culture emerged as particularly critical, see Appendix J Delphi Round 2 Results.

Leanness remains a fundamental, but as the case site findings revealed, Lean principles require significant adaptation to suit aerospace's low-volume, high-mix production context. Tools such as dual value stream mapping, which capture both operational productivity and Sustainability footprints, represent practical mechanisms for integrating Lean with Sustainability performance metrics.

Information and knowledge capabilities were consistently identified as central enablers. Real-time visibility and cross-functional learning were repeatedly emphasised by both practitioners and experts as essential precursors to LS4.0 deployment. The Delphi feedback reinforced that data alone is insufficient unless it is transformed into actionable information and institutionalised as organisational knowledge that supports continuous improvement.

Culture and people capabilities embody the social Sustainability dimension of the model. Chapter 4 and Chapter 5 employee empowerment and leadership visibility are essential for overcoming resistance and ensuring that digital tools are used to augment, not replace, skilled workers. These human-centred dimensions ensure that LS4.0 implementation remains grounded in respect for people, aligning with Lean's foundational philosophy.

Collaboration, both within internal functions and across supplier-customer ecosystems, was also identified as a capability requiring significant development. Findings revealed that these ecosystems remain fragmented and often underprepared for Sustainability requirements and digital integration. Strengthening collaboration thus becomes essential for enabling value-chain-wide alignment and shared capability building.

Collectively, these capabilities act as dynamic mechanisms that allow organisations to adapt resilience and future-readiness demands. Together, these capabilities provide the organisational foundation through which the LS4.0 model can be operationalised effectively within complex, regulated industrial environments like aerospace.

### 7.4.4 LS4.0 as an Enabler for High-Volume Trends

The aerospace sector is gradually shifting towards higher production volumes, particularly in the civil aviation platform, where OEMs like Airbus and Boeing are ramping up output to meet large order backlog (ADS, 2025, Airbus, 2024, Boeing, 2024). However, as the post-COVID recovery demonstrated, this transition will test the sector's ability to scale operations without compromising quality, safety, or sustainability.

LS4.0 offers a resilience-oriented approach by combining Lean efficiency with digital adaptability and Sustainability imperatives. The model's feedback loops, particularly those linking SQDCEP outcomes back to strategy and leadership, enable organisations to continuously re-evaluate performance metrics in light of emerging market conditions.

This is particularly relevant for balancing high-volume demands with stringent regulatory requirements and environmental targets e.g., net-zero aviation by 2050. By focusing on real-time information flow, cross-functional collaboration, and human-centric practices, LS4.0 ensures that process improvements are both scalable and sustainable.

#### 7.4.5 A Practical Roadmap for LS4.0 Implementation

Based on empirical findings and Delphi insights, this thesis proposes a three-phase strategic roadmap for practitioners in implementing the LS4.0 model.

The first phase, *Diagnose and Align*, begins with a readiness assessment to evaluate organisation's current Lean maturity, digital infrastructure, and Sustainability metrics. This diagnostic stage enables leaders to identify gaps and opportunities for integration. This phase also involves developing a compelling 'burning platform' narrative that articulates why LS4.0 is necessary, linking the transformation to both operational gains and workforce benefits. As Delphi Expert Two emphasised, organisations must "create the need, why are we doing this? How does it benefit our people?"

The second phase, *Pilot and Demonstrate Value*, focuses on action and early success. Implementation should begin with workforce-level projects where Lean and I4.0 tools can visibly improve performance. The emphasis, as highlighted by Delphi Expert One, is on "doing, not telling." During this stage, dual value stream mapping can be used to demonstrate both cost savings and Sustainability improvements, ensuring that quick wins reinforce cultural buy-in and establish confidence in the approach.

The third phase, *Scale and Embed*, extends the model across value streams and institutionalises feedback mechanisms into governance structures. Regular reviews, such as quarterly evaluations of SQDCEP should be embedded into strategic oversight. This phase also calls for sustained investment in capability building, particularly in data literacy, cross-functional collaboration, and leadership visibility. Such investments are essential to ensure that LS4.0 implementation remains resilient, human-centred, and align with long-term organisational objectives.

Ultimately, this roadmap is designed to be adaptive, allowing organisations to tailor LS4.0 deployment to their specific context, operational maturity, and strategic priorities. This roadmap provides a structured yet flexible approach that enables continuous learning and progressive integration, ensuring that transformation efforts translate into tangible and enduring value.

## 7.5 Limitations

Whilst this research offers valuable theoretical and practical contributions, it is not without limitations. Recognising and critically reflecting on these constraints is essential, not only to acknowledge potential weaknesses but also to clarify the study's boundaries and identify opportunities for future research. These limitations concern methodological, theoretical and practical dimensions, each of which is discussed below.

### 7.5.1 Single-Site Case Study Design

One of the most significant limitations is the single-site focus. The case study was conducted in a leading UK-based aerospace organisation, which, although well-suited to the study's interpretivist and exploratory aims, inherently limits the generalisation of findings. Whilst rich qualitative data enabled a deep contextual understanding, the specificities of the site's operations, culture, and maturity may not fully represent the broader aerospace sector.

The unique organisational characteristics, mean that the findings may not readily transfer to other organisations or sectors. The case study approach prioritised depth over breadth, a methodological decision aligned with the exploratory nature of this research, but one which the reader may view as a limitation in terms of external validity.

In qualitative inquiry, however, transferability rather than statistical generalisability is the appropriate aim in qualitative research (Lincoln & Guba, 1985). To strengthen transferability, the research incorporated methodological triangulation including fifteen interviews, company documents, and on-site observations, so that insights were not dependent on a single data source. Additionally, the subsequent Delphi validation expanded the perspective by incorporating expert feedback from across organisation's wider network, offering additional viewpoints and enhancing the credibility of the model.

### 7.5.2 Researcher Positionality and Bias

The researcher's insider position, with prior professional experience in the aerospace sector, offered both advantages and challenges. On one hand, this familiarity enabled rapport-building with participants and a deeper understanding of industry-specific terminology, processes, and challenges. On the other hand, there is a risk of interpretive bias, where the researcher's assumptions or prior experiences may have influenced data interpretation.

To mitigate this risk, reflexivity was maintained through flexible, reflective research journal and field notes, which complemented triangulation and Delphi member-checking. In qualitative research, such flexibility is acceptable as long as reflexivity is visible and documented, which this study achieves through triangulation and transparent reporting of methodological decisions (Lincoln & Guba, 1985).

### 7.5.3 Qualitative Delphi Limitations

The Delphi validation in Chapter Five provided valuable expert feedback and consensus on the LS4.0 model but also presents limitations. The panel consisted of only four experts, which, whilst sufficient for a firm-specific, high-expertise panel, may be perceived as narrow (Brady, 2015, Hasson & Keeney, 2011, Okoli & Pawlowski, 2004). The homogeneity of expertise, largely within the same organisational context, could have limited divergence of perspectives and reduced the diversity of critical feedback (Hsu & Sandford, 2007, Rowe & Wright, 1999).

The Delphi rounds were structured into two formal stages, one qualitative and one mixed method, followed by a final consensus communication, consistent with Delphi applications

(Brady, 2015, Hasson & Keeney, 2011). The researcher scheduled 30 minutes upon the request of the experts, it was not something initially planned in the Delphi process, but it seemed natural, as each expert felt the need to express their views and clarify their responses. Expert three provided also an additional email to summarise their responses and provided concrete example of their life experience. Although the anonymity is a strength of Delphi, this mode of communication may have constrained richer collaborative insights, as if there was a possibility of open-table debate and clarification of disagreements among the experts (Hasson & Keeney, 2011, Linstone & Turoff, 1975, Rowe & Wright, 1999).

### 7.5.4 Data Collection Methods and Depth

Whilst the semi-structured interview method was appropriate for exploring perceptions, enablers, and barriers, its effectiveness depended heavily on the researcher's ability to probe and adapt to participant responses. As noted in Chapter Three, pilot interviews revealed that participants often framed Lean Sustainability positively, drawing on prior experience rather than critiquing current practices. Although the interview protocol was adjusted to ask deeper, more critical questions, the risk of "polished narrative" remains, especially when interviewing senior managers who may be inclined to present their organisation in a favourable light (Flick, 2021).

Additionally, whilst documentary evidence e.g., Sustainability reports, company data provided contextual insights, such documents were sometimes selectively curated (Bowen, 2009). This highlights the limitation of secondary data in reflecting the realities of operational challenges. Observations conducted on-site, whilst helpful, were limited in scope and duration due to access constraints, which may have reduced opportunities to capture unfiltered operational realities (Patton, 2014, Yin, 2018).

### 7.5.5 Conceptual Boundaries of the LS4.0 Model

The LS4.0 model, whilst novel and context-specific, is a conceptual framework that has not yet been implemented and tested in a live operational environment. The model's validation through Delphi experts ensures practical credibility, but empirical testing of its long-term effectiveness remains beyond the scope of this study.

The SQDCEP framework, for example, was identified as a valuable enhancement to performance measurement, but the extended SQDCEP actual operationalisation, especially for people and environment metrics, remains conceptual at this stage (Eisenhardt & Graebner, 2007, Meredith, 1998). Whilst this aligns with the exploratory aims of the thesis, it may invite reader questions about how the model would be implemented and measured in practice.

### 7.5.6 Timeframe and Evolving Industry Dynamics

The study was conducted during a period of significant post-COVID disruption and digital transformation momentum within aerospace. Whilst this timing enhanced the study's relevance, it also means that findings reflect a specific moment in the sector's recovery trajectory (Bushey, 2021, Hyder, 2021). The shift towards high-volume production, anticipated in the next 5 to 10 years (Amrani & Ducq, 2020), could alter the applicability of some findings. For example, Lean-Sustainability integration strategies designed for low-volume environments may require substantial adaptation as production ramps up.

### 7.5.7 Reflections on Methodological Rigour

A reader might also critique the absence of quantitative methods. Whilst the qualitative approach was deliberately chosen to explore an under-theorised integration model, the reliance on qualitative narratives means that quantifiable validation of the SQDCEP framework was beyond the study's scope (Eisenhardt, 1989, Lincoln & Guba, 1985). This is not a weakness per se, given the exploratory, model-building aim, but it does limit the empirical evidence for causality between Lean, Sustainability, and I4.0 integration and performance metrics.

## 7.6 Recommendations for Future Research

The study opens several avenues for future research to build on its findings and address its limitations. First, multi-site studies across different aerospace organisations, including those in other regions including North America, Asia, Africa, could enhance the generalisability of the LS4.0 model. Such studies could explore variations in contingency characteristics such as compliance and complexity and test the model's adaptability in diverse contexts (Sousa & Voss, 2001, Voss et al., 2002).

Second, longitudinal research could track implementation over time to assess long-term impacts on operational and Sustainability performance. For instance, following progress towards the site's net-zero operational target beyond 2030 would allow evaluation of the model's continuous improvement mechanisms. Maware and Parsley (2023) offer useful precedents for longitudinal evaluation.

Third, future research should probe supply-chain Sustainability, addressing the immaturity identified by participants. Studies might test supplier education and collaboration interventions and examine how the collaboration capability performs across tiers. See McDermott et al. (2023) and Powell and Coughlan (2020) for relevant approaches.

Fourth, expanding the participant sample to include frontline workers and a broader Delphi panel would capture diverse perspectives, addressing the study's sample limitations. This could provide richer insights into social Sustainability, including staff burnout noted by participants and would help refine the voice of the customer and stakeholders construct further. Hsu and Sandford (2007) provide guidance on Delphi panel design.

Finally, quantitative studies should test the model's effectiveness using metrics like emission reductions or turnaround times, complementing the qualitative findings and providing and providing empirical validation of the SQDCEP framework. For methodological direction, see Sousa and Voss (2001). These research directions extend the study's contributions and advance knowledge and practice in aerospace.

### 7.7 Final Reflections

From a retrospective and reflective perspective, this research journey has been far more than an academic exercise; it has been a profound process of professional and personal transformation. Over five years of sustained effort, without pause, I found that when I was not writing, I was reflecting, testing my arguments, reshaping my ideas, and challenging myself to sharpen my reasoning. Balancing a demanding professional role in aerospace supply chain operations, personal commitments, and research, required resilience and sacrifice, but it has also generated an enduring conviction that the LS4.0 model offers practical and theoretical value for the sector.

As practitioner, I entered the academic space not simply to contribute to scholarly debates, but because of a vision: the aerospace sector is undergoing profound change, and there remains a striking absence of published studies in operations and business management that critically engage with this evolution. The industry is already discussing transformative shifts such as the emergence of air taxis and new sustainable propulsion systems. These trajectories demand operational frameworks that are both resilient and sustainable, yet few academic studies address this. The LS4.0 model, therefore, represents both a research contribution and a practitioner-driven response to a sector in flux.

Alongside this thesis, I have developed research outputs that I intend to publish. Chapter Two, the scoping review, was written as a journal-ready paper, Chapter Five, which introduces the integrative operational LS4.0 model, likewise lends itself to publication. In addition, I have prepared working papers on aerospace supplier development and risk-mitigation frameworks. Taken together, these outputs reflect my determination to translate doctoral research into accessible contributions that inform both academic theory and industry practice.

The process of engaging with academic conferences and University doctoral consortiums has been pivotal. Presenting early findings to international audiences not only strengthened my conviction that this line of research is timely but also confirmed the global relevance of aerospace operation to broader debates on Lean, Sustainability, and digitalisation. These experiences, combined with dialogue with scholars and practitioners, have encouraged me to continue this journey beyond PhD, aiming to contribute to the field through publication, collaboration, and mentoring.

On a personal level, this work has been life changing. It has required me to reflect deeply on my own values and aspirations and cultivate new ways of thinking that extend beyond technical domains of my professional training. I have learned to hold in tension the demands of rigour and relevance, to see theory as a tool for making sense of practice, and to treat reflection as an integral part of research, not an afterthought. In many ways, the thesis embodies the dual identity I have developed: the practitioner who confronts daily operational realities, and the scholar who seeks to theorise them in ways that can inform broader communities.

As this stage of the journey concludes, I am conscious that is not an end but a beginning. In the immediate future, I will take time to prepare for my oral examination, reflect on the lessons learnt throughout this research, and develop publications from the chapters that were written with journal submission in mind, including the scoping review in Chapter Two and the LS4.0 model in Chapter Five. The LS4.0 model itself is a foundation, not a final word, offering a platform for future refinement through longitudinal studies, supply chain applications, and comparative research across regions. Above all, the journey has taught me the importance of perseverance, critical reflection, and authenticity, qualities that will continue to guide me as both as scholar and a practitioner in the evolving aerospace sector.

### 7.7.1 Concluding Note

At the start, this project felt like a research challenge; with hindsight, it has been a journey of personal transformation. It has not always been straightforward. At times it required difficult choices, sacrifices, and leaps into unfamiliar ways of thinking. Yet those very challenges have reshaped how I see myself as both a practitioner and a researcher. This journey has governed my life for over five years, demanding persistence but rewarding me with sharper thinking, deeper self-awareness, and a renewed belief in the value of resilience and authenticity. I now see this thesis not as an end, but as the beginning of a new chapter, one where I continue to contribute to aerospace operations and supply chain, both through academic publications and through practice. The journey has been life-changing, and it will continue.

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## Appendix A Reviewed Articles of Scoping Review

| ID | Source-e | Title | Authors | Publication Yea |
|---|---|---|---|---|
| 1 | EBSCOHOST | Linkages between smart, lean, and resilient manufacturing for sustainable d | Benkhati, Imane; Belhadi, Amine; Kamble, Sachin S.; Ezahra Touriki, Fatima | 2023 |
| 2 | EBSCOHOST | Enabling the Circular Economy transition: a sustainable lean manufacturing | Ciliberto, Cristina; Szopik-Depczyńska, Katarzyna; Tarczyńska-Łuniewska, Małgorzata; Ruggieri, Alessandro; Ioppolo, Giuseppe | 2021 |
| 3 | EBSCOHOST | Integrated Impact of Circular Economy, Industry 4.0, and Lean Manufacturin | Ghaithan AM; Alshammakhi Y; Mohammed A; Mazher KM | 2023 |
| 4 | EBSCOHOST | Industry 4.0 and lean manufacturing practices for sustainable organisation | Kamble S.; Gunasekaran A.; Dhone N.C. | 2020 |
| 5 | EBSCOHOST | Modelling interactions of select enablers of Lean Six-Sigma considering sust | Khanzode, Akshay G.; Sarma, P. R. S.; Goswami, Mohit | 2023 |
| 6 | EBSCOHOST | Enhancing the adaptability: Lean and green strategy towards the Industry Re | Leong W.D.; Teng S.Y.; How B.S.; Ngan S.L.; Rahman A.A.; Tan C.P.; Ponnambalam S.G.; Lam H.L. | 2020 |
| 7 | EBSCOHOST | Analyzing the integrated effect of circular economy, Lean Six Sigma, and Indu | Skalli, Dounia; Charkaoui, Abdelkabir; Cherrafi, Anass; Garza-Reyes, Jose Arturo; Antony, Jiju; Shokri, Alireza | 2023 |
| 8 | IEEE | Integrated Sustainable Production Value Measurement Model Based on Lear | Ganjavi N.; Fazlollahtabar H. | 2023 |
| 9 | Scopus | A new vision of LARG Manufacturing — A trail towards Industry 4.0 | Amjad M.S.; Rafique M.Z.; Hussain S.; Khan M.A. | 2020 |
| 10 | Scopus | The Contribution of Lean Management—Industry 4.0 Technologies to Improv | Arana-Landín G.; Uriarte-Gallastegi N.; Landeta-Manzano B.; Laskurain-Iturbe I. | 2023 |
| 11 | Scopus | Does lean and sustainable manufacturing lead to Industry 4.0 adoption: The | Dixit A.; Jakhar S.K.; Kumar P. | 2022 |
| 12 | Scopus | Towards a smart lean green production paradigm to improve operational pe | Fiorello M.; Gladysz B.; Corti D.; Wybraniak-Kujawa M.; Ejsmont K.; Sorlini M. | 2023 |
| 13 | Scopus | Impact of industry 4.0 and lean manufacturing on the sustainability perform | Ghaithan A.; Khan M.; Mohammed A.; Hadidi L. | 2021 |
| 14 | Scopus | Lean & Green on Industry 4.0 Context – Contribution to Understand L&G Driv | John L.; Sampayo M.; Peças P. | 2021 |
| 15 | Scopus | Can Industry 4.0 Assist Lean Manufacturing in Attaining Sustainability over | Maware C.; Parsley D.M., II | 2023 |
| 16 | Scopus | Lean Manufacturing in Industry 4.0: A Smart and Sustainable Manufacturing | Rahardjo B.; Wang F.-K.; Yeh R.-H.; Chen Y.-P. | 2023 |
| 17 | Scopus | Assessing interactions between Lean Six-Sigma, Circular Economy and indus | Skalli D.; Charkaoui A.; Cherrafi A. | 2022 |
| 18 | Scopus | Analysis of factors influencing Circular-Lean-Six Sigma 4.0 implementation | Skalli D.; Charkaoui A.; Cherrafi A.; Shokri A.; Garza-Reyes J.A.; Antony J. | 2023 |
| 19 | Scopus | A Sustainable Methodology Using Lean and Smart Manufacturing for the Cle | Tripathi V.; Chattopadhyaya S.; Mukhopadhyay A.K.; Sharma S.; Li C.; Di Bona G. | 2022 |
| 20 | Scopus | A Sustainable Productive Method for Enhancing Operational Excellence in Sh | Tripathi V.; Chattopadhyaya S.; Mukhopadhyay A.K.; Sharma S.; Li C.; Singh S.; Ul Hussan W.; Salah B.; Saleem W.; Mohamed A. | 2022 |
| 21 | Scopus | Lean and industry 4.0: Mapping determinants and barriers from a social, en | Yilmaz A.; Dora M.; Hezarkhani B.; Kumar M. | 2022 |
| 22 | Scopus | Identification of Key Brittleness Factors for the Lean–Green Manufacturing S | Zhu X.; Liang Y.; Xiao Y.; Xiao G.; Deng X. | 2023 |
| 23 | Snowballing | Examining legitimatisation of additive manufacturing in the interplay betwe | Abby Ghobadiana, Irene Talaverab, Arijit Bhattacharyac, Vikas Kumard, Jose Arturo Garza-Reyese, Nicholas O'Reganf | 2020 |
| 24 | Snowballing | Integrating Green Lean Six Sigma and Industry 4.0: A Conceptual Framework | Kaswan, Mahender Singh;Rathi, Rajeev; Cross, Jennifer; Garza-Reyes, Jose Arturo; Antony, Jiju;Yadav, Vishwas | 2023 |
| 25 | Snowballing | Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Su | Leonilde Varela , Adriana Araújo, Paulo Ávila, Hélio Castro, Goran Putnik | 2019 |
| 26 | Snowballing | The integrated effect of big data analytics, lean six sigma and green manufac | Belhadi, A., Kamble, S. S., Zkik, K., Cherrafi, A., & Touriki, F. E | 2020 |
| 27 | Snowballing | The dimensions of Lean-Green 4.0 readiness a Systematic literature review | Duarte, Susana; Mc Dermott, Olivia | 2025 |
| 28 | Scopus | Integrating Industry 4.0 and Lean Manufacturing for a Sustainable Green Tra | Duarte, Susana, Mc Dermott, Olivia | 2025 |
| 29 | Scopus | Unveiling the interaction among circular economy, industry 4.0, and lean pr | Violetta Giada Cannas; Rossella PozziNicolò; SaporitiAndrea Urbinati | 2025 |
| 30 | Scopus | Process innovation through industry 4.0 technologies, lean practices and gr | Pietro De Giovanni Alfio Cariola | 2021 |
| 31 | Scopus | A maturity model for assessing Digital Green Lean leadership and culture im | Gatell I.S.; Avella L. | 2024 |
| 32 | Scopus | Impact of Industry 4.0 and circular economy on lean culture and leadership | Gatell I.S.; Avella L. | 2024 |
| 33 | Scopus | The Impact of Industry 4.0 Technologies on Operational Excellence Methods | Arora M.; Ahmad V.; Kumar R.; Singh R. | 2025 |
| 34 | Scopus | Implementation of an Integrated Framework of Lean Manufacturing and Indu | Bhadu J.; Bhamu J.; Singh D.; Saraswat P.; Agrawal R. | 2025 |
| 35 | Scopus | Analyzing the integrated effect of circular economy, Lean Six Sigma, and Indu | Skalli D.; Charkaoui A.; Cherrafi A.; Garza-Reyes J.A.; Antony J.; Shokri A. | 2023 |
| 36 | Scopus | Applying the Delphi Method to Assess Critical Success Factors of Digitalizati | Goktas H.O.; Yumusak N. | 2024 |
| 37 | Scopus | Synergizing lean management and circular economy: Pathways to sustainab | Sasso R.A.; Filho M.G.; Ganga G.M.D. | 2025 |
| 38 | Scopus | The lean link: exploring industry 4.0's influence on sustainable operational | Sharma S.; Gupta N.; Thakur P. | 2024 |
| 39 | Scopus | Integrated Green Lean Six Sigma-Industry 4.0 approach to combat COVID-19: | Kaswan M.S.; Rathi R.; Antony J.; Cross J.; Garza-Reyes J.A.; Singh M.; Preet Singh I.; Sony M. | 2023 |
| 40 | Scopus | Towards the integrated supply chain practices through industry 4.0: A biblio | Mahajan P.S.; Raut R.D.; Kumar P.R.; Ghoshal S. | 2024 |
| 41 | Scopus | Driving success through digital transformation: influence of Industry 4.0 on | Piprani A.Z.; Khan S.A.R.; Yu Z. | 2024 |
| 42 | Scopus | Environmental sustainability consideration with just-in-time practices in in | Singhal V.; Maiyar L.M.; Roy I. | 2024 |
| 43 | Scopus | Green lean six sigma practices: a scale development and measurement mode | Gholami H.; Lee J.K.Y.; Garza-Reyes J.A.; Salameh A.A. | 2025 |

## Appendix B Interview Agenda

### Interview Agenda: Exploring Lean, Sustainability, and Industry 4.0 Integration in Aerospace

### Introduction (5 minutes)

- **Welcome and Purpose:** Thank you for participating in this interview. This study explores the integration of Lean, Sustainability, and Industry 4.0 technologies in the UK aerospace sector to enhance operational and sustainable performance. Your insights as a senior practitioner are crucial to understanding perceptions, factors, and impacts of this integration.
- **Ethical Considerations:** The interview will last about one hour and will be recorded with your permission for transcription and analysis purposes. All data will be anonymised, stored securely, and used only for this research. You may withdraw at any time without consequence. Do I have your permission to record this interview?
- **Structure Overview:** We'll start with a background about your role, followed by three main themes: Lean application in aerospace, Lean-Sustainability integration with I4.0, and factors influencing a Lean-Sustainability 4.0 model. I'll ask open-ended questions and may follow up for clarification. At the end, I'll summarise key points and discuss next steps.

### Icebreaker and Background (5-10 minutes)

- **Background Question: "**Can you briefly describe your current role and your experience in general, particularly with Lean and Sustainability?"
- **Icebreaker Question:** "Do you enjoy it here?"

### Themed Questions (40-45 minutes)

### Theme1: Lean application in the aerospace (RQ 2.1: Perceptions, RQ 2.2: Factors)

- **Lean aerospace definition:** "How would you define Lean in the context of aerospace manufacturing?"
- **Relevance and Challenges:** "How do you find Lean application in the aerospace sector?", "Can you describe specific challenges or obstacles the site faces when integrating Lean practices with Sustainability objectives"?

- **Factors Affecting Deployment:** “What are the factors that affect Lean deployment in your organisation?”
- **Adaptation:** “How do you adapt Lean applications in your case?”
- **Benefits and Limitations:** “What are the benefits and limitations of Lean deployment in aerospace?”
- **Lean Evolution:** “How do you see the evolution of Lean in general, and specifically in aerospace?”

### Theme 2: Lean Integrating Sustainability principles in the context of I4.0 (RQ 2.1: Perceptions, RQ 2.3 Impacts)

- **Sustainability Integration:** “How do you find Sustainability integration within operational processes?”
- **Lean-Sustainability Integration**: “What do you think about Lean and Sustainability interrelationships?”
- **Role of Industry** 4.0: “How do you see the role of Industry 4.0 technologies in this integration?”
- **Technology impact on Lean:** “Do you use advanced technologies in your decision-making? And what are these technologies?”, “How do advanced technologies like AI, IoT, Cloud Computing, and Big Data Analytics improve Lean applicability?”

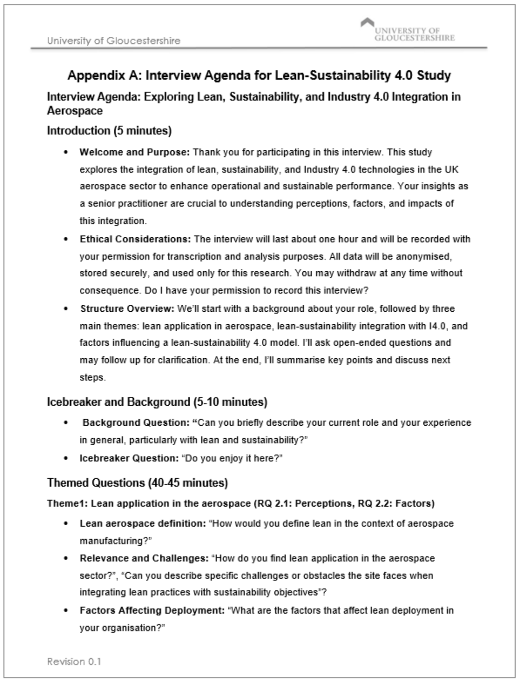
### Theme 3: Lean-Sustainability 4.0 Factors, Enablers, and Barriers (RQ 2.2: Factors, RQ 2.3: Impacts)

- **Capabilities:** “What are the capabilities required to make the Lean-Sustainability 4.0 integration work effectively?”
- **Steps for implementation:** “What are the steps needed to explicitly achieve a Lean-Sustainability 4.0 operational model?”
- **Evaluation criteria**: “Have you encountered Lean evaluation before? What are the non-negotiable criteria that should be included in evaluating a Lean-Sustainability 4.0 model?

### Closing (5 minutes)

- **Summarised Key Points**
- **Thank participants:** Thank you for your time and valuable insights. Your input is crucial to this study.

- **Next Steps:** I'll transcribe the interview and analyse the data as part of my PhD thesis. A summary of findings can be shared upon request, and the result will inform the Lean-Sustainability 4.0 model in my thesis.



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**Appendix A: Interview Agenda for Lean-Sustainability 4.0 Study**

**Interview Agenda: Exploring Lean, Sustainability, and Industry 4.0 Integration in Aerospace**

**Introduction (5 minutes)**

- **Welcome and Purpose:** Thank you for participating in this interview. This study explores the integration of lean, sustainability, and Industry 4.0 technologies in the UK aerospace sector to enhance operational and sustainable performance. Your insights as a senior practitioner are crucial to understanding perceptions, factors, and impacts of this integration.
- **Ethical Considerations:** The interview will last about one hour and will be recorded with your permission for transcription and analysis purposes. All data will be anonymised, stored securely, and used only for this research. You may withdraw at any time without consequence. Do I have your permission to record this interview?
- **Structure Overview:** We'll start with a background about your role, followed by three main themes: lean application in aerospace, lean-sustainability integration with I4.0, and factors influencing a lean-sustainability 4.0 model. I'll ask open-ended questions and may follow up for clarification. At the end, I'll summarise key points and discuss next steps.

**Icebreaker and Background (5-10 minutes)**

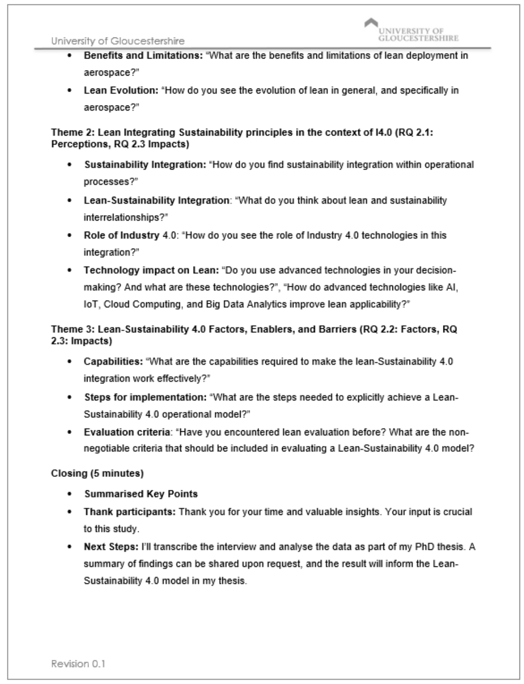
- **Background Question: "**Can you briefly describe your current role and your experience in general, particularly with lean and sustainability?"
- **Icebreaker Question:** "Do you enjoy it here?"

**Themed Questions (40-45 minutes)**

**Theme1: Lean application in the aerospace (RQ 2.1: Perceptions, RQ 2.2: Factors)**

- **Lean aerospace definition:** "How would you define lean in the context of aerospace manufacturing?"
- **Relevance and Challenges:** "How do you find lean application in the aerospace sector?", "Can you describe specific challenges or obstacles the site faces when integrating lean practices with sustainability objectives"?
- **Factors Affecting Deployment:** "What are the factors that affect lean deployment in your organisation?"

Revision 0.1



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- **Benefits and Limitations:** "What are the benefits and limitations of lean deployment in aerospace?"
- **Lean Evolution:** "How do you see the evolution of lean in general, and specifically in aerospace?"

**Theme 2: Lean Integrating Sustainability principles in the context of I4.0 (RQ 2.1: Perceptions, RQ 2.3 Impacts)**

- **Sustainability Integration:** "How do you find sustainability integration within operational processes?"
- **Lean-Sustainability Integration**: "What do you think about lean and sustainability interrelationships?"
- **Role of Industry** 4.0: "How do you see the role of Industry 4.0 technologies in this integration?"
- **Technology impact on Lean:** "Do you use advanced technologies in your decision-making? And what are these technologies?", "How do advanced technologies like AI, IoT, Cloud Computing, and Big Data Analytics improve lean applicability?"

**Theme 3: Lean-Sustainability 4.0 Factors, Enablers, and Barriers (RQ 2.2: Factors, RQ 2.3: Impacts)**

- **Capabilities:** "What are the capabilities required to make the lean-Sustainability 4.0 integration work effectively?"
- **Steps for implementation:** "What are the steps needed to explicitly achieve a Lean-Sustainability 4.0 operational model?"
- **Evaluation criteria**: "Have you encountered lean evaluation before? What are the non-negotiable criteria that should be included in evaluating a Lean-Sustainability 4.0 model?

**Closing (5 minutes)**

- **Summarised Key Points**
- **Thank participants:** Thank you for your time and valuable insights. Your input is crucial to this study.
- **Next Steps:** I'll transcribe the interview and analyse the data as part of my PhD thesis. A summary of findings can be shared upon request, and the result will inform the Lean-Sustainability 4.0 model in my thesis.

Revision 0.1

## Appendix C Participant Consent Form

Participant Consent Form

**Title of the research:** Development of manufacturing production system evaluation framework that combines the principles of Lean manufacturing with sustainable manufacturing in the context of Industry 4.0 for the aerospace sector.

**Researcher:** Mohamed Addajou (PhD researcher at the University of Gloucestershire)

Please check the box if you agree with the statements below:

☐ I confirm that I have read and understand the introduction package explaining the research topic.

☐ I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.

☐ I understand that my responses will be kept strictly confidential. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research

☐ I understand that the data collected from me will be destroyed after the completion of this study. However, I will get when requested the transcript of my interview for final agreement

☐ I give permission for recording and for taking notes.

☐ I agree to take part in the above research and will inform the lead researcher if any changes occur.

___________________ ___________________ ___________________

**Name of participant** **Date** **Signature**

__Mohamed Addajou_ ___________________ ___________________

**Name of researcher** **Date** **Signature**

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Participant Consent Form

**Title of the research:** Development of manufacturing production system evaluation framework that combines the principles of lean manufacturing with sustainable manufacturing in the context of Industry 4.0 for the aerospace sector.

**Researcher:** Mohamed Addajou (PhD researcher at the University of Gloucestershire)

Please check the box if you agree with the statements below:

☑ I confirm that I have read and understand the introduction package explaining the research topic.

☑ I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.

☑ I understand that my responses will be kept strictly confidential. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research

☑ I understand that the data collected from me will be destroyed after the completion of this study. However, I will get the transcript of my interview for final agreement

☑ I give permission for recording and for taking notes.

☑ I agree to take part in the above research and will inform the lead researcher f any changes occur.

| | | |
|---|---|---|
| [redacted] | 29/08/23 | |
| **Name of participant** | **Date** | **Signature** |
| __Mohamed Addajou_ | 29/08/23 | |
| **Name of researcher** | **Date** | **Signature** |

Revision 0.1

## Appendix D Email Example to participant - Introductory research pack

**From:** Addajou, Mohamed ([redacted] Aerospace) <Mohamed.Addajou@[redacted]com>
**Sent on:** Wednesday, June 14, 2023 7:39:34 AM
**To:** Addajou, Mohamed ([redacted] Aerospace) <Mohamed.Addajou@[redacted]com>; [redacted]>
**BCC:** AvChelt CH2Crickley <AvChelt.CH2Crickley@[redacted]>; ~AEROSPACE Conference Room, CH2 Malvern - 7 <AvChelt.CH2Malvern[redacted].com>; AvChelt CH2May <AvChelt.CH2May[redacted].com>
**Subject:** Workout-01 / Lean sustainable manufacturing evaluation framework in Industry 4.0
**Attachments:** Lean manufacturing evaluation framework that integrates sustainability requirements_v0.3.pptx (4.72 MB), Participants consent form.docx (26.54 KB)

**Categories:** Research Time; Must join

Hi [redacted],

Please find herewith the research introduction package, it includes :

1. **Presentation of the research** explaining the aim, area of investigation and the approach.
2. **Participant consent form.** As the research is based on the principal of anonymity: ie the company and participants cannot be identified, they will remain anonymous.

Our discussion will be around 3 themes : 1) Lean manufacturing in the Aerospace 2) Lean manufacturing incorporating sustainable manufacturing and the era of digitalisation (Industry4.0), what are the enablers and barriers 3) The evaluation framework. Additional themes may emerge during our discussion.

I'd like to use your extensive experiences in the automotive and aerospace how you perceive the above-mentioned concepts and their combination together in order to develop an evaluation framework.

Thank you,
Mohamed

---

**From:** Addajou, Mohamed ([redacted]Aerospace)
**Sent on:** Tuesday, September 12, 2023 2:27:46 PM
**To:** [redacted] Aerospace) <[redacted]s@[redacted].com>
**Subject:** [redacted] / PhD Research
**Attachments:** Participants consent form.docx (27.48 KB), [redacted] requirements_v0.3.pptx (4.72 MB)

**Categories:** Research Time

Hi Kate,

Thank you very much for our quick chat,
To offer you further insights, I have attached a brief introduction to the research. It outlines the purpose of the research, approach, and its contribution to practice.

Our discussion will evolve around your perceptions of lean manufacturing and its relation to emerging concepts like sustainability in the age of digitalisation. The main themes we will explore are as follows :

- Lean manufacturing in the aerospace sector, in terms of evolution and implementation considering the aerospace- specific characteristics / Challenges.
- Lean manufacturing incorporating sustainability principles and the triple bottom line dimensions – Enablers & Barriers
- Lean manufacturing incorporating Industry 4.0 technologies – Enablers & Barriers
- Evaluation framework – Your perspective on assessing the effectiveness of the current lean system.

It's also possible that additional themes might emerge during our conversation.

The research is based on the principle of anonymity. Therefore, the names of participants and the company won't be identified in the final thesis (See participant consent form attached). However, the thesis report will be available, and I'll be more than happy to share a copy with you.

We shall meet in CH19 and head to CH5. In the meantime, let me know if I need to book a meeting room.

Kind regards,
Mohamed

**Date:** 17 February 2025 at 15:52:00 GMT+1
**Subject: Lean-Sustainability 4.0 Model - Review & Refinement Using Delphi Study**

Hi Charles,

As discussed, I have developed the lean-sustainability 4.0 model based on insights gathered through interviews with departments leaders. This next step is to critically review and refine the model through expert feedback, ensuring it is both theoretically robust and practically applicable.

**Purpose of this phase:**
The Delphi study seeks to refine the lean-sustainability 4.0 model through structured feedback and iterative rounds of review. Your participation will involve:

1. Reviewing the model and providing critical feedback on its structure, logic, and practical application.
2. Commenting on specific sections where you have observations or suggestions for improvement.
3. Answering a questionnaire to ensure structured feedback is captured.

**How it works:**

1. **First round:** Review the current version of the model.
2. **Second round**: based on consolidated feedback from all participants, a refined version will be shared for additional insights, ensuring collaborative, iterative refinement process.
3. **Subsequent round (if needed)**. In case where opinions diverge, additional rounds may be conducted to reach a consensus on specific elements of the model.

**What I need from you:**

1. Your critical perspective on the model - Does it align with industry realities? Are there gaps in the framework?
2. Specific feedback on key sections - Where do you see potential improvements.
3. Completion of the questionnaire.

I truly appreciate your time and continued support in this research and look forward your valuable contributions to this study.

## Appendix E Ethical Letter Approval

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Cheltenham, 15 June 2023

**From:** Mohamed Addajou PhD student researcher at the University of the Gloucestershire.

**To:** [redacted] company

**Subject:** Confidentiality letter as requested by HR [redacted] in Cheltenham site: 18th of April 2023.

Dear Sir or Madam,

We Mohamed Addajou (The researcher) and the research committee at the University of Gloucestershire confirm that Mohamed Addajou's research is based on the principle of anonymity: ie the case study organisation and participants cannot be identified, they will remain anonymous.

The primary data collection will be in the form of interviews that require" informed consent" of the participants and will follow the University of Gloucestershire research ethics guidelines from *Research Ethics: A Handbook of Principles and Procedures.* (Available at https://www.glos.ac.uk/information/knowledge-base/research-ethics-a-handbook-of-principles-and-procedures/).

No confidential data, be it commercial, technical or strategic will be presented within the thesis and a copy of the thesis will be available to the company.

Yours faithfully,

**Dr. Richard Harper**
PhD Supervisor
Email:
Gloucestershire Business School
University of Gloucestershire
Oxstalls Campus
Gloucester GL2 9HW

**Mohamed Addajou**
PhD Student
Email:
Gloucestershire Business School
University of Gloucestershire
Oxstalls Campus
Gloucester GL2 9HW

Appendix F Participants Profile Table

| Participant# | Identifier | Current Role | Covered Functions | Years of experience | Covered Industries |
|---|---|---|---|---|---|
| Participant #1 | 01DGPH1 | Senior Supplier Quality Engineering Staff Manager | Suppliers' development, Quality Customers management | 25 | Aerospace, Automotive |
| Participant #2 | 02APPH1 | Senior Quality Production Manager | Design engineering, operations, Quality management, customer claims management | 25 | Aerospace, Automotive |
| Participant #3 | 03RMPH1 | Value Stream Leader | Supply chain, Operations, Inventory management, Lean manufacturing | 15 | Aerospace, General Industry |
| Participant#4 | 04MTPH1 | Planning and Inventory Leader | Supply chain, Operations, fulfilment, Inventory management, scheduling | 15 | Aerospace |
| Participant#5 | 05PWPH1 | Manufacturing Engineering Director | Manufacturing engineering, Operations | 20 | Aerospace |
| Participant#6 | 06KHPH1 | Lean Manufacturing Manager | Operations, Quality, Manufacturing Engineering | 25 | Aerospace |
| Participamt#7 | 07SPPH1 | Chief of Manufacturing – Senior Director | Project management, Operations, Manufacturing engineering | 30 | Aerospace |

| | | | | | |
|---|---|---|---|---|---|
| Participant#8 | 08JKPH1 | Quality Senior - Director | Air service, Aircraft fleet management, Regulation, aircraft repairs and certifications, Operations, Quality | 24 | Aerospace |
| Participant#9 | 09DOPH2 | Digital Technology Director | IT, Operational Connectivity | 30 | Aerospace |
| Particiapant#10 | 10PSPH2 | Lean Engineering Senior Executive | Lean, IT, Design Engineering | 30 | Aerospace |
| Participant#11 | 11GBPH2 | Senior Executive – Sustainability Global Leader | Sustainability, Global Strategy | 30 | Aerospace Automotive |
| Participant#12 | 12LOPH2 | Lean Operations Division Leader - Defence | Lean, Operations, manufacturing | 35 | Aerospace |
| Participant#13 | 13BPPH2 | Value Stream Leader | Value Stream, Operations, Lean, MRO | 25 | Aerospace |
| Participant#14 | 14BMPH2 | Sustainability Leader | Sustainability - Operations | 15 | Automotive Aerospace |
| Participant#15 | 15ANPH2 | Lean Operations Executive – Commercial Platform | Lean, Operations, Quality | 30 | Aerospace |

## Appendix G Codebook

| Participant 1 | | | | | |
|---|---|---|---|---|---|
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Regulatory Constraints | Describes the impact of compliance, standards, and certification on Lean implementation | Lean implementation, Aerospace sector practices | Used when participant refers to regulation as a barrier or critical influence in process design or execution | *"The whole kind of setup of aviation is very driven by... partly by regulation... rule number one is follow the rules."* | Compliance, Process Change, Product Safety. |
| Design Complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturing, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | *"Our designs are not easy to manufacture. And that's a that's a big step forward that needs to be to be looked at. And things like a APQP will help with that."* | Waste, Rework, Manufacturability |
| Lean Misconception | Points to misunderstanding or misapplication of Lean principles | Cultural Change, Training | Used when participant critiques Lean being treated as a project rather than a philosophy | *"There are some very tried and tested tools used in automotive that are finding their way into the aviation industry now..."* | Culture, Training, Continuous Improvement |
| Employee Engagement | Discusses motivation, training, and staff involvement in Lean and Sustainability | Change Management, Engagement | Used when talking about people's involvement or disengagement | *"People tend to feel more constrained by the regulation... less open to not change but... being a little bit more inventive..."* | Training, Kaizen |
| Digital Awareness | Discusses understanding or gaps in digital literacy | I4.0 integration, Culture | Used when participant references the workforce's or management's familiarity with digital tools | *"Everybody... there's a perception that [aviation] is leading edge technology and the reality is it's really not."* | Digital Capability, Training |
| Compliance Burden | Perceives regulatory requirements as barriers to innovation or agility | Aerospace Regulation, Quality | Used when regulation is seen restricting flexibility or experimentation | *"The whole kind of setup of aviation is very driven by... partly by regulation, partly by safety, partly by customers."* | Regulatory Constraints, Innovation Limitation |
| Data Fragmentation | Issues with accessing or trusting available operational data | Digitalisation and planning | Used when the participant expresses difficulty in accessing consistent, reliable data for decision-making | *"I don't make enough parts to get the data to really get capability in these kinds of things…..The big problem I see at the moment in this* | Real-time data, visibility |

| | | | | | |
|---|---|---|---|---|---|
| | | | | *business is we you know a lot of the time we capture loads of data but you've got to be able to get that data back out of the systems you put it into in order to analyse it and and sometimes that can be a challenge and it … to get information"* | |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | *"Aviation is very slow to change... it makes applying those things a bit more challenging..."* | Design for manufacturing, Waste, Efficiency, Supply Chain |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | *"...lead free... it's a big thing in automotive... we're still not lead-free in aviation."* | Environmental targets, Cultural shift |
| Immaturity in Ecosystem | Refers to underdeveloped processes and suppliers in aerospace | Sector Maturity, Capability Gaps | When participant talks about weak or inconsistent practices | *"The whole supply chain in my experience is very immature in those kinds of processes."* | Supply Chain, Learning, Resilience |
| Technology Gap | Highlights the outdated state of aerospace technology compared to other sectors | Digitalisation, Innovation | When the slow pace of tech adoption is cited | *"We're years behind in the use of technology... there's definitely opportunity to catch up..."* | Flow, Innovation, Modernisation |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | *"As we start to look at new suppliers, we are going for ones that are much more... technologically advanced..."* | Governance, leadership role, KPIs |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders' involvement in Lean deployment or vision-setting is discussed. | *"So yeah... there's definitely opportunity... Part of it's held up by the pace of change."* | Strategic, Alignment, Culture |
| **Participant 2** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Design complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturing, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | "If your designs are good, if you don't design in rework, then you design in waste... Engineering designed a propeller that has a 40% yield, so 60% of | Waste, Desing for manufacturing, Rework, Process inefficiency |

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| | | | | everything they build is scrapped." | |
| Lean Misconception | Points to misunderstanding or misapplication of Lean principles | Cultural Change, Training | Used when participant critiques Lean being treated as a project rather than a philosophy | "Lean isn't just about your manufacturing. Your Lean is in your design stage as well." | Design integration, Holistic Lean, Cross-functional Collaboration |
| Rework and waste | Highlights rework as a source of waste in manufacturing | Operational inefficiencies, Lean waste | "Used when rework is mentioned as an outcome of poor design or quality" | "People are celebrating their sales and their output… but they're forgetting about the three scrap components that we built along the way." | Scrap, Rework, Waste Normalisation, Performance Blind Sports |
| Supplier Engagement | Issues related to supplier performance and communication gaps | Supply chain and quality interfaces | When suppliers are mentioned as lacking in problem-solving capability, communication or Sustainability. | | Waste, Communication Gaps, Supplier Capability, Problem-Solving capability |
| Data Fragmentation | Issues with accessing or trusting available operational data | Digitalisation and planning | Used when the participant expresses difficulty in accessing consistent, reliable data for decision-making | *"we've got the data, but we don't do anything with it."* | Real-time data, visibility |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | *"Lean … Sustainability on a reduction in scrap or reduction in rework or reduction in power usage and all those things"* | Environmental targets, Cultural shift |
| **Participant 3** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Problem-solving capability | Refers to the strategic importance of problem-solving capabilities | Operational inefficiencies, Lean waste, Maturity | Used when referencing structured root cause problem-solving processes in operations. | "Turnaround time today is 30 days, I want it to be 5… that becomes the project." | Root cause, Continuous improvement, Lean maturity, Collaboration, Learning Culture |
| Lean Misconception | Points to misunderstanding or misapplication of Lean principles | Cultural Change, Training | Used when participant critiques Lean being treated as a project rather than a philosophy | "I think a natural way to look at it is to try and copy what the automotive industry has done, which doesn't, I don't believe, work in aerospace." | Contextualisation, Cultural Change, Operational Adaptation |
| Test specification overengineering | Excessive non-critical tests create inefficiencies | Test procedures, performance requirements | When test failures are non-critical but block progress | "We built in our striving for perfection… we feel inefficiency… Product is safe, but a confidence test stops it." | Overengineering, Perfectionism, Flow Disruption |

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| Sustainable workforce | Links Lean with workforce well-being and burnout prevention | Social dimension of Sustainability | When Lean is viewed as a way to reduce overburden, stress, inefficiencies | "If your organisation isn't efficient… you're creating a lot of additional work, lots of complexities… we will burnout our staff." | Social Sustainability, Flow, Efficiency |
| Design for Manufacturing | Challenge of complex designs in Lean implementation | Aerospace product design and assembly | When design complexity undermines manufacturability and process | "We make electronics… you get a failure and you really don't know what's caused it… it takes that long to debug and understand." | Root cause, Rework, Test Failures |
| Regulatory burden | Safety and compliance slow down problem solving and process iteration | Aerospace safety, compliance | When safety/regulatory systems extend resolution times | "You've got compliance, these complex parts… NCs we have to raise, all that admin work… slows down urgency." | Compliance, Safety, decision-making |
| Testing Bottlenecks | Tests extend cycle time, disrupt flow | Testing processes in aerospace production | When participants discuss test phase as a constraint to continuous flow | "We have products that have 32-hour test cycles… we can't stop the line… we see this queuing of material." | Flow, inventory, bottlenecks |
| Data Fragmentation | Issues with accessing or trusting available operational data | Digitalisation and planning | Used when the participant expresses difficulty in accessing consistent, reliable data for decision-making | *"We have lots of good data around… but the data is only good if we do something with it."* | Real-time data, visibility, technological readiness |
| Jumping to Tools | Implementation digital tools without process clarity | Lean digitalisation, I4.0 | When tools are used without defining the underlying Lean standard | "One of the traps we fall into is we go straight to the tools… we don't look at what the process should be first." | Tech Integration, Process Redefinition |
| RFID Application | RFID enhances efficiency and traceability | Lean logistics, waste reduction | When RFID is used to improve movement and reduce error | "We used it to reorganise our stores… the heatmap visually showed us how many steps were wasted." | Visual management, Digital Lean, Process Design |
| Environmental Sustainability | Emissions, power, waste minimisation in production | Environment al waste in sourcing and production | When participant discusses impact of long-distance shipping, scrap, and power | "We used to buy castings from China… all this waste material… a whole truckload of castings… scrap." | Rework, Supply Chain, Waste, Sustainability |
| Human Rights & Global Ethics | Links Sustainability to ethical sourcing and labour rights | Global supply chain, ethical procurement | When sourcing decisions consider labour conditions and national policies | "Do we agree with their policies? Do we want to buy material from them?" | Social Sustainability, Global sourcing |
| Circular Economy Awareness | Discussion of lifecycle thinking and recycling | Emerging Sustainability concepts | When participant consider reuse, | "What about if we 3D printed our castings instead? So then our | Innovation, Additive Manufacturing |

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| | | | recycle, 3D printing, end-of-life | castings are 3D printed and there's no material waste." | |
| Smart Lean | Lean enhanced by I4.0 technologies | RFID, sensors, digital traceability | When Lean is merged with tech for smarter operations | "We used RFID… it reduced kitting time… reduced human error." | I4.0, Lean Enhancement |
| Metrics Alignment | KPIs should drive Lean behaviour and mindset | Performance measuremen t | When participant questions misaligned KPIs | "We have too many KPIs… what metrics are we implementing that drive Lean mindset?" | Performance, Behavioural Metrics |
| Turnaround time as effectiveness | Turnaround time used as proxy to measure Lean | Operational efficiency, effectiveness | When Lean is evaluated through problem-solving cycle time | "Turnaround time today is 30 days, I want it to be 5… that becomes the project." | SQCDEP, Cultural Change, Flow |
| **Participant 4** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Process Complexity | Perceived operational complexity due to multiple overlapping systems | Planning and operations | Used when referring to inefficiencies caused by process or systems not aligning | "We try and do 100 things when we should really focus and bring them into maybe 10 things." | Strategic Alignment, Value Stream |
| Visual Management | Value of clear visual tools and intuitive system thinking | Operational Lean tools and process control | When visual management or simplification are suggested as improvement enabler | "There is kind of two goals: One, you can understand what the problem is within three seconds… the second is within two metres." | Kaizen, Real-Time Data, Problem-Solving |
| Maturity | Refers to the current state of Lean tools or system foundations before adopting advanced technology | Lean implementati on Readiness | Used when participant critiques the readiness of systems or processes before adding smart tools or sensors. | "We don't have the fundamentals of good Kanban... We need to fix the system first and then exploit digital sensor real-time information afterwards." | Implementation objectives, Kanban, Readiness |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and Sustainability outcomes. | Lean as a tool to achieve Sustainability . | Used when waste reduction, flow, or process control are framed as environmentally beneficial. | "Now some of the actions might have an effect on Sustainability and power usage... But I don't think that's by planning it." | Energy Monitoring, Environments, Strategic Gaps |
| Human-Centric | Emphasises the role of people, shop-floor insights, and buy-in improvement and digitalisation | People Engagement & Technology Acceptance | Used when the participant stresses the importance of employee input alongside data or tools | "The person who knows the problems the best is the person who manufactures the parts... there's got to be... a hybrid between the two." | Gemba, Participation, Change Culture |
| **Participant 5** | | | | | |

| Code | Short Description | Scope | Condition of Use | Quote Example | Related Codes |
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| Efficiency Focus | Emphasis on productivity gains, doing more with less resources. | Process improvement initiatives in Lean and Sustainability. | When discussing output targets, simplification, or increased productivity. | "It is the Lean element but also the productivity. So if you listen to Amy, you listen to kind of Larry around the drive for productivity and getting efficiency out of people and products." | Flow, Kaizen, Resource Utilisation |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | "What does it mean to be sustainable? What does it mean to be kind of Lean from a production capability…?" | Environmental targets, Cultural shift |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and Sustainability outcomes. | Lean as a tool to achieve Sustainability. | Used when waste reduction, flow, or process control are framed as environmentally beneficial. | "It is about building the right things right… building that culture to say that these are a priority." | Waste, Kaizen, Environmental impact |
| Data Fragmentation | Issues with accessing or trusting available operational data | Digitalisation and planning | Used when the participant expresses difficulty in accessing consistent, reliable data for decision-making | "Because being able to access that data quickly… I turn my engineers into data manipulators… into people that can access that information quickly." | Real-time data, visibility |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | "You build ten, you test ten, you get ten through the process." | Design for manufacturing, Waste, Efficiency, Supply Chain |
| Manual intensive process | Refers to the intensity of manual operations | Labour-heavy environments and digital readiness | Used when digitalisation is discussed as a way to reduce manual tasks | "It comes to philosophy which is intensity… I came in the morning I have to do that… how can you reduce that as well?" | Flow, automation |
| Design Complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturing, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | "We're using 23-year-old technology… how do we get that Lean?" | Waste, Rework, Manufacturability |
| **Participant 6** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and | Lean as a tool to achieve | Used when waste reduction, flow, or process control are framed as | "So then, we're not getting as much supplies and not as much raw materials | Lean mindset, Cultural change, VSM |

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| | Sustainability outcomes. | Sustainability. | environmentally beneficial. | being made…there's environmental gains. […] If we can reduce the burning time…our power usage is now reduced and they're interconnected." | |
| Lean in Aerospace | Comments on the maturity, applicability, and evolution of Lean in aerospace. | Lean implementation, operational excellence | When discussing the history, evolution, or distinctiveness of Lean practices in the aerospace sector. | "Here, Lean is something we do still, and it's in discrete pockets. And we're on the journey to get it to be something that we just think Lean. And we're not there yet." | Lean mindset, Cultural Change, VSM |
| Employee Engagement | Emphasis on workforce involvement in improvement and Lean activities. | Lean-Sustainability implementation | Used when discussing frontline employee roles, Kaizen, or engagement in problem solving | "Because as soon as you start trying to just say do it quicker, faster…you're not working hard enough…these are the messages that they hear…Lean is take out the waste, basically." | Kaizen, Culture, Training |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | "We're talking downtime of hours. So it's quite a gulf between those." | Design for manufacturing, Waste, Efficiency, Supply Chain |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders' involvement in Lean deployment or vision-setting is discussed. | "It's still an action that is done…rather than we just think can we do everything in a Lean way with a Lean mindset…That's from where we are. I think it's a culture here. Still lots of work to do." | Strategic, Alignment, Culture |
| Visual Management | Value of clear visual tools and intuitive system thinking | Operational Lean tools and process control | When visual management or simplification are suggested as improvement enabler | "To move to real time which is accessible visual to everybody would be very powerful." | Maturity, Training |
| Resistance to Change | Barriers caused by legacy culture, inertia or reluctance. | | When participants describe cultural inertia or employee/management resistance. | "Those who write the procedures are not the ones that are doing the job…More collaboration at that point actually might help start the process off fairly efficiently." | Culture, Change Management |
| Design Complexity | Refers to difficulties in manufacturing due to | Design for manufacturing, Lean, Waste | Used when referencing product design creating | "I think that design for performance overridden a design for manufacture." | Waste, Rework, Manufacturability |

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| | engineering design | | inefficiencies or excessive waste | | |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | "So we understand our footprint as well as productivity value stream. That's what we're just starting to look at." | Environmental targets, Cultural shift |
| | | | **Participant 7** | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementati on in aerospace context. | When leaders' involvement in Lean deployment or vision-setting is discussed. | "If you want to get a conversation with Larry, you need to put Lean in it somehow… and he walks the talk." | Strategic, Alignment, Culture |
| Performance Transparency | Real-time monitoring of SQDC metrics | Visual management systems | Use when discussing access to performance data through dashboards | Is my machine on or off? Is it consuming power? Is it idle?... we're not able to answer those questions because we haven't implemented the systems." | Digital tolls, Data, I4.0 |
| Problem-solving capability | Refers to the strategic importance of problem-solving capabilities | Operational inefficiencies, Lean waste, Maturity | Used when referencing structured root cause problem-solving processes in operations. | "Just tell me how much I scrapped. What I need help with is: why is it getting scrapped?" | Root cause, Continuous improvement, Lean maturity, Collaboration, Learning Culture |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | "I would prefer an EV than a diesel car… we have that awareness… we're more sensitive now to environmental impact." | Environmental targets, Cultural shift |
| Visual Management | Value of clear visual tools and intuitive system thinking | Operational Lean tools and process control | When visual management or simplification are suggested as improvement enabler | "Smart sustainable VSM… live data… every workstation shows power, waste, people development." | Maturity, Training |
| Resistance to Change | Barriers caused by legacy culture, inertia or reluctance. | LS4.0 model integration, digital transformatio n | When participants describe cultural inertia or employee/managem ent resistance. | "PMR has melted away… Lean Academies have melted away… the fundamentals just disappeared." | Culture, Change Management |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | I4.0 integration | Use when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | "If you connect work centres to the cloud… you get live data on why it's idle: parts, people, or breakdown." | I4.0. Performance tracking, Analytics |
| Regulatory Constraints | Describes the impact of | Lean, implementati | Used when participant refers to | "We put a big cybersecurity wrap | Compliance, Process |

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| | compliance, standards, and certification on Lean implementation | on, digital integration, Aerospace sector practices | regulation as a barrier or critical influence in process design or execution | around ourselves... and we're not able to exchange information we need to.” | Change, Product Safety. |
| Design Complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturin g, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | “We keep asking you for concessions… because we’re not anywhere near the middle of the tolerance.” | Waste, Rework, Manufacturabilit y |
| Lean Misconception | Points to misunderstanding or misapplication of Lean principles | Cultural Change, Training | Used when participant critiques Lean being treated as a project rather than a philosophy | “Way too many Kaizens just shift inventory down the line… rather than fix the root issue.” | Culture, Training, Continuous Improvement |
| Employee Engagement | Discusses motivation, training, and staff involvement in Lean and Sustainability | Change Management , Engagement | Used when talking about people’s involvement or disengagement | “Before a Kaizen, benchmark team capability. Have they even been trained in what Lean is?” | Training, Kaizen |
| Digital Awareness | Discusses understanding or gaps in digital literacy | I4.0 integration, Culture | Used when participant references the workforce’s or management’s familiarity with digital tools | “A lot of people have never used a PC before… just learning to turn a computer on.” | Digital Capability, Training |
| Compliance Burden | Perceives regulatory requirements as barriers to innovation or agility | Aerospace Regulation, Quality | Used when regulation is seen restricting flexibility or experimentation | “AeroSkyward prefers to use its own safety system instead of ISO… I’m not sure if they think ISO isn’t good enough or too European.” | Regulatory Constraints, Innovation Limitation |
| Digital Maturity Gap | Highlights organisational immaturity in digital integration | Industry 4.0 and smart operations | Used when operational decision-making suffers due to lack of real-time systems | We're not able to answer those questions because we haven't implemented the systems.” and “I have to go and talk to the guy on the shopfloor and go: ‘Hey, is your machine running?’” | I4.0, Real-Time Data |
| Technology Before Gemba | Critique of prioritising tech over process understanding | Lean-Digital transformatio n strategy | Used when tech adoption precedes understanding operational needs | “There is a risk… tech gets developed before we even understand what the Gemba needs.” | Cultural shift, |
| Strategic Capabilities for Future-readiness | Reference to building capabilities that | Strategic vision and transformatio n capability | When future-oriented investments in systems and people are discussed | “Smart sustainable VSM” and “real-time analytics linked to people development | Digital Tools, People Development, |

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| | enable future performance | | | and Sustainability metrics” | Strategic Planning |
| Training Gap | Gaps in training to support Lean and tech transformation | Capability development and LS4.0 maturity | When training limitations are described as barriers to implementation | “Have they even been trained in what Lean is?” and “You can't expect people to do Kaizen if they don’t understand what they’re doing.” | Employee Engagement, Learning, Culture |
| **Participant 8** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Compliance pressure | Regulatory compliance as a driver for digital and operational transformation | Aerospace operations and Sustainability | When discussing regulations as external motivators | “The regulators are now starting to question how much we are doing on the environmental side… so we’re starting to put more effort into it.” | Regulation, Sustainability Strategy |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | “The focus on Sustainability is becoming more embedded—it’s no longer just a nice-to-have, it’s part of how we’re judged.” | Environmental targets, Cultural shift |
| Quality management | Comments on the importance of robust quality systems linked with Lean objectives | Safety metrics and operational performance | When safety is discussed as an overarching principle in operations | “You always start with safety—that’s the number one thing, before you talk about Lean or digital.” | SQDC, Compliance, Lean |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders’ involvement in Lean deployment or vision-setting is discussed. | “It really has to be leadership-led, otherwise it just doesn’t get the attention it needs.” | Strategic, Alignment, Culture |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Industry 4.0, digital transformation, cultural maturity | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | “There’s been talk for years about digital twin, but we still go into meetings with printouts, and no one looks at the dashboards.” | I4.0. Performance tracking, Analytics |
| Resistance to Change | Barriers caused by legacy culture, inertia or reluctance. | LS4.0 model integration, digital transformation | When participants describe cultural inertia or employee/management resistance. | “You still get that pushback—‘this is how we’ve always done it.’ That attitude is really hard to break.” | Culture, Change Management |
| **Participant 9** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Cloud Sovereignty Challenge | Limitation in adopting commercial cloud | Digital integration | Used when acknowledging aerospace unique | “With military datasets comes higher levels of data regulation… And | Compliance, Digital Infrastructure |

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| | tools due to defence/military compliance regulations | | characteristics, and LS4.0 integration barriers | at the moment, the service providers who would be offering us new capabilities just aren't able to offer that government certified cloud type environments." | |
| Data-Driven Future | The organisation's ambition to move toward data-led decisions | Digital Integration, Operational Excellence, Decision making capability | When discussed about factories of the future and how data is transforming the business model | "We want to be a data driven organisation." | Strategic Alignment, Information Capability |
| Digital Transformation | Ongoing changes in operational systems through advanced technologies | LS4.0 Enablers | When referencing end-to-end connectivity, historians, capability building | "So that will then create the opportunities for yield calculations... you more effectively utilize the equipment that you've already got." | Infrastructure, Digital Capability, Operational Efficiency |
| Operational Maturity Gap | Gap between existing and desired digital maturity in infrastructure and practices | Lean-Sustainability 4.0 readiness | When participant explicitly states current maturity is low or efforts are at early stages | "At the moment, we here are very immature in terms of our journey." | Capability Building, Transformation Readiness |
| Skillset gap | Absence of roles or competencies needed for LS4.0 transformation | Workforce capability and structure | When IT-OT-engineering bridging skills are absent | "It's not a traditional IT role... and not also traditionally a manufacturing engineering role." | Digital Awareness, Capability Structure |
| Strategic-Problem Solving Alignment | Importance of aligning Lean problem-solving to broader strategic objectives | Strategy and Lean Practice Integration | When improvement efforts are discussed as being aligned with long-term business goals | "You need to have that strategic business intent... and then start implementing the Lean principles." | VSM, Strategic Planning |
| Digital Twin Aspiration | Interest in developing a factory digital twin for process simulation and optimisation | LS4.0 strategic vision | When participant mentions digital twin as future direction | "Digital twin is the concept of you recreate your factory digitally... simulate changes to the environment." | Smart Factory, Predictive Analytics |
| External Service Dependence | Reliance on third parties to support digital transformation in operations environments | Digital execution structure | When vendors are mentioned as necessary for OT connectivity projects | "We are talking to Siemens, Tech Mahindra, Capgemini..." | Outsourcing, Capability Gap |
| Information Infrastructure Enablement | Providing a digital backbone for manufacturing to | Digital support role | Used when referring to IT's enabling role for manufacturing data analytics | "We are creating an environment that we can hand over to the | Digital readiness, Digital Infrastructure |

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| | extract and analyse data | | | manufacturing engineering team.” | |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Industry 4.0, digital transformation, cultural maturity | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | “That would allow us to capture time-phased metric data… like temperature profile, vibration, etc.” | I4.0. Performance tracking, Analytics |
| **Participant 10** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Design Complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturing, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | “There is a lot of the focus is on the design of the engine and not necessarily the design for manufacturability…so that means you cannot create as much flow as you’d like.” | Waste, Rework, Manufacturability |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | “...you can’t create good flow between things…supply chains tend to be a little longer and they are very complex.” | Design for manufacturing, Waste, Efficiency, Supply Chain |
| AI for Design and Problem Solving | Use of artificial intelligence to improve tolerance, flow, or iterative design | Digital transformation of engineering | Use when AI supports Lean and sustainable design improvement | “Things that used to take 10 years can be done with simulations now.” | Generative Design, I4.0 Tools, Digital Innovation |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | “...we're using traditional value stream mapping... but apply semantic search and AI tools to help us manage and curate that data.” | I4.0. Performance tracking, Analytics |
| Data Fragmentation | Issues with accessing or trusting available operational data | Digitalisation and planning | Used when the participant expresses difficulty in accessing consistent, reliable data for decision-making | “...how are people using that information in order to make high quality decisions...” | Real-time data, visibility |
| Supply Chain maturity | Observations on supply chain’s limited capability to meet Lean/sustainable standards | External supply chain collaboration | Used when discussing suppliers’ digital and Sustainability readiness or responsiveness | “...very specialized supply base...you can’t do everything in-house...can’t create good flow.” | Ecosystem, Supplier Integration, Maturity |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business, not an add-on | “Lean will just help you execute any of those strategies better.” | Governance, leadership role, KPIs |

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| Lean-Sustainability Synergy | Perceived alignment between Lean practices and Sustainability outcomes. | Lean as a tool to achieve Sustainability. | Used when waste reduction, flow, or process control are framed as environmentally beneficial. | "...respect for every individual…your involvement in the community and your effect on the environment." | Culture, Enviromental Impact, People Develpment |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders' involvement in Lean deployment or vision-setting is discussed. | "… is something that has to be led from the top...there has to be this humility at the CEO level...most are unwilling to do that." | Strategic, Alignment, Culture |
| Human-Centric | Emphasises the role of people, shop-floor insights, and buy-in improvement and digitalisation | People Engagement & Technology Acceptance | Used when the participant stresses the importance of employee input alongside data or tools | "...one of the foundational principles in Lean is respect for every individual...that includes employee safety and involvement in the community." | Gemba, Participation, Change Culture |
| | | | **Participant 11** | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Sustainability maturity | Degree to which Sustainability is institutionalised across operations | Strategy / Implementation | Used when referring to structured processes, metrics, or programmes supporting Sustainability integration | "So at least we are setting the baseline… for scope one, two, and three." "We are trying to build the team, the strategy, still very, very early stages." | Sustainability awareness, governance, compliance, Metrics |
| Measurement and Reporting | Refers to KPIs and structured reporting for Sustainability performance | Metrics, accountability | When participants refers to systems of KPIs tracking system | ""Now we have a KPI in the MOR… to track carbon emissions." "We use kilowatt hour, megawatt hour on a monthly basis." | Sustainability maturity, Data, Visual Management |
| Compliance as Enabler | Role of regulations in accelerating Sustainability integration | Regulatory strategy | Mention of compliance as a catalyst rather than barrier | "A lot of what we do in emissions tracking comes from compliance… but it opens other opportunities." | Regulation, Sustainability maturity |
| Supply Chain maturity | Observations on supply chain's limited capability to meet Lean/sustainable standards | External supply chain collaboration | Used when discussing suppliers' digital and Sustainability readiness or responsiveness | "You depend on one supplier. If something goes wrong, you are screwed." "Some of our suppliers, they don't even know what Sustainability means." | Ecosystem, Supplier Integration, Maturity |
| People empowerment | Refers to people-centric Lean practices, growth, and employee involvement | Engagement, Learning, Daily Management | Used when discussing how Lean empower people, promotes surveys, or support well-being | "Are we making sure that we put them first? Are we making sure that the people are growing and learning?" | Engagement, Training, Survey Use, SDDC |

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|---|---|---|---|---|---|
| Social Sustainability | Includes Diversity and Inclusion, human rights, and community impact | Social reporting and practices | When referring to broader social dimensions, including upstream audits, Diversity and Inclusion and human rights | We talk about (Diversity and Inclusion) DEI, talent attraction, human rights, communities… but none of those are integrated into Lean.” | CSR, People Empowerment |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | That is what I came here to do… building the team, the strategy.” “It came from …from top down.” | Governance, leadership role, KPIs |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When referring to cascading strategy, KPIs, and enabling cultural or operational change. | “… at her level would measure… and it cascaded.” “How do we make sure that the leaders are leaders and not just managers?” | Strategic, Alignment, Culture |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and Sustainability outcomes. | Lean as a tool to achieve Sustainability. | Used when waste reduction, flow, or process control are framed as environmentally beneficial. | “When you work on making the operation more efficient… it helps with Sustainability.” | Waste, Efficiency, Environmental Impact |
| Immaturity in Ecosystem | Refers to underdeveloped processes and suppliers in aerospace | Sector Maturity, Capability Gaps | When participant talks about weak or inconsistent practices | *"There may be just one supplier… you depend on one supplier and if things go wrong, then you're in trouble.”* | Supply Chain, Learning, Resilience |
| Visual Management | Value of clear visual tools and intuitive system thinking | Operational Lean tools and process control | When visual management or simplification are suggested as improvement enabler | “In GM we had PSQCD – and the P (People) was first.” | Maturity, Training |
| SQDC Framework | Application of extended Lean metrics beyond traditional SQDC | Performance measurement philosophy | When corporate performance frameworks were referenced | “In GM we had PSQCD – and the P (People) was first.” | SQDC, People, Digitalisation, Real-time visibility |
| Regulatory Constraints | Describes the impact of compliance, standards, and certification on Lean implementation | Lean implementation, Aerospace sector practices | Used when participant refers to regulation as a barrier or critical influence in process design or execution | “You can’t change the material without retesting everything… that’s why aerospace is so slow.” | Compliance, Process Change, Product Safety. |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | “We have sensors… sending real time data to a host… potentially linked to cloud computing.” “There is BMS that tracks daily energy use.” | I4.0. Performance tracking, Analytics |

| Participant 12 | | | | | |
|---|---|---|---|---|---|
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | "What do we want to be in the next three to five years, and what's our yearly steps to actually see if we're winning or losing and going in that direction?" | Governance, leadership role, KPIs |
| Human-Centric | Emphasises the role of people, shop-floor insights, and buy-in improvement and digitalisation | People Engagement & Technology Acceptance | Used when the participant stresses the importance of employee input alongside data or tools | "…it's very different from a culture, a society of people who are growing up seeing more digital concepts." | Gemba, Participation, Change Culture |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When referring to cascading strategy, KPIs, and enabling cultural or operational change. | "Kate is actually the Sustainability lead and the Lean leader, or flight deck leader, as we're now calling them." | Strategic, Alignment, Culture |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and Sustainability outcomes. | Lean as a tool to achieve Sustainability. | Used when waste reduction, flow, or process control are framed as environmentally beneficial. | "Our Kaizen events all have a Sustainability aspect within them." | Waste, Efficiency, Environmental Impact |
| Knowledge Sharing / Capability | Emphasised the importance of people development and coaching others in the value stream. | Continuous improvement | Used when the participant discusses passing on knowledge and supporting team capability. | "…it's very different from a culture, a society of people who are growing up seeing more digital concepts." | Training, Learning Culture, Value Stream support |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | "They're looking for that next set of tools... they can now digitize it themselves and make the output something that's clear, simple, and drives action." | I4.0. Performance tracking, Analytics |
| **Participant 13** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | "There's a lot of waste, there's a lot of inefficiency, which comes through our planning tools… we're not connected as a value stream." | Design for manufacturing, Waste, Efficiency, Supply Chain |
| Problem-solving capability | Refers to the strategic importance of | Operational inefficiencies, | Used when referencing structured root cause | "We've had very good experiences with A3 problem solving. It's | Root cause, Continuous improvement, |

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| | problem-solving capabilities | Lean waste, Maturity | problem-solving processes in operations. | about teaching people to think more systematically.” | Lean maturity, Collaboration, Learning Culture |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | What we’re starting to do is map out performance trends, so digital data is becoming the bedrock of our improvement work.” | I4.0. Performance tracking, Analytics |
| Sustainability Awareness | Recognition of Sustainability goals as a strategic or operational priority. | Sustainability alignment in operations or strategic vision. | Used when acknowledging Sustainability impact, goals, or cultural importance. | “We now have a Sustainability lead and our KPIs include energy intensity, scrap cost and recycling ratios.” | Environmental targets, Cultural shift |
| Immaturity in Ecosystem | Refers to underdeveloped processes and suppliers in aerospace | Sector Maturity, Capability Gaps | When participant talks about weak or inconsistent practices | “Some of our suppliers are still on Excel, so integrating digital dashboards is just not possible yet.” | Supply Chain, Learning, Resilience |
| Employee Engagement | Discusses motivation, training, and staff involvement in Lean and Sustainability | Change Management , Engagement | Used when talking about people’s involvement or disengagement | “We still have a problem with getting people to see the why. They comply, but they’re not convinced.” | Training, Kaizen |
| SQDC Framework | Application of extended Lean metrics beyond traditional SQDC | Performance measurement philosophy | When corporate performance frameworks were referenced | “We track SQDC metrics weekly, but energy and scrap metrics are still reported separately.” | SQDC, People, Digitalisation, Real-time visibility |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | “It has to be embedded in the strategy – otherwise it’s a side project with no teeth.” | Governance, leadership role, KPIs |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders’ involvement in Lean deployment or vision-setting is discussed. | “Our director’s been pushing for digital Lean – it gives credibility and makes it easier to roll out.” | Strategic, Alignment, Culture |
| Social Sustainability | Refers to workforce well-being, inclusion or community impact | Sustainability culture | When participants mention people dimension of Sustainability | “We don’t just look at emissions; we’ve started to report on employee well-being and inclusion too.” | Well-being, People Engagement |
| | | | **Participant 14** | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Lean-Sustainability Synergy | Perceived alignment between Lean practices and | Lean as a tool to achieve Sustainability . | Used when waste reduction, flow, or process control are framed as | “You cannot be sustainable if you're not Lean.” | Waste, Efficiency, Environmental Impact |

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| | Sustainability outcomes. | | environmentally beneficial. | | |
| Social Sustainability | Refers to workforce well-being, inclusion or community impact | Sustainability culture | When participants mention people dimension of Sustainability | “People are motivated by cost reduction... but not everyone is driven by the environmental narrative.” | Well-being, People Engagement |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | “Sustainability is definitely a must in the survival of the company.” | Governance, leadership role, KPIs |
| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders’ involvement in Lean deployment or vision-setting is discussed. | “…. stated that we will eliminate 50% of our emissions by 2030 from a 2019 base year.” | Strategic, Alignment, Culture |
| Measurement and Reporting | Refers to KPIs and structured reporting for Sustainability performance | Metrics, accountability | When participants refers to systems of KPIs tracking system | “We have targets, and we track electricity, natural gas, jet fuel, and SF6.” | Sustainability maturity, Data |
| Compliance as Enabler | Role of regulations in accelerating Sustainability integration | Regulatory strategy | Mention of compliance as a catalyst rather than barrier | “The main driver… regulatory compliance… we need to report our emissions.” | Regulation, Sustainability maturity |
| Supply Chain maturity | Observations on supply chain’s limited capability to meet Lean/sustainable standards | External supply chain collaboration | Used when discussing suppliers’ digital and Sustainability readiness or responsiveness | “Purchasing will have to include carbon in their decisions… AeroSkyward will have to buy credits. | Ecosystem, Supplier Integration, Maturity |
| Employee Engagement | Discusses motivation, training, and staff involvement in Lean and Sustainability | Change Management, Engagement | Used when talking about people’s involvement or disengagement | “If Lean is our language, let’s bring Sustainability into Lean… we have to incorporate it into the culture.” | Training, Culture |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | “We are integrating AI… the more data we have, either from people or AI, the more issues we can solve ahead of time.” | I4.0. Performance tracking, Analytics |
| Integration Challenges | Barriers in aligning Lean and Sustainability within existing systems and culture | Implementation complexity | When participants referenced lack of structure, fragmentation, or competing priorities | “Sustainability projects compete against safety and quality – they often lose.” | Resistance to Change, Governance, Budget Constraints. |

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| Budget Constraints | Lack of dedicated funds for LS4.0 projects | Financial planning, project prioritisation | When Sustainability is deprioritised in favour of safety, quality initiatives | “Sustainability needs a dedicated budget… because it cannot compete with quality or safety projects.” | Strategic barriers, resource limitation |
| Sustainability Maturity | Field-based, Lean-aligned initiative to identify energy-saving opportunities | Practical enabler | When participant describes Kaizen or GEMBA-based walkthroughs for Sustainability gains | “We ran a Shing event… and did energy treasure hunts – we found HVAC opportunities.” | Kaizen, gemba, Waste |
| **Participant 15** | | | | | |
| **Code** | **Short Description** | **Scope** | **Condition of Use** | **Quote Example** | **Related Codes** |
| Lean Misconception | Points to misunderstanding or misapplication of Lean principles | Cultural Change, Training | Used when participant critiques Lean being treated as a project rather than a philosophy | ...I think we sometimes try and Lean our way out of poor design and that’s not possible. There’s got to be an integration between the teams that are responsible for that.” | Design integration, Holistic Lean, Cross-functional Collaboration |
| Design Complexity | Refers to difficulties in manufacturing due to engineering design | Design for manufacturing, Lean, Waste | Used when referencing product design creating inefficiencies or excessive waste | “We had designs that required extensive rework… they weren't designed for manufacturing.” | Waste, Rework, Manufacturability |
| Rework and waste | Highlights rework as a source of waste in manufacturing | Operational inefficiencies, Lean waste | Used when rework is mentioned as an outcome of poor design or quality | “...we’ve got to stop seeing design, production and Sustainability as separate lanes—they’re one flow. | Design complexity, Cost Impact |
| Flow | Inability to achieve smooth and continuous product or information flow | Lean implementation in aerospace context. | When describing production disruptions, part mismatches, or long lead times. | “...we don’t want to build product we’re not going to ship... which Leans into a just in time concept, right?” | Flow, Demand Alignment |
| Lean in Aerospace | Comments on the maturity, applicability, and evolution of Lean in aerospace. | Lean implementation, operational excellence | When discussing the history, evolution, or distinctiveness of Lean practices in the aerospace sector. | “...Lean is a mindset, it’s a way of behaving. And it’s got to be how you show up every day.” | Lean mindset, Cultural Change, VSM |
| Resistance to Change | Barriers caused by legacy culture, inertia or reluctance. | LS4.0 model integration, digital transformation | When participants describe cultural inertia or employee/management resistance. | “I think we still find pockets where people think ‘this is how we’ve always done it’...” | Change Management, Cultural Shift |
| Strategic alignment | Refers to the need of LS4.0 connected with broader business strategy | Corporate vision | Used when LS4.0 integration is viewed as core to the business not an add-on | “We need to link Sustainability, digital and Lean into one direction of travel, not just separate initiatives.” | Governance, leadership role, KPIs |

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| Role of Leadership | Reference to leadership responsibility for driving Lean-Sustainability. | Lean implementation in aerospace context. | When leaders' involvement in Lean deployment or vision-setting is discussed. | "Leadership needs to model Lean behaviours… not just support the events." | Strategic, Alignment, Culture |
| Measurement and Reporting | Refers to KPIs and structured reporting for Sustainability performance | Metrics, accountability | When participants refers to systems of KPIs tracking system | "...we have dashboards that track emissions and energy consumption – this helps keep us accountable." | Sustainability maturity, Data |
| Data & Digital Tools | Perception of digital technologies and their role in Lean-Sustainability transformation. | Digital Lean-Sustainability Integration | Used when referring to Industry 4.0 tools, dashboards, digital twins, or analytics. | "...our digital twin simulations help us test Sustainability scenarios before investing." | I4.0. Performance tracking, Analytics |
| Integration Challenges | Barriers in aligning Lean and Sustainability within existing systems and culture | Implementation complexity | When participants referenced lack of structure, fragmentation, or competing priorities | "...we've got to stop seeing design, production and Sustainability as separate lanes—they're one flow." | Resistance to Change, Governance, Budget Constraints. |

Appendix H Thematic Analysis Development

| Theme | Lean Adoption in Aerospace |
|---|---|
| Summary | This theme captures how Lean has evolved in the aerospace context, including sector specific adaptations, maturity levels, and misconceptions. |
| Sub-themes | Misconceptions about Lean as a short term initiative<br>Design and manufacturing disconnect<br>Flow challenges due to high-mix low-volume conditions, and supply chain complexities |
| Representative Codes | Flow<br>Design for manufacturing<br>Design complexity<br>Lean misconception<br>Manual-intensive process<br>Lean in aerospace |
| Illustrative Quotes | “Lean isn't just about your manufacturing. Your Lean is in your design stage as well.”<br>“Aviation is very slow to change... it makes applying those things a bit more challenging...” |
| Contingency factors Influencing Theme | Compliance<br>Complexity<br>Ecosystem |

| Theme | Lean-Sustainability Synergy |
|---|---|
| Summary | This theme captures how Lean’s focus on waste reduction and value creation aligns with environmental and social Sustainability goals, revealing perceived win-win opportunities as well as measurement challenges |
| Sub-themes | Synergy in Waste Reduction<br>Social Sustainability<br>People-Centred view |
| Representative Codes | Sustainability linkage<br>Sustainability Kaizen<br>Social Sustainability<br>Burnout<br>Environmental waste |

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| | Energy efficiency<br>Human-centric |
| Illustrative Quotes | “By doing Lean, you get Sustainability for free…it’s a win-win”<br>“If we don’t Lean out processes, staff will burnout”<br>“We are very intentional also to run Sustainability Kaizen” |
| Contingency factors Influencing Theme | Compliance<br>Ecosystem |

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| Theme | Role of Advanced Technologies |
| Summary | This theme explores practitioners’ views on how I4.0 technologies enable Lean and Sustainability practices through enhanced visibility, automation, and real-time data, whilst also acknowledging readiness and cultural barriers. |
| Sub-themes | Infrastructure and Readiness Challenges<br>Data Accessibility and Use |
| Representative Codes | Data insight<br>Operational connectivity<br>Technology enabler<br>Digital waste<br>Cloud constraints<br>AI integration<br>Generative Design<br>Data and Tools |
| Illustrative Quotes | “We are very data rich…not very good at harvesting it “<br>“Companies of the future are driven by data”<br>There’s a danger that you automate something that’s wrong” |
| Contingency factors Influencing Theme | Compliance<br>Complexity<br>Novelty |

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| Theme | Strategic Alignment and Leadership Role |
| Summary | This theme addresses the role of leadership commitment and strategic deployment in enabling Lean-Sustainability 4.0, particularly through |

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| | Hoshin-Kanri, cultural transformation, and consistent leadership behaviour. |
| Sub-themes | Leadership Commitment<br>Strategic Alignment through Hoshin-Kanri<br>Cultural Transformation and Change Mechanisms |
| Representative Codes | Leadership commitment<br>Vision<br>Culture<br>Hoshin-Kanri<br>Executive behaviour<br>Change mechanisms |
| Illustrative Quotes | “Lean must be led from the top”<br>“You have to have a vision…”<br>“It’s a cultural thing…how you get people to be thinking in that particular way” |
| Contingency factors Influencing Theme | Novelty<br>Complexity |

Appendix I Capabilities, Enablers, Barriers and Contingency Factors from Codebook

| Capability | Definition | Lower-Order Capabilities (Micro foundations) | Enablers | Barriers | Contingency Factors |
|---|---|---|---|---|---|
| **Leanness** | Ability to reduce waste, improve flow, and enhance operational responsiveness | • Systematic problem solving<br>• Digital VSM<br>• Flow diagnostics<br>• Standard work routines<br>• Design for manufacturing<br>• Design for performance | Kaizen events, executive buy-in, Lean toolkit | Manual processes, fragmented supply chain, complex design | Complexity, Compliance, Ecosystem |
| **Knowledge** | Structured learning through problem solving, data interpretation, and knowledge reuse | • A3 and root-cause learning<br>• Knowledge-sharing systems<br>• AI-enhanced diagnostics<br>• Coaching routines<br>• Kaizen | Kaizen, turnaround reduction targets, knowledge platforms | Slow learning cycles, limited feedback loops | Novelty, Complexity |
| **Information** | Data access, processing, and usage for operational and Sustainability decision-making | • Operational connectivity<br>• Cloud-based dashboards<br>• EMIS<br>• Structured Gemba data flows | AI-VSM integration, data, cloud analytics | ITAR compliance, legacy systems, interoperability gaps | Compliance, Novelty |

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| **Culture** | Shared values and behaviours supporting Lean-Sustainability and human-centric digitalisation | • D&I embedded into Lean<br>• Psychological safety<br>• Shopfloor-led improvement<br>• Daily rituals | Leadership modelling, green teams, engagement surveys | Conservatism, resistance, techno-centrism | Ecosystem, Novelty |
| **Collaboration** | Cross-functional and cross-boundary engagement in Lean-Sustainability initiatives | • Supplier involvement<br>• Cross-functional Gemba walks<br>• Interdisciplinary workgroups<br>• Knowledge co-creation | Supplier cocreation, Hoshin-Kanri, inter-team projects | Silos, misaligned incentives, unclear ownership | Ecosystem, Compliance |
| **Technological Infrastructure** | Readiness and integration of I4.0 to support Lean and Sustainability | • Cloud platforms<br>• Digital twins<br>• Generative design tools<br>• Predictive maintenance systems | Sensor-based feedback, AI for design, secure cloud | Fragmented IT/OT, limited analytics skills | Compliance, Complexity, Novelty |
| **People** | Empowering employees through skills, autonomy, and tools to contribute to Lean-Sustainability transformation | • Respect for people<br>• Skills development platforms<br>• Digital literacy programmes<br>• Empowered decision-making<br>• AI-based task augmentation | AI assistant platform, continuous improvement culture, self-directed teams | Skill mismatch, resistance to role changes, lack of incentives for innovation | Novelty, Ecosystem |

## Appendix J Delphi Method Rounds – Questionnaires

**All company-identifying information has been anonymised to preserve confidentiality, as per ethical research guidelines.**

### ROUND 1 - EXPERT 1 (AP)

**Questionnaire:**

**Section 1: Relevance and Understanding of the Model**

**Relevance:**

- How relevant do you find the proposed model to the current challenges faced by XX Aerospace in achieving operational excellence, Sustainability, and technological integration?
- Extremely relevant to XX and multiple other aerospace businesses that I have visited. The industry is lagging in the sector and this helps to address it.

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- Does the model address key operational issues, such as supply chain resilience, regulatory compliance?
- I believe that the model sets out a standardised framework that will result in greater resilience and through the framework a natural byproduct is increased compliance.

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**Clarity:**

- Is the model clear and easy to understand in terms of its components and how they interrelate?
- Yes, easy and clear.

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- Are there any elements of the model that you feel require further explanation or simplification?
- No.

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**Section 2: Capabilities identified in the model**

**Higher-Order Capabilities:**

- Do you agree that the identified capabilities (data, knowledge, technological infrastructure, collaboration, culture, people and Leanness) are essential for achieving operational excellence at XX Aerospace?
- Absolutely. The aerospace industry has allowed itself to fall behind in all of these areas and in particular the areas of lack of good clear data, an insular culture leading to a lack of knowledge shared from the rest of industry and poor technological infrastructure. These are key pillars in addressing that both at XX Aerospace and in the supply chain.

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- Are there any additional capabilities you believe are critical that the model does not currently address?
- My experience of aerospace is that it has fads about what it is concentrating on for operational excellence, unlike automotive who tend to continually add to their tool box. Things like Six Sigma methodology and Apollo tools should be part of an ongoing improvement strategy and not a short term flow-down that doesn't get the chance to meet maturity.

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**Alignment with organisational practices:**

- Based on your experience, how well do the identified capabilities align with XX Aerospace's existing Lean practices and Sustainability initiatives?
- XX Aerospace is already changing since Larry Culp took over and therefore this fits very well in with the current direction of the company.

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- Are there specific areas where these capabilities could be further developed or integrated within the company?
- Development of culture and knowledge are key for business survival, these areas are still lacking behind and need focus.

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### Section 3: Integration of Lean, Sustainability, and Industry 4.0

**Lean practices:**

- Does the model effectively position Lean as a foundation for achieving both Sustainability and technological advancement at XX Aerospace?
- Lean should drive both Sustainability and technological advancement through improving processes and elimination of waste. Lean alone will not fix the issues however it gives a clear methodology for improvement.

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- Are the proposed transition (Lean-> Lean Sustainability-> Lean Sustainability 4.0) reflective of how practices are evolving within the company?
- I think it is too early to determine. Lean was already introduced and replaced and faded away. It takes time and commitment to stay focussed and achieve.

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**Sustainability Integration:**

- How well does the model integrate Sustainability principles into XX's current operational practices?
- The model is an obvious next step once the company is already accepting and on the path to achieving operational excellence.

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- What additional Sustainability goals or challenges should the model consider to better align with the company's priorities?
- Sustainability is all around us and is clearly the future. This will become the focus over time and therefore needs to be adopted early.

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**Technological integration:**

- Does the model sufficiently incorporate advanced technologies (e.g, IoT, AI, automation) that are relevant to XX Aerospace?
- Yes. It is clear that the company is moving in this direction within the current model.

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- Are there specific technologies or tools currently in use or planned at XX that the model should highlight?
- N/A

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### Section 4: Practicality and Outcomes

**Implementation feasibility:**

- How feasible is it to implement the model within XX Aerospace considering its current resources, infrastructure, and capabilities?
- The model should be a natural follow on from the foundations that are already in place. Using this model will cut costs, free up resource and increase capability.

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- What barriers or challenges might the company face in adoption this model, and how could these be addressed?
- Change management is the hardest thing to do in an aerospace company. There are multiple people, systems and customers that shall resist change because they see all change as risk. This is common across aerospace even when trying to make simple improvements.

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**Alignment with Performance Metrics (SQDCIE)**

- Do you find the alignment between the identified capabilities and measurable outcomes (Safety, Quality, Delivery, Cost, Improvement, Environment) appropriate for XX Aerospace?

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- Are there additional performance metrics or priorities specific to the company that should be considered?

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## Section 5: Contextual Adaptability

**Sector-Specific Relevance:**

- Does the model adequately account for the unique characteristics of the aerospace sector, such as regulatory requirements, supply chains complexities, or customer expectations?
- Yes, however can be applied to multiple sectors of the industry.

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- Are there contingency factors specific to XX Aerospace that the model should address?

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**Cultural alignment:**

- Does the model align with XX Aerospace's organisational culture, particularly regarding Lean practices, innovation, and Sustainability?
- Yes I believe it does in a big way. XX Aerospace is at the start of this journey.

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- What cultural shifts, if any, would be needed to implement this model effectively?
- It again comes back to perseverance and change management to make this succeed.

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## Section 6: Open-Ended Feedback

**General impressions:**

- What are your overall impressions of the proposed model?
- It aligns well with XX Aerospace thinking and the industry as a whole.

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- Are there specific elements or aspects of the model that you feel require further refinement?
- Not at this point

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**Future Considerations:**

- Based on your experience, are there emerging trends, challenges, or opportunities that the model should address in the future?
- I think it is too early to say. The model needs time to become embedded and then it shall naturally progress.

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## ROUND 1 - EXPERT 2 (LO)

**Questionnaire:**

**Section 1: Relevance and Understanding of the Model**

**Relevance:**

- How relevant do you find the proposed model to the current challenges faced by XX Aerospace in achieving operational excellence, Sustainability, and technological integration?

Very relevant, however how do you implement the model

- Does the model address key operational issues, such as supply chain resilience, regulatory compliance?

I would like to see how the model addresses the relationships between Supplier, XX and Customer to have technology plans for the future

**Clarity:**

- Is the model clear and easy to understand in terms of its components and how they interrelate? Yes
- Are there any elements of the model that you feel require further explanation or simplification? May the steps to implement

**Section 2: Capabilities identified in the model**

**Higher-Order Capabilities:**

- Do you agree that the identified capabilities (data, knowledge, technological infrastructure, collaboration, culture, people and Leanness) are essential for achieving operational excellence at XX Aerospace? Yes I do, however I would change data to information
- Are there any additional capabilities you believe are critical that the model does not currently address? Within current XXX operating reviews where and how do you see this being covered IE what are the key metrics?

**Alignment with organisational practices:**

- Based on your experience, how well do the identified capabilities align with XXX Aerospace's existing Lean practices and Sustainability initiatives?

They go a few steps further than we currently are today, but would say its where we are aiming to be

- Are there specific areas where these capabilities could be further developed or integrated within the company?

**Section 3: Integration of Lean, Sustainability, and Industry 4.0**

**Lean practices:**

- Does the model effectively position Lean as a foundation for achieving both Sustainability and technological advancement at XXX Aerospace?
- Are the proposed transition (Lean-> Lean Sustainability-> Lean Sustainability 4.0) reflective of how practices are evolving within the company? Not at this point to the end vision for this model

**Sustainability Integration:**

- How well does the model integrate Sustainability principles into XXX's current operational practices? I think the model aims to add Sustainability as a core function within Lean and how the business operates, still interested in how you implement
- What additional Sustainability goals or challenges should the model consider to better align with the company's priorities? Do you think we have clear goals cascaded?

**Technological integration:**

- Does the model sufficiently incorporate advanced technologies (e.g, IoT, AI, automation) that are relevant to XXX Aerospace?
- Are there specific technologies or tools currently in use or planned at XXX that the model should highlight?

**Section 4: Practicality and Outcomes**

**Implementation feasibility:**

- How feasible is it to implement the model within XXX Aerospace considering its current resources, infrastructure, and capabilities?

As per previous questions, how would you say we implement??

- What barriers or challenges might the company face in adoption this model, and how could these be addressed? Change Fatigue is common at the moment

**Alignment with Performance Metrics (SQDCIE)**

- Do you find the alignment between the identified capabilities and measurable outcomes (Safety, Quality, Delivery, Cost, Improvement, Environment) appropriate for XXX Aerospace? I guess what is the measure of improvement? Improvement is a characteristic we require in all KPI's
- Are there additional performance metrics or priorities specific to the company that should be considered?

**Section 5: Contextual Adaptability**

**Sector-Specific Relevance:**

- Does the model adequately account for the unique characteristics of the aerospace sector, such as regulatory requirements, supply chains complexities, or customer expectations?
- Are there contingency factors specific to XXX Aerospace that the model should address? Should there be an element of Business Continuity planning

**Cultural alignment:**

- Does the model align with XXX Aerospace's organisational culture, particularly regarding Lean practices, innovation, and Sustainability? Sustainability is not yet ingrained in leadership or through the culture
- What cultural shifts, if any, would be needed to implement this model effectively? That Sustainability is a key Metric/requirement

**Section 6: Open-Ended Feedback**

**General impressions:**

- What are your overall impressions of the proposed model? Interesting, however I still come back to what does good look like when implemented and how do you implement?
- Are there specific elements or aspects of the model that you feel require further refinement?

**Future Considerations:**

- Based on your experience, are there emerging trends, challenges, or opportunities that the model should address in the future?

Reach will be an ongoing process how does the aerospace industry get ahead of this rather than extending

## ROUND 1 - EXPERT 3 (CD)

**Questionnaire:**

**Section 1: Relevance and Understanding of the Model**

**Relevance:**

- How relevant do you find the proposed model to the current challenges faced by XXX Aerospace in achieving operational excellence, Sustainability, and technological integration?

*The relevance of the proposed model is reflective of the current state of developing a balance between Agile/A.I./4.0 and other digital based process management tools and the intent of Lean (Western World term) or TPS. I am concerned that the more distance placed between the process, either transactional or production based, the wrong real-world problems will be solved. On the other side of the coin, I've seen AI drive significant time out of a process and support decision making capabilities.*

*To sum my thoughts, the appropriate process and input of data through a digital system can provide an asset to a business.*

- Does the model address key operational issues, such as supply chain resilience, regulatory compliance?

*Supply chain resiliency and regulatory compliance are broad subjects. Key operational issues can potentially be refined and have a stronger digital footprint in a business.*

*The supply chain, in simplest terms is the acorn to the sapling, to the tree, to the mill, to the saw, to the kiln, to the construction site…..The real question is how will a digital system link to a mining operation in Chile producing copper, to the bi-product of raw lithium, to a battery in a Tesla. This will require an extremely integrated system, owned by different entities.*

*Compliance has many facets, and digitization doesn't control the process very well. Compliance is from ITAR and other legal aspects in most cases currently and into the future require a very hands-on approach. As a global commerce continues to be developed, compliance is a major ongoing concern.*

**Clarity:**

- Is the model clear and easy to understand in terms of its components and how they interrelate?

*Probably not to the layman. Think in terms of standard work and standard developments processes. Standard work has three elements: takt time; work sequence; standard inventory. The three parts of a standard are: content; process; performance.*

- Are there any elements of the model that you feel require further explanation or simplification?

*See above notes*

**Section 2: Capabilities identified in the model**

**Higher-Order Capabilities:**

- Do you agree that the identified capabilities (data, knowledge, technological infrastructure, collaboration, culture, people and Leanness) are essential for achieving operational excellence at XXX Aerospace?

*yes*

- Are there any additional capabilities you believe are critical that the model does not currently address?

*Dispersed in my notes*

**Alignment with organisational practices:**

- Based on your experience, how well do the identified capabilities align with XXX Aerospace's existing Lean practices and Sustainability initiatives?

*There are still gaps in any Lean program. Toyota has been driving CI for over 70 years and still make changes daily to the TPS system.*

- Are there specific areas where these capabilities could be further developed or integrated within the company?

*Included in my notes and responses.*

**Section 3: Integration of Lean, Sustainability, and Industry 4.0**

**Lean practices:**

- Does the model effectively position Lean as a foundation for achieving both Sustainability and technological advancement at XXX Aerospace?

*I am not perceiving a clear line in the model between "respect for people", "development of people" and the application of a digital model.*

- Are the proposed transition (Lean-> Lean Sustainability-> Lean Sustainability 4.0) reflective of how practices are evolving within the company?

*Lean is continuous journey….to drive towards a "waste" free environment. In most Lean systems being developed, the system is inherently heavy with over-processing, defects, and excess inventory. Lean needs to focus on solving the problems at point of occurrence, at the time the problem occurred.*

**Sustainability Integration:**

- How well does the model integrate Sustainability principles into **XXX**'s current operational practices?

*This view can be obtained from by previous response.*

- What additional Sustainability goals or challenges should the model consider to better align with the company's priorities?

*I would potentially work to understand value stream costing analysis. It is the factor of understanding "should cost" versus "actual cost" by process.*

**Technological integration:**

- Does the model sufficiently incorporate advanced technologies (e.g, IoT, AI, automation) that are relevant to XXX Aerospace?

*I'm not able to comment on this subject.*

- Are there specific technologies or tools currently in use or planned at XXX that the model should highlight?

*I'm not able to comment on this subject.*

**Section 4: Practicality and Outcomes**

**Implementation feasibility:**

- How feasible is it to implement the model within XXX Aerospace considering its current resources, infrastructure, and capabilities?

*That is a question for individuals with that decision making capability.  I'm not one of the individuals.*

- What barriers or challenges might the company face in adoption this model, and how could these be addressed?

*Stability of a Lean program….too many adopted variations by leadership is a common failure mode for most companies.*

**Alignment with Performance Metrics (SQDCIE)**

- Do you find the alignment between the identified capabilities and measurable outcomes (Safety, Quality, Delivery, Cost, Improvement, Environment) appropriate for XXX Aerospace?

*Yes*

- Are there additional performance metrics or priorities specific to the company that should be considered?

*Not at liberty to discuss.*

**Section 5: Contextual Adaptability**

**Sector-Specific Relevance:**

- Does the model adequately account for the unique characteristics of the aerospace sector, such as regulatory requirements, supply chains complexities, or customer expectations?

*Not at liberty to discuss.*

- Are there contingency factors specific to XXX Aerospace that the model should address?

*Not that I can impact.*

**Cultural alignment:**

- Does the model align with XXX Aerospace's organisational culture, particularly regarding Lean practices, innovation, and Sustainability?

*I will need to leave this to others to answer.*

- What cultural shifts, if any, would be needed to implement this model effectively?

*See other notes and responses.*

**Section 6: Open-Ended Feedback**

**General impressions:**

- What are your overall impressions of the proposed model?

*Potential merit…..*

- Are there specific elements or aspects of the model that you feel require further refinement?

*Thoughts are included in responses.*

**Future Considerations:**

- Based on your experience, are there emerging trends, challenges, or opportunities that the model should address in the future?

*There are always emerging technologies and trends, as well a global challenge. I am not sure how the model will manage or control.*

**Expert 3 FURTHER COMMENTS:**

I have spent time reviewing the document attached and I have to commend you on some excellent work. I do have some critiques on some concepts to the developed model.

1. Sustainability – this is a cultural issue and, in my opinion, has two points of conversion. The conversion points are the meeting of top down and bottom up collaboration of people. One of the foundational approaches of the Toyota Production System is “Respect for People”. This point is often overlooked or not led properly by most western based companies. To create a model of sustainment, I believe three criteria are needed 1) Accountability 2) Leadership Model Behavior 3) People Development and Growth.

2. Technology before Physical gemba – I may have missed some points here in what you are telling the reader….I will provide my reflection on the subject and give scenarios of success/failure modes from experience. Data in it’s truest nature is only as good as the inputs, and often systems don’t naturally connect effectively in business. I will give two cases as reference from the UK. The first was a technological smart designed building in the Southampton area. This building was developed to be an industry 4.0 building with multiple data gathering points designed to manage the processes at the highest level outputs. In reality, the system was to elaborate, and the employees didn’t adhere to the request of leadership to follow protocol. The design of the building created many forms of Lean waste; from travel/transportation, waiting, defects, inventory, motion and excess processing. To overcome these mis-guided 4.0 attributes, a standalone rotable-pool system was developed and managed from an excel spreadsheet. The second case was a collaboration between a university in the UK and a new construction based manufacturing facility. The university brought in a team of students and faculty to gLean the existing data of the business to create a 4.0 environment with the goal of increasing output. During a collaboration session, the data from the university was compared to physical data collected from Lean experts from the gemba. If the university’s process was followed, the impact to output would have impacted the production rate with a forty percent loss.

## ROUND 1 - EXPERT 4 (JG)

**Questionnaire:**

**Section 1: Relevance and Understanding of the Model**

**Relevance:**

- How relevant do you find the proposed model to the current challenges faced by XXX Aerospace in achieving operational excellence, Sustainability, and technological integration?

I find the proposed model highly relevant to the current challenges faced by **AEROSKYWARD** Aerospace in achieving operational excellence, Sustainability, and technological integration. What can be addressed if your priority order of SQDCIE.

- Does the model address key operational issues, such as supply chain resilience, regulatory compliance?

I would say it does. Where you are looking at this through the lens of ESG, it covers governance and regulatory compliance.

**Clarity:**

- Is the model clear and easy to understand in terms of its components and how they interrelate?

Not quite. More work needs to be done to simplify the model as discussed in our 1-1.

- Are there any elements of the model that you feel require further explanation or simplification?

I would suggest going back to the original model layout you showed me to help simplify it.

**Section 2: Capabilities identified in the model**

**Higher-Order Capabilities:**

- Do you agree that the identified capabilities (data, knowledge, technological infrastructure, collaboration, culture, people and Leanness) are essential for achieving operational excellence at XXX Aerospace?

Yes, they are. I would also suggest that you consider data, **information** and knowledge to complete the package.

I also align better with the XXXX Aerospace idea that People should sit in the level above with SQDC.

- Are there any additional capabilities you believe are critical that the model does not currently address?

None that have not been addressed. But as an improvement, you could look into **information**.

**Alignment with organisational practices:**

- Based on your experience, how well do the identified capabilities align with XXX Aerospace's existing Lean practices and Sustainability initiatives?

To be completely frank, **AEROSKYWARD** Aerospace Cheltenham are still a way behind adopting the capabilities listed in the model. I cannot say we have adopted any one of them particularly well. We talk a lot about it, but true adoption at all levels is very low.

- Are there specific areas where these capabilities could be further developed or integrated within the company?

Certainly opportunities for integration into the company standard work. But it need a strong local leader to dive the thinking and behaviour.

**Section 3: Integration of Lean, Sustainability, and Industry 4.0**

**Lean practices:**

- Does the model effectively position Lean as a foundation for achieving both Sustainability and technological advancement at XXX Aerospace?

Yes, it does. I think that trying to link Lean with Sustainability, including Industry 4.0 is a novel idea. Specific to XXX Aerospace, the next step is for us to understand a roll out plan to adopt this model.

- Are the proposed transition (Lean-> Lean Sustainability-> Lean Sustainability 4.0) reflective of how practices are evolving within the company?

No. **AEROSKYWARD** Aerospace Cheltenham are still in the Lean realm with little to no Lean Sustainability 4.0 awareness.

**Sustainability Integration:**

- How well does the model integrate Sustainability principles into XXX's current operational practices?

Similar to the previous answers, because of **AEROSKYWARDs** low maturity level with Sustainability, there isn't much to integrate between the model and current practices. It is more a case of **AEROSKYWARD** adopting the model and its philosophies.

- What additional Sustainability goals or challenges should the model consider to better align with the company's priorities?

None that I can think of. ESG is a strong foundation to get us started.

**Technological integration:**

- Does the model sufficiently incorporate advanced technologies (e.g, IoT, AI, automation) that are relevant to **AEROSKYWARD** Aerospace?

Yes, it does. All the above – IoT, AI and automation are relevant to XXX Aerospace.

- Are there specific technologies or tools currently in use or planned at XX that the model should highlight?

None that I am aware of.

**Section 4: Practicality and Outcomes**

**Implementation feasibility:**

- How feasible is it to implement the model within XXX Aerospace considering its current resources, infrastructure, and capabilities?

With the current level of resourcing, infrastructure and capabilities… my opinion is that it will be very difficult to implement the model at XXX Aerospace. My fear is that if we did embark on implementing it with the current resource levels, we would create a bigger mess.

- What barriers or challenges might the company face in adoption this model, and how could these be addressed?

The barriers I can think of are:

- Lack of understanding of the benefits
- Lack of resources
- Lack of investment

**Alignment with Performance Metrics (SQDCIE)**

- Do you find the alignment between the identified capabilities and measurable outcomes (Safety, Quality, Delivery, Cost, Improvement, Environment) appropriate for XXX Aerospace?

Yes, these are appropriate. Although I prefer SQDCEP. Improvement is inherent to some of the other elements of the model already.

- Are there additional performance metrics or priorities specific to the company that should be considered?

The KPIs measured by XXX are all covered in SQDC.

**Section 5: Contextual Adaptability**

**Sector-Specific Relevance:**

- Does the model adequately account for the unique characteristics of the aerospace sector, such as regulatory requirements, supply chains complexities, or customer expectations?

Yes, it does. Aerospace is a highly regulated industry with complex supply chains. This model effectively addresses the regulatory aspects and accounts for the complex supply chains.

- Are there contingency factors specific to XXX Aerospace that the model should address?

None that I can think of.

**Cultural alignment:**

- Does the model align with XXX Aerospace's organisational culture, particularly regarding Lean practices, innovation, and Sustainability?

Yes, it does. I truly believe that XXX Aerospace was to drive towards what this model outlines. It is just a case of figuring out the resources to do the same.

- What cultural shifts, if any, would be needed to implement this model effectively?

At XXX Aerospace CH, we need to embrace change. Overall, we need to see how AI can work alongside what we do to enhance our output. Stop spreading fear that AI will replace the work we do.

**Section 6: Open-Ended Feedback**

**General impressions:**

- What are your overall impressions of the proposed model?

I like the idea. I only ask for it to be simplified to make it easier to understand by anyone with less industry knowledge.

- Are there specific elements or aspects of the model that you feel require further refinement?

Yes, simplifying the model will make it more effective.

**Future Considerations:**

- Based on your experience, are there emerging trends, challenges, or opportunities that the model should address in the future?

IT security risks are increasing. This will be an ongoing challenge that gets more complex over time. Future iterations of the model should consider this.

ROUND 2 – EXPERT 1 (AP)

# ROUND 2

# Lean-Sustainability 4.0: An Integrative Operational Model for the Aerospace Industry in the Age of Digitalisation.

## Introduction:

Thank you for your Round 1 insights. I have summarised key themes below and seek your input to refine and validate the model. This round combines short-answer questions for depth and ratings/rankings for clarity, aiming to reduce effort whilst enhancing the model.

## Round 1 Summary:

- Model is relevant but needs implementation clarity (Steps and priority capabilities)
- Capabilities are essential, suggestions including “Information”, “Organisational Learning”, and “Six Sigma”.
- Feasibility depends on overcoming change fatigue; SQDCIE fits but “Improvement” metric is unclear.
- Cultural element is critical to drive the model integration.
- Implementation steps starting with the voice of the customer and stakeholders through activating sensing

## Refined Model Summary:

- Model figure changed
- Voice of the Customer and Stakeholders added as the model’s input
- Customer satisfaction feedback-loop added and informed leadership and strategy
- Renamed “Data” to “Information” for decision-making focus.
- Emphasised “Respect for People” in Lean-Sustainability 4.0 integration.
- Proposed initial implementation steps: 1) Starting with the Voice of the Customer and Stakeholders (VoCS), 2) Assess current capabilities; 3) Pilot change through Gemba.

## Section 1: Relevance and Implementation

1. Rate the refined model's relevance to XXX Aerospace's challenges with the VoCS and Customer satisfaction loop (1= not relevant, 5= highly relevant) …...
   How do the changes improve its fit? …4…………………….
2. Rate the clarity of the revised figure 1 (1=unclear, 5=clear)…..5..
   What one tweak would enhance its usability for practitioners? …Change through Gemba……………..
3. Suggest 2-3 practical first steps for XXX to implement the model, considering change fatigue? Practical implementation and being at the workface can avoid change fatigue. Doing not telling.…………………….

## Section 2: Capabilities

4. Rate the change from "Data" to "Information" in the refined model (1=not useful, 5=very useful) …1……......................
   Does it fully address decision-making needs, or is more needed?………I don't think it changes anything…………………………
5. Rate the importance of adding "organisational Learning" as a capability (current model embed organisational learning within Knowledge capability) (1= not important, 5= very important).
   ……………4……………………..

## Section 3: Integration

6. Rate how well the model integrates Lean, Sustainability, and Industry 4.0 with the VoCS loop (1=poorly, 5=very well) …5.……………………
7. How does it balance technology with physical gemba? (1=poorly, 5=very well) …5 (its always going to be trial and error to find the best fit)……………………
8. Rate the model's Sustainability focus (1=weak, 5=strong) …5…………
9. What one Sustainability goal (e.g REACH, operational emissions scope 1 and 2 or scope 3) should be prioritised, and why? …Operational emissions scope is very relevant now and easy to impact. REACH is already mature and in progress……………….

## Section 4: Practicality and Outcomes

10. Rate the feasibility of implementing the model (1=not feasible, 5=very feasible) …5……….
11. Rate the customer satisfaction loop's fit with 1=poor fit, 5=strong fit) ……5…………….
12. How should "improvement" be measured (e.g., Kaizen outcomes, customer feedback)?
    …Its not always easy to see correlation from implementation through to defined improvement, however best practice and doing the right thing will culturally improve overall and change will happen……………….

## Section 5: Contextual Adaptability

13. Rate the model's alignment with XXX's culture (1=poor fit, 5=strong fit) ……5…………….
14. Does the VoCs loop help embed Sustainability, and what cultural shift is still needed? …Yes, VoC is key. Customers need to be embedded in the floor culture and not just here for announced spot audits.……………….
15. Rate the need for "Business Continuity Planning" as contingency factor (1=not needed, 5=essential). Why or why not? ……5 Contingency is always key to keeping quality and output…………….

## Section 6: Final Feedback

16. Rate your overall confidence in the model's readiness for XX Aerospace (1=not ready, 5=fully ready) …5……………….
    What one change would make it fully actionable?....................
17. Mark top important capabilities (Information, Knowledge, Tech Infrastructure, Collaboration, Culture, People, Leanness) from 1 (most important) to 5 (least). (Multiple same ranking is allowed)
    - Information 6
    - Knowledge 1
    - Technological Infrastructure 2
    - Collaboration 4
    - Culture 3
    - People 7

- Leanness 5

Briefly justify your top choice XXX has been suffering because of a lack of knowledge – not knowing what the industry is doing and believing that “they are the best” when they are clearly not. Knowledge is key to survival.

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ROUND 2 – EXPERT (LO)

# ROUND 2

# Lean-Sustainability 4.0: An Integrative Operational Model for the Aerospace Industry in the Age of Digitalisation.

## Introduction:

Thank you for your Round 1 insights. I have summarised key themes below and seek your input to refine and validate the model. This round combines short-answer questions for depth and ratings/rankings for clarity, aiming to reduce effort whilst enhancing the model.

## Round 1 Summary:

- Model is relevant but needs implementation clarity (Steps and priority capabilities)
- Capabilities are essential, suggestions including “Information”, “Organisational Learning”, and “Six Sigma”.
- Feasibility depends on overcoming change fatigue; SQDCIE fits but “Improvement” metric is unclear.
- Cultural element is critical to drive the model integration.
- Implementation steps starting with the voice of the Customer and Stakeholders (VoCS) through activating sensing

## Refined Model Summary:

- Model figure changed
- Voice of the Customer and Stakeholders added as the model’s input
- Customer satisfaction feedback-loop added and informed leadership and strategy
- Renamed “Data” to “Information” for decision-making focus.
- Emphasised “Respect for People” in Lean-Sustainability 4.0 integration.
- Proposed initial implementation steps: 1) Starting with the Voice of the Customer and Stakeholders (VoCS), 2) Assess current capabilities; 3) Pilot change through Gemba.

## Section 1: Relevance and Implementation

1. Rate the refined model's relevance to XXX Aerospace's challenges with the VoCS and Customer satisfaction loop (1= not relevant, 5= highly relevant) …...
   How do the changes improve its fit? ……4………………….
2. Rate the clarity of the revised figure 1 (1=unclear, 5=clear).…3...
   What one tweak would enhance its usability for practitioners? Like content, bit busy can you simplify?……………..
3. Suggest 2-3 practical first steps for XX to implement the model, considering change fatigue? Create the need, why are we doing this? How does is benefit People?

## Section 2: Capabilities

4. Rate the change from "Data" to "Information" in the refined model (1=not useful, 5=very useful) ……4 …......................
   Does it fully address decision-making needs, or is more needed?…is there a way of showing data turning to information to take action?? ………………
5. Rate the importance of adding "organisational Learning" as a capability (current model embed organisational learning within Knowledge capability) (1= not important, 5= very important).
   …5 Not only organisational learning but collaborative learning…………..

## Section 3: Integration

6. Rate how well the model integrates Lean, Sustainability, and Industry 4.0 with the VoCS loop (1=poorly, 5=very well) ………4………………
7. How does it balance technology with physical gemba? (1=poorly, 5=very well) 4
8. Rate the model's Sustainability focus (1=weak, 5=strong) …4…………
9. What one Sustainability goal (e.g REACH, operational emissions scope 1 and 2 or scope 3) should be prioritised, and why? …I would say Reach and Scope 1 & 2 together as they both are needed – Reach for the business continuity and scope 1 & 2 for the more moral side for people …………….

## Section 4: Practicality and Outcomes

10. Rate the feasibility of implementing the model (1=not feasible, 5=very feasible) …4……….

11. Rate the customer satisfaction loop's fit with 1=poor fit, 5=strong fit)
    …question who is customer? I can see in this that everyone can be the customer…………4…….
12. How should "improvement" be measured (e.g., Kaizen outcomes, customer feedback)?
    …I think there is a number of elements required to be measured to understand outcome – Ie. Tons of co2e, Business KPI's, People engagement etc………………

## Section 5: Contextual Adaptability

13. Rate the model's alignment with XXX's culture (1=poor fit, 5=strong fit)
    ………4………….
14. Does the VoCs loop help embed Sustainability, and what cultural shift is still needed? …Yes as our customers are driving Sustainability Ie Airbus, same point as above though I think we need to consider who is the customer?………………
15. Rate the need for "Business Continuity Planning" as contingency factor (1=not needed, 5=essential). Why or why not? …5 essential, how do we protect both the business and its customers and employees and the economy ………………

## Section 6: Final Feedback

16. Rate your overall confidence in the model's readiness for XXX Aerospace (1=not ready, 5=fully ready) …3.5
    What one change would make it fully actionable?....Creating the need, without change Fatigue we have made a lot of changes recently as a business FLIGHT DECK 2.0 for example........
17. Mark top important capabilities (Information, Knowledge, Tech Infrastructure, Collaboration, Culture, People, Leanness) from 1 (most important) to 5 (least). (Multiple same ranking is allowed)
    - Information 3
    - Knowledge -2
    - Technological Infrastructure 5
    - Collaboration -2
    - Culture -1
    - People - 1
    - Leanness 3

ROUND 2 - EXPERT 3 (CD)

# ROUND 2

# Lean-Sustainability 4.0: An Integrative Operational Model for the Aerospace Industry in the Age of Digitalisation.

## Introduction:

Thank you for your Round 1 insights. I have summarised key themes below and seek your input to refine and validate the model. This round combines short-answer questions for depth and ratings/rankings for clarity, aiming to reduce effort whilst enhancing the model.

## Round 1 Summary:

- Model is relevant but needs implementation clarity (Steps and priority capabilities)
- Capabilities are essential, suggestions including “Information”, “Organisational Learning”, and “Six Sigma”.
- Feasibility depends on overcoming change fatigue; SQDCIE fits but “Improvement” metric is unclear.
- Cultural element is critical to drive the model integration.
- Implementation steps starting with the voice of the Customer and Stakeholders (VoCS) through activating sensing

## Refined Model Summary:

- Model figure changed
- Voice of the Customer and Stakeholders added as the model’s input
- Customer satisfaction feedback-loop added and informed leadership and strategy
- Renamed “Data” to “Information” for decision-making focus.
- Emphasised “Respect for People” in Lean-Sustainability 4.0 integration.
- Proposed initial implementation steps: 1) Starting with the Voice of the Customer and Stakeholders (VoCS), 2) Assess current capabilities; 3) Pilot change through Gemba.

## Section 1: Relevance and Implementation

1. Rate the refined model's relevance to XXX Aerospace's challenges with the VoCS and Customer satisfaction loop (1= not relevant, 5= highly relevant) ….4
   How do the changes improve its fit?
2. Rate the clarity of the revised figure 1 (1=unclear, 5=clear)…..5
   What one tweak would enhance its usability for practitioners? …phased steps
   Suggest 2-3 practical first steps for XXX to implement the model, considering change fatigue? Start with Voice of the customer, run gemba based pilots, ensure leadership role modelling

## Section 2: Capabilities

3. Rate the change from "Data" to "Information" in the refined model (1=not useful, 5=very useful) …4
   Does it fully address decision-making needs, or is more needed?……Yes
4. Rate the importance of adding "organisational Learning" as a capability (current model embed organisational learning within Knowledge capability) (1= not important, 5= very important).
   …5

## Section 3: Integration

5. Rate how well the model integrates Lean, Sustainability, and Industry 4.0 with the VoCS loop (1=poorly, 5=very well) ……………4
6. How does it balance technology with physical gemba? (1=poorly, 5=very well)
   …………5……………
7. Rate the model's Sustainability focus (1=weak, 5=strong) ………4…….
8. What one Sustainability goal (e.g REACH, operational emissions scope 1 and 2 or scope 3) should be prioritised, and why? ….Scope 1 and 2 emissions

## Section 4: Practicality and Outcomes

9. Rate the feasibility of implementing the model (1=not feasible, 5=very feasible)
   …4…….
10. Rate the customer satisfaction loop's fit with 1=poor fit, 5=strong fit)
    ………4…….

11. How should “improvement” be measured (e.g., Kaizen outcomes, customer feedback)? Kaizen outcomes tied to customer/stakeholder value, complemented with employee-driven problem-solving metrics.

## Section 5: Contextual Adaptability

12. Rate the model’s alignment with XX’s culture (1=poor fit, 5=strong fit) …5…….
13. Does the VoCs loop help embed Sustainability, and what cultural shift is still needed? Yes, but cultural shift still needed, embed accountability, leadership model behaviour, and people development consistently
14. Rate the need for “Business Continuity Planning” as contingency factor (1=not needed, 5=essential). Why or why not? …………5….

## Section 6: Final Feedback

15. Rate your overall confidence in the model’s readiness for XX Aerospace (1=not ready, 5=fully ready) ………5………….
    What one change would make it fully actionable?..........leadership responsibilities for cultural sustainment and respect for people alongside digital transformation...........
16. Mark top important capabilities (Information, Knowledge, Tech Infrastructure, Collaboration, Culture, People, Leanness) from 1 (most important) to 5 (least). (Multiple same ranking is allowed)
    - Information 3
    - Knowledge 4
    - Technological Infrastructure 5
    - Collaboration 3
    - Culture 1
    - People 2
    - Leanness 4

Briefly justify your top choice: Culture drives Sustainability. Without accountability, leadership model behaviour and people development, even the best digital or Lean system will collapse

ROUND 2 – EXPERT 4 (JG)

# ROUND 2

# Lean-Sustainability 4.0: An Integrative Operational Model for the Aerospace Industry in the Age of Digitalisation.

## Introduction:

Thank you for your Round 1 insights. I have summarised key themes below and seek your input to refine and validate the model. This round combines short-answer questions for depth and ratings/rankings for clarity, aiming to reduce effort whilst enhancing the model.

## Round 1 Summary:

- Model is relevant but needs implementation clarity (Steps and priority capabilities)
- Capabilities are essential, suggestions including “Data-Information”, “Organisational Learning”, and “Six Sigma”.
- Feasibility depends on overcoming change fatigue; SQDCIE fits but “Improvement” metric is unclear.
- Cultural element is critical to drive the model integration.
- Implementation steps starting with the voice of the Customer and Stakeholders (VoCS) through activating sensing

## Refined Model Summary:

- Model figure changed
- Voice of the Customer and Stakeholders added as the model’s input
- Customer satisfaction feedback-loop added and informed leadership and strategy
- Renamed “Data” to “Information” for decision-making focus.
- Emphasised “Respect for People” in Lean-Sustainability 4.0 integration.
- Proposed initial implementation steps: 1) Starting with the Voice of the Customer and Stakeholders (VoCS), 2) Assess current capabilities; 3) Pilot change through Gemba.

## Section 1: Relevance and Implementation

1. Rate the refined model's relevance to XXX Aerospace's challenges with the VoCS and Customer satisfaction loop (1= not relevant, 5= highly relevant) …4...
   How do the changes improve its fit? …I have made further changes to the model in line with our discussion……………………
2. Rate the clarity of the revised figure 1 (1=unclear, 5=clear).…4...
   What one tweak would enhance its usability for practitioners? …further explanation of complexity, eco-system, compliance and novelty will be helpful……………..
3. Suggest 2-3 practical first steps for XXX to implement the model, considering change fatigue? …first step: accept that we need radical change to improve, second: collect data and convert it to information and knowledge, third: resource, resource and resource………………….

## Section 2: Capabilities

4. Rate the change from "Data" to "Information" in the refined model (1=not useful, 5=very useful) …5…........................
   Does it fully address decision-making needs, or is more needed?……it is important to explain to the reader the difference between data, information and knowledge and how they tie together to fully address decision making…
5. Rate the importance of adding "organisational Learning" as a capability (current model embed organisational learning within Knowledge capability) (1= not important, 5= very important).
   ……5…

## Section 3: Integration

6. Rate how well the model integrates Lean, Sustainability, and Industry 4.0 with the VoCS loop (1=poorly, 5=very well) …4 – the feedback loop is very important
7. How does it balance technology with physical gemba? (1=poorly, 5=very well) …3 – I am unsure here. Technically if good data is available via technology, it can be accessed anywhere to paint a clear picture thus reducing the need to go to Gemba. This is my opinion
8. Rate the model's Sustainability focus (1=weak, 5=strong) …4.

9. What one Sustainability goal (e.g REACH, operational emissions scope 1 and 2 or scope 3) should be prioritised, and why? …Any Sustainability goal that is driven by governance must be prioritised……………….

## Section 4: Practicality and Outcomes

10. Rate the feasibility of implementing the model (1=not feasible, 5=very feasible) …4……….
11. Rate the customer satisfaction loop's fit with 1=poor fit, 5=strong fit) …5…
12. How should "improvement" be measured (e.g., Kaizen outcomes, customer feedback), and how should "People" be measured? …improvement should be measured by customer feedback (the main driver). People may be measured by turnover and feedback

## Section 5: Contextual Adaptability

13. Rate the model's alignment with XXX's culture (1=poor fit, 5=strong fit) …2 – this is not a reflection of the model, rather the weak culture at XXX……………….
14. Does the VoCs loop help embed Sustainability, and what cultural shift is still needed? …My experience has been that customers are not driving Sustainability. Delivery is still key to them. Should the customer start push for Sustainability improvements, this model is prepared to support the activities……………….
15. Rate the need for "Business Continuity Planning" as contingency factor (1=not needed, 5=essential). Why or why not? …5 – this is essential and where most businesses fall apart. Lack of continuity in business systems and employees. Without business continuity, all the hard work put in can be lost and the business tends to have to start from scratch. This is wasteful……………….

## Section 6: Final Feedback

16. Rate your overall confidence in the model's readiness for XXX Aerospace (1=not ready, 5=fully ready) …4……………….
    What one change would make it fully actionable?...in my experience, the XXX culture needs to change to make this model fully actionable here.................

18. Mark top important capabilities (Information, Knowledge, Tech Infrastructure, Collaboration, Culture, People, Leanness) from 1 (most important) to 5 (least). (Multiple same ranking is allowed)
    - Information
    - Knowledge
    - Technological Infrastructure
    - Collaboration
    - Culture
    - People
    - Leanness

    Briefly justify your top choice ..................

    1. People – top choice because if you have the right people in key positions, they will lead the charge to improve the culture
    2. Culture
    3. Information
    4. Collaboration
    5. Knowledge
    6. Tech Infrastructure
    7. Leanness

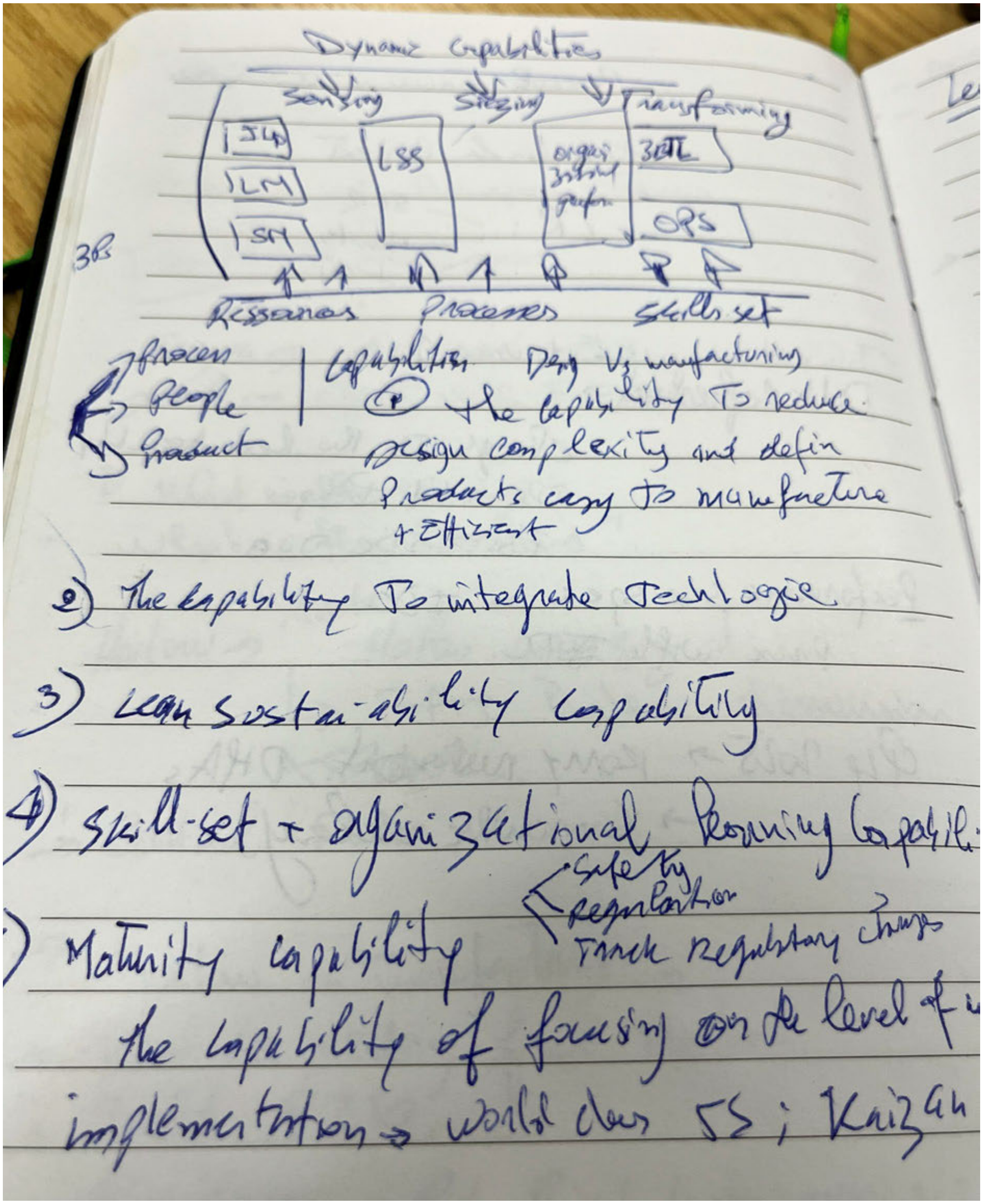
Appendix K Delphi Round 2 Consensus Summary

(n= 4 experts, agreement threshold ≥4, consensus =≥75% ratings ≥4)

| ***Item*** | ***n*** | ***%≥4*** | ***Median*** | ***Mean*** | ***Standard Deviation*** | ***Consensus (≥75% ≥4)*** |
|---|---|---|---|---|---|---|
| Relevance of refined model | 4 | 100% | 4.0 | 4.00 | 0.00 | Yes |
| Clarity of revised Figure 5-1 | 4 | 75% | 4.5 | 4.25 | 0.96 | Yes |
| Usefulness of “Data” to “information” change | 4 | 75% | 4.0 | 3.5 | 1.73 | Yes |
| Importance of Organisational learning | 4 | 100% | 5.0 | 4.75 | 0.50 | Yes |
| Integration of LS4.0 with VoCS | 4 | 100% | 4.0 | 4.25 | 0.50 | Yes |
| Balance technology with physical gemba | 4 | 75% | 4.5 | 4.25 | 0.96 | Yes |
| Sustainability focus | 4 | 100% | 4.0 | 4.25 | 0.50 | Yes |
| Feasibility of implementation | 4 | 100% | 4.0 | 4.25 | 0.50 | Yes |
| Customer satisfaction loop fit | 4 | 100% | 4.5 | 4.50 | 0.58 | Yes |
| Alignment with AEROSkyward Culture | 4 | 100% | 4.5 | 4.00 | 1.42 | Yes |
| Overall confidence/ readiness | 4 | 75% | 4.5 | 4.38 | 0.75 | Yes |

Appendix L Extracts of Reflexive research notes – Field notes

Notes regarding the development of the model through core constructs



Dynamic Capabilities

Sensing Seizing Transforming

LSS

OPS

Resources Processes Skills set

Process | Capabilities Design Vs manufacturing

People | 1) the capability to reduce

Product | design complexity and define products easy to manufacture + Efficient

2) The capability to integrate Technologie

3) Lean sustainability capability

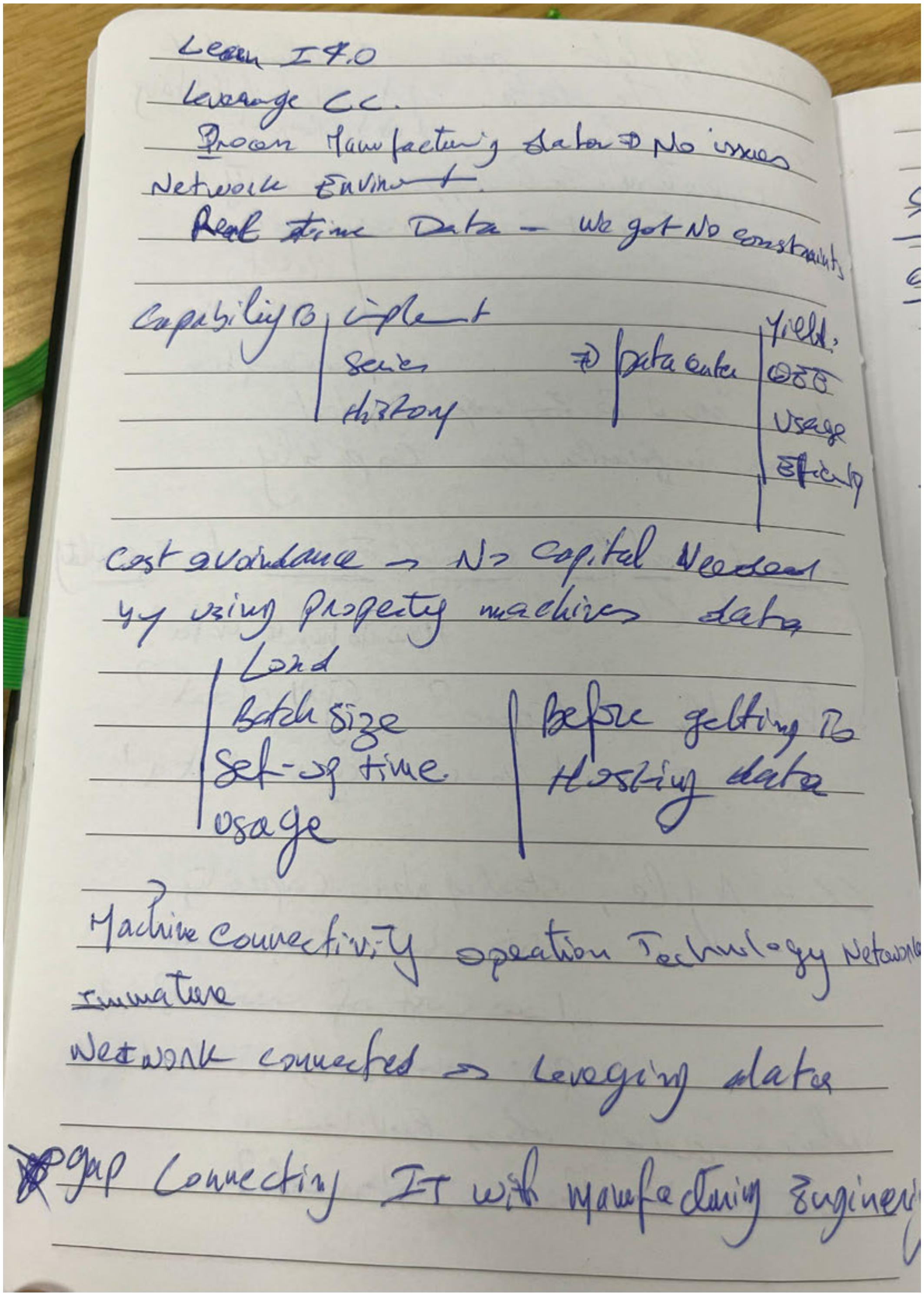
4) skill-set + organizational learning capabili

) Maturity capability Safety regulation Track regulatory changes

the capability of focusing on the level of i

implementation => world class 5S ; Kaizen

Reflections on Industry 4.role



Lean I4.0
Leverage C.C.
Proven Manufacturing data ⇒ No issues
Network Environment.
Real time Data – we got No constraints

Capability to implement
Series
history
⇒ Data centre
Yield,
OEE
Usage
Efficiency

Cost avoidance → No capital Needed
by using property machines data
Load
Batch size
Set-up time
Usage
Before getting to
Hosting data

Machine connectivity operation Technology Network
Immature
Network connected → Leveraging data

Gap Connecting IT with manufacturing Engineering

Data Regulation - issue as to where Host
The data. Export controls / Military
UK data Regulat

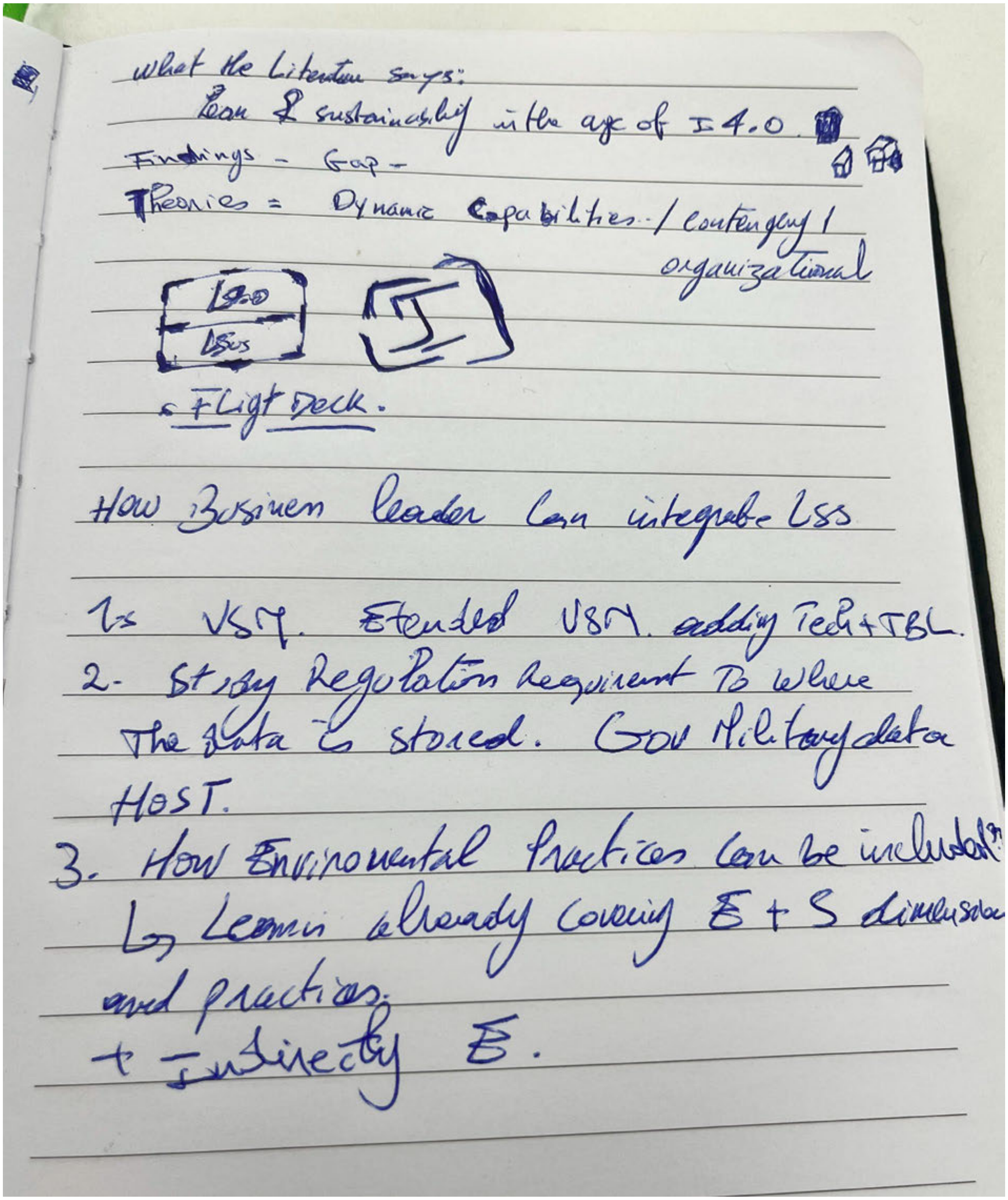
Simon Peckham:
Operational Technology connectivity
Create an Environment improved OEE
Yield
capability
Consumption

Areas on How To ~~Explode~~ Exploit
Basic infrastructure Capability.

Govment certified Cloud Environment Capability
Oracle Cloud. How to handle data?
what is the outcome? Gov cloud?
stores transact process gov. data?

CC = Agile; stand up new capacity
close down capacity
low cost of ownership
pay somebody to do it
who's admin the environment?
Not known where is stored?

Reflections on LS4.0 model outcomes


what the Literature says:
Lean & sustainability in the age of I4.0
Findings - Gap -
Theories = Dynamic Capabilities / contingency / organizational
LS4.0
LSS
Flight Deck.
How Business leader can integrate LSS
1x VSM. Extended VSM. adding Tech + TBL.
2- Strategy Regulation Requirement To where The data is stored. Gov Military data HOST.
3. How Environmental Practices can be included?
↳ Lean is already covering E + S dimension and practices.
+ Indirectly E.

/06/24

Case study organisation

Exploring New Phenomenon

* How business leader are getting ready To incorporate SM + I4.0

* Skills set ; Culture ; Processes

* Developing theory from empirical study

→ with ground theory

What are the results of my phase 1?

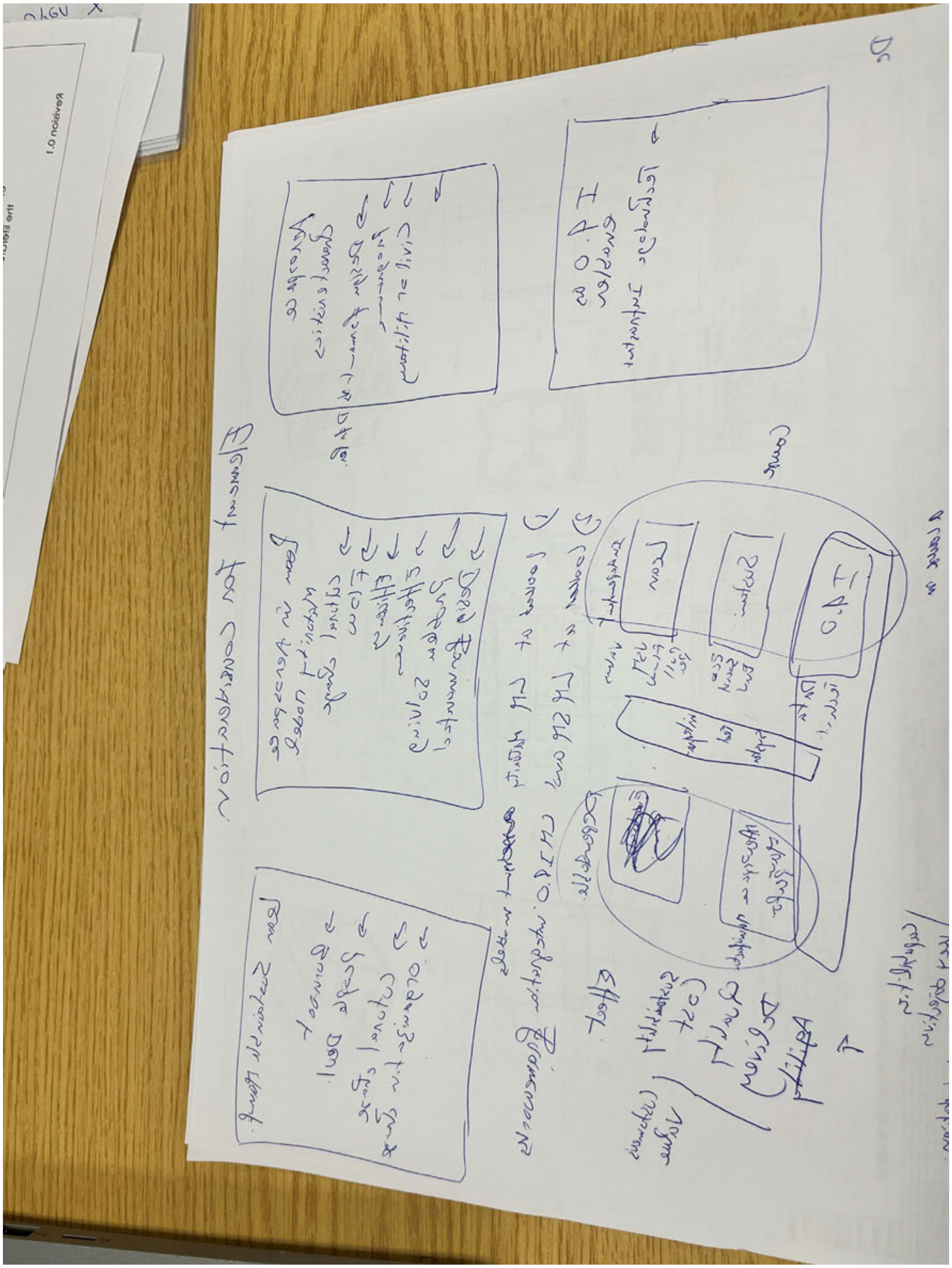
Dynamic capabilities

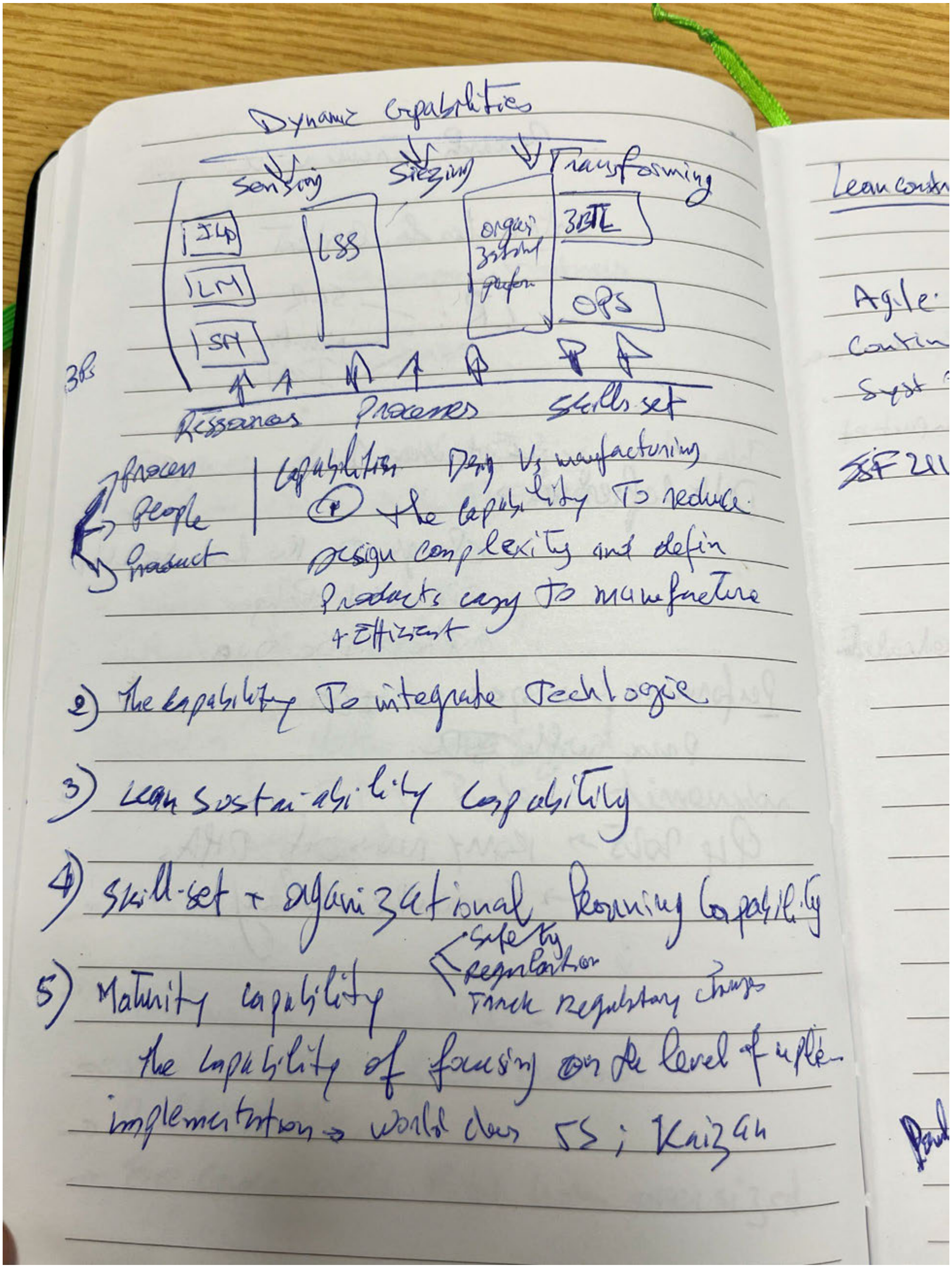
organizational learning

organizational Contingency theory

→ The company Lauched AI Tool.

LS4.0 model early development




Dynamic capabilities
Sensing
Siezing
Transforming
JIP
LSS
ILM
SM
organi
zational
perform
3BTL
OPS
Ressources
Processes
Skills set
Process
People
Product
Capabilities Design Vs manufacturing
1 the capability to reduce design complexity and define products easy to manufacture + Efficient
2) The capability to integrate Technologie
3) Lean sustainability capability
4) skill-set + organizational learning capability
5) Maturity capability
safety
regulation
Track regulatory changes
the capability of focusing on the level of imple-
implementation → world class 5S ; Kaizen
Lean constr
Agile
Contin
Syst
ISF